THE MINERALIZATION IN SAN CRISTOBAL MINE

by

Julio Aquiles\Pastor Figueroa

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STATEMENT BY AUTHOR

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PREFACE

The San Cristobal Mine is one of the base-metal mines operated by the Cerro de Pasco Corporation in Peru. The San Cristobal Mine is fifty kilometers by road from Oroya where a smelter and the Sierra headquarters of the Cerro de Pasco Corporation are located.

The writer is indebted to the Cerro de Pasco Corporation for permitting the preparation of this work to be submitted as a Master's Thesis to The University of Arizona.

Recognition is given to W. Haederle, Petrologist of the Cerro de Pasco Corporation, for the preparation of polished and thin sections and to the geological staff of the San Cristobal Mine for their help in drafting sections and plans.
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ABSTRACT

The San Cristobal Mineral District contains two types of ore deposits: veins and mantos. The San Cristobal Main Vein is one of several cross fractures cutting the northwesterly trending Chumpe Anticline. The Chumpe Anticline is part of a major structure, the Yauli Dome.

A study of the metal and mineral distribution in the vein reveals a well-defined horizontal zoning which is compatible with paragenesis and suggests a source of ore-bearing solutions below the Chumpe intrusive in the center of the anticline. In general, early minerals were deposited close to the inferred source, whereas late minerals were deposited remote from the source. The paragenesis is: pyrite, wolframite, quartz, chalcopyrite, dark sphalerite, brown sphalerite, galena, and carbonates.

The study of sections showing contours of assays of different metals, metal ratios, and inferred direction of flow of mineralizing solutions reveals the existence of favorable areas for ore. These areas are of particular interest for future exploration.

Mineral assemblages, ore textures, and alteration of wall rocks place the San Cristobal Main Vein among mesothermal deposits according to Lindgren's (1933) classification of hydrothermal ore deposits.
INTRODUCTION

**Purpose and Scope of Investigation**

The purpose of the present work is to contribute to geologic understanding of the mineralization of the San Cristobal mine, as well as to provide a reliable foundation for geologic advice in the further development of the mine.

This report brings up to date the geological knowledge of the San Cristobal mine regarding mineral distribution, paragenesis, zoning, direction of flow of mineralizing solutions, origin and its relationship with the local geology. Extension of ore shoots down dip to unknown areas is of particular interest for future exploration. Contour maps for different metal assays have been prepared to be compared and interpreted separately.

This work is also submitted to the Department of Geology as a thesis for the Degree of Master of Science.

**Location of Area**

The San Cristobal mine is located on the eastern slope of the Central Cordillera mountain range of Peru, 13 kilometers east of the continental divide of South America. The mountainous region is referred to as the Sierra Section of Central Peru and lies between the coastal zone to the west and the jungle area to the east. The longitude of the mine is 76°05' West and the latitude is 11°42' South.
Distance by road to the mine from Lima, capital of Peru, is 190 kilometers. This road passes through the towns of Chosica, Matucana, San Mateo, Casapalca, Morococha, Mahr Tunnel, and Yauli, the town nearest to the mine (Figure 1).

**Previous Investigations**

The San Cristobal mine has been studied to various extents by several men.

Broderick and Snively (1942) related the tungsten mineralization to dikes present in the area in their "Preliminary Report on the Tungsten Deposits near San Cristobal".

Snively and Kruger (1944) mapped the surface and related the surface mapping to the underground workings in their "Geology of the San Cristobal Mine Area."

R. W. Phendler (1959) mapped and described the rocks and veins of the district in his report "Geology of the San Cristobal Mine and District."

Wright and Medrano (1962) in their report "Paragenesis, Mineral and Metal Distribution, San Cristobal Main Vein" drew contours for copper, zinc, lead, and silver assays for the western part of the San Cristobal Main Vein.

W. R. Guggenheimer and N. Rivera (1964) in the second part of the report "Ten Year Program for the San Cristobal Division" proposed several geological models to explain the formation of ore deposits in the San Cristobal district.
History

Mining in the San Cristobal district has proceeded on a small scale at the end of the last century and in various decades of the present century. It was first investigated for the Cerro de Pasco Corporation in 1923-24 by H. Dillingham and later in 1927 by P. Chase. A three-year lease was negotiated as a result of the Chase's report on the mine of Jose Hernandez, covered by six claims. Exploratory work began in April 1928, and the adjacent areas were claimed by the company. In 1935 the mine was purchased and preparations were made for production.

In 1948, the San Cristobal mine was closed down after nine years of operation, which yielded a total of 383,000 tons of ore. The mine was reopened in 1950, but it was not until 1955 that the actual production began. From 1955 to 1963, the San Cristobal mine has produced 1,569,248 tons of ore averaging 1.14% copper, 0.92% lead, 9.15% zinc, and 5.30 ounces per ton of silver. Production in 1966 was 344,680 tons of ore.
GEOGRAPHY

Topographic Expression and Rook Outcrops

The outstanding feature of the area under discussion is its great altitude. The highest peaks have never been surveyed, but are estimated to be around 5,500 meters (18,045 feet) of altitude. The mine buildings are at an altitude of 4,724 meters (15,499 feet). Valleys are narrow and slopes commonly reach 30° of inclination. No plains are present. Local relief is between 500 and 1,000 meters (1,640 and 3,281 feet).

Rock outcrops are abundant in the area, probably comprising close to 35% of the surface. The exposed rocks are generally very fresh. Detrital material is at a minimum, except on the floors of the valleys. Glacial striae can be seen clearly practically anywhere on both sides of valleys. Outcrops are generally well-rounded and are up to a kilometer in length.

Drainage, Vegetation, and Precipitation

The main drainage in the area is by two rivers, the Carahuacra River and the Andaychagua River. The Carahuacra River runs from southeast to northwest and flows into the Yauli River beyond the study area. The Andaychagua River runs from northwest to southeast (Fig. 1). During dry season, the rivers are fed by springs and glacial streams from the glaciers that cluster around the mountain peaks between the San Cristobal and Andaychagua mines.
Vegetation is scarce. No trees grow much above 3,000 meters (9,840 feet) at this latitude. From 3,000 meters up to 4,000 meters (13,120 feet), only grass can survive. Above 4,800 meters (15,744 feet) no vegetation of any kind exists.

Precipitation at the San Cristobal mine is in the form of snow, hail, and rain. Precipitation falls in the six-month rainy season which lasts from December to May. Amount of precipitation for the area is between 300 and 1,000 millimeters.
GEOLOGY

The folded and faulted Andean Cordilleran mountain chain is about 300 kilometers wide through the San Cristobal district. The area under discussion lies about in the middle. The major structural feature in the area of the mine is a twenty-kilometer long anticline, referred to as the Chumpe Anticline. This anticline is part of a larger structure, the Yauli Dome.

Stratigraphy and Petrography

A brief description of each rock type, with reference to its local aspect, is the subject of this section. The rocks to be described are the Devonian Excelsior phyllites, the Permian Mitu volcanic rocks, the Jurassic Paria limestone, the lower Cretaceous Goyllarisquisga sandstone, the middle Cretaceous Machay limestone, and the Cretaceous to Tertiary intrusive rocks (Figure 2). Although the Goyllarisquisga sandstone and the Machay limestone have no economic importance in the area, they will be described in order that a complete picture of the stratigraphy in the area under study is available.

The geological plan of the area (Figure 2) is a reduction of the original geological plan prepared by H. W. Kobe in 1964 with a few additions and changes taken from other sources.
Excelsior Phyllites

The Excelsior phyllites of the Excelsior Series represent the oldest rock type in the area and form the core of the Chumpe Anticline. The phyllites are exposed over an area 19 kilometers long and one and a half kilometers wide striking northwest along the long dimension of the anticline. The phyllites are highly-sheared and easily weathered and form the lowest part of the Chumpe Valley. They are protected on both sides of the anticline by harder, more resistant volcanic rocks.

Texture of the phyllites is fine-grained. They contain white quartz lenses which generally strike along the shear planes. Quartz lenses are commonly associated with pyrite blebs. The phyllites are black in the unaltered state, but two types of alteration exist that give the phyllites either a whitish grey or a greenish-black color. The whitish grey variety has been described as sericite-schist. This variety occurs where the San Cristobal Main Vein cuts across the contact fault between the Excelsior phyllites and the overlying Mitu volcanic rocks. This variety also occurs near the Chumpe intrusive. In underground workings, these sericitized and argillized phyllites form a band on both sides of the vein. The greenish black variety is a chloritized phyllite which occurs immediately against the whitish grey variety away from the Chumpe intrusive and away from the veins.
The thickness of the phyllites is not known in the area and what rocks are formed beneath the Excelsior phyllites is also unknown. There is an unconformity between the phyllites and the overlying Mitu volcanic rocks. The contact dips about 60° SW on the southwest side of the Chumpe Anticline and about 40° NE on the northeast side of the anticline.

The Excelsior phyllites in the area under study have been determined to be of Devonian age.

Mitu Volcanic Rocks

The Mitu volcanic rocks are part of the Permian Mitu Formation. They overlie the phyllites on both sides of the Chumpe Anticline and extend to the southwest as far as the Carahuacra Valley and to the northeast out of the present area of study.

The Mitu volcanic rocks are resistant to weathering and form the ridges between the Carahuacra and Chumpe valleys, and also between the Chumpe and Andaychagua valleys. Steep cirque walls have been formed by glaciers on highlands overlooking either side of the Chumpe Anticline. Outcrops below these highest peaks are gently rounded and show glacial striations.

Volcanic rocks in the area are fine to medium-grained with abundant quartz and plagioclase. Both limbs of the Chumpe Anticline show very different types of volcanic rocks. The northeast limb or Andaychagua side of the anticline has a variety of volcanic rocks which include andesites, basalt porphyries, tuffs, and dacites. The volcanic rocks on the southwest limb or San
Cristobal side of the anticline are practically homogeneous throughout. The most common type is described as a quartz latite porphyry.

Like the phyllites, the volcanic rocks have been sericitized close to the area where the San Cristobal Main Vein crosses the phyllite-volcanic contact. The sericitized volcanic rocks appear bleached. Chloritization showing the typical deep-green coloration is also common. Pyritization is conspicuous with pyrite gradually increasing as the San Cristobal Main Vein is neared. This increase can be clearly seen on surface by the very noticeable strengthening of orange coloration of the outcrops.

Thickness of the Mitu volcanic rocks is 700 meters on the southwest side of the Chumpe Anticline. Thickness is unknown on the northeast side, but it appears much thicker.

A regional unconformity exists between the Mitu volcanic rocks and the underlying Excelsior phyllites and also between the Mitu volcanic rocks and the overlying Paria limestone. The Mitu volcanic rocks on both sides of the Chumpe Anticline show innumerable transverse veins and faults.

Paria Limestone

The Paria limestone is part of the Jurassic Pucara Formation which overlies the Mitu volcanic rocks.

In the area under study, this limestone is confined to the southwest side of the anticline and forms the floor of the
Carahuacra Valley. In the northeast side of the anticline, the Paria limestone is absent.

The limestone is dark grey to white and fine-grained.

N. Snively measured a section of the Paria limestone in the Carahuacra Valley. The thickness of this section was 353 meters from the underlying Mitu volcanic rocks up to the overlying Goyllarisquisga sandstone. The entire Pucara Formation is up to 1,300 meters thick, but in the area under study the part known as Paria limestone measured just 353 meters. Ten distinct horizons were recognized, mapped, and measured by Snively in the Paria limestone. These ten horizons varied from 10 to 77 meters in thickness and included many varieties of limestone.

Limestone beds dip to the southwest between 50° and 60°. Running along the limestone side of the limestone-volcanic contact for about 5 kilometers is a replacement-type mineralized zone. This mineralized zone forms mineable mantos in the San Antonio and Carahuacra mines.

The Paria limestone lies unconformably over the Mitu volcanic rocks while the overlying Goyllarisquisga sandstone is conformable. The age of the Paria limestone has been determined as Jurassic.

Goyllarisquisga Sandstone

Overlying the Paria limestone conformably is the lower Cretaceous Goyllarisquisga sandstone, about 200 meters thick in the area. In the Carahuacra zone, the basal beds are conglomerates composed of rounded quartz pebbles set in a sandy matrix.
Above the conglomerates, the beds are characteristically red and reddish-brown, cross-bedded sandstones and shaly sandstones. Strike of the beds is N 50° W and dip is about 50° southwest.

Machay Limestone

The middle Cretaceous Machay limestone overlies conformably the Goyllarisquisga sandstone. The limestone is light grey in color, fine-grained, and shows distinct banding of harder and softer members. The outcrops are generally well-rounded and are elongated along the strike of the bedding, which is N 50° W. Dip of the bedding varies between 45° and 85° to the southwest. The basal member is very light grey with a few interbedded basaltic flows.

Intrusive Rocks

Intrusive rocks in the area are represented by Cretaceous or Tertiary quartz monzonite plugs and alaskite dikes along or near the axial zone of the Chumpe Anticline.

Two important plugs exist in the area, the Carahuacra intrusive and the Chumpe intrusive. The Carahuacra intrusive is a quartz monzonite plug, 1.5 kilometers by 1 kilometer, in the Carahuacra zone northwest of the San Cristobal area. The long dimension strikes N 40° W, parallel to the axis of the Chumpe Anticline. The quartz monzonite is in contact with the Excelsior phyllites and has cut into the Mitu volcanic rocks.
The Chumpe intrusive is located in the San Cristobal zone along the axis of the Chumpe Anticline. This intrusive forms the highest peak of the area and is covered in part by a glacier. The part exposed measures 250 by 500 meters. The long dimension strikes N 40° W and is parallel to the axis of the Chumpe Anticline.

A few, small, irregularly-shaped quartz porphyry plugs have been observed in the area intruding the Mitu volcanic rocks and the Paria limestone.

A series of lensy and irregular dikes have intruded into the Excelsior phyllites along or very near the axis of the Chumpe Anticline. This type of intrusive is a buff to white, fine to medium-grained rock, with abundant quartz and orthoclase and few dark minerals. It also contains finely disseminated sericite, biotite leaves, and pyrite mineralization. The dikes are referred to as alaskite dikes. The name granite porphyry is also applicable for this type of rock. These dikes appear to be an extension of the Chumpe intrusive. They range in width from a few meters to thirty meters. The complexity of these dikes is clearly seen on surface with their irregularities and displacements by transverse faults.

Two major alaskite dikes have been recognized in the San Cristobal mine. They extend on surface for about 1.5 kilometers to the northwest of the Chumpe intrusive. They are not continuous over this distance, but are in massive lenses about two or three
hundred meters long. From the Chumpe intrusive to the southeast
the dikes are less conspicuous. They are exposed in small lenses
for about 3 kilometers in this direction.

*Strike of the dikes is N 40° W and dip is practically vertical. Weathered surfaces on the dikes are buff to white.*

*Neither wallrock alteration of the phyllites nor chilled contacts or any variation in grain size of the dikes is discernible.*

*There are also a few gabbro intrusives to the northeast side of the Chumpe Anticline. These intrusives are small plugs intruding the Mitu volcanic rocks or close to its contact with Excelsior phyllites.*

**Structure**

*Considered broadly, the Yauli Dome is the foremost structural feature of the San Cristobal region. This dome measures thirty kilometers by twenty kilometers. The long dimension strikes about N 40° W.*

*The center of the Yauli Dome is formed by the Chumpe Anticline, the main structural feature of the San Cristobal area. The anticline is assymetrical and doubly plunging, with an axis striking N 40° W and axial plane dipping steeply northeast. The rock units comprising the anticline are, in order from oldest to youngest, the Excelsior phyllites, the Mitu volcanic rocks, The Paria limestone, the Goyllarisquisga sandstone, and the Machay limestone. The heart of the anticline is composed of a 1.5 by 19-kilometer core of highly deformed black phyllites. These phyllites*
have been intruded along the axial zone by a series of alaskite dikes running parallel to the axis of the anticline and dipping more or less vertically.

A quartz monzonite intrusion outcrops two kilometers northwest of the San Cristobal mine. This intrusion is located opposite the Carahuacra mine along the phyllite-volcanic rock contact and is called the Carahuacra intrusive. The Chumpe intrusive, located in the San Cristobal area, is smaller in size and is the center of the dikes which tend to the northwest and southeast. The alaskite dikes are considered to be a highly differentiated part of the same magma that produced the quartz monzonite plugs.

The anticline is cut by many transverse faults, all of which strike roughly normal to its long axis. The faults located to the northwest of the Chumpe intrusive dip between $45^\circ$ and $60^\circ$ to the southeast and the faults located to the southeast of the Chumpe intrusive dip between $60^\circ$ and $80^\circ$ northwest. These two conjugate fault-systems converge down dip with the Chumpe intrusive in the middle (Figure 3).

The strongest and most important fault on the northwest side of the Chumpe intrusive is the San Cristobal fault system. This fault crosses most of the anticline, beginning in the Mitu volcanic rocks on the northeast side of the anticline, crossing the Excelsior phyllites, continuing southwest into the Mitu volcanic rocks again, and probably dying out in the Paria limestone.
LONGITUDINAL VERTICAL SECTION ALONG AXIS OF THE CHUMPE ANTICLINE
SHOWING VEIN AND FAULT STRUCTURES
Section Line N 45°W — Looking N 45°E
Scale 1: 10,000

September, 1967 — Julio A. Pastor

LEGEND
• Excelsior Phyllite

• Intrusives

• Fault

• Observed structure

• Protected structure

• Inferred structure

Figure 5
The strike of this major fault is N 50° E in general and its dip varies between 45° and 60° southeast. Displacement of 300 meters of the phyllite-volcanic rock contact can be seen on the southwest and northeast limbs of the anticline. This displacement indicates a normal movement, in which the southeast block moved downdip.

On the southeast side of the Chumpe intrusive there are two important faults, the Prosperidad fault and the Andaychagua fault. The Prosperidad fault strikes N 60° E and dips between 60° and 70° northwest, compared with the southeast dip of the San Cristobal fault. This fault also crosses the anticline from the Mitu volcanic rocks in the northeast limb to Mitu volcanic rocks again in the southwest limb, passing across the Excelsior phyllites. Displacement of 250 meters of the phyllite-volcanic rock contact can be seen on the southwest limb. The movement is also normal.

The Andaychagua fault is located about one kilometer southeast of the Prosperidad fault. The fault strikes N 35° E and dips 85° northwest. It is located in the northeast limb of the anticline and displaces the phyllite-volcanic rock contact for about 250 meters. The fault appears to have a reverse movement.

There are other small faults located mainly in the Mitu volcanic rocks on both sides of the anticline and roughly parallel to the major faults. All these faults, the major and the
smaller ones, were the pre-mineral structures in the area, along which the mineralizing solutions deposited their load to form the actual veins.
MINERAL DEPOSITS

There are two types of deposits in the San Cristobal district, veins and mantos. Veins are roughly perpendicular to the axis of the Chumpe Anticline and mantos are emplaced along the Mitu volcanic rocks-Paria limestone contact. (See geological map, Figure 2).

Veins

Most of the faults which cross the Chumpe Anticline or are located on both limbs of the anticline have been more or less mineralized. A description of the most important of these veins is given below.

San Cristobal Vein System

The San Cristobal Vein system is made up of two main mineral-bearing structures, the San Cristobal Main Vein and the Siberia 1 Vein. The Oyama-Triunfo Vein, which is located on the northeast limb of the anticline, appears to be an extension of the San Cristobal Main Vein. Both veins are separated on the surface by Chumpe lake and no underground workings exist below the area that permit a clear correlation.

The San Cristobal Main Vein extends all the way along the San Cristobal fault, considering the Oyama-Triunfo Vein as its extension. The Siberia 1 Vein is located in the axial zone of the
anticline. At present the San Cristobal mine is working in the San Cristobal Main Vein. This vein is well known underground and carries zinc, lead, copper, and silver minerals and locally tungsten minerals. The Siberia 1 Vein is little known in underground workings and carries mainly tungsten mineralization. The Oyama-Triunfo Vein is known underground over a length of 500 meters of old workings. It contains mainly copper and silver minerals, but has not been extensively explored because of its inaccessibility at present. This structure can be traced to the southwest on surface almost to the San Cristobal Main Vein and the two veins line up well.

Other veins which form part of the San Cristobal Vein system are, the Siberia 4 Vein, the 276 Vein, the J, U, and P veins and probably the Siberia 2 Vein. The Siberia 4 Vein is a hangingwall split of the San Cristobal Main Vein and is located on the axial zone of the anticline. The 276, J, U, and P veins are known only in underground workings, and they are splits of the San Cristobal Main Vein. The Siberia 2 Vein is known underground in a few places and appears to be a footwall split of the San Cristobal Main Vein.

Virginia Vein System

The Virginia Vein system runs parallel to the San Cristobal Vein system and is about 850 meters to the northwest. The Virginia Vein system is made up of three veins, the Virginia Vien, which is the main structure, and the 755 and 134 splits.
The Virginia Vein system has been traced on surface across the Mitu volcanic rocks. Underground, it has been followed to the southwest into the Paria limestone where it was found to weaken rapidly. Development to the northeast towards the phyllite-volcanic contact is being done at present.

The Virginia Vein system yields zinc, lead, and silver ores. The known length of the vein is about one kilometer. Strike is N 50° E and dip between 55° and 60° southeast. This vein is one of the producers in the San Cristobal district.

Ferramina Vein

This is the least important vein that crosses the Mitu volcanic rocks on the northwest side of the Chumpe intrusive. It lies between the San Cristobal and the Virginia vein systems and strikes parallel to them. The Ferramina Vein can be traced on surface for about one kilometer.

About 1,500 meters of horizontal development on six levels within a vertical range of 220 meters have been done on this vein. Mineralization is weak and consists mainly of sphalerite with small amounts of galena accompanied by pyrite and siderite. Ore shoots are very erratic and narrow.

Andaychagua Vein

This vein, which is one of the producers in the San Cristobal district, is one of the most important veins on the southeast side of the Chumpe intrusive. The vein lies on the northeast
side of the Chumpe Anticline. About three and a half kilometers southeast of the San Cristobal Vein system. The Andaychagua Vein strikes $N\ 30^\circ\ E$ and dips $85^\circ$ northwest. The vein can be traced on surface for about four kilometers, three of which are in Mitu volcanic rocks and one of which in Excelsior phyllites. The structure continues on surface across the axial zone to the southwest side of the Chumpe Anticline, but only as a fault structure without apparent mineralization. The Andaychagua Vein carries sphalerite, galena, and silver minerals.

Prosperidad Vein

This is another important vein which lies wholly in Excelsior phyllites between the Chumpe intrusive and the Andaychagua Vein. The vein can be traced on surface for about two and a half kilometers striking $N\ 60^\circ\ E$ and dipping $60^\circ$ northwest. No workings at all have been done by the Cerro de Pasco Corporation, but old workings show copper and tungsten ores.

Minor Veins

There are many minor veins located mainly in the Mitu volcanic rocks on both sides of the Chumpe Anticline. These small veins are roughly parallel to the major structures, but they are economically of less importance.
Mantos

Running along the limestone side of the Mitu volcanic rocks-Paria limestone contact is a replacement type mineralized zone distributed in three areas. These areas are the Carahuaora-San Antonio area, the Toldorrumi area, and the Moises area.

San Antonio Mantos

The San Antonio mantos are located in the southeast end of the two-kilometer Carahuaora-San Antonio area. The central and northwest part of this mineable area is owned by Volcan Mines, Ltd. (Carahuaora mantos). The San Antonio mantos are believed to be the southeast extremity of the Carahuaora mantos. The general strike of the San Antonio mantos is N 30° W and their dip is between 60° and 85° southwest. The mantos contain sphalerite and galena as ore minerals. Outcrop of the mantos weather to a black color resulting from the presence of manganese oxides. The San Antonio mantos are one of the contributors to the San Cristobal district production. The San Antonio mantos are located two kilometers northwest of the San Cristobal mine.

Toldorrumi Manto

About one kilometer southeast of the San Cristobal mine lies the Toldorrumi manto. A seven hundred-meter long low-grade manto exists on the Mitu volcanic rocks-Paria limestone contact. The area has two weak veins, the Catalina and the Polonia veins.
Some underground work has been done, but the results appear to be that neither the manto nor the veins have much value at this time.

Moises Manto

Three kilometers southeast of the Toldorrumi manto is another seven hundred-meter long weak manto along the already mentioned volcanic rock-limestone contact. This manto is the Moises manto and no underground workings have been done by the Cerro de Pasco Corporation. It appears that the manto is not economically important at this time.
MINERALIZATION IN THE SAN CRISTOBAL MINE

Introduction

The San Cristobal mine workings have been driven in and into the San Cristobal Vein system. The San Cristobal Vein system is the best known and most explored mineralized structure in the area. It is made up of two main veins, several splits, and cymoid loops described earlier. The two main veins are the San Cristobal Main Vein and the Siberia 1 Vein. The splits are the Siberia 4, the 276, the J, the U, and the P veins and probably the Siberia 2 Vein.

The San Cristobal mine consists of ten levels whose elevations range from 4,593 meters to 4,965 meters above sea level (Figure 4). The ten levels from bottom to surface are the 500, 470, 430, 400, 370, 320, 270, 220, 170, and 120 levels. Three shafts service the mine, two vertical and one inclined at about 50°. The vertical shafts are located about 800 meters apart; the Porvenir sublevel shaft at the west end of the mine goes from the 370 level down to the 500 level. The Santa Barbara shaft further east extends from the 370 level up to the 120 level.

The mine, working along the vein system, has been divided into different sections, for the purpose of mine operation, on the basis of the type of wall rock and distinguishing structural features. From west to east these sections are 1. Volcanic Section,
Figure 4

GEOLOGICAL SECTION THROUGH CHUMPE ANTICLINE
ALONG SAN CRISTOBAL MAIN VEIN SHOWING METALS DISTRIBUTION
Looking N 37° W
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located in the western part of the San Cristobal mine in the Mitu
volcanic rocks from the phyllite-volcanic rock contact to the
west; 2. Contact Section, limited to the zone where the San Cris­
tobal Main Vein displaces the phyllite-volcanic rock contact,
that is, the zone between the phyllite-volcanic rock contact be­
hind the vein and the phyllite-volcanic rock contact in front of
the vein; 3. Phyllite Section, the area located between the Con­
tact Section and the coordinate 10,600 E; 4. Dike Section, the
area where the vein crosses the dikes or where tungsten mineral­
ization is present. This section extends from the coordinate
10,600 E to the eastern end of the mine.

Description of Veins of the San Cristobal Vein System

San Cristobal Main Vein

The San Cristobal Main Vein has been developed for two
kilometers, from 500 meters west of the Porvenir shaft on the 500
level to 150 meters east of the eastern dike in the dikes area
(Figure 4).

The surrounding rocks have had a marked influence on the
structural character of the vein. In volcanic rocks the structure
is well-defined with sharp walls. However, in the phyllites the
structure is ill-defined, is more apt to be a stringer zone than
a single structure, and in places consists solely of gouge. These
differences reflect the different degrees of competency of the
two rocks. The volcanic rocks are more competent; they are
brittle rocks and appear to have ruptured abruptly and cleanly. The phyllites are incompetent rocks and yielded first by folding and flowage and then by rupture along closely spaced planes. The vein lies within the San Cristobal fault and is of the fissure filling type deformed and brecciated in places by post-mineralization movements. Spatial mineralogical changes are related to depth and proximity to the dikes and to the phyllite-volcanic rock contact.

The vein within the Volcanic Section strikes N 50°-60° E and dips between 50° and 60° southeast. Both, strike and dip, show little variation outside this range. The western and central portions of the vein in this section form a well-defined structure, but to the east, as the phyllite-volcanic rock contact is approached, the vein becomes diffuse, breaking up into innumerable splits and stringers ranging up to one meter wide. Within 20 to 30 meters of the phyllite-volcanic rock contact, the vein is properly termed a vein zone. The vein in this Volcanic Section has been broken by post-mineralization movements; angular fragments of ore showing open space depositional features are enclosed in carbonate matrix or in a matrix of light grey to light brown gouge.

The predominant ore minerals are sphalerite and chalcopyrite. Chalcopyrite increases toward the contact, while secondary chalcocite is found coating sphalerite above the 370 level. Gangue minerals include carbonates, pyrite, and minor quartz.
Development of the vein to the west is still 250 meters from the volcanic rock-limestone contact. Whether the structure continues on into the limestone has not been ascertained yet, but an impoverishment of the mineralization can be noted in the structure to the west. Chloritization of the volcanic host is the dominant alteration. Close to the phyllite-volcanic rock contact the zone of chloritization is accompanied by pyrite and hematite veinleists and disseminations.

In the Contact Section the vein widens and consists of the main structure flanked by a network of stringers. These features, which are peculiar to the Contact Section, are a result of two different types of structural movement: (1) a reverse movement along the phyllite-volcanic rock contact caused by folding; and (2) a normal movement along the San Cristobal fault. These two movements appear to have created a shatter zone which allowed the mineralizing solutions to escape outwards from the main structure. This movement of solutions and the large specific surface in this section formed a stringer zone where replacement was prominent. In some places the trend of the vein has been obscured by an intensive pyritic replacement. The Contact Section is one of the richest parts of the mine in chalcopyrite, sphalerite, and silver minerals. Chalcocite forms prominent coatings on other minerals from the surface down to the 370 level. Gangue minerals include massive and disseminated pyrite, quartz, and carbonates. The Contact Section is defined as that area in which the phyllite-volcanic rock contact is tangential to the mineralization of the
San Cristobal Main Vein. However, the vein does not follow the fault contact between the phyllites and volcanic rocks in all its extension. In the upper levels, from the 320 level up to the 170 level, the vein crosses the contact at an angle of intersection of about 30°. In the lower levels, from the 370 level down to the 500 level, the vein follows the contact for a distance of 140 meters as a maximum in the 430 level and 50 meters as a minimum in the 500 level (Figure 5). The vein changes strike abruptly upon crossing the fault from N 50°-60° E to N 70°-80° E. Although the strike thus refracts upon crossing the phyllite-volcanic contact, the dip rarely deviates between 50° and 60° southeast. The refraction of the structure was caused by the difference in competency of the volcanic rocks and phyllites. At this point of refraction in the upper levels, several parallel splits appear in the phyllites in both the hangingwall and footwall of the main structure. These splits are the J Vein in the footwall and the P and U veins in the hangingwall.

The vein in the phyllites has an entirely different aspect when compared with its extension in the volcanic rocks. This difference is probably due to different mechanical properties of the two rocks, difference in composition of the host rocks and also different spatial position with respect to the source of the mineralizing solutions. The vein in the Phyllite Section is richer in chalcopyrite than the vein in the Volcanic Section, but it has less well-defined continuity and is more apt to break up
UNDERGROUND COMPOSITE GEOLOGICAL PLAN
IN THE PHYLLITE - VOLCANIC CONTACT ZONE
Levels: 170, 270, 370, 430, and 500
Scale: 1:2000

September 1967 — Julio A. Pastor

Legend
- Mile, volcanics
- Metasedimentary rock, phyllites
- Pyrite, quartz
- Zinc, lead
- Copper
- Fault
- Observed, contact, vein
- Approximate, contact, vein

Figure 5
into diffuse stringer zones. In the phyllites the vein is a typical shear structure.

The vein in the Phyllite Section, as mentioned above, is richer in chalcopyrite than the vein in the Volcanic Section. It contains about the same percentage of galena, is much poorer in sphalerite, and is much richer in silver minerals. Secondary chalcocite is prominent above the 370 level, but is almost non-existent below this level. Most of the ore has been mined out above the 370 level. Gangue minerals include carbonates, quartz, and minor pyrite. Below the 370 level there is an impoverishment of the mineralization in the central zone of the Phyllite Section. The vein at the eastern end of this section changes its strike from N 90° E to S 60° E in the lower levels, and from N 80° E to N 90° E in the upper levels. Dip decreases from 60° southeast to 50° southeast in the eastern part of the section. Alteration of the phyllites varies from a slight to a strong argillization and softening of walls.

The Dike Section is referred to as the part of the mine which is in the axial zone of the Chumpe Anticline and carries tungsten ore. In this section the phyllites are highly-deformed, sheared and intruded by two major alaskite dikes. These dikes have been displaced by the San Cristobal Main Vein. The first dike, the western one, is about 10-15 meters wide and the second dike, the eastern one, is about 20-30 meters wide. There are also smaller irregularly-shaped intrusions in the western part of this
section. The vein in this section undergoes a noticeable change of strike. In the upper levels, the strike changes from east-west to N $50^\circ$ E upon crossing the first dike. In the lower levels the strike changes from S $60^\circ$ E to N $30^\circ$ E before crossing the first dike and changes to N $50^\circ$ E upon crossing this dike. Dip of the vein changes from $35^\circ$-45$^\circ$ southeast to $50^\circ$ southeast upon crossing the first dike. Development beyond the second dike extends about 150 meters and strike changes where the vein crosses the second dike from N $50^\circ$ E to N $35^\circ$ E. Mineralization includes chalcopyrite, sphalerite, galena, silver minerals, and wolframite. Gangue minerals are abundant pyrite, quartz, and carbonates. The walls are not well-defined due to a pronounced pyritic replacement. Alteration of the phyllites in the Dike Section is described by a strong argillization, slight silicification, pyritization, and chloritization.

**Siberia 1 Vein**

The Siberia 1 Vein starts on coordinate 10,500 E (Figure 2). From this coordinate, where the vein joins the San Cristobal Main Vein, it extends towards the east as far as coordinate 11,000 E. Underground, the Siberia 1 Vein has been developed on the 220, 270, 320, and 370 levels (Figure 4).

The vein strikes E-W in the area west of the first dike and N $55^\circ$ E in the area between the dikes. The Siberia 1 Vein appears to have been displaced by the San Cristobal Main Vein (Figure 6).
SAN CRISTOBAL CROSS SECTION
Section No. 5 + 00 E
Looking N 80° E
Scale 1 : 5000

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Figure 6
Mineralization is characteristically pyrite, wolframite, and quartz in the area between dikes. In the area west of the dikes the vein is characterized by predominant pyrite which has been shattered and infilled by small amounts of wolframite, chalcopyrite, sphalerite, and galena.

Splits

The most important splits of the San Cristobal Main Vein are the J Vein, the P Vein, and the U Vein in the Phyllite Section and the 625 Vein in the Dike Section.

The J Vein is a footwall split of the San Cristobal Main Vein, with which it forms a cymoid loop. The vein strikes N 78° E and dips 55°-65° southeast. It extends between coordinates 9,900 E and 10,300 E. Down dip the vein extends from above the 170 level to just below the 320 level (Figure 7). Chalcopyrite is the principal ore mineral. Chalcocite is present in amounts which decrease downward. Gangue minerals are pyrite and quartz. Slight to moderate silicification is the principal alteration suffered by the phyllites.

The P Vein is a hangingwall split of the San Cristobal Main Vein. It extends from coordinate 9,900 E to 10,200 E. The vein strikes N 75° E and dips 55° to 65° southeast. The principal ore mineral is sphalerite. Quartz and pyrite form the gangue minerals. Strong argillization of the phyllites has been observed.

The U Vein is a hangingwall split of the P Vein. The general strike is E-W and dip is 60° southeast. The vein consists
SAN CRISTOBAL CROSS SECTION

ELEVATION IN METERS ABOVE SEA LEVEL

LEGEND
- Escavator phyllites
- Mica volcanics
- Pyrite, quartz
- Zinc, lead
- Copper
- Fault
- Observed vein, fault, contact
- Projected vein, fault, contact
- Inferred vein

SAN CRISTOBAL CROSS SECTION
Section No 1 + 50 W
Looking N 80° E
Scale 1: 5000
0 50 100 METERS
September, 1967—Julio A. Pastor
Figure 7
chiefly of rich closely-spaced chalcopyrite stringers. Sphalerite and galena are locally concentrated in small pockets and tetrahedrite crystals line cavities. There is a strong argillization of the walls.

No splits in the central part of the Phyllite Section are present (Figure 8).

The 625 Vein is a hangingwall split of the San Cristobal Main Vein with which it forms a loop. The vein is located in the Dike Section between coordinates 10,600 E and 10,700 E and has been developed on the 430 and 370 levels. The vein has a general strike of S 80° E and a dip of 60° southeast (Figure 6). Economic mineralization consists of sphalerite, chalcopyrite, galena, and wolframite. Pyrite, carbonates, and quartz are the gangue minerals.

Another split is the 276 Vein, a hangingwall split of the Siberia 1 Vein. It is located in the zone between the Phyllite and Dike sections and is developed for about 200 meters on the 320 level (Figure 6). The Siberia 4 Vein is yet another hanging-wall split of the San Cristobal Main Vein. This split is located in the Dike Section (Figure 9). The Siberia 2 Vein, probably another footwall split of the San Cristobal Main Vein, lies far in its footwall in the Dike Section (Figure 9).

The early work of Broderick and Snively (1942) pointed out the vein relations in the Dike Section. The veins were named and suggested by them. On surface, the northernmost vein is
SAN CRISTOBAL CROSS SECTION
Section No. 2 + 50 E
Looking N 80° E
Scale 1:5000
0 50 100
METERS
September, 1967 — Julio A. Pastor

LEGEND
- Observed vein, fault
- Projected vein, fault
- Inferred vein
- D.H. Diamond drill hole
Siberia 2, the middle structure is Siberia 3 and the southernmost structure Siberia 1. Located between Siberia 3 and Siberia 1 veins is another fault structure mapped by Broderick and Snively and referred to by them as Siberia 3 Middle Vein, now referred to as Siberia 4 Vein. Systematic geological cross sections drawn every fifty meters by the writer in the Dike Section and part of the Phyllite Section indicate that the Siberia 3 Vein on surface is only the extension of the San Cristobal Main Vein (Figures 2 and 9). The same occurred in the area between coordinates 10,400 E and 10,800 E where the San Cristobal Main Vein was named W Vein and considered a hangingwall split of the San Cristobal Main Vein. This latter vein was supposed to be in the footwall of the W Vein. It appears, however, that the W Vein is in fact the San Cristobal Main Vein and that the supposed Main Vein is the western part of the Siberia 1 Vein.

Types of Mineralization and Mineral Distribution

Mineralization, as presently known, occurs in the San Cristobal Vein system in three distinct types: tungsten alone, combined metals with tungsten, and combined metals without tungsten. The tungsten-type mineralization occurs in the assemblage pyrite-wolframite-quartz. This type of mineralization is located in the Siberia 1 Vein in the area east of the first dike. The combined metals with tungsten mineralization occurs in the San Cristobal Main Vein in the Dike Section. The combined metals
without tungsten mineralization is located in the rest of the mine, in the Phyllite, Contact, and Volcanic sections.

Ore minerals in the San Cristobal mine are wolframite, chalcopyrite, sphalerite, galena, minor tetrahedrite and minor pyrargyrite. Chalcocite and native silver occur as supergene minerals. Gangue minerals include abundant pyrite and carbonates, quartz, and minor marcasite. Wolframite is found in idiomorphic and hypidiomorphic crystals up to 8 centimeters long. Both the size and abundance of wolframite crystals decrease from the dikes area outwards.

In 1965, a total of 21 wolfram-mineral specimens from the San Cristobal Main Vein and the Siberia 1 Vein in the Dike Section were analyzed by J. A. Lord, Research Metallurgist. Of the 9 samples from the Siberia 1 Vein, 8 were found to be in the ferberite portion of the ferberite-huebnerite series with MnWO₄ ranging from 12 % to 18 %. The remaining one was wolframite at 26 % MnWO₄. Of the 12 samples taken from the San Cristobal Main Vein, 8 were again in the ferberite portion of the ferberite-huebnerite series. The remaining 4 were wolframite with MnWO₄ ranging from 28 % to 32 %.

Summarizing we see that all the specimens (Figure 12) are in the ferberite-wolframite portion of the solid solution series with from 12 % to 32 % MnWO₄ and 68 % to 88 % FeWO₄. No huebnerite was found in these samples (Tables I and II).
Table I

Results on Samples of Wolfram Mineral from Siberia 1 Vein

<table>
<thead>
<tr>
<th>Original Reference</th>
<th>Location</th>
<th>MnWO$_4$%</th>
<th>FeWO$_4$%</th>
<th>Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-R 953</td>
<td>270 level</td>
<td>18</td>
<td>82</td>
<td>Ferberite</td>
</tr>
<tr>
<td>4-R 953</td>
<td>270 level</td>
<td>12</td>
<td>88</td>
<td>Ferberite</td>
</tr>
<tr>
<td>1-32</td>
<td>320 level</td>
<td>14</td>
<td>86</td>
<td>Ferberite</td>
</tr>
<tr>
<td>5-R 969</td>
<td>320 level</td>
<td>13</td>
<td>87</td>
<td>Ferberite</td>
</tr>
<tr>
<td>7-R 969</td>
<td>320 level</td>
<td>13</td>
<td>87</td>
<td>Ferberite</td>
</tr>
<tr>
<td>1-37</td>
<td>370 level</td>
<td>14</td>
<td>86</td>
<td>Ferberite</td>
</tr>
<tr>
<td>3-37</td>
<td>370 level</td>
<td>18</td>
<td>82</td>
<td>Ferberite</td>
</tr>
<tr>
<td>5-37</td>
<td>370 level</td>
<td>17</td>
<td>83</td>
<td>Ferberite</td>
</tr>
<tr>
<td>7-37</td>
<td>370 level</td>
<td>26</td>
<td>74</td>
<td>Wolframite</td>
</tr>
</tbody>
</table>
Table II

Results on Samples of Wolfram Mineral from Main Vein

<table>
<thead>
<tr>
<th>Original Reference</th>
<th>Location</th>
<th>MnWO₄%</th>
<th>FeWO₄%</th>
<th>Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-17</td>
<td>170 level</td>
<td>13</td>
<td>87</td>
<td>Ferberite</td>
</tr>
<tr>
<td>3-17</td>
<td>170 level</td>
<td>17</td>
<td>83</td>
<td>Ferberite</td>
</tr>
<tr>
<td>5-17</td>
<td>170 level</td>
<td>28</td>
<td>72</td>
<td>Wolframite</td>
</tr>
<tr>
<td>1-22</td>
<td>220 level</td>
<td>14</td>
<td>86</td>
<td>Ferberite</td>
</tr>
<tr>
<td>3-22</td>
<td>220 level</td>
<td>20</td>
<td>80</td>
<td>Ferberite</td>
</tr>
<tr>
<td>7-22</td>
<td>220 level</td>
<td>29</td>
<td>71</td>
<td>Wolframite</td>
</tr>
<tr>
<td>2-R 930</td>
<td>220 level</td>
<td>29</td>
<td>71</td>
<td>Wolframite</td>
</tr>
<tr>
<td>1-27</td>
<td>270 level</td>
<td>16</td>
<td>84</td>
<td>Ferberite</td>
</tr>
<tr>
<td>3-27</td>
<td>270 level</td>
<td>18</td>
<td>82</td>
<td>Ferberite</td>
</tr>
<tr>
<td>5-27</td>
<td>270 level</td>
<td>17</td>
<td>83</td>
<td>Ferberite</td>
</tr>
<tr>
<td>7-27</td>
<td>270 level</td>
<td>32</td>
<td>68</td>
<td>Wolframite</td>
</tr>
<tr>
<td>3-32</td>
<td>320 level</td>
<td>16</td>
<td>84</td>
<td>Ferberite</td>
</tr>
</tbody>
</table>
Chalcopyrite is found in the Contact, Phyllite, and Dike sections, although the major concentration of chalcopyrite is located in the Contact Section. Chalcopyrite is generally massive, although small crystals about 4 millimeters have been found in vugs in the dikes area.

Although sphalerite is found in all the sections, it is most abundant in the Volcanic Section. Sphalerite is found in three different colors, dark sphalerite mainly in the Volcanic Section, brown sphalerite in the Phyllite and Dike sections, and red sphalerite in minor quantities in veinlets and in crystals in vugs in all the sections. Sphalerite is generally massive, granular and brittle, but in the Dike Section it is also found in crystals.

Galena is commonly found associated with sphalerite. The richest galena is found in the Dike and Phyllite sections associated with or separated from the sphalerite and showing well-crystallized cubes, although galena has also been seen in its cubic-octahedral form. Galena is found in minor amounts in the Volcanic Section. Galena also occurs in fine mixtures with sphalerite. Tetrahedrite is found as small inclusions in chalcopyrite, galena, and sphalerite. Pyrargyrite is also found as small inclusions in galena and occasionally in sphalerite.

All the above mentioned ore minerals appear in every respect to be of hypogene origin. The principal supergene mineral is chalcocite which replaces chalcopyrite, sphalerite, and galena.
in varying degrees. Sphalerite shows abundant coatings of chalco-
cite. Chalcocite in the Contact and Phyllite sections is confined
to the upper levels between the 370 level and the surface. Super-
gen chalcocite commonly contains native silver seen under the
microscope as small grains.

Gangue minerals are pyrite, carbonates, quartz, and minor
marcasite. Pyrite is the most abundant gangue mineral in the mine.
It is located mainly in the Dike and Contact sections. Pyrite
occurs well-crystallized and also fine-grained. Crystals are
larger, at about 10 centimeters, in the Dike Section than in the
other sections.

Carbonates are more abundant in the Volcanic Section than
in the rest of the mine. Carbonates are well-banded and the color
of bands varying in shades of greyish brown, dark brown, light
brown, brown, pinkish light brown, light yellow, and whitish
yellow. W. Kobe studied a few samples of carbonates of the San
Cristobal mine and stated that the carbonates are mainly impure
rhodochrosites, with tendencies toward siderite and smithsonite.
But determinations made by the writer based on physical proper-
ties and assay results for representatives samples of carbonates
from San Cristobal and San Antonio mines give the following re-
sult: The carbonates appear to be impure siderites containing a
few per cent or less of the rhodochrosite and smithsonite compo-
nents, probably due to the substitution of iron of the siderite
by manganese and zinc (Table III).
Table III

Assay Results on Samples of Carbonates

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Zn%</th>
<th>Mn%</th>
<th>Fe%</th>
<th>CaO%</th>
<th>MgO%</th>
<th>CO₂%</th>
</tr>
</thead>
<tbody>
<tr>
<td>038317</td>
<td>Phyllite Section</td>
<td>3.50</td>
<td>1.03</td>
<td>23.1</td>
<td>1.82</td>
<td>0.34</td>
<td>33.5</td>
</tr>
<tr>
<td>038318</td>
<td>Dike Section</td>
<td>0.16</td>
<td>0.61</td>
<td>35.9</td>
<td>0.57</td>
<td>1.17</td>
<td>38.2</td>
</tr>
<tr>
<td>041147</td>
<td>San Antonio Mine</td>
<td>0.08</td>
<td>1.32</td>
<td>33.6</td>
<td>0.71</td>
<td>0.41</td>
<td>37.0</td>
</tr>
<tr>
<td>041148</td>
<td>San Antonio Mine</td>
<td>0.12</td>
<td>1.44</td>
<td>31.0</td>
<td>0.90</td>
<td>1.06</td>
<td>37.6</td>
</tr>
<tr>
<td>041149</td>
<td>San Antonio Mine</td>
<td>0.71</td>
<td>1.37</td>
<td>29.5</td>
<td>1.68</td>
<td>1.12</td>
<td>37.6</td>
</tr>
</tbody>
</table>

In general, the Table III shows high percentage for Fe and CO₂ which indicate that the carbonates are mainly siderites and low percentage for Zn, Mn, CaO, and MgO which indicate that there are a few per cent or less of the smithsonite, rhodochrosite, calcite, and dolomite components. The carbonates contain also sulfur, barium, and insoluble SiO₂ which are not shown on the table.

The carbonates occur mainly massive, however in some places of the Dike Section they show hypidiomorphic crystals oriented perpendicularly to the layers. Also, small idiomorphic crystals of siderite, dolomite, and barite are present in vugs.

Quartz is the less abundant gangue mineral. It is present along the whole vein, although more abundant in the Dike Section. Quartz occurs as massive material and as crystals in vugs.

Marcasite, a minor gangue mineral, is present mainly in the Volcanic Section. It occurs in narrow bands between layers of carbonates (Figure 10).
MINERAL DISTRIBUTION AT 370 LEVEL ALONG SAN CRISTOBAL MAIN VEIN

SCALE 1 = 20,000
September, 1967 — Julio A. Pastor
Figure 10
Ore and gangue minerals within the structure form well-defined and separate bands. This banding is clearly seen in the Dike and Phyllite sections and less defined in the Contact and Volcanic sections, as shown in the diagrammatic representation of the San Cristobal Main Vein in the Dike Section (Figure 11). Bands from hangingwall to footwall are: (1) pyrite-wolframite-quartz, (2) chalcopyrite, (3) sphalerite-galena, and (4) carbonates.

Pyrite-Wolframite-Quartz Band

In this band pyrite is the main constituent and wolframite and quartz form narrow veins crossing the pyrite. Deposition is symmetrical with pyrite forming the walls and wolframite and quartz in the middle. Wolframite crystals are oriented perpendicular to the pyrite walls. In some places wolframite crystals interlock with pyrite crystals and the two appear to have been deposited contemporaneously. The wolframite crystals commonly occur suspended in massive quartz with either no orientation at all of the crystals or as discontinuous lines of crystals parallel to the pyrite walls. It is also common to find pyrite, wolframite, and quartz interlocked with one another in a texture indicating contemporaneous deposition.

Chalcopyrite Band

Nearly pure chalcopyrite form this band. Chalcopyrite is mixed with some pyrite at the hangingwall contact and with some
LEGEND

LEGEND

DIAGRAMMATIC REPRESENTATION OF THE SAN CRISTOBAL MAIN VEIN
SHOWING ALTERATION OF THE PHYLLITES, DIKE SECTION

Geology by Julio A. Pastor
September, 1967
sphalerite in the footwall contact. It is also common to find chalcopyrite suspended in quartz and in this case is not uncom-
mon to find chalcopyrite together with wolframite.

Sphalerite-Galena Band

In this band both minerals are commonly mixed, although in some places part of the galena is separated from the sphalerite and forms a separate band. In some places the band lacks galena and is composed of sphalerite alone with minor fine-grained disseminated galena. Chalcopyrite is also present in veinlets or small patches within the sphalerite.

Carbonates Band

This band generally includes broken pieces of sphalerite and galena suspended in the layers of carbonates. Veinlets of carbonates extend out of the main band and cross the sphalerite-galena band, filling cracks in it. These same carbonates veinlets cut the chalcopyrite and even the pyrite bands in some places. Where the carbonates are banded they contain thin layers of sphalerite or galena alternating with carbonate layers. Thin layers of marcasite are also present.

All these bands are present and well-defined in many places in the Dike Section. The pyrite and quartz of the hanging- wall band extend into the phyllites as veinlets, lenses, patches, or disseminations. Here it is common to find ribbon structures with quartz and phyllites or with pyrite and phyllites. This
ribbon structures are considered due to a process of replacement of the phyllites by gangue minerals.

In some places of the Dike Section and in the eastern part of the Phyllite Section, where there is no wolframite mineralization, the hangingwall band consists of pyrite and quartz only. Towards the west of the Dike Section, the structure does not show all the bands described above. They may also be mixed together. In the Volcanic Section the pyrite-quartz band and the chalcopyrite band are lacking and there is found only sphalerite with minor galena in a carbonate matrix. In the Contact Section the pyrite-quartz band is ill-defined whereas in the Phyllite Section is very narrow or lacking. The carbonate band is also locally lacking in any section.

The footwall of the structure, over all its area, is limited by a fault with abundant gouge which includes broken pieces of carbonates, sphalerite, and galena.

**Formation of Pre-mineral Structures in the Chumpe Anticline**

Formation of the Yauli Dome and its Chumpe Anticline occurred under regional compressive forces. Release of these regional compressive forces appears to have produced tensional longitudinal fractures along the axial plane of the Chumpe Anticline. These fractures were later filled with a felsic, highly differentiated magma forming the alaskite dikes. The Chumpe intrusive probably penetrated the apex of the doubly-plunging Chumpe Anticline. Only part of this intrusive is exposed on surface.
A later differentiation of this magma was probably the source of the felsic magma which filled the fractures and formed the alaskite dikes.

Tectonic reactivation acting upon the already formed domal structure produced the maximum plastic deformation. These compressive forces continued their action upon the Chumpe Anticline and produced a longitudinal bending along the axis of the anticline. This bending produced tension fractures transverse to the axis of the anticline and in a radial pattern from the axis of bending (Figure 3).

These transverse fractures are the pre-mineral structures located on the northwest and southeast sides of the Chumpe intrusive which converge down dip. The area of transverse pre-mineral structures in the Chumpe Anticline is about 4 kilometers and a half along the axis of the anticline from the Virginia to the Andaychagua structures.

The fractures have formed two well-defined systems: one is that of the Virginia-San Cristobal structures located in the northwest side of the Chumpe intrusive and dipping $45^\circ$-$60^\circ$ southeast; the other system is formed by the Prosperidad-Andaychagua structures located in the southeast side of the Chumpe intrusive and dipping $60^\circ$-$85^\circ$ northwest. Besides these longest and well-mineralized structures there are other minor structures which do not cross the core of phyllites of the Chumpe Anticline. These minor structures are located on both sides of the Chumpe
Anticline in volcanic rocks parallel to the major structures and
dipping according to the system where they are located.

The major fractures, which cross the Chumpe Anticline
from one limb to another, have undergone refraction in passing
from one medium to another. This is due to diversity in the com­
petency of the different rocks which form the Chumpe Anticline.
The effect of refraction in vein attitude is traduced in a change
of strike, although the dip has little change. Refraction occurs
when the structure passes from volcanic rocks to phyllites. Re­
versal of the vein attitude is observed on surface at the vol­
canic-phyllite contact across the Chumpe Anticline.

After the formation of fractures, pre-ore movements along
the San Cristobal Main Vein displaced the dikes. Later on, cir­
culation of mineralizing solutions and mineral deposition suc­
ceeded the pre-ore movements.

**Metal Distribution**

Longitudinal vertical sections along the San Cristobal
Main Vein showing contours of copper, zinc, lead, and silver
assays for the Volcanic and Contact sections were made first by
C. M. Wright in 1962. Later in 1964 N. Rivera made contours of
copper, zinc, and lead assays, contours of vein width and con­
tours of zinc/lead ratios for the same sections mentioned above.
At present, assay data for the different metals are available for
the Phyllite and Dike sections and the writer has prepared assay
contour maps and metal ratio maps for the different metals and
for the whole mine. The sections along the San Cristobal Main Vein showing contours are intended to establish the metal distribution and the apparent pitch of the metal anomalies. Besides, zones of different concentration for each metal have been delimited arbitrarily in order easily to detect the areas of major concentration. The plan and section projections along the San Cristobal Main Vein is included for reference, perspective, and scale. (Figure 12).

Wolfram Distribution

The distribution of wolfram in the Dike Section is shown on Figure 13. The contours represent percentage of \( \text{WO}_3 \).

There are 4 wolfram anomalies distributed in the Dike Section, of which three are located in the dikes area and one is in the western limit of the Dike Section.

In short, Anomaly 1 and Anomaly 2 in the dikes area extend down dip to unknown areas roughly parallel to the dikes, although the concentration decreases noticeably. Extension of these two anomalies up to the surface shows an increase in the concentration, but to the west and east sides of the anomalies the concentration decreases quickly. The trend of Anomaly 4 tends to converge with anomalies 1 and 2 in a zone below the dikes area about 700 meters vertically from the 370 level down. Anomaly 3, which is a round-shaped anomaly, is located between the two dikes and extends vertically from the 320 level up to the 220 level.
Copper Distribution

Copper anomalies are distributed along the whole vein, but in general the concentration of copper in the mine increases from east to west (Figure 14).

Anomalies 1 and 2 are in the area of the dikes with a roughly vertical pitch of the trends. Anomalies 3, 4, 5, 6, and 7 run from the dikes area to the west with a pitch of the trends of high concentration ranging from 45° to 65° east. Anomalies 9 and 10 appear to be extension of the anomalies 4 and 3.

The most important anomaly is Anomaly 8, which is located in the Contact Section and roughly follows the zone between the phyllite-volcanic rock contacts in front of and behind the vein. This anomaly extends from the surface down dip to the 500 level. The greatest concentration within the anomaly is 9.0 % Cu between the 320 and 400 levels where the anomaly has a local pitch of 90°. From this zone up to the surface the pitch of the trend is variable. From the 400 level down dip the anomaly splits into two branches, one following the contact zone with a pitch of 50° west and the other crossing the contact zone with a pitch of 50° east.

In conclusion, the copper anomalies in the dikes area have a general vertical pitch extending down dip parallel to the dikes. The rest of anomalies to the west of the dikes area have a pitch of 45°-65° east. All the anomalies extend down dip to unknown areas and appear to converge in a zone below the dikes area about 900 meters vertically from the 500 level. Concentration of copper also decreases slightly towards higher levels,
while down dip the anomalies maintain their high concentration. Furthermore, copper content of all the anomalies decreases from the center to both, the east and west sides of the trends.

The anomalies in the upper levels, which extend up to the surface, appear to have been modified by supergene activity. Supergene chalcocite is common in the upper levels from the 370 level up to the surface and mainly in the Contact and Phyllite sections. Although data is not sufficient to allow contouring of assay values in the upper levels of the Phyllite Section, it is known that the area was mined principally for copper.

Zinc: Distribution

Eight anomalies are distributed along the San Cristobal Main Vein (Figure 15). Anomalies 1, 2, 3, and 4, which are located in the Dike Section, have a variable pitch. Anomalies 5 and 6 are located in the Phyllite Section with a general pitch of about 40° east.

Anomalies 7 and 8 are located in the western part of the San Cristobal Main Vein. Anomaly 7 is a complex anomaly, but in general it is formed by a main trend in the 500 level and many branches extending to the levels above. The pitch of the main trend is 50° east whereas the branches have different pitches and directions. This large anomaly extends through the Volcanic Section and a great part of the Contact Section. We can say that these two sections form a zinc anomaly in themselves.
In conclusion, the anomalies are distributed in pairs along the San Cristobal Main Vein, with the exception of Anomaly 7 which is a complex anomaly. Between pairs of anomalies the concentration of zinc is very low. Anomalies 1, 2, 3, and 4 have in general a pitch of 90° parallel to the dikes. Anomalies 5, 6, 7, and 8 have a pitch to the east and tend to join the rest of anomalies in a zone below the dikes area, about 850 meters vertically from the 500 level down. Although the concentration of zinc tends to decrease slightly with depth, Anomalies 2, 3, 4, and 5 tend to form a large zinc zone below the 430 level. Same can be said for the area below the 500 level in the Volcanic and Contact sections.

Lead Distribution

There are 10 anomalies along the San Cristobal Main Vein (Figure 16). The best concentration of lead is in the anomalies located in the Dike Section, decreasing gradually this concentration to the west. The lowest concentration of lead is in the Volcanic Section. Besides, the concentration of lead decreases quickly from the center of anomalies to both sides.

In general, distribution of lead within the anomalies is not uniform; rather, lead-rich zones are separated in nucleus. Pitches of the anomalies flatten noticeably from east to west, from a pitch of 90° in Anomaly 1 to 40° east in Anomaly 10. Anomalies 2, 3, 4, 5, and 6 tend to join down dip in a zone about 400 meters below the 500 level. Anomalies 1 and 10 can be projected to a zone below the dikes area about 900 meters from the 500 level.
Silver Distribution

Silver distribution along the San Cristobal Main Vein is shown on Figure 17. The silver content along the vein increases from east to west. The best concentration of silver is in the Contact Section and the lowest concentration is in the Volcanic Section. All the anomalies extend down dip to unknown areas with concentration of silver decreasing slightly. One exception is Anomaly 9 with its axis of major concentration parallel to the surface. This anomaly, which is located in the upper levels of the Contact Section, may be due to supergene enrichment through the action of surface solutions.

Pitches of the anomalies in the western side of the mine are flatter than pitches of anomalies in the eastern side of the mine. Extending Anomaly 1 and Anomaly 8 down dip, they appear to join in a zone below the dikes area about 850 meters vertically from the 500 level.

Correlations Between Metal Anomalies

Comparing the wolfram anomalies with the copper anomalies (Figures 13 and 14), we can say that in general there is no coincidence between them in orientation and concentration of metals. The wolfram concentration decreases to the west whereas the copper concentration increases in this direction.

Comparing the copper anomalies with the zinc anomalies, it is noted that some anomalies coincide in part, others are different, and finally others are parallel. Copper grade in the
mine increases from east to west, but decreases abruptly to a very low concentration in the Volcanic Section. Zinc concentration increases from east to west with the best concentration in the Volcanic Section. Zones of low grade for copper and zinc roughly coincide.

Most of the lead anomalies coincide with zinc anomalies. Although the axis of some anomalies do not coincide, at least the areas of high concentration of metal do, or nearly do. Comparing the distribution of both metals, we note that the zinc grade increases from east to west, whereas the lead grade decreases from east to west. The Volcanic Section is the place of highest concentration of zinc and also the place of lowest concentration of lead.

The copper anomalies coincide roughly with the silver anomalies, a high grade copper zone corresponding a high grade silver zone. Both metals increase their grade from east to west with the highest concentration in the Contact Section. From this section, the grade decreases abruptly in passing to the Volcanic Section. Lowering of copper grade is more pronounced than lowering of silver grade. Silver anomalies coincide exactly with lead anomalies in the Phyllite, Contact, and Volcanic sections.

Comparing the anomalies of all the metals, it is significant to note that the areas of low concentration for all metals coincide and that the low concentrations are located between anomalies. Metals are concentrated along separate elongate anomalies,
with areas of low grade between them with the exception of the Volcanic Section which forms a whole anomaly in itself. The anomalies of the Dike Section tend to join with the anomalies of the Volcanic, Contact, and Phyllite sections in an area below the 500 level. Junction of the two extreme anomalies, east and west, join in a zone below the dikes area no more than 900 meters below the 500 level. The rest of anomalies tend to join in an area above this deepest zone.

All the anomalies extend down dip below the 500 level with grades decreasing slightly. With this in mind and projecting contours down dip, it is probable that economic mineralization will extend no more than 100 meters below the 500 level, unless other unknown concentrations appear down below.

Distribution of Metal Zones

A section showing the distribution of metal zones along the San Cristobal Main Vein (Figure 18) has been prepared on the base of the individual metal contour sections. The section shows the zones of high concentration of wolfram, copper, zinc-lead, and non-economic zones.

In general, we can say that the wolfram zone is concentrated to the Dike Section. The copper zone extends along the Phyllite and Contact sections, and the zinc zone is located in the Volcanic Section. The lead does not form a characteristic zone, but it is included in the zinc zone mainly in the Phyllite and Dike sections. The same occurs for silver which does not form
a zone, because it is mixed with chalcopyrite in the Phyllite, Contact, and Dike sections, and with lead and zinc in the Contact and Volcanic sections.

The largest non-economic zone is located in the Phyllite Section, with two more small ones in the Dike Section.

**Metal Ratios**

Sections showing contours for zinc/lead and copper/silver ratios have been prepared in order further to outline the zoning. Besides, if the metal ratios are temperature dependent, they also may show the paragenetic sequence.

**Zinc/Lead Ratios**

Contours for zinc/lead ratios are shown in Figure 19. We note in the section that the axis of the high zinc/lead ratios are disposed at regular intervals, almost parallel and with a steep pitch. From the center of each axis the zinc/lead ratio decreases to both sides. Comparing this section with the sections showing metal contours for zinc and lead, we see that the axes of the zinc/lead ratios in most cases cross the axes of the zinc and lead anomalies.

There are only a few places where the zinc/lead ratios are equal or less than one. This means that concentration of zinc is virtually always more than concentration of lead and that to a high concentration of zinc corresponds a low concentration of lead and to a low concentration of zinc corresponds a high concentration of lead.
Copper/Silver Ratios

In the dikes area the copper/silver ratio is fairly constant, but in the Phyllite and Contact sections the ratio decreases rapidly from the center of the axis to both sides. The axes of copper/silver ratios cross the axes of lead anomalies, but they are more or less parallel to the copper anomalies. In the Dike Section and eastern part of the Phyllite Section, silver is concentrated in or around the copper concentrations. In the western part of the Phyllite Section and in the Contact and Volcanic sections the best silver concentration corresponds to areas of low copper concentration, with the exception of the big copper anomaly where there is high concentration of copper and silver. (Fig. 20).

Vein Width, Strike and Dip

Vein Width

Contours for vein width are shown in Figure 21. Comparison of this figure with Figures 13, 14, 15, 16, 17, and 18, which show contours for different metals and distribution of metal zones, indicates that:

1. The variations in concentration of metals have an apparent relation with variations in vein width. Highest concentrations of metals correspond to highest values in vein width and lowest concentrations of metals correspond to lowest values in vein width.

2. The highest values in vein width are located in the Contact Section and the lowest values in the Phyllite Section.
3. The vein suffers an abrupt decrease in width in passing from the brittle volcanic rocks to the plastic phyllites.

4. Pinches and swells are elongate, very steep, and almost parallel.

5. Extending vein width contours down dip, below the 500 level, we note that there is a tendency for decrease in vein width with depth in the Volcanic and Contact sections, whereas in the Phyllite and Dike sections the vein width tends to remain constant with its pinches and swells.

Strike and Dip

Figure 22 shows contours for dip variations and zones of strike change. Comparing this figure with Figures 13, 14, 15, 16, 17, and 18 we can conclude that:

1. The variations in concentration of metals have no apparent relation to the variations in strike and dip of the vein.

2. Strike changes along the entire vein. From N 50°-60° E in the Volcanic Section, the strike changes to N 60°-70° E in the Contact Section and then to N 70°-90° E in the Phyllite Section. In the Dike Section, the strike changes even more to S 60° E and then turns abruptly to N 55°-75° E, to N 35°-55° E, and to N 15° E. From here the strike changes upon crossing the first dike to N 40°-60° E in the lower levels and to N 70°-90° E in the upper levels.

3. In general, strike in the Volcanic Section is very similar compared with strike in the dikes area. The greatest
variations occur where the vein passes the phyllite-volcanic rocks contact before entering the dikes area. The vein makes a remarkable turn in phyllites due to refraction of the structure in passing from volcanic rocks to presumably more plastic phyllites and from these plastic phyllites to more competent phyllites in the dikes area.

4. The vein in the Volcanic and Contact sections and in the western part of the Phyllite Section is steeper than the vein in the eastern part of the Phyllite Section and in the Dike Section. The vein in the area between the Contact Section and the dikes area, where the vein has been refracted and forms a curve, is flatter than the vein in the Volcanic Section and the dikes area where the vein has not been refracted. Dip decreases upwards, mainly in the Dike Section and in part of the Phyllite Section.

5. Zones of high concentration of metals are crossed by contours of different values for strike and dip.

Paragenetic Sequence

The time sequence of mineral deposition is known as the paragenetic sequence and the spatial distribution is described as zoning. These two depositional dimensions, time and space, are recorded in the deposits. Paragenetic sequence for the San Cristobal mine has been studied in mineral relationships under the microscope. Zoning has been established by the study of metal distribution in contour maps.
Microscopic study of the mineral sequence found in the San Cristobal Main Vein has been done on 33 polished sections prepared from samples taken in different places in the mine. Further, underground exposures yield excellent evidence from which the salient features of the paragenetic sequence may be deduced.

The vein shows evidence for formation through three mineralization periods, a first mineralization period represented by pyrite-wolframite-quartz, a second mineralization period by chalcopyrite-sphalerite-galena mineralization with minor tetrahedrite and pyrargyrite, and a third and last mineralization period represented by carbonates with minor sphalerite and marcasite.

The most complete sequence of mineral deposition is exposed in places in the Dike Section. A diagrammatic sketch of the mineral relations seen in the Dike Section is shown in Figure 11. The vein is composed from hangingwall to footwall by a band of coarsely crystalline, slightly vuggy pyrite. This band of pyrite varies in width from 0.5 to 3.0 meters. After deposition of pyrite, renewed movement along the structure created open fractures within the pyrite band. Such fractures were subsequently sealed or partially sealed by younger mineralization of wolframite and quartz which exhibits symmetrical deposition by symmetrical banding of mineral layers. The first layer deposited after pyrite consists of wolframite and after wolframite was deposited
quartz. These two minerals form veins within the pyrite. Wolframite crystals and the c axis of the quartz crystals are oriented more or less perpendicular to the pyrite walls. Also, wolframite crystals are found in massive pyrite or more commonly in quartz. These several modes of wolframite occurrence indicate that it in part crystallized contemporaneously with pyrite, but its deposition continued beyond pyrite and was in part contemporaneous with quartz. Wolframite crystals are generally in disorder within pyrite or quartz, although it is not uncommon to find wolframite crystals arranged in lines within the quartz, in quartz veins, parallel to pyrite walls or parallel to already deposited wolframite veins.

The mineral suite, pyrite-wolframite-quartz represents the first mineralization period and is limited to the Dike Section. Elsewhere in the world, as at Climax mine in Colorado or Boriana mine in Arizona in the United States for example, there is a general relationship between aplite dikes, pegmatites, or alaskite dikes and tungsten deposition. These dikes are considered to be end-stage products of granitic intrusions. The temperature and pressure of formation of ordinary tungsten minerals are widely variable, but the prevailing conditions may be inferred in part from the associated minerals. It is also known that the pressures and temperatures of most tungsteniferous veins are probably lower than for contact deposits. All types of tungsten deposition are believed to be connected with marginal or
end-stage phases of silicic igneous invasion, but the pressure of formation of the tungsten deposits may not be assumed equal to those in the center of the intrusion.

In the San Cristobal Main Vein it can be concluded that the absence of high temperature minerals in the vein and in the rocks around the Chumpe intrusive and association of tungsten mineralization with sulfide mineralization is an indication that the tungsten deposition occurred at a temperature lower than for hypothermal deposits. Deposition of wolframite appears to have occurred closer to the source of solutions than the rest of sulfides. The high content in FeWO₄, from 68 % to 88 % in the ferberite-wolframite series, indicates that the tungsten mineral was formed in an iron-rich medium with respect to manganese.

After deposition of tungsten mineralization, additional movements reopened the structure along the footwall. This is revealed by the presence of chalcopyrite veinlets filling cracks in pyrite. A layer of quartz-chalcopyrite was deposited along the new reopening in the footwall. Quartz is commonly emplaced between a massive band of chalcopyrite and pyrite. Chalcopyrite is also in variable quantities disseminated within quartz and in some places in direct contact with pyrite. Although uncommon, wolframite crystals are mixed together with chalcopyrite and quartz. These modes of occurrence of chalcopyrite indicate that after the first mineralization period, quartz continued to be deposited along the footwall. The quartz probably was deposited
at the beginning of this period with a last and minor quantity of wolframite crystals, as well as the first chalcopyrite mineralization. All these minerals were deposited concomitantly. After this deposition, chalcopyrite in quartz increased rapidly until nearly pure chalcopyrite formed a well-defined band.

As a part of the second mineralization period, and below the chalcopyrite band, was deposited first a band of dark sphalerite with minor galena, then another band consisting of a mixture of brown sphalerite with galena, and finally a band of galena crystallized in cubes. In the Phyllite, Contact, and Volcanic Sections, there is abundant dark sphalerite whereas in the Dike Section the brown sphalerite is more abundant. The dark sphalerite is commonly mixed with spots of chalcopyrite. Under the microscope, this sphalerite shows abundant chalcopyrite blebs. Undoubtedly, the dark sphalerite is the first sphalerite in the paragenetic sequence. The explanation for a more extensive deposition of dark sphalerite in the western part of the mine than in the eastern part is that at the beginning of the second mineralization period, the solutions, still rich in iron, deposited chalcopyrite and sphalerite, probably giving the sphalerite a high content in iron and a dark color. Chalcopyrite was deposited through the Dike, Phyllite, and Contact sections. Sphalerite started precipitating in minor amounts in the Dike Section, and increased towards the west until the Volcanic Section, where dark sphalerite is the main constituent. The dark sphalerite was
precipitated over a greater distance than the chalcopyrite. Chalcopyrite was deposited closer to the source of solutions than the dark sphalerite, causing a noticeable zoning from the copper zone to the zinc zone. After the deposition of the dark sphalerite, brown sphalerite was deposited mainly in the Dike Section. This sequence suggests that the solutions that precipitated dark sphalerite were of higher temperature than the solutions that precipitated brown sphalerite if the solution source was at depth. This reveals a decrease of intensity conditions from the deposition of pyrite-wolframite-quartz mineralization until the deposition of sulfides. The deposition of chalcopyrite, sphalerite, and galena represent the second mineralization period.

After the deposition of sulfides a renewed movement along the footwall of the structure took place, fracturing mainly the galena and sphalerite bands. After this event, carbonates were deposited along the footwall. These carbonates include broken pieces of sphalerite and galena, which are surrounded by thin layers of carbonates. Carbonates were deposited mainly in layers parallel to the structure and commonly show colloform texture. Very thin layers of sphalerite and marcasite are between carbonate layers. Carbonates also cross the galena and sphalerite mineralization in veinlets. These carbonates veinlets in some places cross the chalcopyrite band. Carbonates represent the third mineralization period. The presence of layered carbonates and marcasite showing evidence of open space deposition, suggests a low
temperature of formation for these minerals. Again, it is interpreted that the temperature decreased in this third mineralization period. We can say that there was a rapidly decreasing rate of temperature since the deposition of minerals in the first period until the third period. Temperature probably transgressed the limits in both directions of mesothermal deposits. All this suggests that each mineralization period was of different composition, temperature, and pressure. This caused an overlapping of the later minerals upon the early minerals, such as brown sphalerite, galena, and carbonates over the pyrite-wolframite-quartz minerals.

In general, the above sequence is found only on those fractures that have not been completely sealed. Narrower, sealed fractures commonly contain only the first or the first and second mineralization periods. Besides, in some places of the Dike Section, the sequence from hangingwall to footwall is found in reverse position, that is to say, the early minerals pyrite-wolframite-quartz are located in the footwall and the sulfides are in the hangingwall. This sequence is because the reopening after the deposition of pyrite-wolframite-quartz was not always along the footwall, but sometimes along the hangingwall and rarely along the middle of the already-formed vein.

After the third mineralization period, as a last event, a strong fault along the footwall of the structure took place. The fault is formed by a zone of gouge of about one meter width.
The fault has brecciated in some places the carbonates and also sphalerite and galena. This fault is present along the whole vein and is used as a mineral guide in exploration and exploitation operations.

Microscopic study of the mineral sequence in the San Cristobal Main Vein gives the same general mineral relations that those seen to naked eye in the mine. But, it also gives a more complete and detailed relationship between all minerals.

1. Barren quartz crosses wolframite and pyrite crystals (Figure 23). This relationship means that between the first and second mineralization periods, quartz continued to be deposited in cracks in the already crystallized wolframite and pyrite, or that quartz is relatively late in the first phase.

2. Chalcopyrite of the second mineralization period fills cracks and replaces early deposition of pyrite. Chalcopyrite is also located along pyrite-quartz contacts (Figures 24 and 25). This relation means that chalcopyrite also penetrated along contacts between pyrite and quartz replacing and filling cracks in pyrite.

3. Sphalerite replaced in small degree the earlier chalcopyrite or filled cracks crossing pyrite and chalcopyrite deposition (Figure 26). Sphalerite also contains chalcopyrite as exsolution blebs (Figure 25).
Fig. 23. Barren quartz crossing wolframite and pyrite crystals. (X60)

Fig. 24. Chalcopyrite filling cracks and replacing pyrite. (X120)
Fig. 25. Chalcopyrite filling cracks in pyrite crystals and also as exolution blebs in sphalerite. (X60)

Fig. 26. Sphalerite crossing the earlier pyrite and chalcopyrite deposition. (X120)
4. Later deposition of galena in veinlets cut and replaced sphalerite (Figure 27), and galena is mixed with sphalerite (Figure 32).

5. Veinlets of a mixture of chalcopyrite, pyrite, and quartz or chalcopyrite alone cut and replaced sphalerite. Chalcopyrite replaces sphalerite, or veinlets cross it (Figures 28 and 29). This means that after deposition of sphalerite and galena a younger deposition of chalcopyrite-pyrite-quartz, took place. Deposition of quartz was long-continued during the three mineralization periods. Two generations of pyrite and chalcopyrite are present.

6. Tetrahedrite is present in small inclusions probably as exsolution products in chalcopyrite and galena and in minor amounts in sphalerite (Figures 30 and 31).

7. Pyrargyrite is present in galena, in small possibly exsolution blebs, and in sphalerite (Figure 32).

8. The last mineralization period represented by carbonates cuts the sphalerite and galena bands and rarely the chalcopyrite band (Figure 33).

9. Supergene chalcocite replaces chalcopyrite, sphalerite, and galena in various degrees. Sphalerite shows abundant alteration coatings of chalcocite. Native silver is also present in chalcocite (Figure 34).
Fig. 27. Galena Veinlets cutting and replacing sphalerite. (X60)

Fig. 28. Veinlet containing pyrite, chalcopyrite, and quartz cuts the earlier sphalerite. Chalcopyrite replaces sphalerite or veinlets cross it. (X60)
Fig. 29. Chalcopyrite crossing and replacing sphalerite. (X120)

Fig. 30. Tetrahedrite in galena as exolution products. (X120)
Fig. 31. Tetrahedrite in sphalerite as exsolution products. (X120)

Fig. 32. Pyrargyrite in small possibly exsolution blebs in sphalerite and galena. Sphalerite is mixed with galena. (X60)
Fig. 33. Carbonate veinlets cut earlier sphalerite. (X120)

Fig. 34. Chalcocite replacing chalcopyrite, sphalerite, and galena in various degrees. (X60)
10. Deposition of sulfides and carbonates is asymmetrical with the exception of the pyrite-wolframite-quartz mineralization (Figure 35).

From the study of polished sections and observations on underground workings, the paragenetic sequence is as follows:

- First
  - Pyrite
  - Pyrite-wolframite
  - Wolframite
  - Wolframite-quartz
  - Quartz

- Second
  - Quartz-chalcopyrite
  - Chalcopyrite
  - Sphalerite (dark)-chalcopyrite
  - Sphalerite (dark)
  - Sphalerite (brown)-galena
  - Galena
  - Chalcopyrite-pyrite-quartz

- Third
  - Carbonates
  - Marcasite

This paragenetic sequence is shown in Figure 36
Fig. 35. Asymmetrical deposition of sulfides. (X60)
### PARAGENESIS OF THE SAN CRISTOBAL MAIN VEIN

September, 1967 — Julio A. Pastor

#### Legend
- Fracturing
- Dissemination

<table>
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<tr>
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<th>SUPERGENE PHASE</th>
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<td>Native Silver</td>
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**FIRST PERIODS OF MINERALIZATION**

**SECOND PERIODS OF MINERALIZATION**

**THIRD PERIODS OF MINERALIZATION**
Zoning

From the study of isopleth maps showing metal distribution and grade we can say that, broadly, the San Cristobal Main Vein exhibits well-defined horizontal and vertical zoning. Three metal zones can be established in the plane of the vein (Fig. 45, p. 102).

**Wolfram zone.** This zone is characterized by the presence of wolfram ore together with pyrite and quartz. There are also chalcopyrite, sphalerite, galena, carbonates, and minor silver minerals. This zone is located in the Dike Section.

**Copper zone.** This zone is characterized by the presence of copper ore which is abundant in comparison with the rest of the vein. The copper zone is located in the Phyllite and Contact sections. There are also sphalerite, galena, silver minerals, and carbonates.

**Zinc zone.** This zone is located chiefly in the Volcanic Section and is characterized by the abundance of sphalerite together with carbonates. Galena and silver minerals also occur there.

The paragenetic study reveals that the pyrite-wolframite-quartz assemblage was first in the deposited sequence and formed the bulk of the vein in the Dike Section. Wolframite, presumably a high temperature mineral, is interpreted to have been deposited near the source than the rest of minerals. It travelled a comparatively short distance and formed the wolfram zone in the dikes area. Pyrite and quartz were deposited over a much greater distance, as far as the Contact Section.
At the beginning of the second mineralization period, ore-bearing solutions deposited chalcopyrite and dark sphalerite in different portions of the vein system. Chalcopyrite was deposited mainly in the Phyllite and Contact sections forming the copper zone, while dark sphalerite was deposited mainly in the Volcanic Section forming the zinc zone. The solutions which deposited brown sphalerite and galena had probably dropped in temperature, because these minerals did not form any particular zone but rather overlapped the early minerals along the whole vein.

The third mineralization period was also an overlapping of carbonates with the early minerals. The major concentration of carbonates is in the Volcanic Section. Carbonates increase towards the west, whereas sphalerite decreases noticeably in this same direction. The vein near the limestone-volcanic rocks contact is filled with nearly pure carbonates.

This generalized picture reveals that zoning is consistent with paragenetic sequence. However, as mentioned above, sphalerite, galena, and carbonates overlap the early minerals. This must be due to a change in the prevailing environment at the time of deposition. With declining activity within the intrusive, its range of influence would decrease and an environment suitable to the deposition of the later minerals, such as brown sphalerite, galena, and carbonates, would move closer to the intrusive. These later minerals overlapped the early deposition of pyrite-wolframite-quartz and also overlapped the deposition of chalcopyrite and dark sphalerite.
Figure 18 shows that horizontal zoning is well-defined along the San Cristobal Main Vein whereas vertical zoning is less well-defined. Vertical zoning may be ill-defined because development has not gone deep enough to reveal it. However, in the section showing isopleths of copper assays (Fig. 14), anomalies have a tendency to form a copper zone below the 500 level towards the dikes area. Besides, in the sections showing Zn/Pb and Cu/Ag ratios (Figures 19 and 20) it may be noted that from the axis of high ratios, concentrations of zinc and copper decrease both to the sides and above. This reveals locally a horizontal zoning as well as a vertical zoning, although in gross aspect only horizontal zoning is well-defined.

Controls of Mineral Deposition

Mineral deposition was affected by structural and lithologic controls as well as pressure, temperature, and composition of the hydrothermal solutions.

Structural Controls

The whole San Cristobal structure in itself was a gross structural control for the movement of solutions underground. This vein system is a general control for the formation of the whole vein, but there is also another local control within the structure. The study of mineral and metal distribution reveals that horizontal zoning changes smoothly from east to west, with the exception of the Contact Section. This section constitutes
a great dumping of pyrite and chalcopyrite that took place in the highly shattered ground which is peculiar to this area. As was already mentioned, the phyllite-volcanic rock contact is a junction between competent and incompetent rocks. In this area, volcanic rocks were forced during folding to ride over the underlying phyllites. Shearing was set up on each side of the contact. The incompetent phyllites responded to these stresses largely by folding and flowage, whereas the more competent volcanic rocks shattered. Mineralizing solutions travelling from east to west encountered a relatively open area in the contact zone. As there was a greater surface area available for passing of the solutions, the amount of deposition and reaction of solutions with wall rocks increased, changing the composition of solutions and decreasing the horizontal rate of flow by depositional constriction. These factors acting together appear to have caused a dumping of minerals, such as pyrite and chalcopyrite, from the solutions. Dark sphalerite was not precipitated. Another control for the variation of deposition of minerals, was the presence of pinches and swells created by movements along the San Cristobal structure separating the hangingwall from the footwall. Certainly the ore-bearing fluids migrated along the more open parts of the structure and were deflected around the tighter zones.

Lithologic Control

One of the reasons for ore deposition is that of chemical changes in the system, such as changes in pH due to reactions
Between the ore-bearing solutions and the host rocks. Besides the apparent influence of the wall rock in the zoning along the San Cristobal Main Vein, some other aspects will be mentioned. Deposition of minerals in volcanic rocks formed well-defined veins. In phyllites veins are ill-defined possibly due to escape of solutions along bedding planes. Although some local and small ore shoots have been formed along the bedding planes, the largest barren zone is located in the Phyllite Section. This barren-ness was probably due to the plasticity of the phyllites. Phyllites in the Dike Section are more competent than they are in the Phyllite Section because of the influence of the Chumpe intrusive which silicified the rock. Silicification made the phyllites more competent and more receptive to the introduction of fluids and deposition of ore. In other words, silicification was the ground preparation for further deposition of minerals. Silicification decreases to the west and is almost nil in the volcanic rocks. Partly as a result of silicification of phyllites in the Dike Section, veins in this area are well-mineralized. Phyllites in the Contact Section were also well-mineralized, apparently due to the influence of shearing which increased the permeability of the rock. This too was a process of ground preparation.

In conclusion, we can say that phyllites were well-mineralized where ground preparation took place, including silicification in the Dike Section and increase of structural permeability
in the Contact Section. In the Phyllite Section, where there was no ground preparation, lesser mineralization occurred.

**Alteration**

Hydrothermal alteration products depend upon the chemical and physical characteristics of the original rock and of the invading fluids and the temperature and pressure at which the reactions took place. When the wall rocks are unstable in the presence of hydrothermal fluids or of ore-bearing solutions, physical and chemical changes take place in the rocks in order that they reach equilibrium under the prevailing conditions. Resulting alteration is different at various distances into the walls from the vein because conditions of temperature and chemistry are usually different at different distances in the envelopes. These different types of alteration are likely to have been produced simultaneously (Sales and Meyer 1948, 1950). Wall rocks along the San Cristobal Main Vein are phyllites and volcanics. Alteration products found in these rocks are given below.

**Alteration of Phyllites**

Fresh phyllites, which are black in color, already contained sericite, chlorite, pyrite, quartz, and clay minerals in their composition (Figure 37). Hydrothermal alteration variably increased the amounts of these minerals and bleached the rock. Fresh phyllites show foliation very clearly, whereas the foliation has been somewhat destroyed in altered phyllites. Alteration
of phyllites is of three different types, each type forming a characteristic zone.

**Silicification zone.** This zone is adjacent to the vein. Thickness is about two meters in the Dike Section, but it diminishes towards the west. In this zone there is also a slight sericitization and argillization of phyllites between quartz grains (Figure 38). Pyrite dissemination is also present in this zone.

**Sericitization-argillization zone.** This zone is between 3 and 5 meters wide, but diminishes towards the west. This zone is characterized by an argillic and sericitic alteration (Figure 39).

**Chloritization zone.** This zone has between 7 and 14 meters wide, but increases towards west. It is characterized by the presence of abundant chlorite (Figure 40). There is also a slight sericitization and argillization in this zone.

Analyses of the composition of fresh and altered phyllites on the 500 level in the Dike Section have been run in order to see the chemical changes in rock composition. The results are shown in Table IV. A graphic representation of the changes in composition of the phyllites is shown in Figure 44. In this graph we note that release of magnesium by destruction of chlorite occurred mainly in the sericitization-argillization zone, with the maximum content of magnesium just in the area between the chloritization and sericitization-argillization zones. Also, the increase of iron undoubtedly affected the specific gravity of the
rock, as it is noted in the graph. This means that the iron introduction largely compensated the losses occurred in the phyllites in the area mentioned above. This also means, for example, that the strong drop in the percentage of SiO₂ is relative as a consequence of iron introduction.

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Fig. 37. Fresh phyllites showing foliation. (X60)

Fig. 38. Phyllites showing silicification. (X nicols.) (X60)
Fig. 39. Sericitization and argillization of phyllites. (X nicols.) (X60)

Fig. 40. Strong chloritization of phyllites. (X60)
Alteration of Volcanic Rocks

In fresh volcanic rocks, feldspars are slightly altered showing euhedral crystals (Figure 41). Fresh volcanic rocks are light grey in color. Alteration of volcanic rocks shows only two zones, the sericitization-argillization zone which is yellowish white in color and the chloritization zone which is green. The silicification zone is either not present or it is very narrow.

**Sericitization-argillization zone.** This zone is between 2 and 3 meters wide. It is characterized by a nearly complete destruction of feldspars, a very slight silicification and the presence of sericite and kaolin (Figure 42). Disseminated pyrite and slight carbonatization are noted close to the vein.

**Chloritization zone.** This zone, which is the largest one, is between 30 and 47 meters wide with chlorite decreasing gradually away from the vein. There is also some destruction of feldspars (Figure 43).

Results of analyses of the composition of fresh and altered volcanic rocks are shown in Table V.

A graphic representation of the changes in composition of the volcanic rocks is shown in Figure 44. In this graph, a rapid decrease in silica, lime, and soda content from the fresh rock toward the vein and across the chloritization and sericitization-argillization zones is noted. This decrease, greater in the volcanic rocks than in the phyllites, is due to a greater quantity of feldspars in the volcanic rocks than in the phyllites.
Plagioclases were hydrolyzed forming clay minerals and releasing silica, calcium, and sodium. Silica increases noticeably near the vein in the phyllites due to hydrothermal silicification.

Table V
Analyses of Fresh and Altered Volcanic Rocks

<table>
<thead>
<tr>
<th></th>
<th>Silicification Zone</th>
<th>Ser.-Arg. Zone</th>
<th>Chloritization Zone</th>
<th>Fresh Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5 meter from vein</td>
<td>3 m.</td>
<td>4 m.</td>
<td>20 m.</td>
</tr>
<tr>
<td>SiO₂</td>
<td>59.0</td>
<td>57.3</td>
<td>57.2</td>
<td>64.2</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.6</td>
<td>14.7</td>
<td>10.5</td>
<td>16.8</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.7</td>
<td>2.3</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Fe</td>
<td>8.3</td>
<td>8.2</td>
<td>12.8</td>
<td>4.7</td>
</tr>
<tr>
<td>MgO</td>
<td>0.44</td>
<td>0.32</td>
<td>2.20</td>
<td>1.18</td>
</tr>
<tr>
<td>CaO</td>
<td>0.31</td>
<td>0.33</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td>Na</td>
<td>0.30</td>
<td>0.28</td>
<td>0.23</td>
<td>0.25</td>
</tr>
<tr>
<td>K</td>
<td>1.95</td>
<td>2.24</td>
<td>0.28</td>
<td>2.22</td>
</tr>
<tr>
<td>CO₂</td>
<td>6.2</td>
<td>8.7</td>
<td>4.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Spec. Gravity</td>
<td>2.85</td>
<td>2.77</td>
<td>2.50</td>
<td>2.58</td>
</tr>
</tbody>
</table>

It is also noted that the magnesium content decreases slightly in the chloritization zone and more rapidly in the sericitization-argillization zone. This means that the ferromagnesian minerals of the fresh volcanic rocks were altered to chlorite releasing only minor magnesium and iron. In the sericitization-argillization zone, magnesium content drops rapidly
Fig. 41. Fresh volcanic rock showing euhedral to anhedral feldspars. (X nicols.) (X60)

Fig. 42. Sericitization and argillization of the volcanic rock showing complete destruction of feldspars. (X nicols.) (X60)
Fig. 43. Chloritization of volcanic rock showing partial destruction of feldspars (white spots). (X60)
CROSS SECTION OF THE SAN CRISTOBAL MAIN VEIN
SHOWING PHYSICAL AND CHEMICAL CHANGES THROUGHOUT THE ZONE OF ALTERATION
HORIZONTAL SCALE 1:5000

September 1967 — Julio A. Pastor

Figure 44
due to release of even more magnesium near the vein by destruction of chlorite.

Alteration of ferromagnesian minerals releases magnesium and iron, but Figure 44 shows in general an increase of iron from the rock toward the vein. This increase is due to a strong dissemination of pyrite in veinlets and spots which replace the wall rock. This pyrite was probably added to the pyrite formed by release of iron in the presence of sulfur in the fluids.

Further alteration affected the orthoclase, which with addition of potassium, formed sericite near the vein. Alumina content is higher away from the vein than near the vein. Releasing of silica, calcium, and sodium, and the formation of clay minerals would increase the proportion of alumina, but due to the addition of iron from the solutions, the proportion of alumina decreased.

It is also important to note the addition of carbon dioxide near the vein. This addition is greater in the volcanic rocks. The presence of carbon dioxide is explained by the formation of carbonates (carbonatization) with calcium, magnesium, and iron released from the wall rock fixed by carbon dioxide from the solutions. In Figure 44, a slight increase in calcium, iron, and magnesium close to the vein are noted.

Specific gravity is also affected by alteration of the rock. Alteration of the feldspars and ferromagnesian minerals of the rock with the consequent release of silica, calcium, sodium,
magnesium, and iron makes the bulk rock lighter, diminishing its specific gravity. In the phyllites, specific gravity decreases in the sericitization-argillization zone, but increases in part of the chloritization zone, whereas in the volcanic rocks specific gravity increases in the sericitization-argillization zone and in part of the chloritization zone. This is due to an introduction of iron in these areas.

Comparing alteration in phyllites with alteration in volcanic rocks, it is noted that silicification is about two meters wide in the Dike Section. The width of the silicification zone diminishes toward the west; in the Volcanic Section, it is very narrow or absent.

The sericitization-argillization zone is wider in the eastern part of the mine than it is in the western part. In the phyllites, this zone is about 3-5 meters, whereas in the volcanic rocks it is about 1-3 meters and in some places is nil. This variation in width suggests a drop in temperature of the hydrothermal fluids from east to west.

The chloritization zone is wider in the western part of the mine than it is in the eastern part. In the Dike Section, the chloritization zone is about 7-14 meters, whereas in the Volcanic Section it is from 30 to 47 meters wide. The chloritization zone is wider as one goes from east to west. In some places in the Volcanic Section it is against to the vein, being the only zone of alteration present.
Guides to Ore

Guides to ore in the San Cristobal Main Vein are the alteration of wall rocks and the presence of faults.

Alteration Guide

Alteration zones are a guide to ore deposits. The presence of the chloritization zone followed inward by the sericitization-argillization zone indicates the presence of a vein. The alteration zones are not necessarily guides to immediately adjacent ore, because hydrothermal fluids which have passed along fissures have universally altered the wall rocks although no ore minerals may have been deposited locally. The only difference is that in this latter case the alteration zones are thinner.

Structural Guide

Along the footwall of the San Cristobal Main Vein there is a well-defined post-mineral fault. This fault indicates the presence or the nearness of the vein. This guide is not always trustworthy, because there are other faults near and parallel to the vein although they are commonly thinner.

Oxidation and Supergene Enrichment

Limonite is present along the outcrop of the San Cristobal Main Vein. Pyrite, which is present in the vein as a gangue mineral and as disseminations in the wall rock, was attacked by meteoric waters. Iron sulfate and sulfuric acid were formed.
Limonite was the final product of the iron sulfate in the oxidation zone. Sulfuric acid attacked chalcopyrite and formed soluble copper sulfate which migrated downward to the phreatic zone to be deposited as chalcocite. Chalcocite replaced hypogene chalcopyrite, sphalerite, and galena, and filled cracks in these minerals. Chalcocite is present mainly in the Contact Section from the 370 level upward. Enrichment was not intense. Chalcocite is present mainly as thin coatings replacing chalcopyrite, sphalerite, and galena, and also filling cracks in these minerals.

Native silver is also present in minor quantities with chalcocite. Native silver is found mainly in the Contact Section and near the surface.

**Formation of the San Cristobal Main Vein**

This study of the San Cristobal Main Vein has suggested the sequence of events which formed the vein. These events are discussed in the following paragraphs.

**Formation of the Pre-mineral Structure**

Longitudinal bending of the Chumpe Anticline produced tensional fractures transverse to its axis. One of these fractures was the pre-mineral structure of the San Cristobal Main Vein. This structure was refracted at the phyllite-volcanic rock contact. Movements along this pre-mineral structure displaced the alaskite dikes in the zone of the axis of the Chumpe Anticline. Fracturing and pre-ore movements were succeeded by mineral deposition.
Source of Mineralizing Solutions

Migration of the ore-bearing fluids is controlled by structure. Structure determined the avenues of permeability or paths along which the ore solutions travelled. The study of metal distribution, metal ratios, mineral paragenetic sequence, and zoning along the San Cristobal Main Vein indicates that the location of the source of the mineralizing solutions, or at least the main channelway for these solutions, was below the dikes area, or below the Chumpe intrusive, more or less 900 meters down vertically from the 500 level or 1,300 meters from the actual surface. The Chumpe intrusive must be part of a bigger underlying intrusive from which the ore-bearing solutions were developed.

Direction of Flow of Mineralizing Solutions

From the indicated main channel of mineralizing solutions, approximately 900 meters below the 500 level, secondary channels, probably either in a radial pattern or dendritic as with the branches of a tree, were probably formed which permitted invasion of the whole San Cristobal structure with mineralizing solutions (Figure 45). Mineralizing solutions probably started depositing their load about 100 meters below the 500 level, an assertion based on metal distribution along the San Cristobal Main Vein and extension down dip of the metal anomalies. No assumptions have been made about the existence of new anomalies below the 500 level and possibilities of finding more ore below this inferred limit are unknown.
DIRECTION OF FLOW OF MINERALIZING SOLUTIONS ALONG THE SAN CRISTOBAL MAIN VEIN
SCHEMATIC REPRESENTATION IN AN IMPORTANT POSITION

LONGITUDINAL VERTICAL SECTION
Looking N 37°W

LEGEND

- Direction of flow in the San Cristobal Mine
- Dashed line indicates direction of flow away from the San Cristobal Mine
- Limits of metal zones
- Interbed limits of metal zones

- Tungsten zone
- Copper zone
- Zinc zone

Figure 45
Periods of Mineralization

The San Cristobal Main Vein was formed through three successive periods of mineralization.

First period. It is during this period that solutions invaded the San Cristobal structure and deposited the mineral assemblage pyrite-wolframite-quartz, mainly in the Dike Section. Solutions which carried this mineral assemblage probably were differentiated from a deep seated quartz monzonite intrusive. These solutions may have been an intermediate stage between the rest magma which formed the acidic dikes and the solutions which later carried sulfides. Wolframite was probably deposited not far from the source and around the dikes area because of its apparent high temperature of formation. Pyrite and quartz are abundant in this area, too, but they are also present along the whole vein, although in minor amounts. After the deposition of these minerals, the structure was reopened mainly along the footwall of the already-formed vein. The Siberia 1 Vein, a hangingwall split of the San Cristobal Main Vein, was mineralized in the first period. There is no evidence of reopening on this structure after the first period of mineralization.

Second period. The second mineralizing period is represented by the sulfides chalcopyrite, sphalerite, galena, and minor amounts of tetrahedrite and pyrargyrite. These sulfides were deposited mainly along a reopening in the footwall of the already formed pyrite-wolframite-quartz vein and formed
asymmetrical bands with the paragenetic sequence chalcopyrite, sphalerite, and galena. Quartz deposition was long continued and was the nexus of the first and second mineralization periods. Quartz was the first mineral deposited in the second period and the last mineral deposited in the first period. Evidence for this relationship is that quartz contains disseminated wolframite crystals deposited at the end of the first period and then disseminations of chalcopyrite deposited at the beginning of the second period.

The presence of sulfides of the second period overlapping minerals of the first period suggests a decrease in activity of the underlying intrusive, possibly a drop in temperature of the solutions of the second period. Sulfides were deposited not only in the dikes area but also far from the source to the west and to the east forming the chalcopyrite and sphalerite zones. The degree of mineralization and the formation of zones from the dikes area eastward as far as the Oyama-Triunfo mine is little known. The Siberia 1 Vein was not mineralized with sulfides during this second period, probably due to lack of reopening of the structure, although there are a few places in the western part of the Dike Section where this vein contains sulfide mineralization.

Metal zones to the west of the dikes area are those of copper in the Phyllite and Contact Sections and zinc in the Volcanic Section. If lithologic and structural symmetry prevails and the center of mineralization imput has been successfully
interpreted, then this same distribution of metals should be present to the east of the dikes area as far as the Oyama-Triunfo mine. Although this mine is inaccessible at present, some old information about sampling reveals the presence of copper and silver ores. After the deposition of minerals of the second period, a new reopening along the footwall of the vein took place, crushing the sphalerite and galena mineralization.

Third period. The third period of mineralization is formed almost completely by carbonates with minor amounts of sphalerite, galena, and marcasite. Carbonates were deposited in layers parallel to the structure or in thin layers around pieces of sphalerite or galena. After the deposition of carbonates, a new movement along the footwall of the vein took place. This fault has brecciated the carbonates, sphalerite, and galena.

Classification of the Deposit

Mineral assemblages, ore textures, and alteration products in wall rocks place the San Cristobal Main Vein in the classification of a mesothermal deposit according to Lindgren's classification of hydrothermal ore deposits (Lindgren 1933). Many general features of the deposit were taken into consideration in classifying the deposit as mesothermal.

One means of identifying mesothermal deposits is by the absence of typically hypothermal or epithermal minerals. In the case of the San Cristobal Main Vein, typically hypothermal minerals such as tourmaline, topaz, and sillimanite are absent.
In the same way, typically epithermal minerals such as zeolites and precious metal sulfosalts are absent.

In general, the presence of banded base metal vein controlled sulfides with minor amounts of certain base metal sulfantimonides and sulfarsenides is characteristic of mesothermal deposits. In the San Cristobal Main Vein, the assemblage chalcopyrite-sphalerite-galena with minor amounts of tetrahedrite and pyrargyrite is in accord with the characteristics mentioned above. It is also not uncommon to find tungsten minerals in mesothermal deposits. Tungsten-bearing solutions appear to have been originated in the later differentiation of the underlying quartz monzonite intrusive. Tungsten-bearing solutions also brought abundant pyrite. Consequently the temperature of formation of the deposit was probably higher at the initial stage than in the later phases.

Pyrite, quartz, and carbonates are also common in mesothermal deposits. In the San Cristobal Main Vein we find these gangue minerals but the carbonates and marcasite show evidence of colloidal deposition. This type of deposition reflects moderate to low temperature and free circulation at the end stage of mineralization. Vugs are also present, but this is not a characteristic of the deposit.

Pyrite and quartz of the first mineralization period slightly replaced or permeated the wall rock as disseminated veinlets and specks. This is conspicuous in the Dike Section,
where in some places we find ribbon structures as a consequence of repeated reopenings which give the appearance of shear zones. These ribbon structures were formed mainly in the Dike Section where the phyllites were partially replaced by pyrite or quartz. Banding of quartz and pyrite is a common occurrence in mesothermal deposits (Park and MacDiarmid 1964).

In mesothermal deposits, unmixing can be of considerable textural importance. In the microscopic study of the paragenetic sequence for the San Cristobal Main Vein, two important examples of unmixing were found. Chalcopyrite blebs occur in dark sphalerite in typical exolution relationships. The temperature determined by Buerger for this exolution point is about 350° C. The other example of unmixing is pyrargyrite in galena, the exolution temperature of which is much lower.

Further, the repeated association of certain minerals in an ore deposit have some value as a geological thermometer. For example, the association chalcopyrite-sphalerite-galena-tetrahedrite is considered to be formed at an intermediate temperature. In the same way, the association marcasite-siderite-rhodochrosite is considered to be deposited at low temperature. Again, with this criteria we see that the San Cristobal Main Vein was formed from an intermediate to a low temperature for the sulfides and carbonates respectively. Although tungsten minerals are commonly formed at high temperatures, it may be that their deposition in the San Cristobal Main Vein was at a lower temperature, perhaps at a temperature between hypothermal and mesothermal zones.
This assumption is based in the fact that there are no other characteristic high temperature minerals associated with tungsten minerals.

Alteration products of the wall rocks are characteristic of mesothermal deposits. In the San Cristobal Main Vein, silification and pyritization are close to the vein in the phyllites, whereas in the volcanic rocks, pyritization and carbonatization are characteristic close to the vein. Next to these zones is the sericitization-argillization zone, which varies from 5 meters in the eastern part of the mine in phyllites to one meter or absence in the western part of the mine in volcanic rocks. This zone is surrounded by a chloritization zone which varies from 7 meters in the eastern part of the mine to 47 meters or more in the western part. We know that sericite and quartz are the most persistent and abundant alteration minerals in mesothermal deposits. Chlorite is more characteristic of epithermal deposits, but it may also be formed next to sericite in the outer fringes of mesothermal deposits.

Another point which must be considered is the relation of the vein to the intrusive that appears to have been the source of mineralizing solutions. Generally, epithermal deposits are not closely related to the intrusives which originated their mineralization, because of the long distance the solutions have to travel before depositing their load. Contrarily, hypothermal deposits generally are closely related to the intrusive which was
the source of ore-bearing solutions. The San Cristobal Main Vein is not closely spatially related to the intrusive which is the source of the mineralizing solutions. The presence of alaskite dikes and the small Chumpe intrusion, and other small adjacent stocks, indicate the existence of a major underlying intrusion, of which they are apophyses or derivatives which generated solutions which formed the actual mineralized veins.

In addition, it is known that epithermal deposits generally are associated with geologically young volcanic rocks. This is true in Peru, Mexico, the United States, and elsewhere. In the same way, hypothermal deposits are associated mostly with Precambrian rocks. The San Cristobal Main Vein is associated with rocks of Devonian, Permian, Triassic, and Jurassic age.

Bearing in mind all these characteristics of the San Cristobal Main Vein and that the temperature of formation of the deposit has no fixed limits but rather changes over a long time and space range, we can conclude the following. Mineralization of the San Cristobal Main Vein was formed at different decreasing temperatures. Deposition of pyrite-wolframite-quartz during the first mineralization period probably took place at high temperature, but probably only slightly over 300° C and restricted to the dikes area. The assemblage chalcopyrite-sphalerite-galena of the second mineralization period was deposited at an intermediate temperature between 200° C and 300° C and located along the whole vein and forming the copper and zinc-lead zones. The third and
last of the three continuous mineralization periods formed mainly carbonates, deposited at temperatures less than 200° C and restricted mainly to the Volcanic Section. We know that the temperature divisions are only approximate figures. In our case for example, deposition probably took place between 200° C and 300° C, but early and late deposition may transgress these limits. From this point of view we can establish that the San Cristobal Main Vein has more characteristics of a mesothermal deposit with a higher temperature at the first stage of mineralization and a lower temperature at the end stage. Therefore, by Lindgren's classification of hydrothermal ore deposits, the San Cristobal deposit is mesothermal.
CONCLUSIONS

Mineralization in the San Cristobal mineral district is of two different types, namely veins and mantos. Veins are emplaced transverse to the axis of the Chumpe Anticline, whereas mantos are located on the limestone side of the Paria limestone-Mitu volcanic rocks contact.

The San Cristobal Vein system is one of the long fault structures that crosses the Chumpe Anticline. The Chumpe Anticline forms part of the Yauli Dome, a major regional structure.

The axial zone of the Chumpe Anticline is intruded by a quartz monzonite intrusion and two major alaskite dikes parallel to the axis of the anticline.

Mineralization of the San Cristobal Main Vein is of three different types: tungsten mineralization alone, combined metals with tungsten, and combined metals without tungsten.

There is a well-defined horizontal zoning in the mine from east to west consisting of a Tungsten zone located in the Dike Section, a Copper zone located in the Phyllite and Contact sections, and a Zinc zone located in the Volcanic Section.

Vertical zoning is less well-defined, probably because development has not gone deep enough to reveal it.
Paragenetic sequence in the San Cristobal Main Vein from oldest to youngest is: pyrite, wolframite, quartz, chalcopyrite, dark sphalerite, brown sphalerite, galena, carbonates, and marcasite.

The tungsten content in the dikes area increases upward and the richest area is located above the 170 level.

The Prosperidad Vein, which is the structure dipping opposite to the San Cristobal Main Vein, is of particular interest for future exploration beyond the San Cristobal mine. Both structures tend to join in a zone below the Chumpe intrusive where the inferred source of ore-bearing solutions is located.

Alteration of wall rocks in the San Cristobal Main Vein is of three different types forming zones away from the vein which include the silicification, the sericitization-argillization, and the chloritization zones.

The source of mineralizing solutions or at least their main channel, is indicated by zoning relationships to be located 1,300 meters from the present surface in the area below the Chumpe intrusive. From this main channel, secondary channels invaded the whole structure in a dendritic pattern.

Lapping of late minerals over early minerals indicates a change in temperature of the ore-bearing solutions due to a decrease of activity of the intrusion which generated the ore fluids.
Mineral assemblages, ore textures and alteration of wall rocks place the San Cristobal Main Vein in the mesothermal classification.
RECOMMENDATIONS

Zinc and copper ores should be sought below the 500 level along the Volcanic and Contact sections. Study of contours of zinc and copper assays show an extension down dip of the zinc and copper anomalies in this area.

Concentrations of copper should be sought below the 430 and 500 levels along the area between the eastern part of the Phyllite Section and the western part of the Dike Section. Extensions of copper anomalies indicate a concentration of this metal below this area.

Continue the exploration and development of the area below the 370 level in the Dike Section for combined metals probably with some tungsten ore.

Seek wolfram ore in the richest zone located above the 170 level up to the surface in the dikes area, although this area appears to have been partially mined out.

Direct exploration for wolfram ore in the levels above and below the 370 level in the Siberia 1 Vein.

Explore for ore in the area east of the Dike Section as far as the Oyama-Triunfo mine. Study of the direction of flow of mineralizing solutions shows that this zone may well have been mineralized too. An exploration model should consider this area as the eastern half of the whole mineralized structure.
Direct exploration outside of the San Cristobal mine.

Geologically, the Prosperidad Vein is the most important because of its similarity to the San Cristobal Main Vein in structural characteristics and nearness to the Chumpe intrusive.
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LONGITUDINAL VERTICAL SECTION ALONG THE SAN CRISTOBAL MAIN VEIN SHOWING WORKINGS WITH LOCATION OF CROSS SECTIONS, DINES AND RESULTS OF SAMPLES OF TUNGSTEN MINERAL

Line of Section: N 55° E
Looking: N 37° W
Scale: 1: 2000
September 1967 — Julio A. Pastor

Figure 12

LONGITUDINAL VERTICAL SECTION ALONG THE SAN CRISTOBAL MAIN VEIN SHOWING WORKINGS WITH LOCATION OF CROSS SECTIONS, DINES AND RESULTS OF SAMPLES OF TUNGSTEN MINERAL

Line of Section: N 55° E
Looking: N 37° W
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Line of Section: N 55° E
Looking: N 37° W
Scale: 1: 2000
September 1967 — Julio A. Pastor

Figure 12
Figure 13. JULIO A. PASTOR, GEOLOGY THESIS, 1970
LONGITUDINAL SECTION SHOWING CONTOURS OF COPPER ASSAYS ALONG THE SAN CRISTOBAL MAIN VEIN

Figure 14

JULIO A. PASTOR, GEOLOGY THESIS, 1970
Chumpe Lake

Trend of high concentration Aloskite dikes

Figure 15

LONGITUDINAL SECTION SHOWING CONTOURS OF ZINC ASSAYS ALONG THE SAN CRISTOBAL MAIN VEIN

Line of Section N 53° E

Looking N 37° W

Scale 1:2000

Contour Interval: 1.0% Zn. East Side 5.0% Zn. West Side

September 1967 Julio A. Pastor

JULIO A. PASTOR, GEOLOGY THESIS, 1970
Figure 16: Longitudinal Section Showing Contours of Lead Assays Along the San Cristobal Main Vein

LEGEND

- Contour Interval: 0.5% Pb.
- Line of Section
- Trend of high concentration
- September 1967 Julio A. Pastor
- Alaskite dikes

JULIO A. PASTOR, GEOLOGY THESIS, 1970
ELEVATION ABOVE SEA LEVEL

Chumpe Lake

Adit 6

METERS 5000

Adit 7

NO ASSAY DATA IN THIS AREA

LEVEL

120

170

4900 4900

520

270 LEVEL

LEVEL

4800 4800

430

470

400 LEVEL

4700 4700

LONGITUDINAL SECTION ALONG THE SAN CRISTOBAL MAIN VEIN SHOWING ZONES OF HIGH CONCENTRATION FOR DIFFERENT METALS

LEGEND

Tungsten Zones 1.0 % WO3

Copper Zones 2.0 % Cu.

Zinc-Lead Zones 5.0 % Zn.Pb

Looking Aloskite Dikes

Figure 8

JULIO A. PASTOR, GEOLOGY THESIS, 1970
LONGITUDINAL SECTION SHOWING CONTOURS OF ZINC-LEAD RATIO ALONG THE SAN CRISTOBAL MAIN VEIN

Figure 19

JULIO A. PASTOR, GEOLOGY THESIS, 1970
LONGITUDINAL SECTION SHOWING CONTACTS OF VEIN WIDTH ALONG THE SAN CRISTOBAL MAIN VEIN

Line of Section: N 52° E
Looking: N 52° W
Scale: 1:2000
Contour Interval: 0.5 meters, East Side 10 meters, West Side 5.0 meters

Trend of high width Alaskite dikes

Figure 21

JULIO A. PASTOR, GEOLOGY THESIS, 1970
LONGITUDINAL SECTION ALONG THE SAN CRISTOBAL MAIN VEIN SHOWING CONTOURS FOR DIP AND ZONES OF STRIKE CHANGE.

Line of Section: N 53° E
Looking: N 37° W
Scale: 1:2000

Limits of strike change

September 1967 Julio A. Pastor