GEOLOGICAL STUDY ON THE POLYMETALLIC ORE DEPOSITS IN THE QUECHISLA DISTRICT, BOLIVIA

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Abstract

Geology of the Quechisla district located in the most southern part of a metallic mineralization belt along of the Eastern Cordillera of bolivian Andes consists of the Ordovician, Cretaceous and Tertiary systems with some igneous intrusions such as quartz porphyry and dacite. There are many polymetallic ore deposits of hydrothermal fissure filling type such as Tasna, Chorolque, Siete Suyos, Animas, Gran Chocaya, Tatasi, San Vicente and Asunta etc. in the district. They occur in Ordovician slate and sandstone, Miocene conglomerate and dacitic pyroclastics such as tuff, tuff breccia and lava, and dacite stock, and are composed of many ore minerals of tin, tungsten, zinc, antimony, bismuth, silver and copper etc. such as cassiterite, wolframite, pyrite, marcasite, arsenopyrite, pyrrhotite, chalcopyrite, galena, sphalerite, wurtzite, stannite, kesterite, hocartite, canfieldite, argyrodite, roquesite, luzonite, tetrahedrite, bismuthinite, stibnite, native bismuth, native antimony, dyscrasite, electrum, hessite, tetradymite, franckeite, aikinite, cosalite, gustavite, stephanite, pyrargyrite, miargyrite, polybasite, andorite, ramdohrite, fizelyite, diaphorite, aramayoite, bournonite, jamesonite and boulangerite etc. associated with gangue minerals such as quartz, tourmaline, kaolinite, gibbsite, sericite, siderite, calcite, aragonite, smithsonite, barite, gypsum, alunite, natroalunite, minamiite, jarosite, apatite, vivianite, variscite, strengite and monazite etc. These minerals have been formed as the results of successive mineralizations as follows: tin-quartz mineralization (cassiterite, quartz and tourmaline), tungsten-bismuth mineralization (wolframite, bismuthinite and quartz), tin-pyrite mineralization (cassiterite, pyrite and quartz), tin-silver mineralization (stannite, silver bearing sulfosalt minerals and pyrite) and silver-lead-zinc mineralization (silver sulfosalt minerals, galena and sphalerite) in order from early to late stages. Among them, the tin-quartz mineralization is recognized as most essential one in the Chorolque mine. Both the tin-pyrite and tin-silver mineralizations are found obviously in the Siete Suyos and Animas mines, and while in the Gran Chocaya mine the silver-lead-zinc mineralization is principal. The ore deposits of the Tatasi and San Vicente mines are mainly formed by the tin-silver and silver-lead-zinc mineralizations, respectively. Cassiterite is crystallized by both the tin-quartz and tin-pyrite mineralizations, assembling with quartz, tourmaline and slight amounts of pyrite and stannite, and pyrite, quartz and small quantities of arsenopyrite, sphalerite and stannite, respectively. Wolframite is usually formed by the tungsten-bismuth mineralization, intimately associating with bismuthinite, quartz and small amounts of arsenopyrite, pyrite and stannite. Stannite, franckeite and hocartite are generally produced by the tin-silver mineralization associating with pyrite, sphalerite and arsenopyrite. Silver sulfosalt minerals such as stephanite, pyrargyrite, miargyrite, polybasite, andorite, fizelyite, diaphorite and aramayoite are crystallized by the tin-silver and silver-lead-zinc mineralizations as drusy minerals, mainly assembled with pyrite, galena, sphalerite, bournonite, jamesonite, boulangerite, stannite and quartz etc. as seen in the Animas and Gran Chocaya mines. Tetrahedrite also occurs as a silver bearing mineral during the tin-silver and the silver-lead-zinc mineralizations at the Chorolque and San Vicente mines, respectively. By such mineralizations as described above, there is often recognized zonal arrangement of ore minerals. For instance, at the Chorolque mine, there is clear observed mineral zoning of cassiterite-quartz-tourmaline assemblage by the tin-quartz mineralization, wolframite-pyrite-bismuthinite-arsenopyrite-sphalerite assemblage by the tungsten-bismuth mineralization and stannite-tetrahedrite-chalcopyrite-sphalerite-pyrite-galena assemblage by the tin-silver mineralization in order from the center of mining area toward its outer side. Also, in the Siete Suyos and Animas mining area, there are recognized distinctly zonal arrangement of minerals such as cassiterite-pyrite-quartz zone formed by the tin-pyrite mineralization, stannite-franckeite-hocartite-silver sulfosalts-pyrite zone by the tin-silver mineralization and silver sulfosalts-sphalerite-galena-lead antimony sulfosalts zone by the silver-lead-zinc mineralization from the Colorada vein, which is thought to be a center of the mineralization in the area, toward outer side.

Such zonal arrangement of minerals as mentioned above is also proved by data of homogenization temperature and salinity in NaCl equivalent concentration of liquid inclusion in quartz. For example, in the Siete Suyos and Animas mining area, homogenization temperatures and salinities of liquid inclusions are 228° to 379°C and 4.7 to 11.9 wt% NaCl (tin-pyrite zone), 178° to 279°C and 3.8 to 4.9 wt% NaCl (tin-silver zone), and 176°-268°C and 4.6-5.2 wt% NaCl (silver-lead-zinc zone), respectively. Also, at the Tatasi mine, homogenization temperatures and salinities of fluid inclusion are 232°-345°C and 1.8-8.9 wt% NaCl (tin-pyrite mineralization) and 180°-299°C and 8.2-10.6 wt% NaCl (tin-silver mineralization), respectively. Those for fluid inclusion in quartz from the tin-quartz and tungsten-bismuth zones in the Chorolque mine indicate very high values as 261°-500°C, 24.9-53.2 wt% NaCl and 268°-493°C, 33.2-48.2 wt% NaCl, respectively. Also the homogenization temperatures and salinities of fluid inclusion in quartz crystallized by tungsten-bismuth mineralization at the Tasna mine show 250°-499°C and 24.6-50.4 wt% NaCl, respectively

Some sulfur isotope values δ^{34}S obtained for common sulfide minerals such as pyrite, sphalerite and galena from the mines in the Quechisla district are −4.1- −2.9‰ for pyrite (tungsten-bismuth zone, Tasna); −2.1- −1.6‰ for pyrite (tin-quartz zone, Chorolque); −4.7- +1.4‰ for sphalerite, −0.4- +3.5‰ for pyrite and −0.8- +0.0‰ for galena (tin-silver zone, Siete Suyos); +2.6- +6.4‰ for pyrite and +0.4- +3.1‰ for galena (tin-silver zone, Animas); +0.4- +1.4‰ for sphalerite, +2.5‰ for pyrite and −6.4- +1.8‰ for galena (silver-lead-zinc zone, Gran Chocaya); −3.2- +2.0‰ for sphalerite and −3.3- +0.5‰ for galena (tin-silver zone, Tatasi); −4.1- +0.9‰ for sphalerite and −2.6- −0.6‰ for galena (silver-lead-zinc zone, San Vicente).

INTRODUCTION

The polymetallic ores such as tin, tungsten, silver, lead, zinc, antimony, bismuth and copper etc. from many mines located in the Eastern Cordillera of Andes range in Bolivia are very important not only economically but also academically (Clark *et al.*, 1976; Kelly and Turneaure, 1970; Turneaure, 1960, 1971). The deposits producing such polymetallic ores are so-called bolivian type tin deposits which are thought to be typically xenothermal ones in the world. The metallic ores from such ore deposits are telescopic and consist of many kinds of ore and gangue minerals formed under wide range conditions from high to low temperatures at shallow depth. In a case making study on the process of the xenothermal mineralization, such bolivian type tin deposits are important and give us very useful data. Thus, we have been making field and laboratory studies on the polymetallic ore deposits in Bolivia since 1979 up to now continuously.

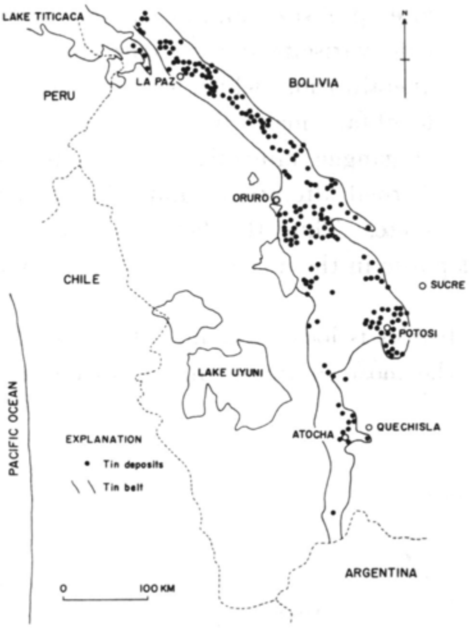

FIGURE 1. TIN MINERALIZATION ZONE IN THE EASTERN CORDILLERA OF BOLIVIAN ANDES (AFTER CLAURE AND MINAYA, 1979)

The distribution area of such ore deposits in Bolivia is generally divided into four districts of La Paz, Oruro, Potosi and Quechisla. They, especially tin deposits, are widely distributed along the mountain range of the Eastern Cordillera from the north border with Peru to the south end borderd with Argentina as shown in Figure 1. The ore deposits in the Oruro and Potosi districts were investigated by us in 1979 and 1980, and in 1981 and 1983, respectively. The results of our studies were already reported in some publications by Sugaki *et al.* (1981a, b, c and 1983a, b). The investigations of this time have been focused on the polymetallic ore deposits in the Quechisla district, which were formed by interesting process of the mineralizations of tin, tungsten, silver, antimony, lead and zinc, and the field survey was carried out at two times in 1981 and 1983.

The ore deposits in the Quechisla district are formed by polymetallic mineralization of hydrothermal solution generated by acidic igneous activities, especially subvolcanic type. The metallic ores from such ore deposits in the district consist of many kinds of ore minerals such as cassiterite, wolframite, stannite, kesterite, pyrite, marcasite, pyrrhotite, sphalerite, wurtzite, galena, arsenopyrite, chalcopyrite, bismuthinite, franckeite, hocartite, cosalite, canfieldite, argyrodite, roquesite, boulangerite, pyrargyrite, miargyrite, polybasite, andorite, ramdohrite, fizelyite, diaphorite, aramayoite, electrum, hessite, tetradymite and native bismuth associated with gangue minerals of quartz, tourmaline, siderite, barite, sericite, kaolinite, gibbsite, alunite, natroalunite, minamiite, jarosite, gypsum, vivianite, apatite, variscite and strengite etc. To make clear the process of such polymetallic mineralizations which were formed a lot of minerals as above, it is very significant to obtain many data on the occurrence, assemblages and paragenesis of ore and gangue minerals, ore textures, kind and sequence of mineralization, hydrothermal alterations, and relations between mineralizations and igneous activities etc. Thus the field and laboratory investigations on geology of the ore deposits in the district and mineralogy of their ores have been carried out.

The Quechisla district is located about 520 km south of La Paz, in Bolivia and corresponds to the most southern mining area near Argentina (Figure 2).

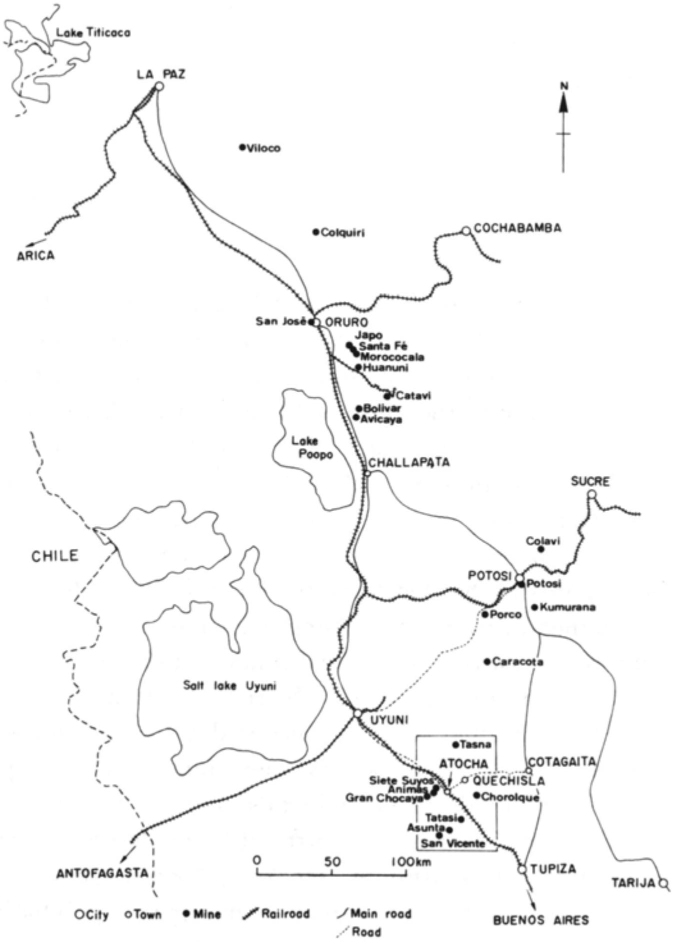

FIGURE 2. MAP SHOWING THE LOCATION OF THE QUECHISLA DISTRICT IN BOLIVIA.

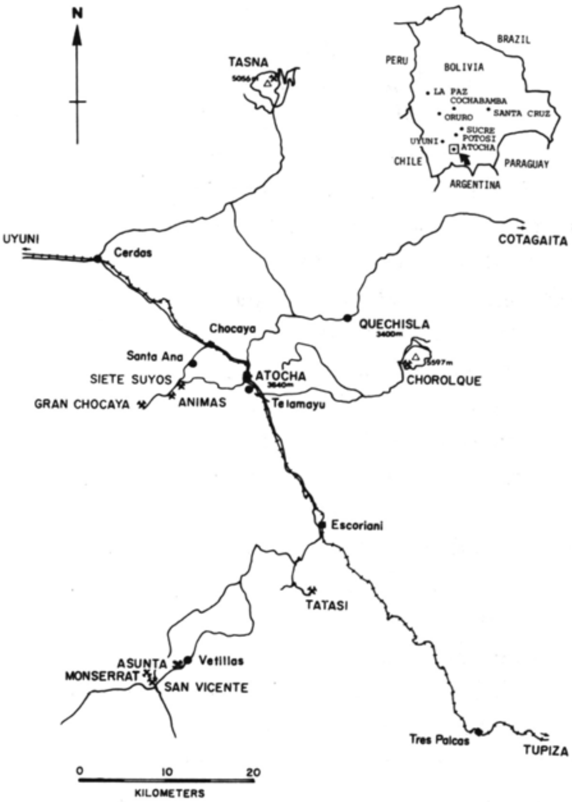

FIGURE 3. LOCATION MAP OF MINES IN THE QUECHISLA DISTRICT, BOLIVIA.

There are many metallic mines of tin, tungsten, silver, lead and zinc etc. such as Tasna, Chorolque, Siete Suyos, Animas, Gran Chocaya, Tatasi and San Vicente, which belong to the organization office "Empresa Minera Quechisla" of Corporacion Minera de Bolivia (COMIBOL) as shown in Figure 3 and are now working. The area investigated in the district is 70 km long in the north-south direction and 45 km along the east-west. Atocha, the biggest town with a population of about 5,000 people in the district, is situated at the center of the district, and has a railway station, hotels and gasoline station. Quechisla located at about 20 km northeast of Atocha is the official center of COMIBOL in the district. There are main office, hospital, school and houses for employees of the Quechisla district of COMIBOL. The main office controls operation of mining and prospecting in the mines as above. Telamayu town separated by the river Allita at just the south of Atocha is the technical center of the Quechisla mining district of COMIBOL. There are ore dressing and mechanical plants and houses for employees and guests of COMIBOL. We have used accomodation facilities of COMIBOL at Telamayu as base camp to make field survey of this district.

To visit to the Quechisla district, there are two ways from La Paz, by train and car. That is, we can arrive at Atocha directly via Oruro and Uyuni from La Paz for 14 hours by train. Meanwhile we can visit to this district by car driving 850 km through Oruro and Potosi from La Paz for about 2 days. The road distance from Potosi to Quechisla via Cotagaita is 255 km. The way between Cotagaita and Quechisla, 70 km, is poor and temporary road along the Quechisla and Cotagaita rivers which run to the east, although that from Potosi to Cotagaita, 185 km, is a main road to Tupiza. On the other hand, there is another way to Atocha by car through the road running parallel to the railway via Uyuni from Oruro, 620 km, and from La Paz, 900 km, but the way between Challapata and Atocha, 540 km, is uneven and sandy bad road.

The climate of the Quechisla district is annually divided into dry and rainy seasons of which distinction is obvious. Dry season is from April to October, and rainy season, November to March. According to Montes de Oca (1983), total amounts of rain are only about 260 mm per year at Chocaya in the district. However, it almost falls during the rainy season and sometimes floods as cutting off traffic road. So, the road along the Quechisla and Cotagaita rivers cannot be occasionally used at the wet season. The humidity in general is as low as 20 to 30% in the dry season and 50 to 60% in the wet season. Accordingly, there is distinctly dry condition except rainy time of the wet season. Thus, our field works have been done during the dry season of winter time. During field survey in July to August, temperatures in the district were −15° to −20°C at early morning or night and 15°C at daytime. Daily temperature change, about 30° to 35°C, was very hard. At early morning the river in the district were always frozen over during period of our field investigation.

Field works at elevations of 4,500 m or above usually were very difficult because of dilute oxygen in air, especially at Chorolque mine, the second highest mine in the world, working at elevation of 4,600 m to 5,100 m in Mt. Chorolque, 5,597 m. The underground of the mines in the district becomes less oxygen state so as cannot use gas lighter for smoking. The geological and mineralogical data obtained by our field and laboratory studies on the ore deposits in the Quechisla district are described in this paper.

TOPOGRAPHY

The Quechisla district is located at a southwestern portion of the Eastern Cordillera of Andes in Bolivia, and consists in mountain and hill land which are the elevation from 3,700 to 5,500 m. The district topographically corresponds to the western margin of the Eastern Cordillera. Topography in the district has intimate relation to geological factors (Figure 4) and is divided into three portions of the northeastern, central and southwestern areas. The northeastern area of the district is generally composed of steeply sloped mountains (Figure 4-B) of 4,000

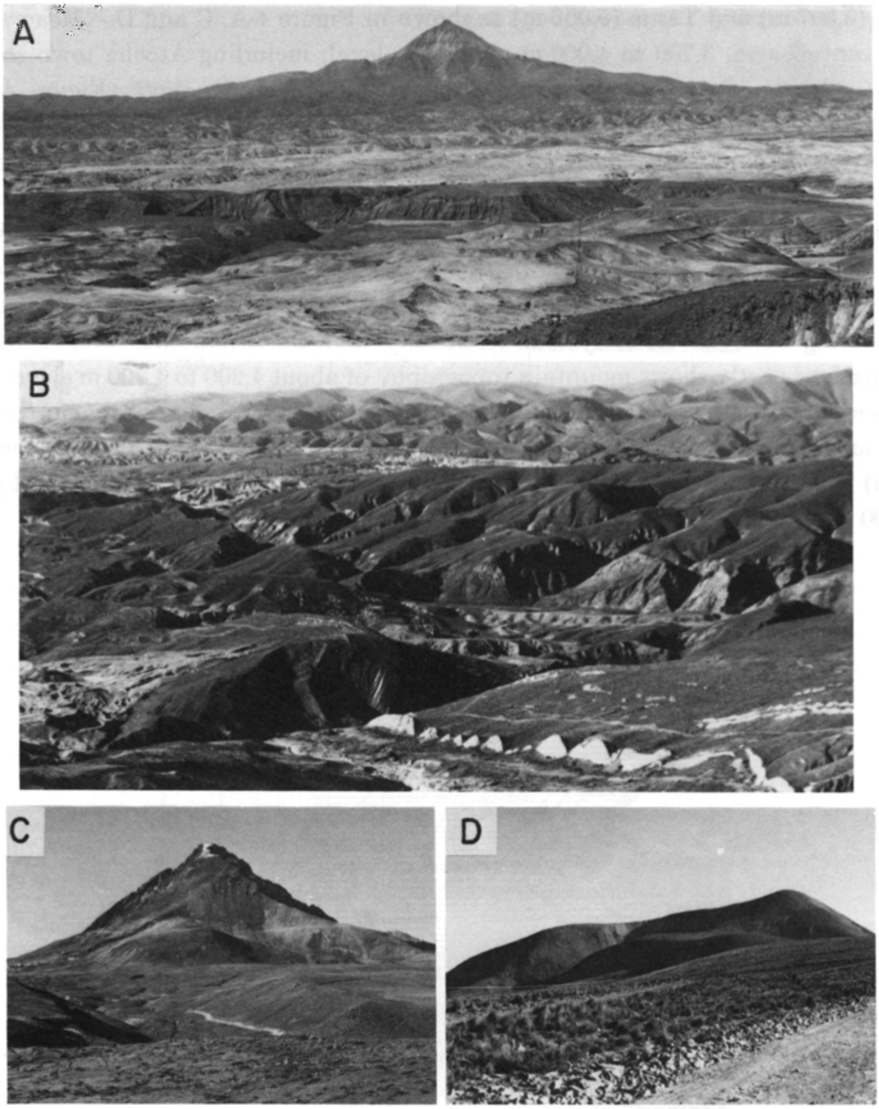

FIGURE 4. TOPOGRAPHY IN THE QUECHISLA DISTRICT.
A : Mt. Chorolque of dacite stock and Tertiary flat hills viewed distantly from Mt. Torre Puta (4 km west of Atocha). B : Eroded mountains of the Ordovician system. C : Mt. Chorolque (5,597 m) looked from the southwest side. D : Mt. Tasna (5,056 m) viewed from the south.

to 5,000 m elevation, mostly consisting of the Ordovician system eroded by well developed valleys running generally to north or south. The Atocha river which is most principal one in the district runs to the east streaming the central part of this area, jointing together many valleys and branch of the river. In this area, there are found some peaks consisting of Tertiary intrusive rocks such as Chorolque (5,597 m) and Tasna (5,056 m) as shown in Figure 4-A, C and D. Meanwhile the central area, 3,700 to 4,000 m above sea level, including Atocha town shows relatively flat topography or gentle rolling hill in youth stage (Figure 4-A). However, some parts as formed by Tertiary volcanic complex rather present mountain feature of 4,000 to 4,700 m elevation as Chocaya and Tatasi. This area consists mainly of Tertiary and Quaternary systems, although the Cretaceous and Ordovician formations appear locally in the area. The Chocaya and Allita rivers run to the south-east and the north-west in the area, respectively and become to the Atocha river after flowing together. The southwestern area in the district consisting of Ordovician system essentially and the Cretaceous and Tertiary formations partly shows mountain topography of about 4,200 to 4,700 m elevation. However, its feature is gentle and low elevation rather than that of the northeastern area. Also, the zone composed of Tertiary formation (San Vicente Formation) in the western side of the area presents low mountain or hill topography of 4,200 to 4,500 m elevation.

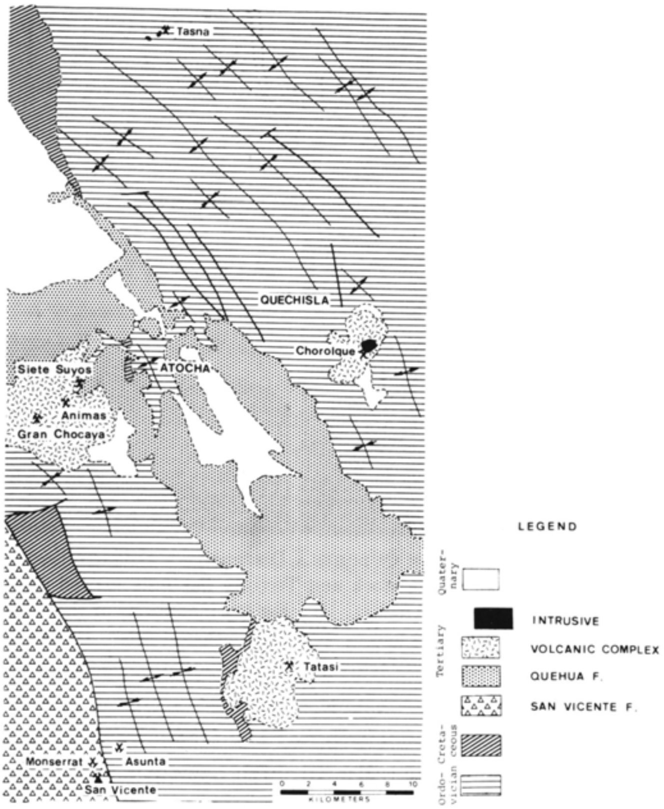

FIGURE 5. GEOLOGICAL MAP OF THE QUECHISLA DISTRICT.

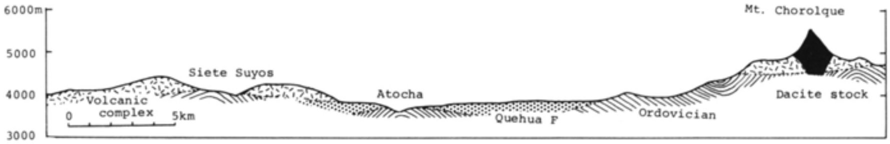

FIGURE 6. GEOLOGICAL SECTION ALONG THE E-W LINE THROUGH CHOROLQUE AND SIETE SUYOS MINES IN FIGURE 5.
Legend is same as that in Figure 5.

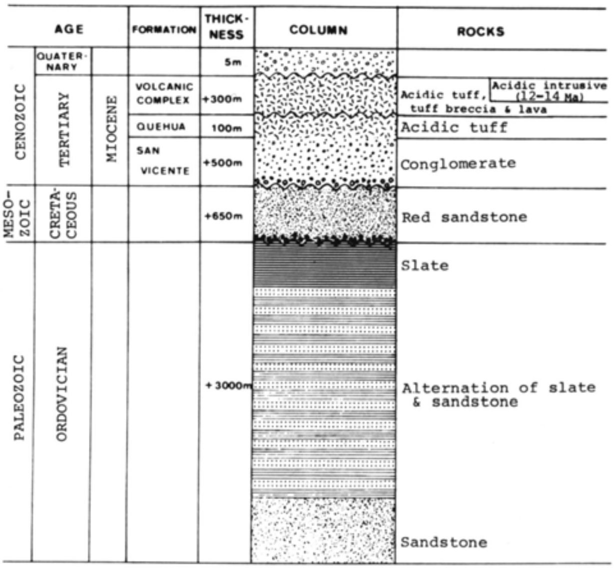

FIGURE 7. GEOLOGICAL COLUMN OF THE QUECHISLA DISTRICT.

GEOLOGY

The Quechisla district consists of the Ordovician, Cretaceous and Tertiary systems, and the Quaternary deposits as shown in Figures 5, 6 and 7. The Ordovician system which is a basement appears widely in the northern and southern areas of the district and is composed of strongly folded slate and sandstone as reported by Ponce and Avila (1966), and Velasco *et al*. (1966). The Cretaceous formation is exposed locally in the western part of the district, and meanwhile the Tertiary system occurs in the central ane western parts. Intrusive rocks of Miocene are found as stocks and dykes in many places of the district.

1. Ordovician system

It consists mostly of alternation of slate and sandstone or graywacke, 5 to 20 cm in thickness (Figures 8-A, B, and 9-A), but in the lower horizon of the system sandstone is dominant, and in the upper part slate becomes abundant as shown in

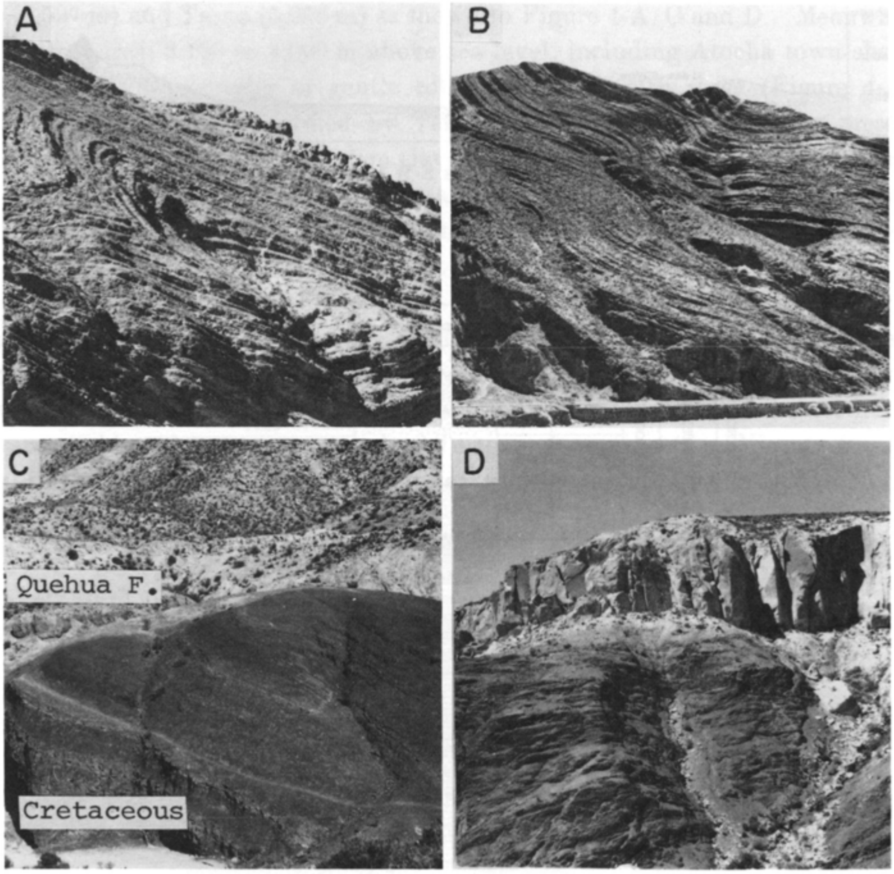

Figure 8. Occurrences of Some Sedimentary Rocks.
A : Folded Ordovician slate at the Mary section, Tasna mine. B : Ordovician slate which was cut by fault, 2.5 km northwest of Atocha. C : Cretaceous sandstone been covered unconformably with dacitic tuff of the Quehua Formation, along the Atocha river. D : Dacitic tuff of the Quehua Formation covering unconformably on Ordovician slate, 2.5 km the southwest of Atocha.

the Figure 7. The thickness of the system is over 3,000 m. Slate is dark gray to black in color sometimes with bedding fissility. It consists microscopically of quartz and sericite, 2 to 20 μm in size, and carbonaceous matter with clayey matrix, and microscopic lamination is often found in it. Meanwhile sandstone or graywacke is grayish white and yellowish brown in color and fine to medium grained compact rock with no lamination. Under microscope, it is mainly composed of rounded quartz grains, 0.05 to 0.2 mm in size, associated with sericite and clayey materials as matrix. Quartzite appears locally instead of sandstone of the alternation with slate. It is grayish white or pale brownish gray in color and massive hard rock with no bedding lamination. It also consists mostly of aggregate of quartz, 0.1 to 0.2 mm in size, with small amounts of sericite and

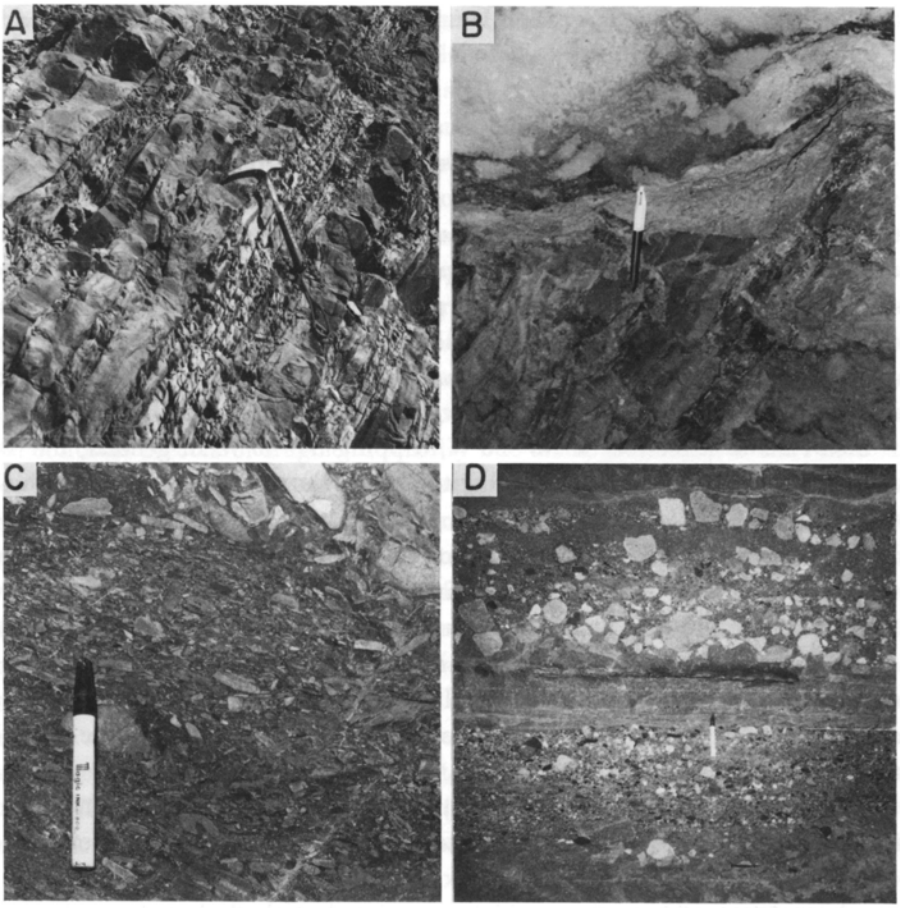

FIGURE 9. OUTCROPS OF SOME SEDIMENTARY ROCKS.
A : Alternation of slate and sandstone of the Ordovician formation near Santa Ana. B : Slate and sandstone of Ordovician been covered unconformably with dacitic tuff breccia of the volcanic complex, the 16 level, Siete Suyos mine. C : Conglomerate of the San Vicente Formation, the -30 level, San Vicente mine. D : Dacitic tuff breccia of the volcanic complex, the 132 level, Gran Chocaya mine.

clayey minerals as matrix.

The Ordovician system is distinctly folded to repeat anticline and syncline structures with axes of the NW-SE direction as seen in Figure 8-A. It also is frequently cut at many place in the Ordovician area by faults among which principal ones are parallel to the folding axes (Figure 8-B). Slate and sandstone occasionally suffer hydrothermal alteration, and in such a case tourmaline is sometimes formed in them as veinlet, network or dissemination as observed at the Tasna and Chorolque mines. The Ordovician system is covered with the Cretaceous system unconformably as found at the west area of Tasna, Tatasi and Atocha, and also overlaid with the Tertiary formation directly as observed in the

Atocha and Tatasi areas (Figures 8-D and 9-B).

2. *Cretaceous system*

It occurs locally in the limited area along the Chocaya river near Atocha and the west areas of the Tasna and Tatasi mines etc. overlaying the Ordovician system unconformably and generally consists of reddish colored sandstone and mudstone. Its bedding is always obvious. At the area along the Chocaya river the Cretaceous formation is mainly composed of alternation of dark red mudstone and brownish or light red and medium grained sandstone, about 1.0 m in thickness, but conglomerate, 40 cm thick, in lowest part of the formation is found as a basal sediment on the Ordovician strata. While in the upper part of the formation, bluish gray mudstone is observed with red mudstone. The formation in the this area runs to direction of N0°-30°W, dipping 30°-45°W in general, but with gentle folding locally. It is covered with the Tertiary formation unconformably as seen in Figure 8-C.

At the western area of the Tasna mine, the Cretaceous system is generally composed of medium grained and laminated sandstone colored reddish brown, 1.0 m thick, and bluish gray, 10 to 50 cm thick. In the middle part of the system in the area, white massive limestone, and pale brown calcareous sandstone are occasionally inserted in brownish and bluish sandstone. In the upper part, dark red mudstone becomes dominant. The Cretaceous formation in the area has strike N10°-30°W and dips to 30°-40°W.

At the west area of the Tatasi mine, the Cretaceous formation covering unconformably on the Ordovician system is mainly composed of conspicuous bedding alternation over 200 m in thickness of dark red mudstone and medium grained sandstone, 0.5 to 2.0 m thick, associated with dark red conglomerate, consisting of cobbles of Ordovician sandstone and slate in the lower potion of the formation. Also pale brown calcareous sandstone, 2 m thick, and bluish gray mudstone, 30 to 70 cm thick, appear partly in the upper portion of the formation.

Velasco *et al.* (1966) divided into five formations in the Cretaceous system of the Quechisla district as follows: Aroifilla-Yura Formation (red colored calcareous sandstone and mudstone), Chaunaca Formation (red calcareous mudstone), El Morino Formation (limestone with mudstone), Santa Lucia Formation (red calcareous mudstone) and Toroto Formation (red sandstone) in ascending order. Howevr, in this paper they have been described as the Cretaceous system in a lump.

3. *Tertiary system*

Tertiary system in the district is composed of the San Vicente Formation, the Quehua Formation and the volcanic complex in ascending order. Within them, the San Vicente Formation, over 500 m in thickness, is only distributed in the southwestern part of the district adjoining to the Ordovician system by fault. It consists mostly of reddish colored conglomerate containing many amounts of pebbles, 2 to 10 cm in size, of Ordovician slate and sandstone with quartz, sericite and iron oxide as matrix (Figure 9-C), and sometimes inserts gray sandstone of medium grain showing roughly a horizontal bedding. The ore veins of the San Vicente mine occur in the Formation.

Meanwhile the Quehua Formation, about 100 m thick, occupies widely the central part in the district, overlaying unconformably with roughly horizontal bedding on the Ordovician system (Figure 8-D) and occasionally the Cretaceous formation (Figure 8-C). But the relation between the Quehua and the San Vicente Formations does not make clear. The lower portion of the Quehua Formation is composed of white fine tuff, and dacitic gray and white tuff breccia which contains breccia or fragment, usually 3 to 5 cm, sometimes 30 cm in size, of Ordovician sandstone and slate and Miocene dacite, and a lot of quartz, biotite, plagioclase and orthoclase, 0.1 to 3.0 mm in size, as phenocrysts and mineral fragments in matrix. There is found alternation of massive dacitic tuff breccia and coarse grained dacite tuff of the Quehua Formation in the southwestern part of the Atocha area. The latter has many amounts of bipyramidal quartz, plagioclase and biotite, 0.1 to 3.0 mm in size, and slight amounts of orthoclase and fragments of Ordovician sandstone and slate. The upper portion of the Quehua Formation consists of alternation of coarse grained dacite tuff and massive fine tuff in which acidic tuff breccia, 0.5 to 1.0 m thick is embedded. According to Grant *et al.* (1979a, b) and Kussmaul *et al.* (1975), the K-Ar ages for biotite from rhyodacitic and dacitic tuff of the Quehua Formation are 16.8 to 17.2 and 17.0 to

TABLE 1. THE K-Ar AGE OF THE VOLCANIC COMPLEX, THE QUEHUA FORMATION AND INTRUSIVE ROCKS IN THE QUECHISLA DISTRICT.

Rock type & locality	Material	Ma	Reference
Dyke			
Quartz porphyry (Tasna)	Whole	16.2-16.5	Grant et al.(1979a)
Dacite (San Vicente)	Whole	18.5	JICA & MMAJ (1977)
Dacite (San Vicente)	Biotite	18.5	JICA & MMAJ (1977)
Dacite (San Vicente)	Biotite	13.4	JICA & MMAJ (1978)
Volcanic complex			
Rhyodacite lava(Chocaya)	Biotite	13.4-14.4	Grant et al.(1979a)
Dacite lava (Chocaya)	Whole	11.7-12.1	JICA & MMAJ (1980)
Altered rhyodacite lava (Chocaya)	Whole	12.5	Grant et al.(1979a)
Altered rhyodacite lava (Chorolque)	Whole	16.0-18.4	Grant et al.(1979a)
Rhyodacite lava (Tatasi)	Biotite	15.4-16.0	Grant et al.(1979a)
Dacite lava (Tatasi)	Whole	17.1-22.8	JICA & MMAJ (1977)
Dacite lava(San Vicente)	Whole	15.8	JICA & MMAJ (1977)
Dacite lava(San Vicente)	Biotite	16.6	JICA & MMAJ (1978)
Quehua Fm.			
Rhyodacitic tuff (Chocaya)	Biotite	17.2	Grant et al.(1979a)
Rhyodacitic tuff (Chorolque)	Biotite	16.8	Grant et al.(1979a)
Dacitic tuff(San Vicente)	Biotite	17.0-22.9	Kussmual et al.(1975)

22.9 Ma respectively, as given in Table 1. The rocks of the Quehua Formation in general are soft and loose except dacitic tuff breccia of its lower portion. Thus, it forms a low hill with gentle slope.

Volcanic complex occurs in Chocaya, Chorolque and Tatasi areas covering on the Quehua Formation and the Cretaceous and Ordovician systems unconformably, and consists mostly of dacitic tuff breccia, massive tuff and dacite lava. However, its lower part is mainly composed of dacitic tuff breccia associated with small amounts of massive tuff, and while the upper part is principally formed by dacitic massive tuff. These rocks are massive and compact with no bedding, and have a lot of quartz and biotite and small amounts of plagioclase and orthoclase as phenocrysts or fragments in glassy matrix. Dacite lava is found as dome and funnel shaped form in tuff breccia and massive tuff. It has usually phenocrysts of quartz, biotite and plagioclase and sometimes hornblende, augite, hypersthene and orthoclase with groundmass consisting of fine grained aggregate of their minerals and glass. Around the Animas and Siete Suyos mines, the volcanic complex covering the Ordovician system (Figure 9-B) and the Quehua Formation unconformably, consists of gray massive tuff breccia and dacite lava. The former has mineral fragments and phenocrysts, 0.1 to 1.0 mm in size, of quartz, plagioclase, biotite and small amounts of orthoclase, and contains breccia, 1 to 10 cm, generally up to 5 cm in size, of dacite and Ordovician slate and sandstone (Figure 9-D). Meanwhile dacite lava occurs in the upper part of the volcanic complex, and has quartz, plagioclase, biotite, augite as phenocrysts, 0.1 to 3.0 mm in size, with small amounts of hornblende, hypersthene and orthoclase in groundmass consisting of lath-shaped plagioclase, glass, and sometimes fine grained aggregate of plagioclase, quartz and biotite etc. (Figure 10-A). At the Chorolque mine area, the volcanic complex overlaying Ordovician strata directly is composed of dacitic tuff breccia mainly and agglomerate partly in the lower portion and massive dacite tuff showing no bedding in the upper portion. Dacitic tuff breccia has a lot of rock fragments, 5 to 10 cm in size, of Ordovician sandstone and slate, and dacite. Massive tuff shows gray to pale greenish gray in color and no bedding, and has quartz and biotite, 0.1 to 3.0 mm in size as phenocrysts or mineral fragments. The volcanic complex surrounding dacite stock suffers hydrothermal alteration, and sometimes is distinctly replaced by tourmaline as changing its color to dark gray. At the Tatasi mine area, the volcanic complex appears as covering unconformably Cretaceous red mudstone, and consists principally of massive dacite tuff with sometimes dacitic tuff breccia. Massive dacite tuff contains biotite, quartz, plagioclase and orthoclase as phenocrysts, 0.1 to 2.0 mm in size, with slight amounts of fine rock fragments of slate and sandstone. Its matrix is mostly glassy with very fine grained quartz, plagioclase and orthoclase. There is found dacite lava or dyke overlaying or cutting massive dacite tuff. The lava has phenocrysts, 0.2 to 5.0 mm in size, of quartz, plagioclase and biotite in

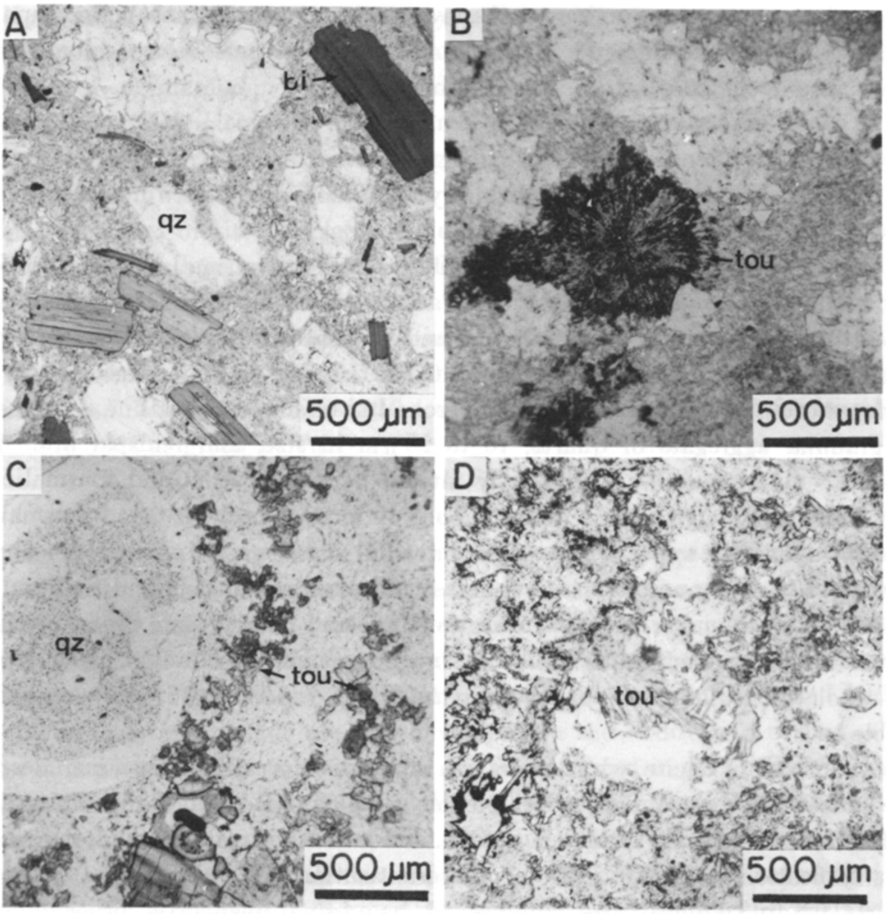

FIGURE 10. PHOTOMICROGRAPHS OF IGNEOUS ROCKS.
A : Dacite lava from 500 m southwest of the Siete Suyos mine. B : Quartz porphyry altered by tourmalinization near the top of Mt. Tasna. Radial aggregate of tourmaline is observed. C : Dacite altered by tourmalinization near the Central shaft, 12 level, Chorolque mine. D : Tourmalinized dacite, Fanny Ramo vein, 6 level, Chorolque mine. qz : quartz, bi : biotite and tou : tourmaline.

glassy groundmass with fine grained aggregate of quartz and plagioclase.

According to JICA and MMAJ (1977, 1978 and 1980) and Grant *et al*. (1979a, b), the K-Ar ages for biotite, whole rocks and altered whole rocks in the volcanic complex are 13.4 to 16.6 Ma, 11.7 to 22.8 Ma and 12.5 to 18.4 Ma respectively, as given in Table 1.

4. Quaternary system

The Diluvial sediments composed of cobble, pebble, sand and silt etc. as terrace deposits distributes in the central and northwestern area of the district. Also moraine deposits such as cobble, pebble and sand are found in the southern area of the Chorolque mine, and now explorated as alluvial tin deposits. Meanwhile the Alluvium deposits only distribute at narrow area along recent rivers as gravel, sand, silt and mud.

5. *Intrusive rocks*

Stocks and dykes of quartz porphyry and dacite occur often in the Quechisla district, but in small scale except Chorolque stock.

Quartz porphyry : Stock and dyke of quartz porphyry in small scale intrude into Ordovician slate and sandstone at Mt. Tasna. It in general suffers hydrothermal alteration of sericitization, silicification and tourmalinization. As its phenocrysts quartz, 1 to 4 mm in size, and feldspar, 0.2 to 2.0 mm in size, are recognized, but feldspar often changes to sericite. Its groundmass is hollocrystalline and consists of granular aggregate of quartz, 10 to 20 μm in size, and feldspar altered to sericite. Quartz porphyry distinctly altered by silicification and tourmalinization becomes to aggregate of quartz, about 40 to 200 μm in size, and tourmaline. The latter usually appears as granular or radial aggregates of prismatic or fibrous crystals, 70 to 150 μm long, in groundmass. It also occurs as spherulitic form, 200 to 500 μm in diameter, as seen in Figure 10-B and its aggregate replaces phenocrysts of feldspar and quartz. The K-Ar age measured by Grant *et al.* (1979a, b) for whole rock of quartz porphyry at the Tasna is 16.2 to 16.5 Ma as given in Table 1.

Dacite : Stock of dacite, which is grayish white in color and massive, intrudes into the Ordovician rocks and Miocene volcanic complex in the Chorolque mining area. It forms a central body of Mt. Chorolque, and is distinctly altered hydrothermally as silicification, tourmalinization and sericitization. In such a case, although quartz, 0.2 to 3.0 mm in size, stably exists as original phenocryst, other minerals of phenocrysts almost change to fine grained aggregate of sericite, chlorite, tourmaline and magnetite etc. Its groundmass also changes to granular aggregate of quartz, 5 to 30 μm in size, sericite and tourmaline by hydrothermal alterations (Figure 10-C). The stock is frequently cut by a lot of ore veins of the Chorolque mine. In such case, tourmaline often occurs as veinlet, network and disseminated or patch-like forms in dacite adjacent to the veins. Such dacite as strongly suffered tourmalinization and silicification near veins changes its color to dark gray, and becomes almost to aggregate of fine grained quartz and tourmaline (Figure 10-D). Tourmaline in general occurs as short prismatic crystal, 0.03 to 0. 3 mm long, or sometimes fibrous aggregate replacing phenocrysts and groundmass. It shows occasionally growth zoning of dark blue, brown, pale yellow and colorless in color, and usually associates with hydrothermal quartz, sericite and chlorite etc. intimately.

At the Gran Chocaya and Tatasi mining areas, dacite dykes, 5 to 8 m in width, occur in the volcanic complex. They have quartz, plagioclase, biotite and small amounts of hornblende as phenocrysts, 0.2 to 2.0 mm in size, in groundmass consisting of aggregate of quartz, feldspar, biotite, glass and secondary chlorite or aggregate of submicroscopic minerals and glass. Also dacite dyke, about 10 m in width, occurs in conglomerate of the San Vicente Formation at the San Vicente mine. It contains corroded quartz, plagioclase, biotite and altered hypersthene, 0.5 to 2.0 mm in size, as phenocrysts in groundmass of fine grained aggregate of quartz, feldspar, biotite and glass. Feldspar of phenocryst and groundmass partly changes to sericite and calcite. This dyke is observed underground of the San Vicente mine. The ore vein of the mine is formed along boundary between the dyke and conglomerate, and sometimes invades to inside of the dyke.

The K-Ar age obtained by JICA and MMAJ (1977 and 1978) for biotite in dacite at the San Vicente mine is 13.4 to 18.5 Ma, meanwhile that for its whole rock is 18.5 Ma as given in Table 1.

6. *Geological structure*

As shown in Figure 5, the Ordovician system is remarkably folded and faulted in the Quechisla district. That is, a lot of folding axes of anticline and syncline which have a trend parallel to the NW-SE direction, are found in whole Ordovician area. These folds are repeated in almost same scales. While major faults parallel to folding axes, and other many faults and fissures crossed folding axes at roughly right angle are also developed in the Ordovician system. The latter is important as fracture system of ore veins formed in the Ordovician rocks as found in the Tasna mine (Figure 8-A). The Cretaceous system is also folded as same trend as the Ordovician system. On the other hand, Tertiary (Miocene) formations are relatively gentle flat, and distinct folds of them are not recognized. Therefore, the structures folded and faulted distinctly in the Ordovician and Cretaceous systems may be thought to have been formed before Tertiary (Miocene). However, there is a large fault of the NNW-SSE direction running between San Vicente conglomerate and Ordovician slate in the southwestern portion of the district. This fault may act an important role on the formation of fracture system of ore veins in the San Vicente mine.

ORE DEPOSITS

1. *Outline of ore deposits*

The Quechisla district is the one of principal mining areas of Bolivia, and corresponds to the most southern part of tin mineralization belt in the Eastern Cordillera of bolivian Andes as shown in Figure 1. There are many metallic mines of tin, tungsten, silver, lead and zinc etc. in the district (Figure 3). Among them, the Tasna (tin, bismuth and tungsten), Siete Suyos (tin, copper, silver, lead and zinc), Animas (tin, copper, silver, lead and zinc), Gran Chocaya (silver, lead and zinc), Chorolque (tin and tungsten), Tatasi (silver, lead and zinc), San Vicente (silver, lead and zinc) mines are working now. They are hydrothermal deposits of fissures filling type developed in the Ordovician slate and sandstone, Miocene San Vicente conglomerate and volcanic complex and dacite stock etc. The ores from the mines consist of many ore minerals such as cassiterite, wolframite, stannite, pyrite, sphalerite, galena, chalcopyrite, pyrrhotite, bismuthinite, wurtzite, marcasite, hocartite, canfieldite, argyrodite, roquestite, electrum, native bismuth, native antimony, dyscrasite, hessite, tetradymite, stibnite, jamesonite, bournonite, boulangerite, stephanite, pyrargyrite, miargyrite, andorite, fizelyite, diaphorite and aramayoite, with gangue minerals such as quartz, tourmaline, alunite, jarosite, natroalunite, minamiite, variscite, strengite, sericite, kaolinite and siderite. They have been produced by such mineralization as follows: tin-quartz mineralization (cassiterite, quartz and tourmaline), tungsten-bismuth mineralization (wolframite, bismuthinite and quartz), tin-pyrite mineralization (cassiterite, pyrite and quartz), tin-silver mineralization (stannite, silver bearing sulfosalt minerals, galena and sphalerite) and silver-lead-zinc mineralization (silver sulfosalt minerals, galena and sphalerite). Among them, the tin-quartz mineralization is found as most principal one in the Chorolque mine. Both the tin-pyrite and tin-silver mineralizations are recognized obviously in the Siete Suyos and Animas mines, and while the silver-lead-zinc mineralization is essential in the Gran Chocaya mine. The ore deposits of the Tatasi and San Vicente mines are mainly formed by the tin-silver and silver-lead-zinc mineralizations, respectively. By such mineralization as described above, there is formed zonal arrangement of minerals as seen in the Chorolque, Tasna, Siete Suyos, Animas and Gran Chocaya mines etc. The mineralization occurs in intimate relationship with Miocene acidic igneous activities such as quartz porphyry and dacite. In the chapter of ore deposits, geology on the ore deposits of the Tasna, Chorolque, Siete Suyos, Animas, Gran Chocaya, Tatasi, San Vicente, Monserrat and Asunta mines, and ores from them, mineral assemblages, zonal arrangement of minerals and fluid inclusion data are described as below.

2. *Tasna mine*

The Tasna mine which belongs to the Quechisla mining division of COMIBOL is situated at about 35 km north of Atocha in the northern part of the Quechisla district (Figure 3). The production in 1978 was 9,600 tons per month as the crude ore containing 0.48% Bi and 0.56% Cu. However, after 1978 tungsten ore only has been mined, and its productions were 9,400 tons as crude ore containing 0.65% WO_3 in June of 1981 and 10,100 tons having 0.51% WO_3 in June of 1983. The mine is divided into 10 sections such as the Rosario, Farellon Nuevo, Farellon Viejo, Matilde, Eduarda, Mary, Deseada, Mariana, Veneros and Belen. But, only the Rosario section is now under exploitation by COMIBOL (Figure 11-A and B) and the other sections are almost closed. Although observa-

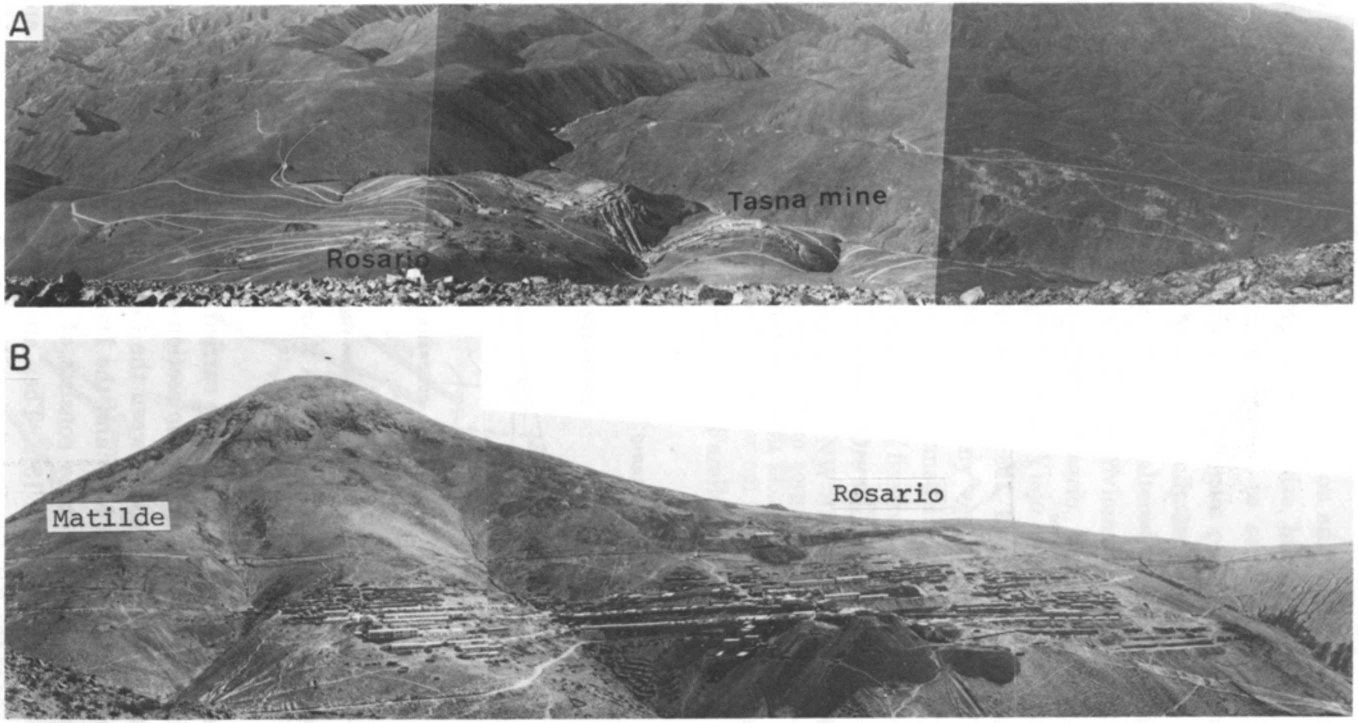

FIGURE 11. SCENERY AROUND THE TASNA MINE.
A : A view looked from the top (5,056 m) of Mt. Tasna. B : The Rosario and Matilde sections of the Tasna mine, at eastern foot of Mt. Tasna.

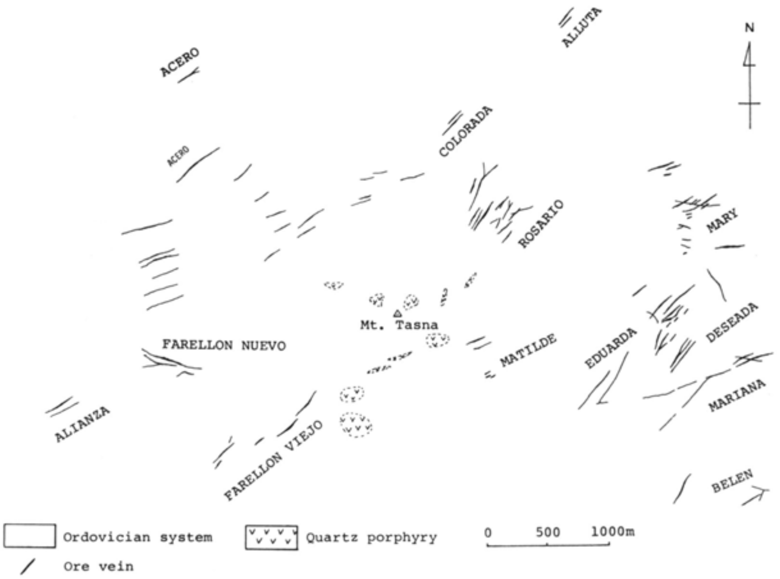

FIGURE 12. DISTRIBUTION OF THE VEINS IN THE TASNA MINE. Names of the sections are indicated in the figure.

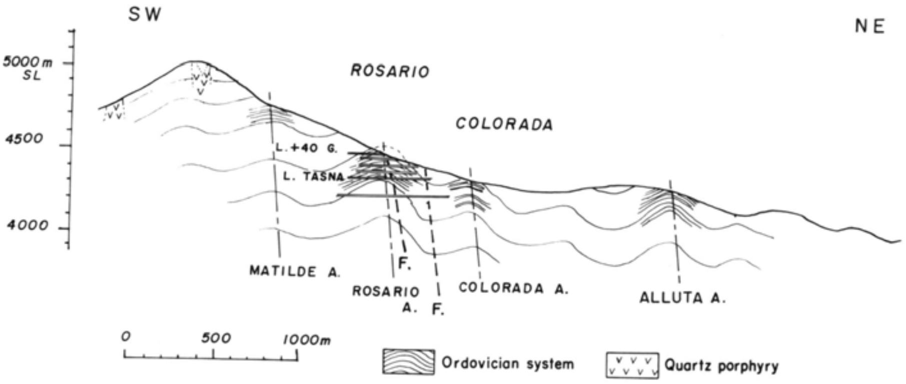

FIGURE 13. CROSS SECTION OF THE TASNA MINE ALONG NE-SW DIRECTION
A: Anticline, F: faults.

tion of the vein and sampling of ores were carried out in all the sections mentioned before, the veins and ores of the Rosario section are mainly described here. The Rosario section has fifteen levels between the Constancia level (0 level, 4,298 m above sea level) using as main level and the Dorada level (4,714 m).

The geology around this mine consists of slate and sandstone of the Ordovician system (Figures 12 and 13). They are folded distinctly with anticline and syncline axes of the NW-SE direction as shown in Figure 13, and cut by strike faults occasionally. Some small stocks and dykes of quartz porphyry are found in the Ordovician system around the top (5,056 m) of Mt. Tasna. They are composed originally of quartz, feldspar, and biotite as phenocrysts, but intensely undergo hydrothermal alterations of sericitization and tourmalinization. Quartz phenocryst, 1 to 4 mm, occasionally 10 mm in size, has dusty rim. Feldspar and biotite, 0.2 to 2 mm in size, almost change to sericite. The groundmass is hollocrystalline and consists of granular aggregate of quartz and secondary sericite. Tourmaline principally replaces groundmass as aggregate of radial or fibrous crystals, about 50 μm long. Strongly altered quartz porphyry becomes to aggregate of quartz and tourmaline. The Ordovician slate and sandstone are also affected by tourmalinization around the Rosario, Farellon Viejo and Farellon Nuevo sections. Especially at the Farellon Viejo section they change to aggregate of tourmaline and quartz. At the top of Mt. Tasna, the Ordovician rocks are suffered by hydrothermal alteration, and many veinlets or network consisting of diaspore, dumortierite and corundum are formed in the rocks.

The ore deposits of the Tasna mine are of fissure filling type developed in slate and sandstone of the Ordovician system. Ore veins mainly fill up fault fissures developed near syncline or anticline axes of NW-SE directions. The veins run to the NE-SW or NEE-SWW strike directions, and dip to 70° to 80°E as seen in Figure 14. The veins have widths from a few cm to over 2 m. The scales of main veins of the Rosario, Farellon Viejo and Farellon Nuevo sections are given in

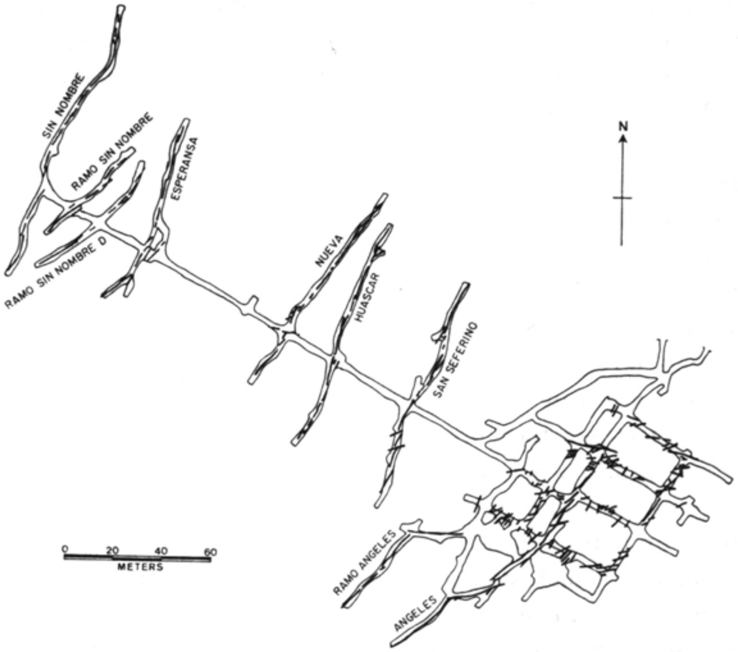

FIGURE 14. VEINS AT THE +40 GABRIELA LEVEL (4,610 m), ROSARIO SECTION, TASNA MINE.

TABLE 2. MAIN VEINS AND THEIR SCALES IN THE TASNA MINE.

Vein	Strike	Dip	Length (m)	Width (m)
Rosario				
Angeles	N35°E	35°E	550	1.4
San Seferino	N30°E	75°E	300	0.95
Huascar	N30°E	70°E	150	0.3
Nueva	N35°E	90°	240	0.35
Esperanza	N25°E	60°E	450	0.7
Sin Nombre	N25°E	58°E	300	0.2
Maria	N30°E	65°E	500	0.3
Farellon Nuevo				
Principal	N65°W	80°N	300	0.05
Ramo 2	N75°W	75°N	230	0.05
Ramo 4	N65°W	80°S	60	0.05
Ramo 5	N75°W	75°N	180	0.05
Farellon Viejo				
Porvenir	N60°E	60°S	50	0.1
Cruz	N18°-45°E	75°W	330	0.2
Glorieta	N35°E	75°W	110	0.15
Inca	N20°E	60°W	80	0.05
San Pedoro	N35°E	65°W	145	0.25
Pacifico	N60°E	50°N	80	0.05
Alluta				
Alluta	N10°E	90°	150	0.1

Table 2. The ore minerals such as wolframite, cassiterite, arsenopyrite, pyrite, chalcopyrite, bismuthinite, sphalerite and marcasite, and small amounts of wurtzite, stannite, jamesonite, galena, antimonian cosalite, gustavite, native bismuth, franckeite and boulangerite associated with gangue minerals such as quartz, tourmaline, kaolinite, sericite, gibbsite, siderite, barite, scorodite, apatite, jarosite, natroalunite, monazite, wavellite, and crandallite occur from the mine.

The ores from the Tasna mine are classified into five types, tungsten-bismuth, tin-quartz, tin-pyrite, tin-silver and silver-lead-zinc. The tungsten-bismuth ore occurs from the veins of the Rosario, Farellon Nuevo and Farellon Viejo sections. The tin-quartz ore is found in the veins of the Farellon Viejo and Matilde sections. The tin-pyrite ore is mainly found in those of the Alluta, Mary, Jaffa and Eduarda sections. The tin-silver ore occurs in the Mariana, Belen and Acero sections. The silver-lead-zinc ore appears in the Veneros section.

The arrangement of the tungsten-bismuth veins such as Angeles, Esperanza, Huascar, Nueva, Pagadora, San Seferino and Sin Nombre in the Rosario section at the +40 Gabriela level (4,610 m above sea level) is shown in Figure 14. They have the scales as given in Table 2, but their width changes remarkably from 0.1 to 1.0 m and sometimes they branch or network (Figure 15-A and B). Many small veinlets of quartz and tourmaline cutting country rocks are found near or around the veins. Country rocks composed mainly of Ordovician slate are strongly altered by tourmalinization near the veins. Fine grained tourmaline is formed with quartz in such slate. Also, a lot of angular fragments of country rock, several cm in size, are often enclosed in the veins. The veins mainly consist of coarse grained aggregate of quartz, wolframite, arsenopyrite, chalcopyrite, bismuthinite and pyrite with small amounts of tourmaline, apatite, cassiterite,

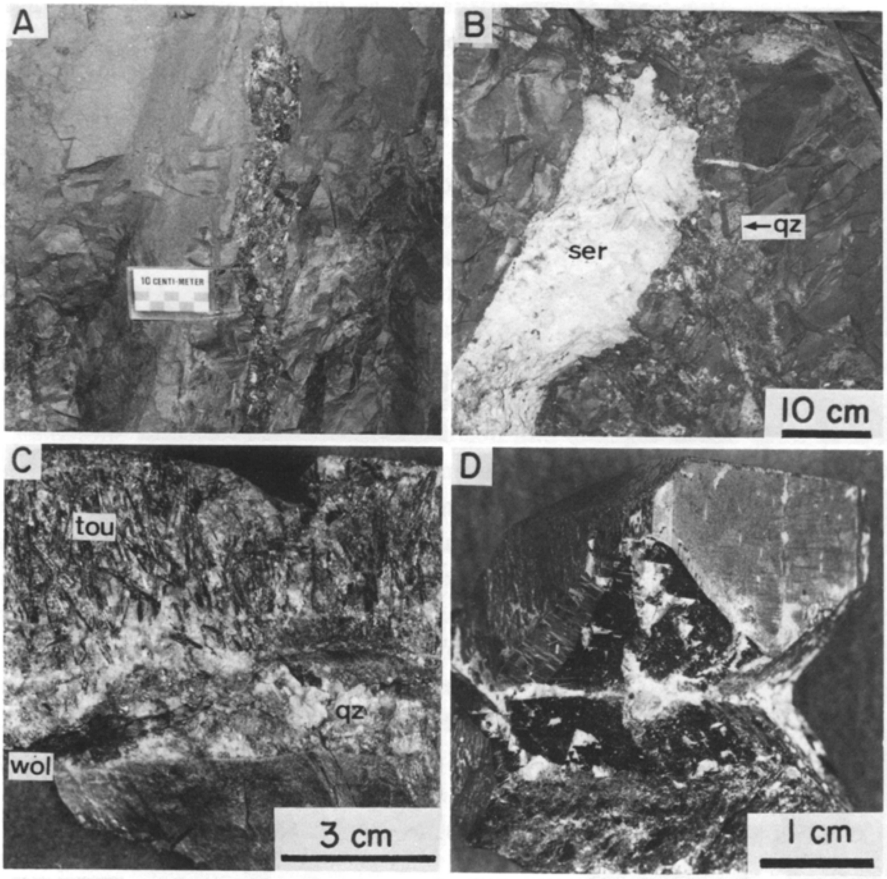

Figure 15. Ore Veins and Minerals of the Tasna Mine.
A: Wolframite (black) -quartz (white) vein (central portion) in slate (gray to dark gray), Angeles vein, +40 Gabriela level, Rosario section. B: Wolframite-arsenopyrite-pyrite-sericite (ser)-quartz (qz) vein in slate (dark gray), Ramo Pagadora vein, +40 Gabriela level, Rosario section. C: Tourmaline (tou)-wolframite (wol)-quartz (qz) ore, Ramo 4 vein, −185 level, Farellon Nuevo section. D: Large wolframite crystals, +120 Gabriela level, Rosario section.

sphalerite, stannite, antimonian cosalite, gustavite, marcasite, native bismuth, siderite, barite, sericite, natroalunite, kaolinite, wavellite and crandallite etc. In the early stage, arsenopyrite, wolframite, pyrite, quartz, tourmaline and apatite are commonly formed. Arsenopyrite occurs dominantly. Wolframite which contains 7 to 8 mole % $MnWO_4$ is usually found as euhedral crystal of 1 to 5 cm in size as shown in Figure 15-D, associating with tourmaline, quartz and arsenopyrite (Figure 16-B). Cassiterite is only found microscopically in cracks of wolframite accompanied with quartz and pyrite. Pyrite fills up the interspaces of arsenopyrite and wolframite. Bismuthinite and chalcopyrite accompanied by arsenopyrite, pyrite and quartz appear at late stage of the mineralization.

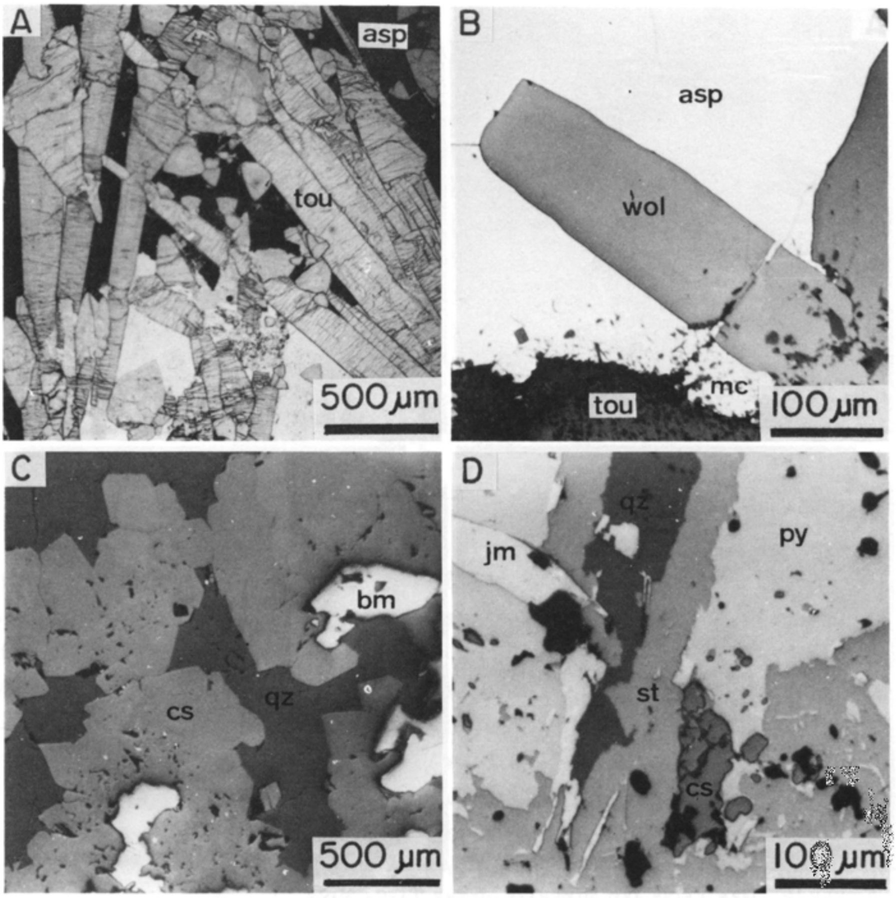

Figure 16. Photomicrographs of Ores from the Tasna Mine.
A ; transmitted light. B, C and D ; reflected light. A : Arsenopyrite (asp) filling up the interspace of aggregate of tourmaline (tou) crystals, Ramo 6, -185 level, Farellon Nuevo section (Sample No. 8181101). B : Idiomorphic wolframite (wol), arsenopyrite (asp), marcasite (mc), and tourmaline (tou), Esperanza vein, +40 Gabriela level, Rosario section (8172708). C : Coarse grained cassiterite (cs) associating with quartz (qz) and bismuthinite (bm) in the ore from the Cruz vein, 3 level, Farellon Viejo section (8182506). D : Assemblage of cassiterite (cs), stannite (st), jamesonite (jm), pyrite (py) and quartz (qz) in the ore from the Acero vein, Acero section (8373021).

Bismuthinite shows prismatic form of a few cm in length. It contains 5 to 7 mole % Sb_2S_3. Chalcopyrite is in intimate association with bismuthinite. It microscopically has sphalerite stars, 1 to 10 μm or less in size. Stannite and sphalerite are only found microscopically in close assemblage with chalcopyrite. Acicular crystal of antimonian cosalite and gustavite occurs in the druse of the veins, associating with arsenopyrite and phosphate minerals such as apatite, wavellite and crandallite. Native bismuth occurs within bismuthinite or along its cleavage. Marcasite is found as concentric growth band with pyrite in druse of veins. As gangue minerals tourmaline, quartz, apatite, siderite, natroalunite and kaolinite are commonly found. Tourmaline appears at the earliest stage of the mineralization, meanwhile natroalunite, jarosite, sericite and kaolinite fill up druse and central portion of the vein as a product of the mineralization at the latest stage (Figure 15-B). Apatite appears in association with tourmaline, quartz and arsenopyrite at early stage of the mineralization, and sometimes occurs as hexagonally prismatic form in the druse at late stage mineralization. Crystallization of quartz continues from the early up to late stages.

Ore veins such as Dos, Tres and Quatro in the Farellon Nuevo section are similar to those of the Rosario section. Their scales are also given in Table 2. Their widths are narrow, 5 to 10 cm. Country rock which is the Ordovician slate and sandstone is affected by tourmalinization and changes to fine grained aggregate of tourmaline and quartz. The veins of the section are mainly composed of tourmaline, quartz, arsenopyrite, wolframite, marcasite, apatite and siderite, and small amounts of chalocopyrite, sphalerite, pyrrhotite, stannite, bismuthinite, native bismuth, cassiterite and franckeite etc. Mineral assemblages and sequences of these minerals are about same as those at the Rosario section and formed by tungsten-bismuth mineralization. Tourmaline in these veins is found as a acicular form up to 3 cm in length in outer zone of the vein assembled with quartz, wolframite and apatite (Figures 15-C and 16-A). Pyrrhotite only occurs as granular forms, 50 to 100 μm in size, in association with chalcopyrite and pyrite microscopically.

There are many veins of the Cruz, Santa Cruz, Porvenir, Glorieta, Inca, San Pedoro, Pacifico and Sucre etc. in the Farellon Viejo section. Country rocks which are Ordovician slate and sandstone strongly suffer tourmalinization, and change to aggregate of tourmaline and quartz. The veins consist of quartz, tourmaline, apatite, wolframite, cassiterite, bismuthinite, arsenopyrite, pyrite and marcasite accompanied with chalcopyrite, stannite, sphalerite, and rarely franckeite. Mineral assemblages and sequence are similar to those of the Rosario and Farellon Nuevo sections. Cassiterite occurs in some veins associating with quartz and tourmaline as aggregate of subhedral form, 0.07 to 0.7 mm in size, sometimes up to 1.5 mm (Figure 16-C). Wolframite mainly assembles with bismuthinite, pyrite and quartz. Franckeite is microscopically found as aggregate of platy or foliated form crystallized at the latest stage of the mineralization. At the Matilde section, principal minerals are quartz, tourmaline, pyrite and marcasite. Small amounts of arsenopyrite, bismuthinite, chalcopyrite, wolframite, cassiterite, monazite and scorodite are found from the veins in the section. Cassiterite occurs as coarse grained aggregate of subhedral crystal, 0.1 to 0.2 mm in size.

Ore veins formed by tin-pyrite mineralization in the Alluta, Mary, Jaffa and Eduarda sections show crustified banding, and are more simple than those in the

Rosario, Farellon Nueva and Farellon Viejo sections. Country rocks are weakly altered by sericitization. The veins are mainly composed of pyrite, cassiterite, quartz and sometimes siderite and marcasite. Cassiterite occurs as band, 1 to 3 mm in width, as aggregate of fine grains less than 10 μm in size associating with quartz and pyrite under microscope. Tourmaline and wolframite are not found in the veins.

Ore veins in the Belen, Mariana and Pando sections which are located in the southeast of the Rosario section are principally composed of quartz, arsenopyrite, pyrite, wolframite and cassiterite accompanied by sphalerite, stannite, chalcopyrite, and sometimes bismuthinite (Mariana section). Cassiterite appears as a minute grain, less than 5 μm in size, associated with pyrite and stannite closely. At Pando section, pyrrhotite is found as a principal mineral associating with ore minerals as above. Occasionally small amounts of jamesonite and franckeite are crystallized at late stage of the mineralization as filling up the central part of the veins in the Pando section. The veins in the Acero section which is situated at the most northern part of the Tasna mine are similar to those of Mariana section, and mainly composed of pyrite, sphalerite, jamesonite, quartz and marcasite etc. Small amounts of cassiterite, stannite, chalcopyrite and unknown Ag-Pb-Bi-Sb sulfosalt are found in intimate association with pyrite (Figure 16-D). Jamesonite also closely assembles with sphalerite, pyrite, stannite and chalcopyrite. Stannite contains star like sphalerite crystal, less than 2 μm in size.

In the Veneros section, quartz, pyrite, arsenopyrite, sphalerite, stannite occur as principal minerals. Small amounts of jamesonite, boulangerite, franckeite and some silver sulfosalt minerals are recognized. Silver sulfosalt mineral (unknown Ag-Pb-Bi-Sb-S mineral) fills up interspace of pyrite microscopically, and is sometimes enclosed in pyrite associating with jamesonite. Boulangerite and franckeite are formed in the central part of the veins at the latest stage of the mineralization at the Veneros section. No cassiterite and wolframite are found.

As mentioned before, the ore veins in the Tasna mining area are principally divided into such five zones from mineral assemblages as the tungsten-bismuth (W-Bi), tin-quartz (Sn-qz), tin-pyrite (Sn-py), tin-silver (Sn-Ag) and tin-lead-zinc (Sn-Pb-Zn) zones arranging from center to outside as seen in Figure 17. The veins of the Rosario, Farellon Nuevo, Farellon Viejo and Matilde sections belong to central W-Bi zone. Characteristic minerals of the W-Bi zone are tourmaline, wolframite, bismuthinite and chalcopyrite and phosphate minerals such as apatite and monazite. Tourmaline, wolframite, arsenopyrite and quartz are in general crystallized at the early stage of the mineralization, and bismuthinite, chalcopyrite and pyrite are formed at the late stage. In the Sn-qz zone, cassiterite appears as aggregate of coarse grains in association with quartz, tourmaline and pyrite at the Farellon Viejo and Matilde sections. In some veins of Farellon Viejo and Matilde sections, wolframite is also found in association with tourmaline, bismuth-

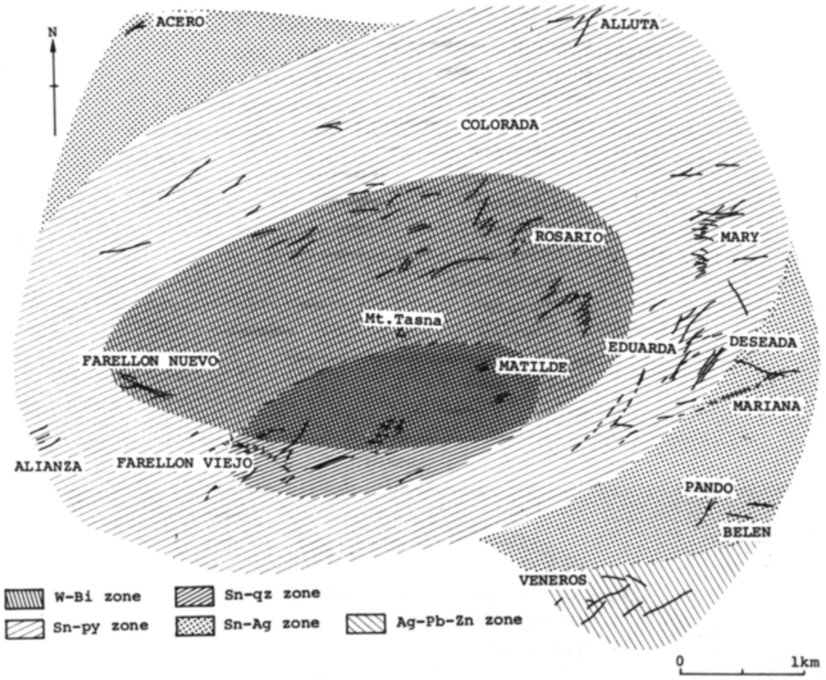

FIGURE 17. ZONAL ARRANGEMENT OF ORE MINERALS IN THE TASNA MINE.

inite, quartz and pyrite. These facts are thought to indicate that the W-Bi and Sn-qz mineralizations are overlapped in the veins of both sections. The ore veins in the Alluta, Mary, Eduarda and Deseada sections which belong to the Sn-py zone, are principally composed of pyrite and cassiterite etc. Cassiterite from this zone is aggregate of very fine crystals, less than 10 μm in size, and associates with pyrite and quartz. The veins of the Acero, Belen, Mariana and Pando sections belonging to the Sn-Ag zone mainly consist of pyrite, sphalerite, chalcopyrite and stannite. Sometimes unknown Ag-Pb-Bi-Sb sulfosalt, wolframite and cassiterite are found in association with pyrite, sphalerite, chalcopyrite and quartz. The Ag-Pb-Zn zone of the outside is characterized by mineralization of silver, lead and zinc. The veins in the Veneros section belong to this zone, and are composed of pyrite, sphalerite, arsenopyrite and stannite as principal minerals. Slight quantities of sulfosalt minerals such as jamesonite, franckeite, boulangerite and unknown Ag-Pb-Bi-Sb sulfosalt mineral usually occur in this zone.

From the data on occurrences and mineral assemblages and parageneses, the sequence of the mineralization of the veins in the Rosario section of the mine is obtained as shown in Figure 18. It indicates that wolframite crystallizes at early stage of the mineralization together with arsenopyrite, pyrite and quartz. Sphalerite, pyrite and chalocopyrite are formed at middle stage of the mineralization associating with bismuthinite and stannite. Small amounts of cassiterite are

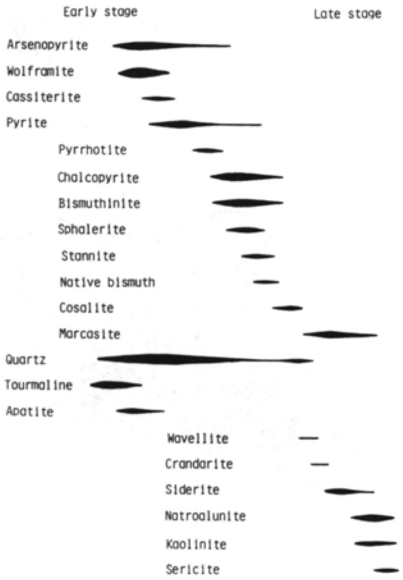

FIGURE 18. CRYSTALLIZATION SEQUENCE OF MINERALS FROM THE ROSARIO SECTION, TASNA MINE.

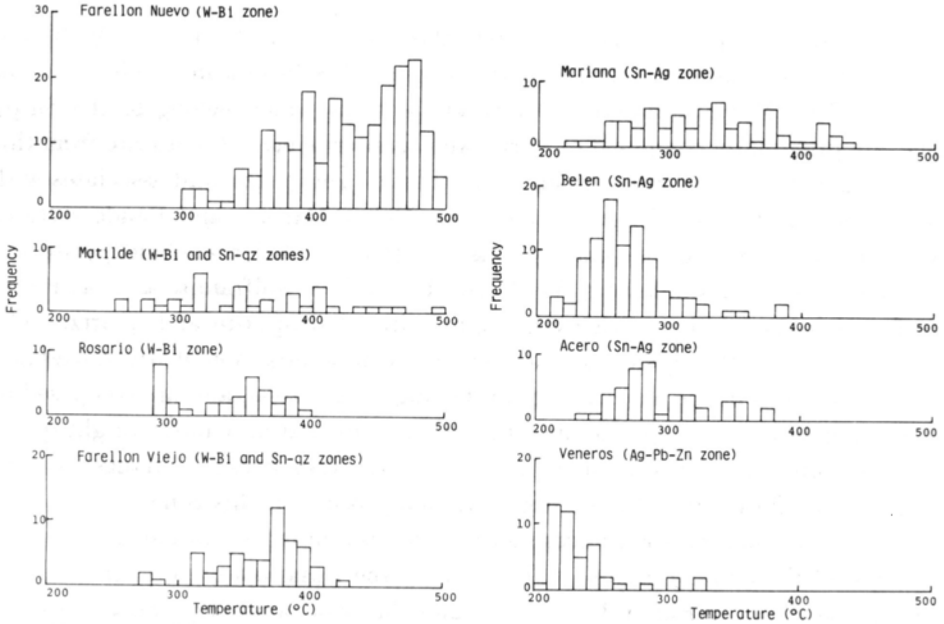

FIGURE 19. HOMOGENIZATION TEMPERATURES OF FLUID INCLUSIONS IN QUARTZ FROM THE VEINS OF THE TASNA MINE.

TABLE 3. RANGES OF HOMOGENIZATION TEMPERATURES AND SALINITIES IN NaCl EQUIVALENT CONCENTRATION OF FLUID INCLUSIONS IN QUARTZ FROM THE TASNA MINE.

Section	Vein	Homogenization temp. (°C)	Salinity (NaCl eq. wt%)
Rosario	San Seferino	281 - 328	24.6-31.2
	Esperanza	354 - 389	33.2-40.1
	Ramo Pagadora	330 - 395	30.5-41.4
Matilde		250 - 499	32.7-50.4
Farellon Nuevo	Ramo 4	302 - 491	29.4-42.3
Farellon Viejo	Cruz	271 - 422	12.4-20.2
Mariana		226 - 437	31.5-34.9
Belen	Ramo Jerusalem	213 - 381	9.9-19.3
Acero		239 - 377	
Veneros		202 - 328	7.4-8.6

FIGURE 20. SCENERY OF THE CHOROLQUE MINE.
A : Mt. Chorolque and mining town. B : The Santa Barbara mining town.

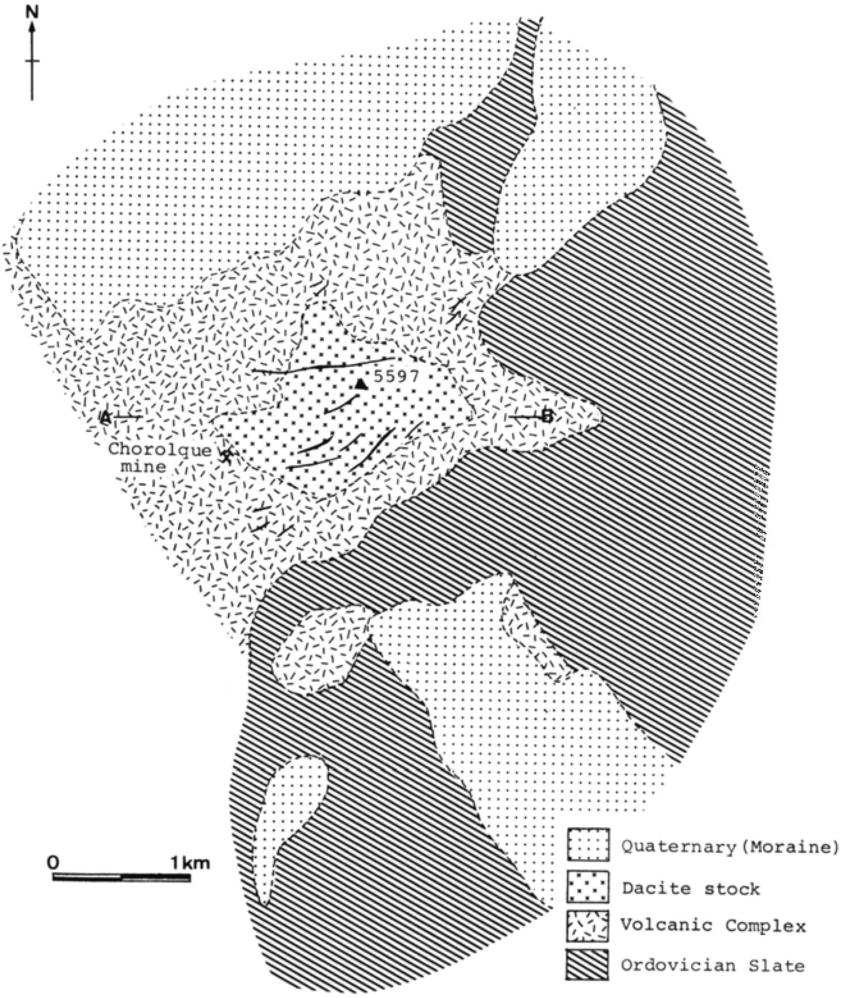

FIGURE 21. GEOLOGICAL MAP OF THE CHOROLQUE MINE.

formed at relatively early stage as coarse grains associating with quartz and wolframite, but it formed at later time than above appears as aggregate of fine crystal assembled with pyrite. Sericite, kaolinite, jarosite and natroalunite fill up the vug or druse in central portion of veins as products of the mineralization at the latest stage.

Quartz from the ore veins in each section of the mine have fluid inclusions. There are two types of fluid inclusions in quartz, one is two phase inclusions of liquid and vapor as seen in quartz from the veins of the Acero, Belen, Veneros and Farellon Viejo sections, and another one is polyphase type of liquid, vapor and some solids as found in quartz from the veins of the Rosario, Matilde, Mariana and Farellon Nuevo sections. Homogenization and freezing temperatures for these inclusions were measured by using the Linkam TH-600 type heating and freezing stage. Results of the homogenization temperatures and salinities in NaCl equivalent concentration obtained from the freezing temperatures are summarized in Figure 19 and Table 3. Generally inclusions in quartz from the veins formed by mineralization of the W-Bi zone show 250°-499°C and 12.4-50.4 wt% in NaCl equivalent of high homogenization temperatures and high salinities, respectively, similar to those from porphyry copper deposits. Also both values for homogenization temperature and salinity of quartz from the Sn-Ag and Ag-Pb-Zn zones are 213°-437°C and 9.9-34.9 wt% and 202°-377°C and 7.4-8.6 wt%, respectively, which become lower values than those of the W-Bi zone.

3. *Chorolque mine*

The Chorolque mine also belongs to the Quechisla division of COMIBOL. It is situated at about 20 km east from Atocha (Figure 3). The mine office is located at Santa Barbara which is at high altitude of 4,770 m above sea level (Figure 20-A and B). Its production is 17,000 tons per month in 1983 as crude ores, 9,400 tons containing 0.75% Sn and 7,600 tons with 0.52% Sn.

Geology around the mine is composed of Ordovician system, Miocene volcanic complex and dacite stock as described by Ahlfeld and Schneider-Scherbina (1964), Sillitoe *et al.* (1975) and Grant *et al.* (1980). Among them, the former consists of folded slate and sandstone as basement which form relatively gentle sloped mountain around Mt. Chorolque. Meanwhile the Miocene volcanic complex of dacitic tuff breccia, agglomerate and massive tuff unconformably lie on the basement (Figures 21 and 22). Dacite stock intrudes into the Ordovician rocks and the Miocene volcanic complex, and forms Mt. Chorolque (5,597 m elevation). However, it is strongly altered by tourmalinization so as be difficult to determine

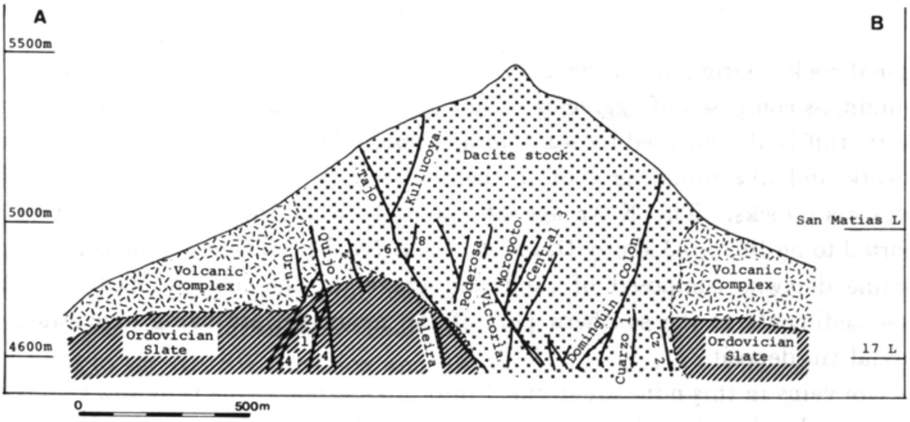

Figure 22. Geological Cross Section of the Chorolque Mine Along A-B Line in Figure 21.

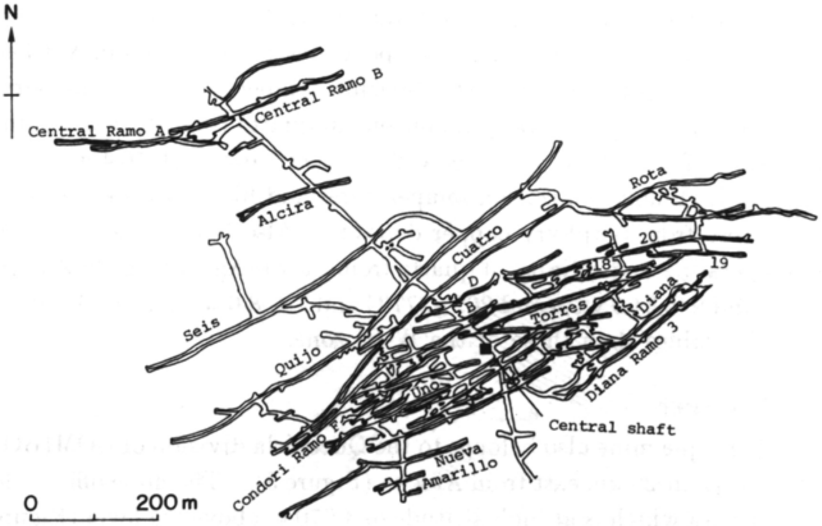

FIGURE 23. VEIN ARRANGEMENT AT THE 9 LEVEL IN THE CHOROLQUE MINE.

TABLE 4. THE SCALES OF MAIN VEINS IN THE CHOROLQUE MINE.

Vein	Strike	Dip	Length (m)	Dedth (m)	Width (m)
Colon	N85°E	68°S	1250	500	2.0
Seis	N60°E	69°N	920	200	2.0 - 2.5
Quijo	N50°E	65°N	800	260	1.5
Quatro	N50°E	74°N	750	330	1.0
Alcira	N60°E	86°N	420	175	1.0 - 1.5
Central					
Ramo A	N65°E	57°S	670	195	0.8
Ramo L	N70°E	58°S	500	150	0.4 - 0.5
Pan	N60°E	72°S	360	160	0.3 - 0.5
Torrez	N55°E	90°	450	190	0.1 - 0.2
Dominguin	N85°E	69°S	420	210	2.0 - 2.5
"A"	N75°E	66°S	480	210	0.4 - 0.5

original rock. Original quartz phenocryst, 2 mm or less in size, is found in a groundmass composed of aggregate of fine grained quartz, sericite and tourmaline. Dacitic tuff is also affected by tourmalinization. Tourmaline is found as veinlet, network and disseminating spot in dacite stock, Miocene pyroclastics and the Ordovician rocks. The K-Ar age of dacite lava in the volcanic complex is reported to be 16.2±0.3 Ma by Grant *et al.*, (1979a, b). There are the Quaternary moraine deposits composed of sand and gravel at the foot of Mt. Chorolque. These sediments at the southern part of the mountain are being explorated as alluvial tin deposit.

Ore veins in this mine are divided into three types. One is quartz vein with cassiterite developed in the intrusive mainly and in Miocene pyroclastic and the Ordovician rocks partly as seen in Figures 21 and 22. The other two types are

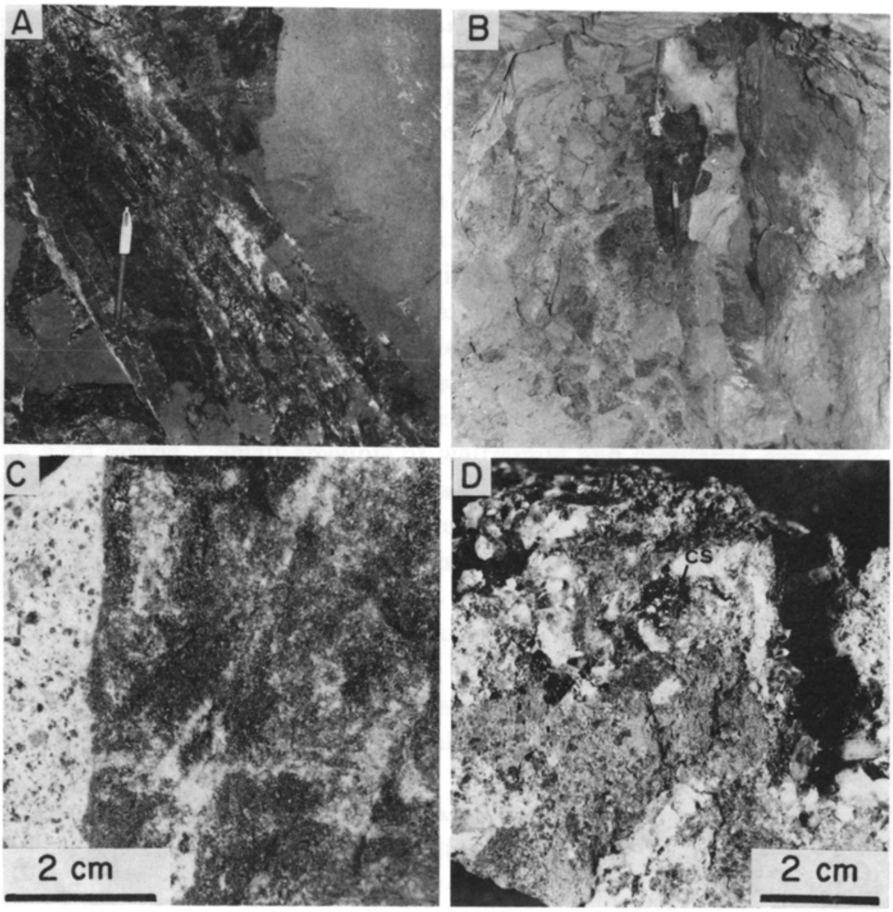

FIGURE 24. ORE VEINS AND VEIN MINERALS FROM THE CHOROLQUE MINE
A : Cassiterite-quartz (white) vein in intrusive dacite (gray), Central Ramo A vein, 12 level. Tourmaline is visible in black color in both the out- and inside of the veins. B : Cassiterite vein (dark gray) in altered dacite (gray), Fanny Ramo 1 vein, 8 level. Alunite (light gray) fills up in the central part of the vein. C : Aggregate of acicular tourmaline (dark gray) in dacite (white, light gray), Central Ramo A vein, 12 level. (sample No. 8180406). D : Euhedral crystals of cassiterite (cs) and quartz (white and gray), 8 Ramo B vein, 6 level (8371414).

sulfide veins; one is mainly composed of pyrite, arsenopyrite, chalcopyrite, wolframite, bismuthinite, sphalerite and quartz, and another consists mainly of tetrahedrite, galena, sphalerite, chalcopyrite and small amounts of stannite. Both type veins occur in Ordovician and pyroclastic rocks. All the veins generally run to the NE-SW direction and dip steeply to N or S. Their arrangements at the 9 level (4,941 m above sea level) is shown in Figure 23, and the scales of the veins are given in Table 4. According to the table, the width of the veins ranges from 0.1 to 3 m.

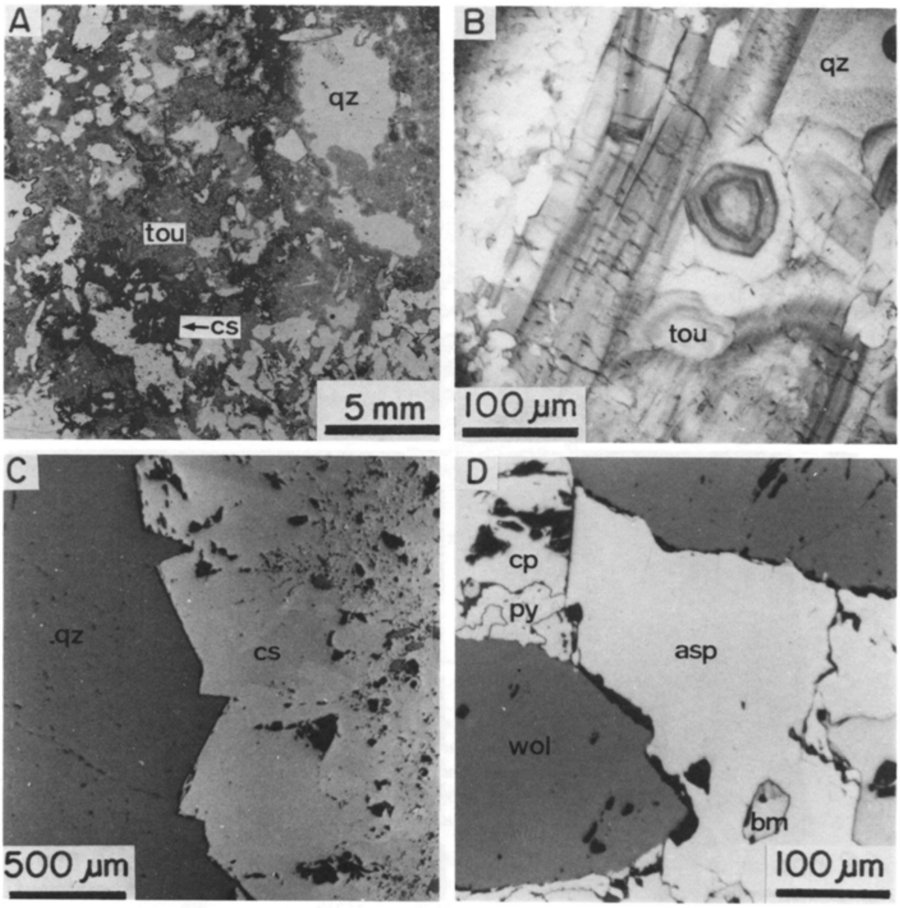

FIGURE 25. PHOTOMICROGRAPHS OF ORE AND GANGUE MINERALS FROM THE CHOROLQUE MINE.

A and B ; transmitted light. C and D ; ore microscope. A : Quartz (qz), aggregate of cassiterite (cs) and tourmaline (tou), Central Ramo 3 vein, 9 level (Sample No. 8180323). B : Zoning tourmaline (tou) associated with quartz (qz) near Central shaft, 12 level (8372620). C : Coarse grained cassiterite (cs) and quartz (qz), Fanny Ramo vein, 6 level (8180309). D : Wolframite (wol) associated with arsenopyrite (asp), pyrite (py), chalcopyrite (cp) and bismuthinite (bm), Sin Nombre vein, 14 level, Sagrario section (8371193).

The quartz veins such as Colon, Quijo, Quatro, Alcira, Fanny, Central and Torrez are mainly composed of cassiterite, quartz, tourmaline, jarosite, alunite, natroalunite and minamiite, and small amounts of pyrite, arsenopyrite, stannite, electrum, hematite, goethite, strengite and variscite. Quartz occupies the outside in the veins and also appears in the country rock near veins as veinlets or network (Figure 24-A). Cassiterite which is only an economic mineral from the mine occurs in the inside of the veins as band which is aggregates of its fine to coarse grains (Figures 24-D, 25-A and C). Small amounts of wolframite are sometimes accompanied by cassiterite. The veins are generally filled up by jarosite and in some case alunite, natroalunite and minamiite in the central portion of them by the late stage mineralization (Figure 24-B). Electrum is microscopically found as fine grains, 200 μm in size, in jarosite and cassiterite of the Fanny Ramo vein. Its chemical composition is $Au_{0.77-0.80}$ $Ag_{0.23-0.20}$. Phosphate minerals such as strengite and variscite also occur in the latest stage of the mineralization, assembled with jarosite in the Central Ramo 3 vein.

The sulfide veins formed by the W-Bi mineralization occur in the Ordovician system and the Miocene volcanic complex around the intrusive rock. The Sin Nombre vein in the Granrecorte adit of the Sagrario section appears in Ordovician slate and sandstone and is mainly composed of sulfide minerals such as arsenopyrite, pyrite, pyrrhotite, bismuthinite, chalcopyrite, sphalerite, stannite and marcasite with quartz. Small amounts of wolframite and cassiterite also occur in close association with sulfide minerals, quartz and tourmaline in the vein. Rarely cosalite, electrum and telluride minerals such as tetradymite and hessite are found microscopically. Tourmaline occurs in the most outside of the vein. Arsenopyrite is crystallized at early stage of the mineralization. Chalcopyrite, pyrite, pyrrhotite and bismuthinite, sphalerite and stannite are closely assembled with each other and accompanied with wolframite (Figure 25-D). Electrum, tetradymite and hessite, 2 to 20 μm in size, are found as inclusions in arsenopyrite and chalcopyrite. Characteristic minerals found from the vein are wolframite and bismuthinite.

The sulfide ore consisting of galena, chalcopyrite, tetrahedrite, sphalerite, quartz and small amounts of stannite, wolframite and bismuthinite is found in the vein of the Reforma section which is located at the southwest portion of the mine.

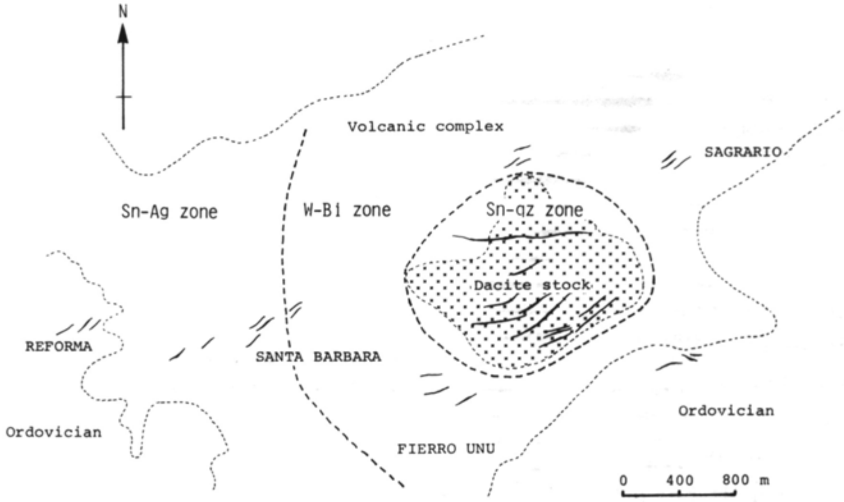

FIGURE 26. ZONAL ARRANGEMENT OF ORE MINERALS IN THE CHOROLQUE MINE.

Small amounts of tetrahedrite and cosalite are enclosed in galena from the vein. At the Santa Barbara section, some sulfide veins are also found. They usually consist of chalcopyrite, bismuthinite, quartz, siderite, barite and small amounts of tetrahedrite. Chalcopyrite occurs in association with bismuthinite, tetrahedrite and quartz in the central part of the veins.

As shown in Figure 26, the quartz veins with cassiterite as mentioned above develop in the tin-quartz (Sn-qz) zone, meanwhile the sulfide vein with wolframite and bismuthinite occurs in the tungsten-bismuth (W-Bi) zone. The veins of the Sn-qz zone are found in the central part of Mt. Chorolque and mostly occur in the intrusive rock. It is characterized by occurring coarse grained cassiterite. Sulfide veins characterized by wolframite, bismuthinite and base metal sulfide are formed in the outer side of the Sn-qz zone. At most outer side, the Sn-Ag zone characterized by silver and tin bearing sulfide minerals such as tetrahedrite and stannite appear.

The sequence of mineral crystallization obtained from the data on occurrences and mineral assemblages and parageneses in ores from the Chorolque mine is shown in Figure 27. It indicates that cassiterite forms at early stage of the mineralization together with tourmaline and quartz. Wolframite crystallizes at middle stage associating with arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite, bismuthinite and stannite. The mineral assemblages with wolframite are very similar to those found at the Rosario section of the Tasna mine. At the latest stage, sulfate and phosphate minerals such as jarosite, alunite, natroalunite, minamiite, variscite and strengite occur.

Polyphase fluid inclusions containing liquid, vapor and more than three kinds of solids are commonly observed in quartz from the Colon, Fanny and

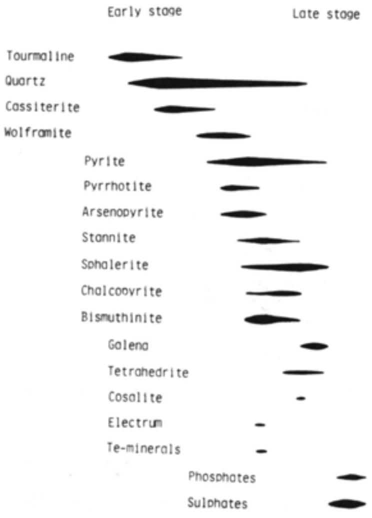

FIGURE 27. MINERALIZATION SEQUENCE OF MINERALS FROM THE CHOROLQUE MINE.

Central veins etc. in the Sn-qz zone and Sin Nombre veins, Sagrario section in the W-Bi zone. Homogenization temperature and salinity in NaCl equivalent concentration of these inclusions in quartz from the Sn-qz zone obtained by using the heating-freezing stage are 276° to 509°C and 32.2 to 53.2 wt% for Colon vein, 261° to 490°C and 30.5 to 47.7% for Fanny Ramo 1 vein, and 285° to 500°C and 24.9 to 25.4% for Central Ramo 3 vein, respectively. Meanwhile both the values of those from the W-Bi zone are 268° to 493°C and 33.2 to 48.2 wt% for Sin Nombre vein. Their results indicate that the values of homogenization temperature and salinity for fluid inclusion in quartz from the Chorolque mine are very high and similar to those of quartz formed by the W-Bi zone in the Tasna mining area. These inclusions correspond to the Types I, III and IV by Grant *et al.* (1980). They described that the fluid inclusions in quartz from the the quartz-cassiterite veins are mainly Type I or II of them and the homogenization temperature and salinity of the inclusions are below 300°C and less 30 wt%, respectively. They have data of high homogenization temperatures of 300° to 500°C and dense salinity of 50 wt% for inclusion of barren quartz which has no relation to tin mineralization. However, as mentioned above the inclusion data obtained by this study for quartz, which is in intimate association with cassiterite and sulfide minerals with wolframite produced by the Sn-qz and W-Bi mineralizations, show higher values than those of Grant *et al.* (1980).

As mentioned above, the hydrothermal alteration is distinctly found in the area. Especially the dacite stock suffers intensely tourmalinization (Figures 24-C and 25-B). Radial and fibrous crystals of tourmaline occur in the wall rocks as veinlet, network and dissemination spot. Such alteration halo extends outward from the intrusive to the Ordovician rocks. For about 1,250 m from the contact boundary of the stock to the entrance of the Fierro Unu adit which is the cross cut at the 17 level, 27 slate samples were taken out for each 50 m and observed under the microscope. Within 100 m from the intrusive contact, strong tourmalinization associated with sericitization is observed in Ordovician slate. Between 100 m and 350 m from the contact, sericitization and weak tourmalinization are found. In the outer zone between 350 m and 1,250 m from the contact, sericitization are only recognized, but no tourmalinization.

4. Siete Suyos mine

The Siete Suyos mine which belongs to COMIBOL is located at 7 km west of the Atocha town (Figure 28-A and B). It is mining about two kinds of ores, tin-silver and silver-lead-zinc, which were produced 2,800 tons and 4,000 tons per month as crude ores containing 0.35% Sn, 190 g/t Ag, 0.25% Cu and 330 g/t Ag, 1.8% Pb, 1.8% Zn, respectively in 1981, and 3,300 tons and 1,900 tons per month as crude ores with grades of 0.49% Sn, 130 g/t Ag, 0.23% Cu and 310 g/t Ag, 2.34%

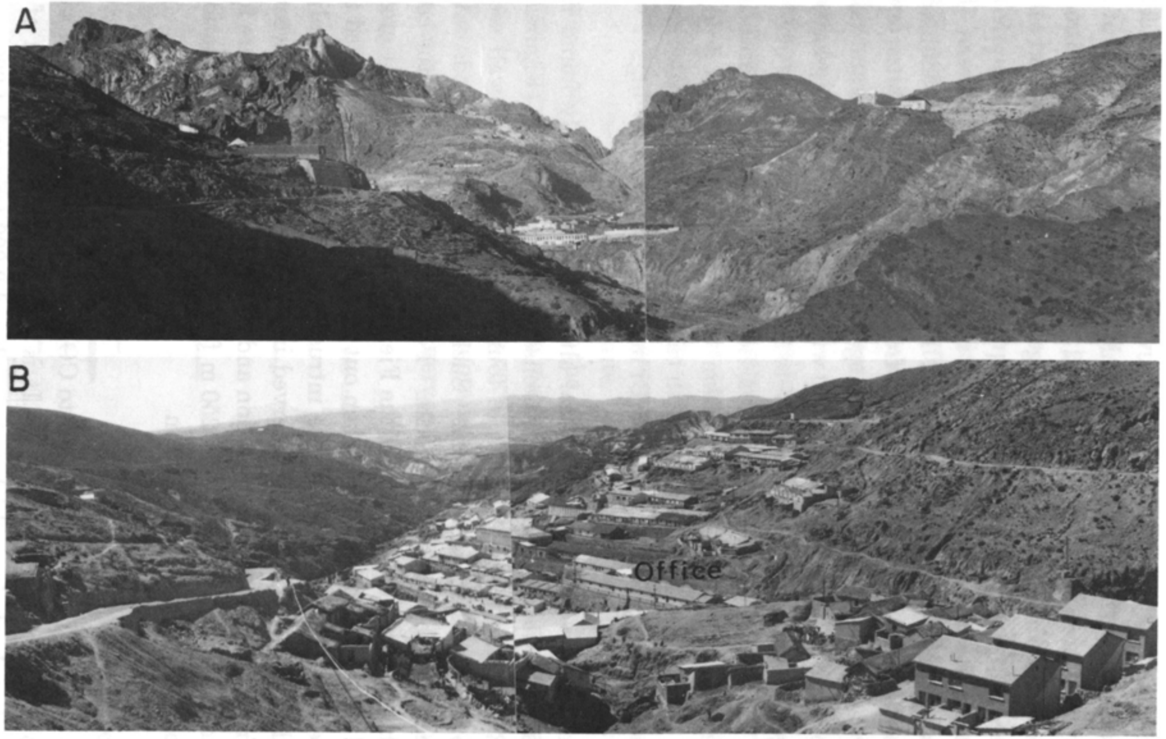

FIGURE 28. SCENERY OF THE SIETE SUYOS MINE.
A : A view of the Siete Suyos mine looked from the north. B : The mining town and office (central portion) of the Siete Suyos mine looked from the southwest.

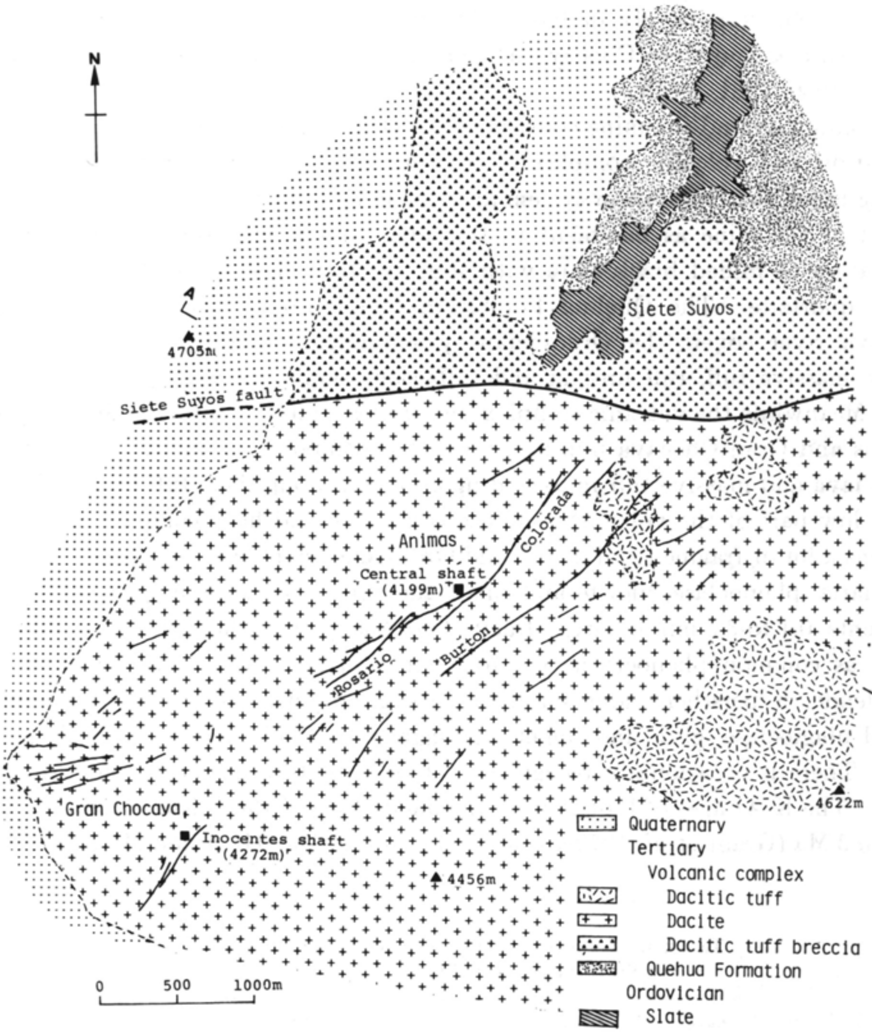

Figure 29. Geological Map of the Siete Suyos, Animas and Gran Chocaya Mining Area.

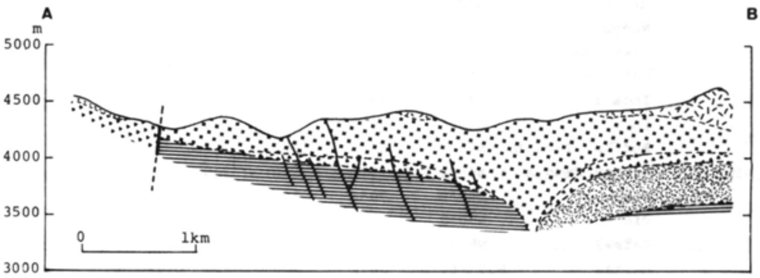

Figure 30. Geological Cross Section along the A-B Line in Fgure 29. Legend is same as that in the Figure 29.

Pb, 2.51% Zn, respectively in 1983. The geology and ore deposits of the Siete Suyos, Animas and Gran Chocaya mining area have been reported by JICA and MMAJ (1980, 1981, 1982).

Geology around the mine consists of the Ordovician system, and the Quehua Formation and volcanic complex of Miocene as shown in Figures 29 and 30. Among them, the Ordovician system appears along the Chocaya river and underground of the mine as basement in this area, and is composed principally of alternation of folded black slate with slightly slaty cleavage and sandstone or partly quartzite. The Quehua Formation found around the mine along the Chocaya river covers the Ordovician system unconformably, and consists of dacitic massive tuff, tuff breccia and tuffaceous sandstone with pumiceous tuff bed. Meanwhile the volcanic complex distributes widely around the Siete Suyos, Animas and Gran Chocaya mining area. It is composed of dacitic tuff breccia, dacite lava and massive tuff in ascending order. Among them tuff breccia found in the low part of the volcanic complex is massive and hard compact rock, and contains a lot of fragments of dacite and Ordovician slate and sandstone. It also has quartz, plagioclase, biotite and small amounts of sanidine as phenocrysts or fragments, 0.1 to 3.0 mm in size. Dacite lava has quartz, plagioclase, biotite and augite as common phenocrysts, 0.1 to 3.0 mm in size, with small amounts of hornblende, hypersthene and sanidine. Its groundmass is composed of lath-shaped plagioclase, glass and sometimes aggregate of submicroscopic felsic minerals. There is occasionally recognized a fluidal texture in dacite under microscope. The K-Ar ages of biotite from the dacite lava of the volcanic complex are 13.8±0.2 Ma (Grant *et al.* 1979a, b) and 11.6 to 12.1 Ma (JICA and MMAJ, 1980).

TABLE 5. PRINCIPAL VEINS AND THEIR SCALES IN THE SIETE SUYOS AND ANIMAS MINES.

Vein	Strike	Dip	Length (m)	Depth (m)	Width (m)
Esperanza	N45°E	80°S	750	270	0.5
San Patricio	N52°E	65°-70°N	520	230	0.3
Salvadora	N45°E	70°S	600	400	0.7
Arturo	N40°E	65°S	570	640	0.35
Nueva	N45°E	70°S	650	350	0.25
Nueva Ramo D	N70°E	80°N	100	120	0.15
Colorada	N35°-50°E	65°S	2450	650	4 - 5
Inca I	N40°E	79°S	920	360	0.4
Inca II	N40°E	80°S	760	180	0.3
Burton, Inca III	N55°E	69°S	1800	780	1.2
Burton Ramo A	N45°E	75°S	250	200	0.25
Orcho	N60°E	70°S	100	90	0.35
Diez	N50°E	75°S	300	90	0.85
Rafael	N50°E	78°S	250	40	0.75
Animas	N50°-60°E	68°N	500	300	0.5-0.8
San Juan	N70°E	67°S	540	120	0.7
Rosario	N53°E	60°N	1400	190	0.25

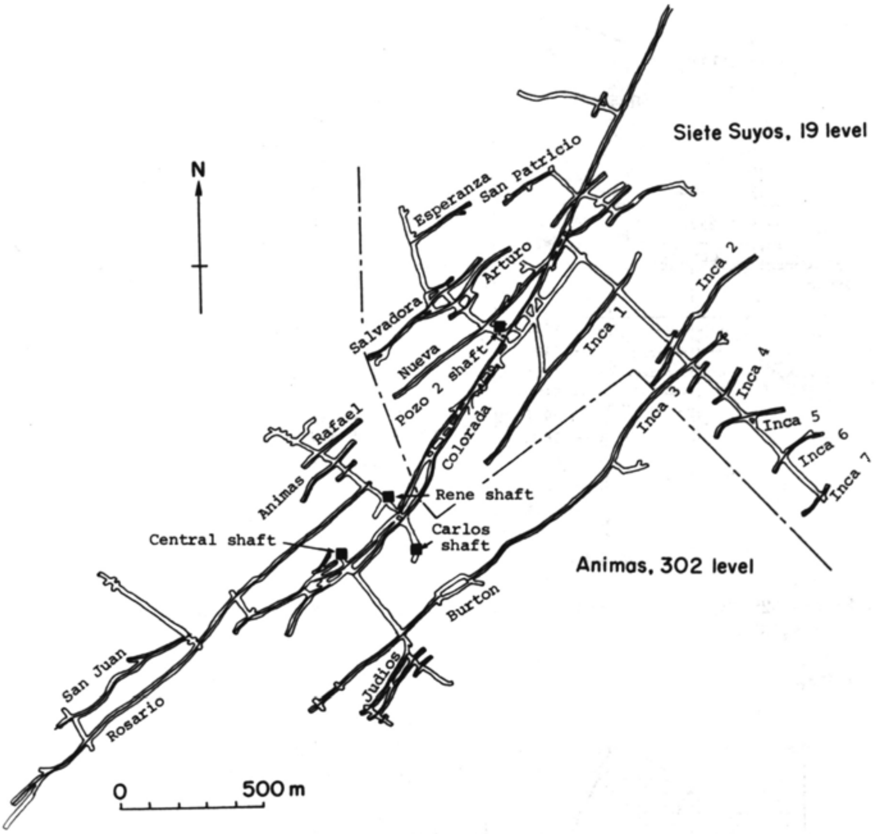

FIGURE 31. VEINS AT THE 19 LEVEL, SIETE SUYOS MINE AND THE 302 LEVEL, ANIMAS MINE.

Massive tuff with no bedding is grayish white in color, and has quartz, plagioclase, biotite and hornblende as phenocrysts or crystal fragments and much amounts of glass. It appears at high land above 4,300 m as upper most member of the volcanic complex. Dacite and its pyroclastic rocks of the volcanic complex suffers generally sericitization and occasionally kaolinization near ore veins. In such case, they change their color to white or grayish white. Also Ordovician slate adjacent to the veins is slightly altered by sericitization.

Many ore veins such as the Esperanza, San Patricio, Salvadora, Arturo, Diez, Nueva, Colorada, Inca 1, Inca 2 and Inca 3 are found in the mine which is being worked from the 0 level (4,202 m above sea level) to the 28 level (3,564 m) with the 19 level (3,881 m) of principal adit of the mine and two shafts named Pozo 2 and Pacheco. The scales of such ore veins are given in Table 5, together with those of the Animas mine which adjoins at the southwest to this mine. The arrangement of the veins of the Siete Suyos and Animas mines are shown in Figure 31. As seen in the figure, both the mines of Siete Suyos and Animas are being

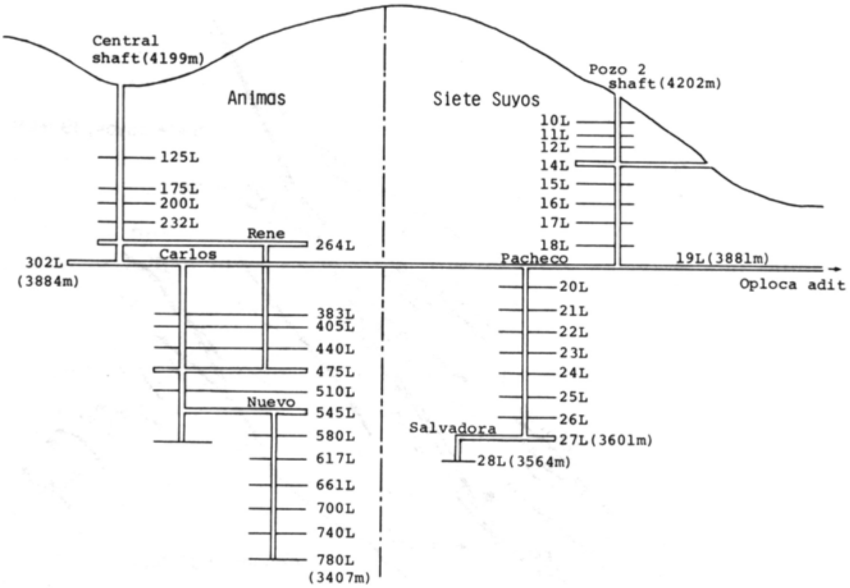

FIGURE 32. RELATION BETWEEN LEVELS OF THE SIETE SUYOS AND ANIMAS MINES.

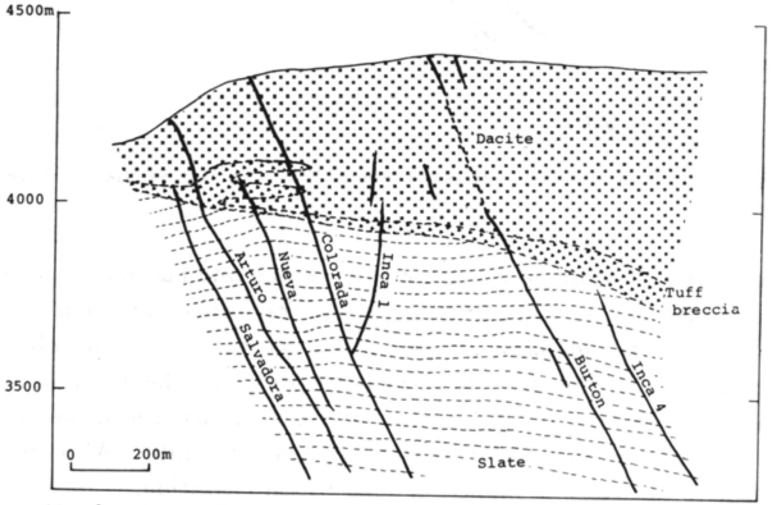

FIGURE 33. GEOLOGICAL CROSS SECTION OF THE SIETE SUYOS AND ANIMAS MINES ALONG THE NE-SE DIRECTION.

worked at same level ranges on same veins, but names of the levels are different. The relation of the level names in the both mines is shown in Figure 32. These veins run to the direction of N40° to 60°E parallel to the strike of the Colorada vein which is the biggest one with 2,450 m in strike length, 650 m in depth and 4 to 5 m in width, but has been almost mined out. They mainly develop in the

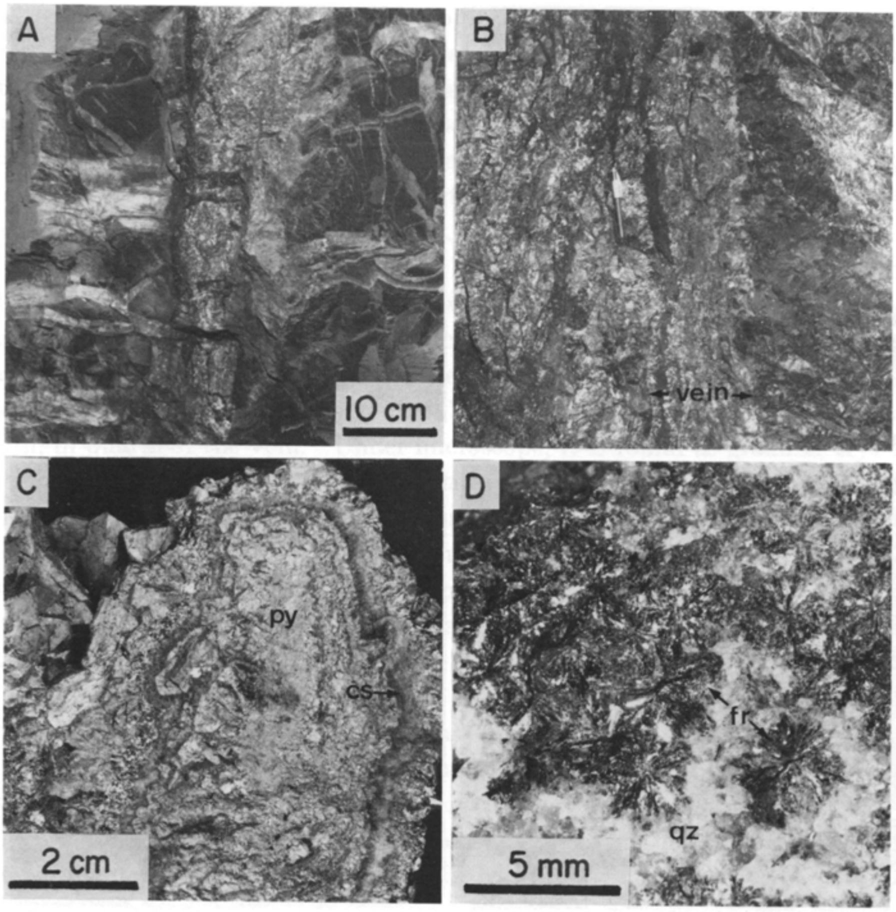

FIGURE 34. ORE VEINS AND VEIN MINERALS FROM THE SIETE SUYOS MINE.
A : Cassiterite-pyrite-quartz vein in Ordovician slate, Colorada vein, 19 level. B : Pyrite-sphalerite-quartz vein in Ordovician slate, Arturo vein, 19 level. C : Pyrite (py)-cassiterite (cs) ore, Arturo vein, 19 level (Sample No. 8172829). D : Idiomorphic franckeite (fr) and quartz (qz), Salvadora vein, 28 level(8181323).

Ordovician slate and sandstone, but they occur in dacite and its tuff breccia partly as seen in Figure 33.

The veins in this mine are usually divided into two types from the mineral assemblages and parageneses of ore and gangue minerals. One of them is mainly composed of quartz, cassiterite and pyrite with simple banding as found in the Colorada, Inca 1 and Nueva veins. The other such as the Esperanza, Salvadora, Arturo and Diez veins are sulfide veins consisting of many ore minerals such as pyrite, sphalerite, stannite and galena principally with small amounts of cassiterite, marcasite, arsenopyrite, chalcopyrite, wurtzite, tetrahedrite, franckeite, hocartite, boulangerite and jamesonite etc. as ore minerals, and small amounts of quartz,

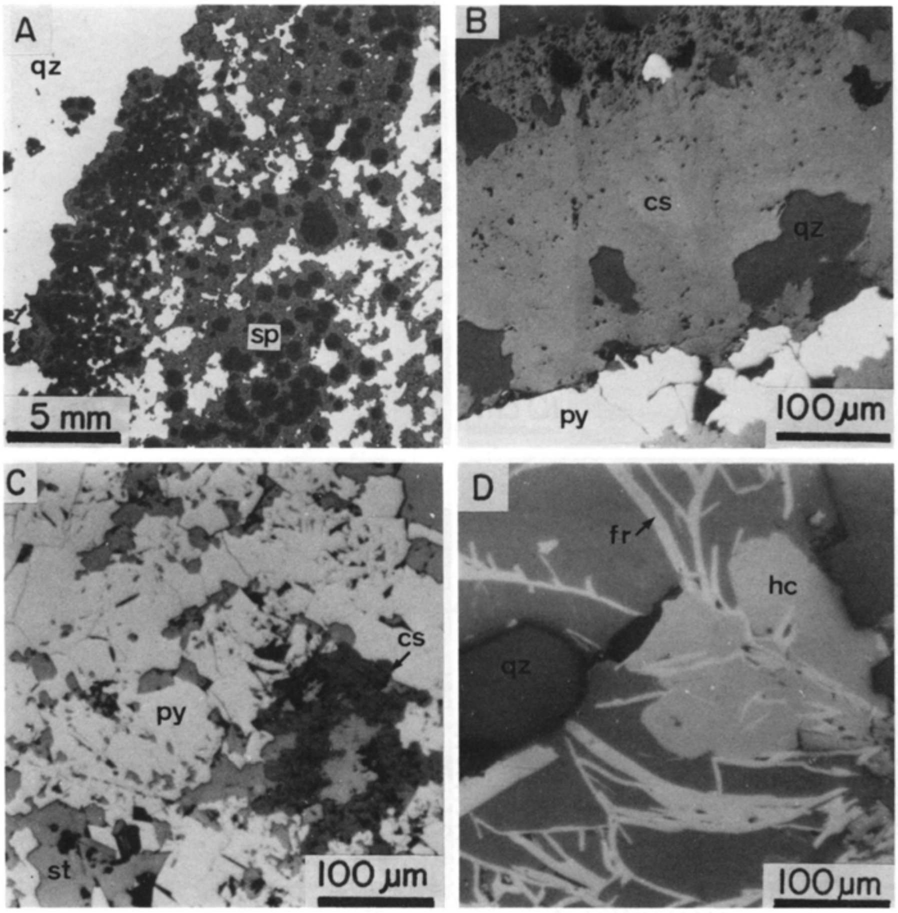

FIGURE 35. PHOTOMICROGRAPHS OF ORES FROM THE SIETE SUYOS MINE.
A ; transmitted light. B, C and D ; reflected light. A : Quartz (qz) and sphalerite (sp), Salvadora vein, 128 level (Sample No. 8172804). There is found growth zoning of sphalerite in which the central part becomes to darker in color than outside rim. B : Cassiterite (cs) associating with quartz (qz) and pyrite (py), Colorada vein, 14 level (8172830). C : Cassiterite (cs) and stannite (st) filling up the interspaces of aggregate of pyrite (py) grains, Arturo vein, 19 level (8172821). D : Hocartite and platy franckeite with quartz (qz), Salvadora vein, 128 level (8172808).

kaolinite, gibbsite and sericite etc. as gangue minerals. It shows distinctly crustified banding and has often druse in central portion of the vein. Among these minerals, stannite, franckeite and hocartite are characteristic as tin minerals from the veins of the latter, and cassiterite occurs as those of the former (Buerger and Maury, 1927). In sulfide vein, pyrite is most abundant mineral and associates with arsenopyrite, sphalerite, galena, cassiterite, stannite and franckeite etc. It occurs sometimes as euhedral crystal showing octahedral form in the druse at central part of the vein. Cassiterite is usually in intimate association with pyrite, sphalerite, stannite and quartz microscopically. Franckeite usually appears in the central part of the vein. It occurs as aggregate of platy crystal assembling with pyrite, sphalerite, galena, stannite and hocartite. Stannite is generally found microscopically in intimate association with pyrite, sphalerite, galena, cassiterite, franckeite and quartz, and sometimes occurs as idiomorphic tetragonal form in the druse of the vein. Hocartite is only found microscopically and accompanied by franckeite and stannite.

Among the quartz-pyrite-cassiterite vein, the Colorada vein consists principally of quartz, pyrite and cassiterite with small amounts of arsenopyrite and stannite, and shows clear banding structure (Figure 34-A). Pyrite occurs as a band, 0.5 to 2.0 mm, sometimes 5 cm wide, of crystal aggregate of octahedral form, 1 to 2 cm in size, in druse of the vein. Cassiterite appears as bands, 1 to 2 mm in width, in quartz of the vein. Under microscope, it is found as granular crystals, 0.1 to 1.0 mm in size, in intimate association with quartz, pyrite, arsenopyrite and stannite (Figure 35-B). The Inca 1 vein which corresponds to a branch of the Colorada vein is mainly composed of quartz and pyrite with cassiterite showing distinct banding. Cassiterite occurs as granular form in quartz. The Nueva vein consists of quartz, pyrite showing clear banding associating with slight amounts of cassiterite and sphalerite.

The Arturo vein among the sulfide veins is principally composed of pyrite with sphalerite, stannite, marcasite, cassiterite, quartz and kaolinite (Figure 34-B). Pyrite occurs as aggregate of granular crystals and associates intimately with marcasite in the central part of the vein. Stannite assembles with sphalerite filling space of granular aggregate of quartz and pyrite, and also appears as an idiomorphic tetrahedron, a few mm in size, with quartz in the druse of the vein. Cassiterite sometimes occurs as thin crustitied band, in pyrite (Figure 34-C) and is found as idiomorphic crystals, 5 to 20 μm, enclosed in pyrite and stannite (Figure 35-C). The central part of the vein is often filled up by kaolinite as a product of the latest mineralization.

The Salvadora vein consists essentially of pyrite, arsenopyrite, sphalerite, galena, franckeite and quartz, presenting clearly crustified banding with small amounts of stannite, cassiterite, hocartite, boulangerite, wurtzite and jamesonite etc. Pyrite, sphalerite and galena are found as each band, 1 to 3 cm wide in the vein. Sphalerite presents a growth zoning as shown in Figure 35-A. Stannite fills up space of aggregate of pyrite crystal and microscopically associates with sphalerite, cassiterite and sometimes galena. Franckeite appears as a band, 1 to 2 mm wide, in the central part of the vein, and is aggregate of foliated crystals, 0. 1 to 1.0 mm in size, assembled with stannite, sphalerite, pyrite, galena, jamesonite and quartz etc. (Figures 34-D). Hocartite, 20 to 100 μm in size, microscopically associates with franckeite as shown in Figure 35-D. Gibbsite occasionally occurs as veinlet cutting this vein. The Diez vein is essentially composed of pyrite,

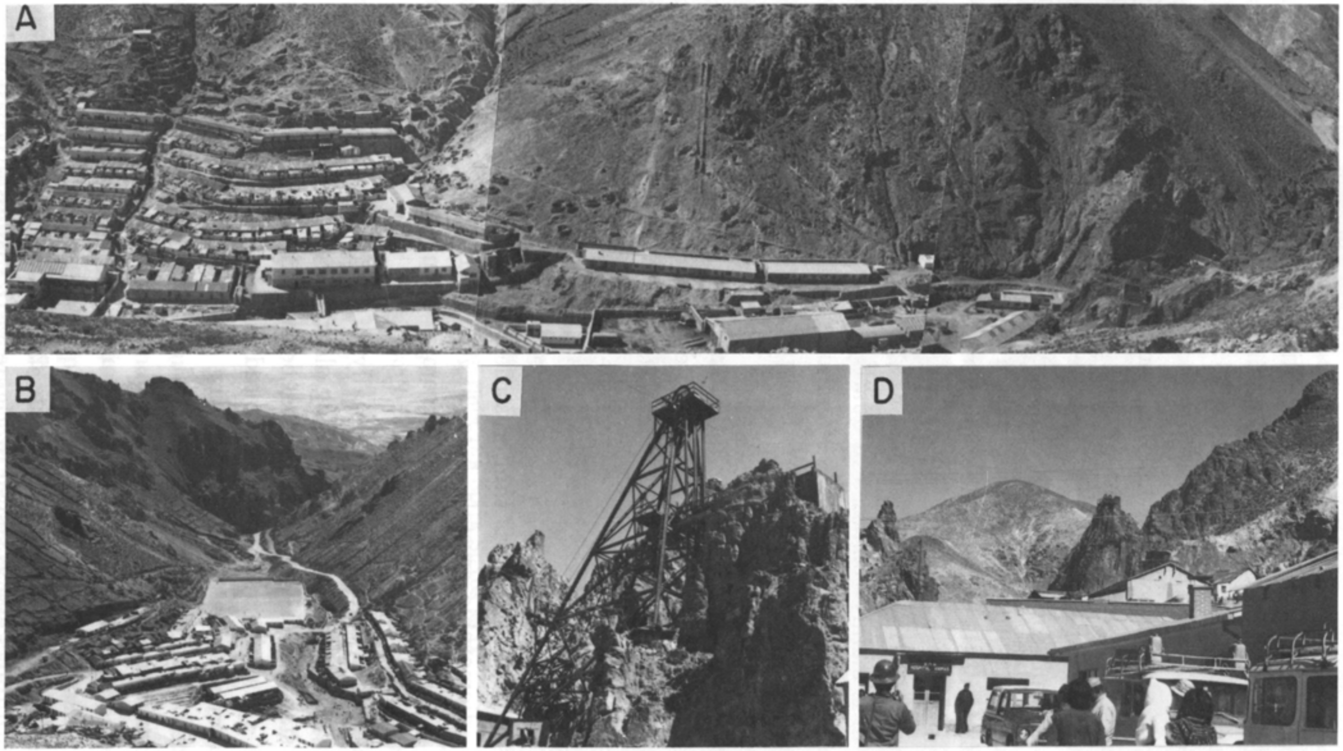

FIGURE 36. SCENERY OF THE ANIMAS MINE.
A: A view of the mine looked from the west. B and D: The mining town of the Animas mine. C: Central shaft.

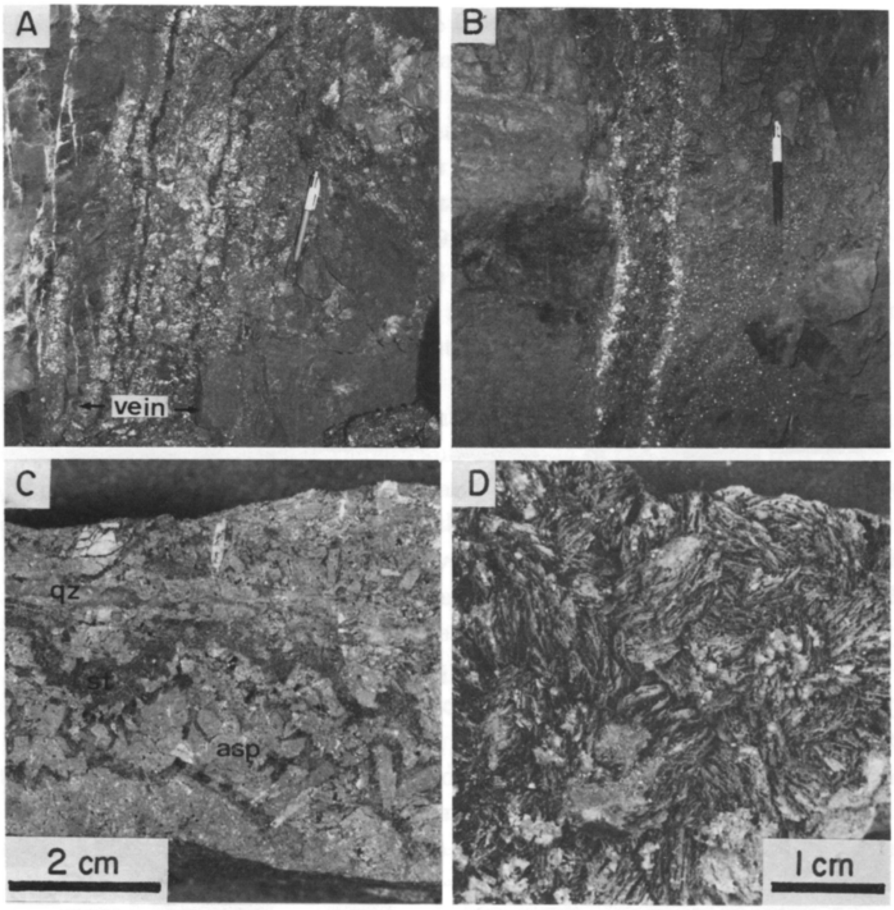

FIGURE 37. VEINS AND ORES OF THE ANIMAS MINE.
A : Pyrite-sphalerite-galena (dark gray bands) vein in slate, Inca Ramo 6 vein, 617 level. B : Sphalerite (dark gray, central part of vein)-galena (light gray, outer side of vein) vein in slate, Burton vein, 661 level. C : Stannite bands (dark gray) in arsenopyrite (asp) and quartz (qz), Burton vein, 661 level (Sample No. 8172923). D : Aggregate of foliated wurtzite in druse, Burton Ramo A vein, 661 level (8172915).

sphalerite and franckeite associated with slight quantities of stannite. Stannite occurs as bands, a few mm in width, in pyrite or between pyrite and sphalerite, and intimately assembles with pyrite, sphalerite, franckeite and quartz etc. Franckeite appears as band or stringer form in the central part of the vein, microscopically associating with stannite, pyrite, sphalerite and quartz etc. Gibbsite and kaolinite are often embedded in the central part of the vein as product of the latest mineralization.

5. *Animas mine*

Animas mine as shown in Figure 3 is located at 3 km the southwest of the

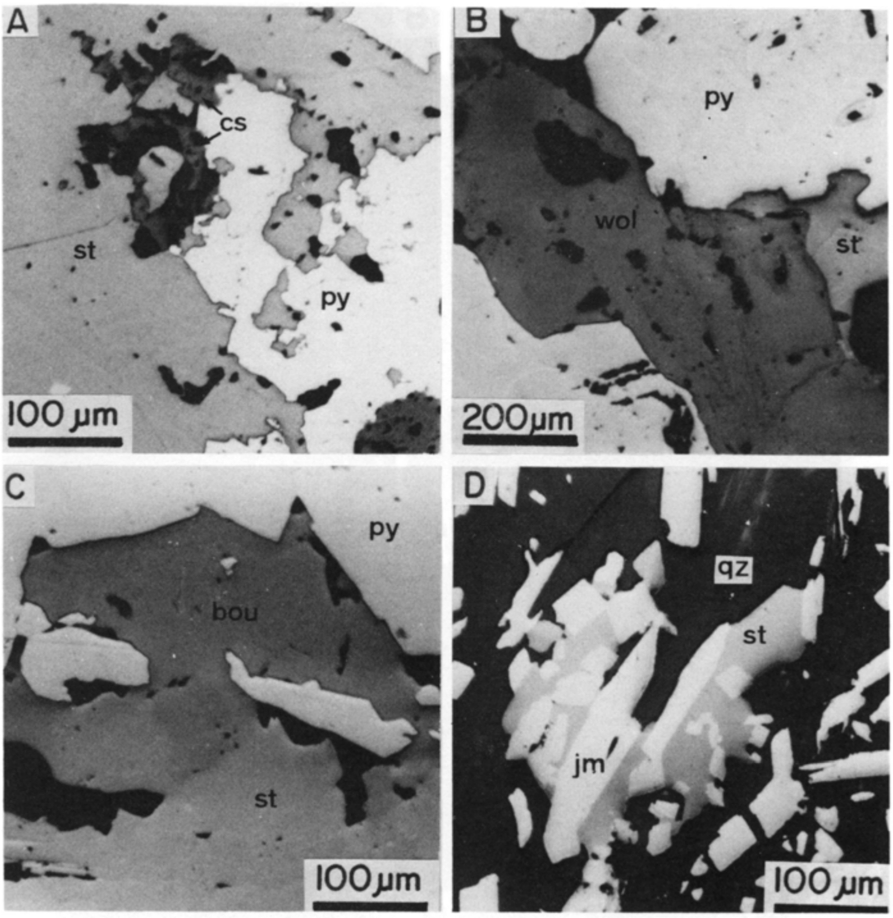

FIGURE 38. PHOTOMICROGRAPHS OF ORES FROM THE ANIMAS MINE.
A : Fine grained cassiterite (cs) within stannite (st) and pyrite (py), Rosario vein, 302 level (Sample No. 8181217). B : Wolframite (wol) and pyrite (py) with stannite (st), Rosario vein, 302 level (8181215). C : Stannite (st) and bournonite (bou) in pyrite (py) druse, Rosario vein, 302 level (8181215). D : Jamesonite (jm) and stannite (st) with quartz (qz), Rosario vein, 302 level (8181215).

Siete Suyos mine (Figure 36). It also is one of the mines within the Quechisla division of COMIBOL. Its productions in 1981 or 1983 are 7,000 tons or 6,600 tons per month as silver crude ore containing with 200-300 g/t Ag, 1.5-2.0% Pb, and 3.0-3.5% Zn or 300 g/t Ag, 2.65% Pb and 3.08% Zn, and 1,700 tons or 1,300 tons per month as tin crude ore with grades of 0.35-0.40% Sn, 0.25% Cu and 180 g/t Ag or 0.72% Sn, 0.32% Cu and 100 g/t Ag, respectively. This mine is being developed down to the 780 level (3,407 m above sea level) from the Central shaft (Figure 36-C and D) of surface (the 0 level, 4,199 m above sea level). The 302 level corresponding to the 19 level of the Siete Suyos mine is used as main adit (Figure 32). In this mine, four shafts named Central (0-302 levels; Figure 36-C), Carlos (302-545 levels), Nueva (545-780 levels) and Rene (246-475 levels) are operating to transport the ores between each adit (Figure 32).

Geology of the Animas mine consists of Ordovician slate and sandstone and Miocene volcanic complex of dacite and its pyroclastic rocks as well as that of the Siete Suyos mine, as shown in Figure 29. The rocks observed at underground roughly are the volcanic complex (Figure 9-B) above the 405 level (3,780 m) and the Ordovician rocks below that level. The ore veins occur in the Miocene pyroclastics and Ordovician system, but most of them develop in slate and sandstone of Ordovician.

As shown in Figure 31, there are many veins such as San Juan, Rosario, Rafael, Animas, Burton, Inca 6, Dejada and Colorada in the mine. Their arrangement and scale are shown in Figure 31 and Table 5 respectively, together with those of the Siete Suyos mine. Among them the Burton vein is the longest and has 1,500 m long along strike, vertically 780 m in depth from outcrop of the surface and 1.2 m in width. The ore veins except the Colorada vein belong to the sulfide type generally consisting of pyrite, sphalerite, wurtzite, galena, arsenopyrite, marcasite, stannite, franckeite and quartz associated with small amounts of tetrahedrite, chalcopyrite, bismuthinite, cassiterite, hocartite, andorite, pyrargyrite, miargyrite, polybasite, aramayoite, bournonite, jamesonite, boulangerite, wolframite etc. as ore minerals, and siderite, aragonite, smithsonite, gypsum, vivianite, sericite, gibbsite and kaolinite etc. as gangue minerals. They generally show clear crustified banding structure as seen in Figure 37-A, B and C. Among these minerals, pyrite, sphalerite and galena commonly assemble with arsenopyrite, stannite, chalcopyrite and franckeite. Sphalerite generally has growth zoning. Cassiterite is found in some veins, and associates with stannite, chalcopyrite, galena, arsenopyrite, pyrite and quartz (Figure 38-A). Franckeite usually appears in the central part of the veins and accompanies by hocartite, stannite, sphalerite, galena and pyrite. Hocartite is only recognized under microscope and assembles with stannite, franckeite, galena, sphalerite and pyrite. Wolframite occurs in minute grains associating with pyrite, sphalerite and stannite (Figure 38-B). Silver bearing sulfosalt minerals such as andorite, pyrargyrite, miargyrite, polybasite and aramayoite and lead-antimony sulfosalt minerals such as bournonite, jamesonite and boulangerite are rarely found in vug or druse of the central part of the veins. Gibbsite, sericite and kaolinite fill up the fissure or vug of the central part of veins. Also, siderite and gypsum occur as veinlet cutting the ore veins.

The Animas vein which distinctly presents symmetrically crustified banding is essentially composed of pyrite, stannite, marcasite and quartz associated with small amounts of arsenopyrite, chalcopyrite and cassiterite. Pyrite occurs as aggregate of granular crystals, 0.1 to 1.0 mm in size, or idiomorphic form with quartz in druse of the vein. Meanwhile stannite appears as band, 1 to 5 mm wide, near the central part of the vein and microscopically associates with cassiterite and chalcopyrite. Marcasite is also found as band, 1 to 2 cm wide, in the center of the vein. On the other hand, cassiterite found under microscope is enclosed as small grains, 5 to 10 μm in size, in stannite, and occasionally assembles with pyrite, arsenopyrite, chalcopyrite and quartz.

The Burton vein also is sulfide type composed principally of pyrite, sphalerite, galena, wurtzite, stannite and franckeite intimately associating with small quantities of arsenopyrite, hocartite, tetrahedrite, jamesonite, boulangerite, pyrargyrite, miargyrite, bournonite and aramayoite etc. In order from the outside to the center of the vein, there are generally recognized banding arrangement of pyrite-stannite-galena-franckeite. Also, in the central part of the vein, druse develops and idiomorphic crystals of stannite, franckeite, galena and wurtzite occur in it (Figure 37-D). Pyrite is granular aggregate assembled with arsenopyrite. Sphalerite closely associates with wurtzite and sometimes altenates banding with each other. Galena appears as aggregate of its crystals, a few mm in general, sometimes 2.0 cm in size, assembled with sulfosalt minerals such as pyrargyrite, miargyrite, tetrahedrite, boulangerite, jamesonite and bournonite in the druse. Franckeite occurs in aggregate of foliated crystals, 1 to 3 mm in size, accompanied by hocartite, sphalerite, stannite and galena. Stannite adjacent to pyrite band is embedded in space of pyrite aggregate. However, it is also found as a drusy mineral assembling with pyrite and sulfosalt minerals such as tetrahedrite, aramayoite, andorite, pyrargyrite, miargyrite, bournonite and jamesonite.

Meanwhile the Rosario vein also is sulfide type composed principally of pyrite, stannite, arsenopyrite, sphalerite, franckeite and quartz with small quantities of cassiterite, galena, chalcopyrite and marcasite etc. It shows crustified banding which consists of bands of pyrite, stannite and arsenopyrite toward inside of the vein from hanging or foot wall sides (Figure 37-C). At the central part of the vein, band or stringer of sphalerite, stannite and franckeite are often found. Among these minerals, pyrite occurs as granular aggregate of which space is filled up by stannite. Stannite appear in a band, 1 to 5 mm wide, as aggregate of granular crystals accompanied by pyrite, chalcopyrite, sphalerite, cassiterite, and wolframite, and is occasionally embedded in crystal gap of pyrite, arsenopyrite and quartz. Cassiterite, 5 to 10 μm in size, is enclosed in stannite or sometimes pyrite crystals (Figure 38-A). Wolframite rarely appears as platy forms, 2 to 5 mm in size, in pyrite and stannite. Under microscope, it is recognized that wolframite corresponding to ferberite primarily changes to fuebnerite (Figure 38-B). Franckeite is usually found as a band of aggregate of its crystal, 0.1 to 0.2 mm in size, in the central part of the vein, intimately associated with sphalerite and sometimes galena. Arsenopyrite occurs as a band of aggregate of short prismatic crystals, 0.5 to 1.5 cm long, grown parallel toward the center of the vein. It assembles with stannite and pyrite. Bournonite and jamesonite appear in the central part of the veins in association with pyrite, stannite and quartz (Figure 38-C and D).

The Rafael vein is also composed mainly of sulfide minerals such as pyrite and stannite associated with some amounts of arsenopyrite, wurtzite, chalcopyrite, cassiterite and quartz. Among them, stannite appears mainly as band-like form, 2 to 5 mm in width, in pyrite, and closely associates with pyrite, sometimes accompanying with small amounts of cassiterite, sphalerite and chalcopyrite microscopically. Meanwhile cassiterite is enclosed in stannite and sometimes pyrite as aggregate of granular crystals, 10 to 30 μm in size.

The Dejada vein consists essentially of pyrite and stannite with small quantities of sphalerite, chalcopyrite and quartz. It often has many fragment or breccia of country rocks. Stannite occurs as band or spot-like form in pyrite and associates with chalcopyrite microscopically. It is often embedded in the interspace of granular pyrite aggregate. Also stannite appears as idiomorphic form, 1 to 3 mm in size, with pyrite in druse of the vein. Chalcopyrite is occasionally found in stannite band, while it also fills up the space of pyrite aggregate together

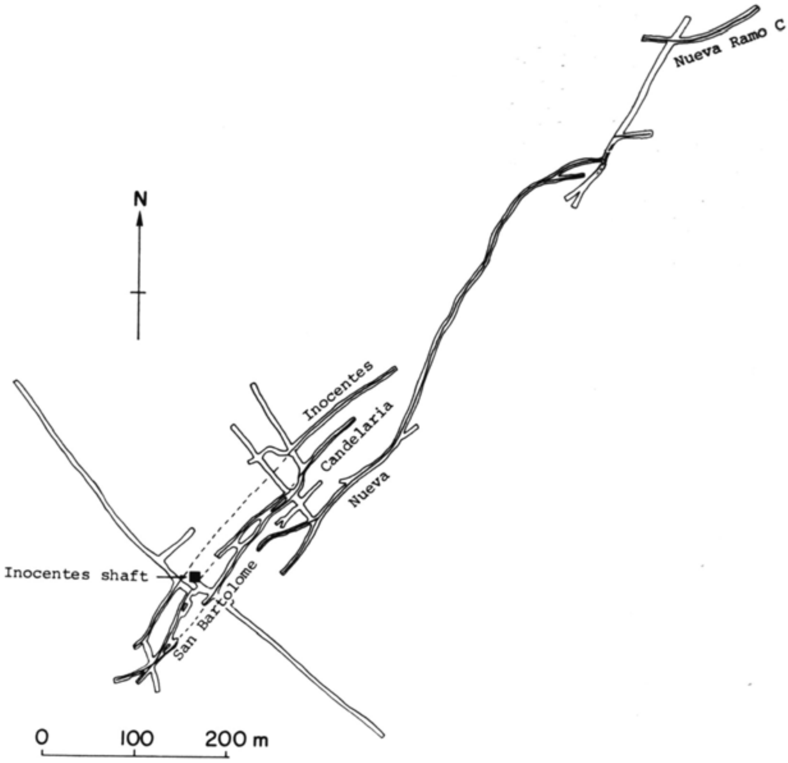

FIGURE 39. VEINS AT THE 132 LEVEL OF THE GRAN CHOCAYA MINE.

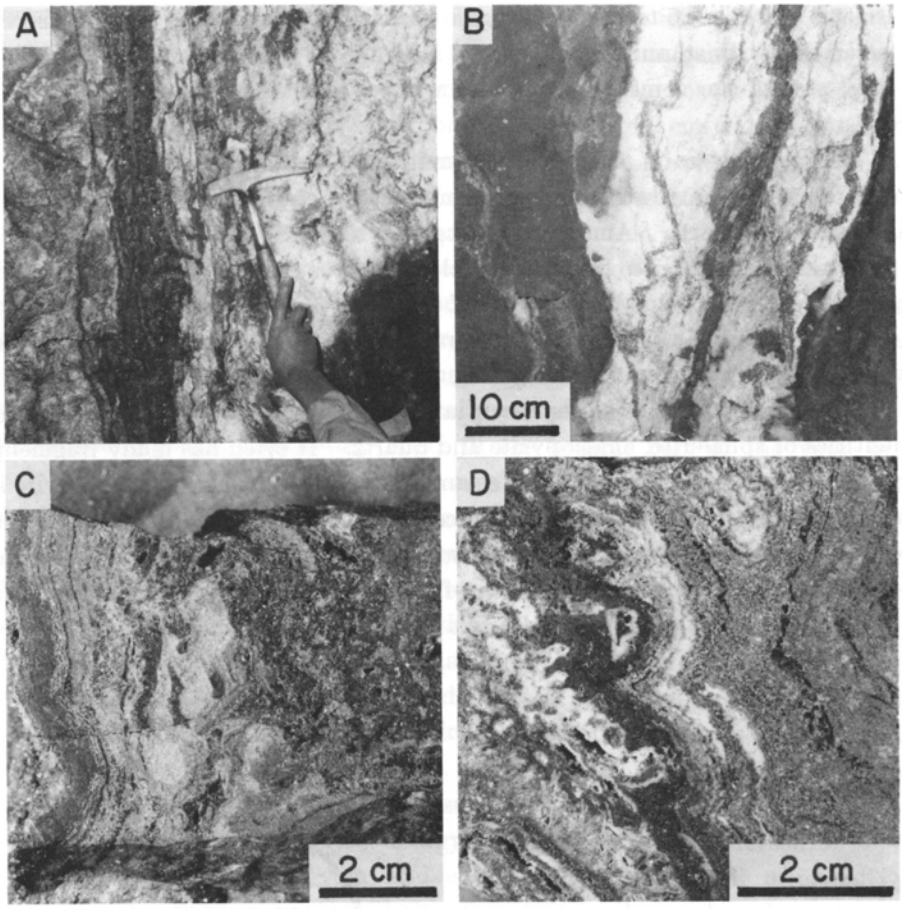

FIGURE 40. VEINS AND ORES OF THE GRAN CHOCAYA MINE.
A : Sphalerite-galena-pyrite vein (dark gray) in dacitic tuff (gray to white), Nueva vein, 172 level. B : Sphalerite-pyrite vein (dark gray in center) in altered dacitic tuff (white). Dark gray parts of both sides show dacitic tuff. Nueva vein, 132 level. C and D : Crustified bandings of sphalerite (gray, dark gray) and galena (black) (C), and sphalerite (gray), galena (black), quartz (white) and marcasite (dark gray) (D), Nueva vein, 132 level (Sample No. 8180520)

with stannite.

The Inca 6 vein is mainly composed of pyrite, stannite, sphalerite and galena associated with small amounts of arsenopyrite and chalcopyrite (Figure 37-A). Within them, stannite occurs as aggregate of its granular crystals assembled with sphalerite, and is sometimes embedded in crystal gap of pyrite aggregate. Galena is found as band in the central part of the vein, sometimes associating with sphalerite. Aragonite rarely appears in pyrite druse of the vein.

6. *Gran Chocaya mine*

Gran Chocaya mine which is under the juridiction of Animas mine office, is situated at 2.5 km southwest of the Animas mine. It was already mined from the surface at the age of Spanish colony, but the underground mining and exploitation is being done at the levels of 132 and 172 using Inocentes shaft. The production of crude ore is about 1,500 tons per month with grade of 200 g/ton Ag, 1.8% Pb and 6.0% Zn.

Geology around the Gran Chocaya mine is composed of the Ordovician and Tertiary systems (Figure 29). The former consists of slate and sandstone, and the latter is the volcanic complex of dacitic tuff, dacitic tuff breccia and dacite lava. Ore veins develop in both of these systems. Principal veins such as the Nueva, Inocentes, San Bartolome and Candelaria in general run to the direction of N35° to 40°E approximately parallel to the veins of the Animas and Siete Suyos mines (Figure 39). Their dips change from 70° to 85°NW.

Among them, the Nueva vein is the longest one, which extends to about 770 m along the strike, and more than 150 m in depth. It develops in the volcanic complex of dacite tuff, tuff breccia and dacite lava at part above the 172 level (Figure 40-A and B). While at lower part than the 172 level it is embedded in Ordovician slate and sandstone. The vein is principally composed of sphalerite, galena, pyrite, wurtzite and quartz, and commonly forms a typical crustified banding (Figure 40-C and D). They associate with some amounts of marcasite, arsenopyrite, pyrrhotite, pyrargyrite, miargyrite, stephanite, polybasite, jamesonite, siderite, calcite and apatite. A lot of druses are found in the vein, and euhedral crystals of quartz, marcasite and sphalerite are observed as druse minerals. Under the ore microscope, pyrite which rarely includes arsenopyrite and pyrrhotite is usually replaced by sphalerite and galena along the grain boundary. Sphalerite and galena associate intimately, and adjoin to each other with mutual boundary. Zonal structure of sphalerite is commonly observed under the transmitting microscope. Silver bearing minerals from the mine are mainly silver antimony sulfosalts such as stephanite, pyrargyrite, miargyrite and polybasite. They are found as druse minerals in sphalerite and galena. Among them, pyrargyrite is a most dominant mineral which shows irregular form and associates with galena intimately. Such galena commonly contains a lot of pyrargyrite inclusions, 0.01 to 0.03 mm in size. Stephanite is accompanied by pyrargyrite and galena, with mutual boundary. Miargyrite and polybasite showing irregular form occur as inclusions in pyrargyrite of 0.2 to 0.3 mm in size. Apatite and siderite sometimes occur as euhedral form, 0.5 to 2 mm in size, in druse of central part of the vein. Dacite or its pyroclastic rock as country rock of the vein is strongly altered by sericitization and changes its color from gray or grayish white to white in both sides, about 10 to 20 cm in width, of the vein as seen in Figure 40-B.

The northeastern part of the Nueva vein, small amount of franckeite occurs in association with galena, sphalerite and pyrite. Under microscope, it appears as aggregate of foliated crystals, 0.1 to 1 mm in size, in association with sphalerite, galena, pyrite and small amounts of hocartite, stannite and jamesonite.

The Nueva Ramo C vein occurring at most northeastern portion of the Gran Chocaya mine is mainly composed of pyrite, sphalerite and galena showing crustified banding. A lot of druses having euhedral crystals of quartz and marcasite are also found in the vein. Dacitic tuff of wall rock is sometimes brecciated, and its fragments are included in the vein. Dacitic tuff is strongly altered by sericitization, and it changes its color from gray to white in about 50 cm wide at both sides of the vein.

The San Bartolome vein mainly consists of sphalerite, galena and pyrite. Siderite usually fills up the center of the vein. Dacitic tuff is also altered by sericitization. Fine grained pyrite disseminates into dacitic tuff, 5 to 10 cm in width, of the both sides of the vein.

As mentioned above, ore veins in the Gran Chocaya mine are principally composed of sphalerite, wurtite, galena, pyrite and quartz in assemblage with small amounts of marcasite, arsenopyrite, silver bearing minerals, siderite, calcite and apatite etc. commonly showing crustified banding. The silver minerals from the mine are mainly silver-antimony sulfosalts such as pyrargyrite, miargyrite, polybasite and stephanite as mentioned above, and appear in the druse in close association with galena, sphalerite and pyrite. No cassiterite occurs from the veins of the Gran Chocaya mine. Tin bearing minerals such as stannite, franckeite and hocartite are not commonly found except the limited part of the Nueva vein. Franckeite occurs only in the northeastern part of the Nueva vein in close assemblage with hocartite, stannite, galena, sphalerite and pyrite microscopically. This mineral assemblage is very similar to that found in the sulfide veins in the Siete Suyos and Animas mines. Therefore, most of the veins in the Gran Chocaya mine are characterized by silver bearing lead-zinc ore, although a limited northeast area of the mine belongs to the zone producing tin-silver ore as well as the sulfide veins in the Siete Suyos and Animas mines.

7. *Zonal arrangement of ore minerals in the Siete Suyos, Animas and Gran Chocaya mines*

As mentioned above, the ores from the Siete Suyos, Animas and Gran Chocaya mines are characteristic to coexist the tin and silver minerals associated with the base metal sulfides and quartz. From the quartz veins which correspond to principal veins such as Colorada, Nueva and Inca 1 of the Siete Suyos mine and some veins such as Colorada and Colorada Ramo A of the Animas mine, cassiterite

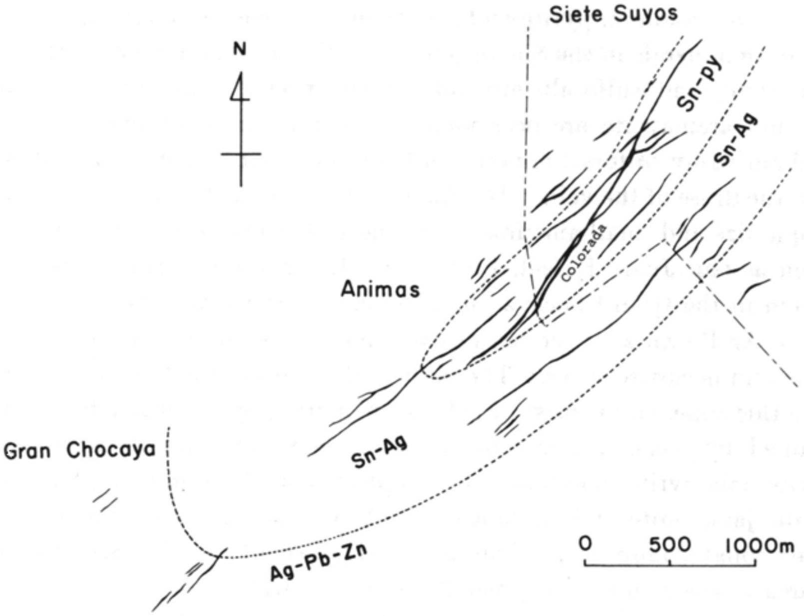

FIGURE 41. ZONAL ARRANGEMENT OF ORE MINERALS FOUND IN SIETE SUYOS, ANIMAS AND GRAN CHOCAYA MINING AREA.

occurs as an essential tin mineral. Meanwhile, from the sulfide veins which correspond to the most of the veins of the Animas mine, stannite, franckeite, hocartite and sometimes small amounts of cassiterite as tin bearing minerals appear. The ores from the sulfide veins of the Gran Chocaya mine have no tin bearing minerals except them from the northeast part of the Nueva vein near boundary with the Animas mine. As silver bearing minerals, pyrargyrite, miargyrite, polybasite, pearceite, aramayoite, stephanite, hocartite and tetrahedrite are found in the sulfide veins. However, the ores of the quartz-pyrite vein usually contain no silver minerals. From these facts, the veins of the Siete Suyos, Animas and Gran Chocaya mining area are divided into three zones of tin-pyrite (Sn-py), tin-silver (Sn-Ag) and silver-lead-zinc (Ag-Pb-Zn) by mineral assemblage as shown in Figure 41. That is, the Sn-py zone is characterized by cassiterite, quartz and pyrite, sometimes in association with small amounts of stannite microscopically, but without franckeite, hocartite and sulfosalt minerals of silver, lead and antimony etc. The veins of Colorada, Nueva and Inca 1 etc. in the Siete Suyos and Animas mines belong to this zone. In the Sn-Ag zone, many sulfide and sulfosalt minerals such as pyrite, stannite, sphalerite, arsenopyrite, galena, marcasite, wurtzite, franckeite, tetrahedrite, hocartite, pyrargyrite, miargyrite, polybasite, pearceite, bournonite, jamesonite and boulangerite occur. Stannite and franckeite among them are characteristic tin minerals in this zone, and intimately associate with hocartite. Cassiterite is also found microscopically in association with stannite, pyrite and quartz in this zone, but slight amounts. As silver bearing minerals in the Sn-Ag zone, hocartite usually appears with stannite and franckeite, and sulfosalt minerals of pyrargyrite, miargyrite, polybasite, andorite and aramayoite are occasionally found in druse of the sulfide veins. Also lead-antimony sulfosalt minerals of bournonite, jamesonite and boulangerite appear in the druse of the vein. Wolframite also is characteristic in this zone, but microscopic size and small amounts. The most of the veins found in the Animas mine such as San Juan, Rafael, Burton and Rosario and northeast part of the Nueva vein in the Gran Chocaya mine belong to the Sn-Ag zone.

In the Ag-Pb-Zn zone, no tin bearing minerals such as cassiterite, stannite, franckeite and hocartite occur. The most of the veins in the Gran Chocaya mine belong to this zone, and consist of galena, sphalerite, pyrite, wurtzite and quartz accompanied by some amounts of silver-antimony sulfosalt minerals such as pyrargyrite, miargyrite, polybasite and stephanite as druse mineral, but without bournonite, jamesonite and boulangerite. As mentioned above, there is clearly recognized zonal arrangement of ore minerals, especially tin and silver minerals, in this area as the result of polymetallic mineralization.

From the data on occurrence, mineral assemblage and paragenesis of ores

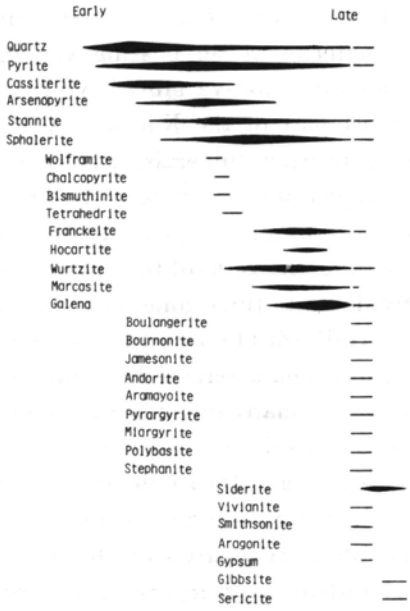

FIGURE 42. MINERALIZATION SEQUENCE OF MINERALS FROM THE SIETE SUYOS, ANIMAS AND GRAN CHOCAYA MINES.

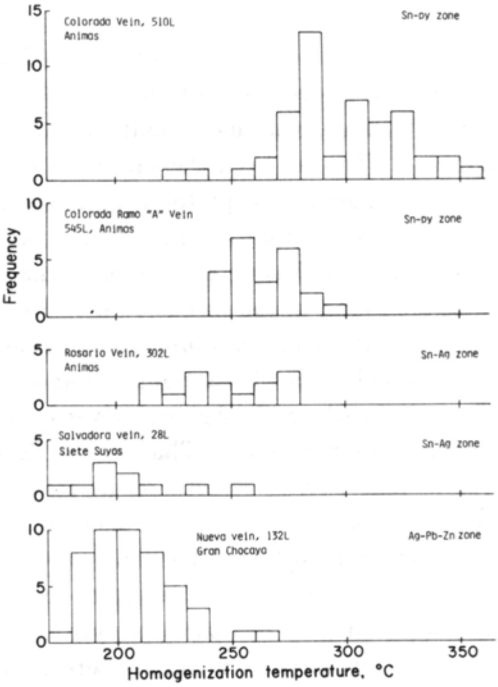

FIGURE 43. HOMOGENIZATION TEMPERATURES OF FLUID INCLUSIONS IN QUARTZ FROM THE VEINS OF SIETE SUYOS, ANIMAS AND GRAN CHOCAYA MINES.

obtained by macroscopic and microscopic observation, crystallization sequence of minerals from the Siete Suyos, Animas and Gran Chocaya mining area is shown in Figure 42. It indicates that cassiterite was formed at early stage of the mineralization together with quartz and pyrite. Meanwhile sulfide minerals such as arsenopyrite, sphalerite, stannite, galena, wurtzite, marcasite and bismuthinite etc. principally occurred in middle stage of the mineralization as essential products. Franckeite and hocartite were also crystallized as the middle stage product in intimate association with each other or sphalerite, stannite, galena, pyrite and quartz etc. Small amounts of wolframite appeared in assemblage with pyrite and stannite at relatively early time of the middle stage.

On the other hand, sulfosalt minerals such as pyrargyrite, miargyrite, polybasite, stephanite, andorite, aramayoite, bournonite, jamesonite and boulangerite were formed at late stage of the mineralization. The most of them occur in the druse or vug found at central part of the sulfide veins. Also silver-antimony sulfosalt minerals such as pyrargyrite, miargyrite, polybasite and stephanite from the Gran Chocaya mine are always found in the druse of the veins as products of the late stage mineralization. Gangue minerals as siderite, gypsum, calcite, aragonite, smithsonite, vivianite, gibbsite and sericite etc. except quartz occur as veinlet cutting principal vein minerals, and euhedral crystals of them were also formed in the druse. Clay minerals filled up vug at late or latest stages of the mineralization.

Homogenization temperature of liquid inclusions in quartz from the Siete Suyos, Animas and Gran Chocaya mines was measured. All the inclusions measured are two phases of liquid and gas. Homogenization temperatures of liquid inclusion are shown in Figure 43. Those of the liquid inclusions in quartz from the Colorada and Colorada Ramo A veins, which belong to the Sn-py zone, in the Animas mine are 220° to 360°C and 240° to 300°C, respectively. While the liquid inclusions in quartz from the Rosario vein of the Animas mine and the Salvadora vein of the Siete Suyos mine belonging to the Sn-Ag zone have homogenization temperatures of 210° to 270°C and 170° to 260°C, respectively, and those from the Nueva vein of the Gran Chocaya mine in the Ag-Pb-Zn zone show 170° to 270°C. There is found a tendency that the homogenization temperatures of the liquid inclusions in quartz from the Sn-py zone are higher than those of the Sn-Ag and Ag-Pb-Zn zones as seen in the figure. The salinities in NaCl equivalent concentration of the liquid inclusions are 4.7 to 8.2 wt% and 4.6 to 11.9 wt% for those in quartz from the Colorada and Colorada Ramo A veins (Sn-py zone), respectively. Those for liquid inclusions in quartz from the Salvadora and Rosario veins (Sn-Ag zone), and Nueva vein (Ag-Pb-Zn zone) are 3.8 to 4.1 wt%, 3.8 to 4.9 wt%, and 3.7 to 5.2 wt%, respectively.

FIGURE 44. SCENERY AROUND THE TATASI MINE PARTLY COVERED WITH SNOW.
A: The Tatasi mine viewed from the southwest. B: A view of the old town, Portugalete, and Mt. Chicharrona Punta (right) looked from the southwest.

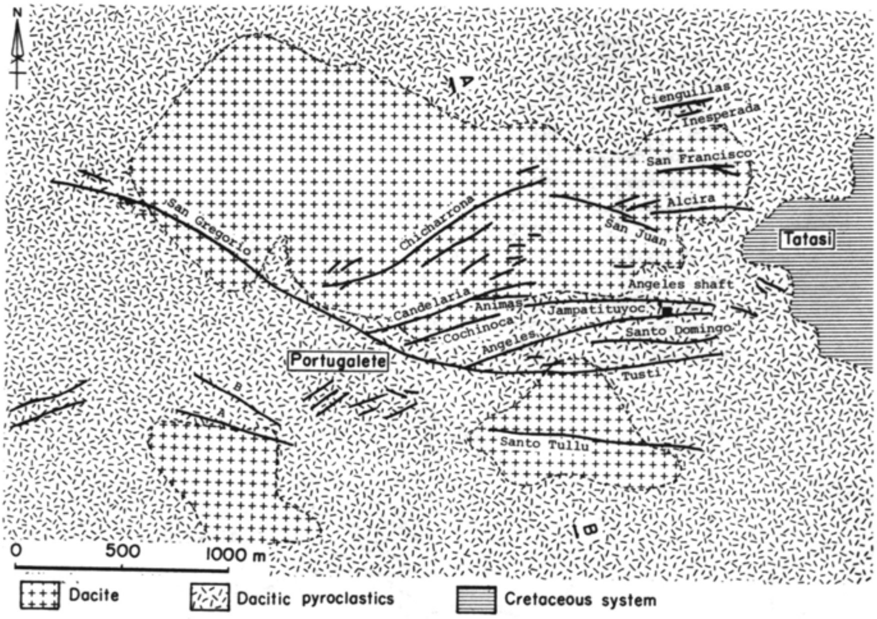

FIGURE 45. GEOLOGICAL MAP OF THE TATASI MINE.
Principal veins are shown in the figure.

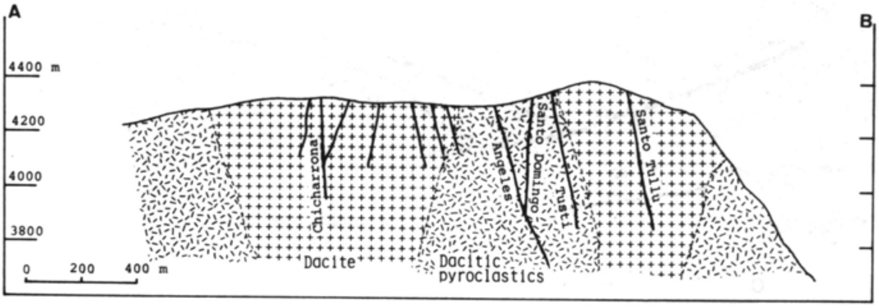

FIGURE 46. GEOLOGICAL SECTION ALONG THE LINE CONNECTING A AND B IN FIGURE 45.

8. *Tatasi mine*

The Tatasi mine which belongs to COMIBOL is situated at 25 km south of Atocha (Figure 3). The monthly production is about 8,000 tons of crude ore containing 260 g/ton Ag, 1.8% Pb, and 2.3% Zn in the first half year of 1983. The mine is working at 5 levels from the +105 San Gregorio level (4,330 m above the sea level) to the 0 San Gregorio level (4,216 m) at the western part, 5 levels from the 3 Cienguillas level (4,317 m) to the Santa Justi level (4,154 m) at the north of

TABLE 6. SCALES OF MAIN VEINS IN THE TATASI MINE.

Vein	Strike	Dip	Length (m)	Depth (m)	Width (m)
San Gregorio	N65°W	80°-90°S	1000	140	0.6
Tusti	N80°W	80°-90°S	800	140	0.4
Ramo San Gregorio	N70°W	80°N	150	175	0.15
Chicharrona	N60°E	85°S	870	260	0.3-0.4
Candelaria	N75°E	58°N	200	70	0.4
Cochinoca	N75°E	70°N	500	140	0.5-0.7
San Francisco	N65°W	85°N	260	90	0.6
Alcira	N85°E	80°S	750	280	0.3
Jampatituyoc	N78°E	76°N	500	70	0.4
Angeles	N75°E	67°S	600	170	2.0
Santo Domingo	N70°W	78°N	600	240	0.3-0.5

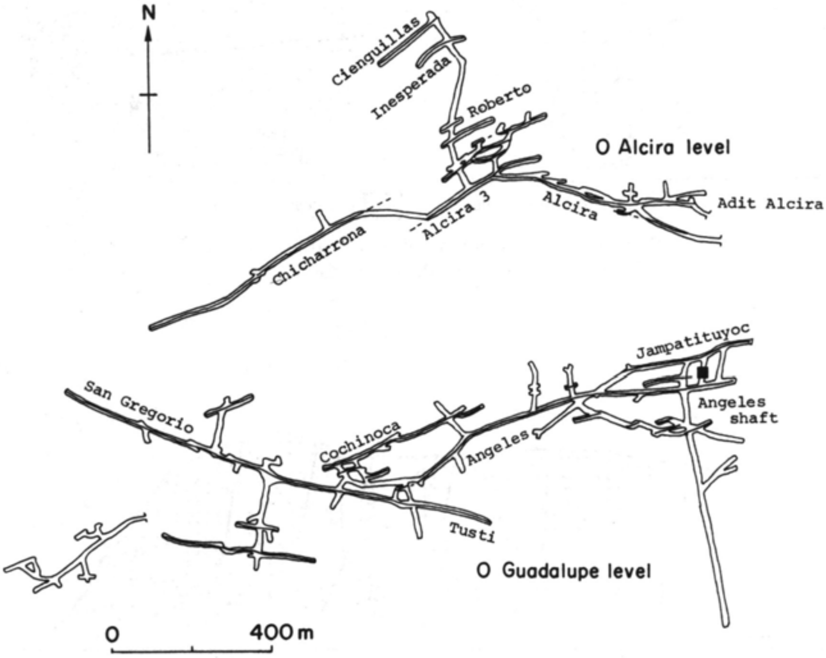

FIGURE 47. VEINS AT THE 0 ALCIRA AND 0 GUADALUPE LEVELS IN THE TATASI MINE.

central part, 9 levels from the 3 Alcira level (4,261 m) to the −140 Alcira level (4, 013 m) at the northeastern part and 8 levels from the +83 Guadalupe level (4,157 m) to the −140 Guadalupe level (3,943 m) at the eastern part of the mining area. The veins of the Tatasi mine distribute in the area of about 1.5 km north to south and 3.5 km east to west. The town of the mine (Figure 44-A) is located at eastern part of the area. In the central part of the area, Portugalete (Figure 44-B), an old mining town of Spanish colonial age, is situated but was abandoned.

Geology and ore deposits of the Tatasi mine have been reported by Ahlfeld and Schneider-Scherbina (1964) and JICA and MMAJ (1977, 1978). Geology around the mine consists of the Cretaceous system and the Miocene volcanic

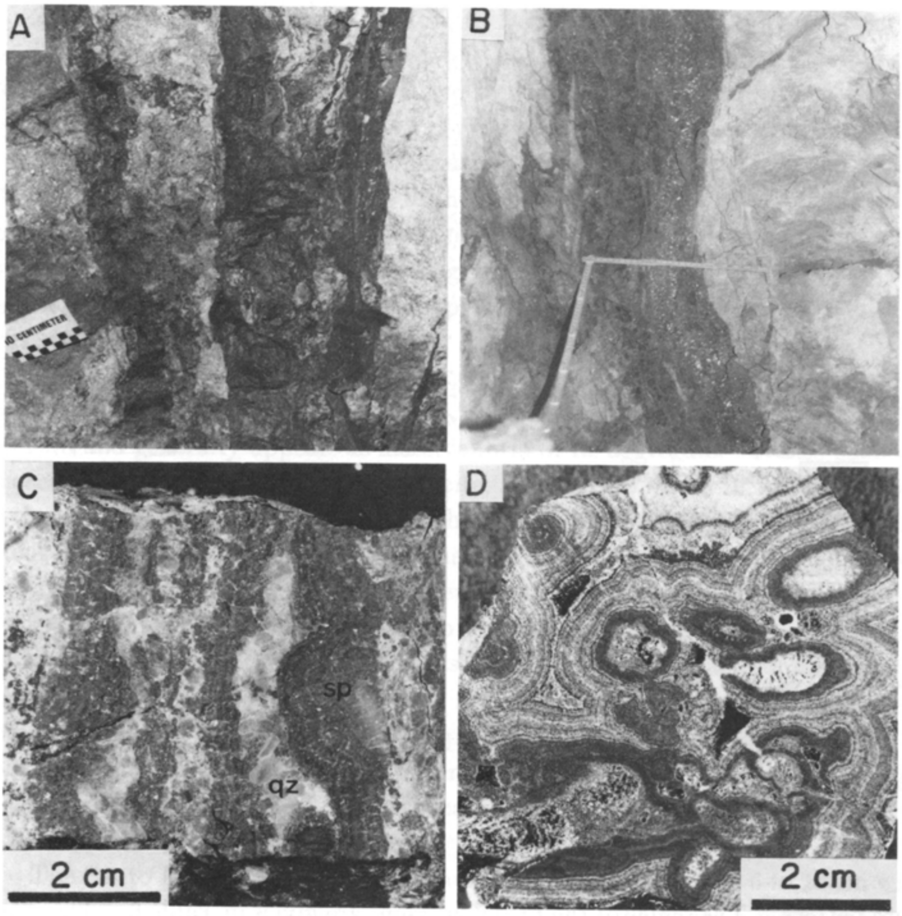

FIGURE 48. ORE VEINS AND MINERALS OF THE TATASI MINE.
A : Pyrite-sphalerite vein (dark gray) in dacitic tuff (gray), Cochinoca vein, −70 Guadalupe level. B : Galena-sphalerite-pyrite vein (dark gray) in dacite (light gray), Candelaria vein, −70 Alcira level. C : Quartz (qz)-sphalerite (sp) ore, Inesperada vein, 0 Alcira level. (Sample No. 8173003). D : Crustified or botryoidal structures of sphalerite (dark gray), wurtzite (gray) and galena (white to light gray), Chicharrona vein (8180716).

complex as shown in the geological map and its section of Figures 45 and 46, respectively. The Cretaceous system is only found at eastern part of the area. It consists of basal conglomerate of the lower part and alternation of red colored sandstone and mudstone with an interbed of limestone. The volcanic complex is composed of dacitic tuff, tuff breccia, and dacite lava and dome. Dacitic tuff covers unconformably the Cretaceous sediments, while dacitic tuff and tuff breccia are laid by dacite flows as described in the earlier section.

The ore deposits in the mine are of fissure filling type, which exist only in dacite and dacitic tuff breccia of the volcanic complex. Veins are divided into three systems of E-W, N60°-70°W and N60°-70°E from their strike directions in the

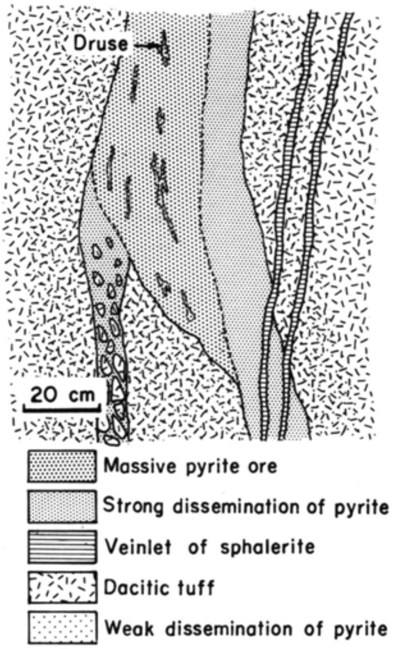

FIGURE 49. SKETCH OF THE COCHINOCA VEIN, THE −70 GUADALUPE LEVEL, TATASI MINE.
Vertical section of the vein looking from east.

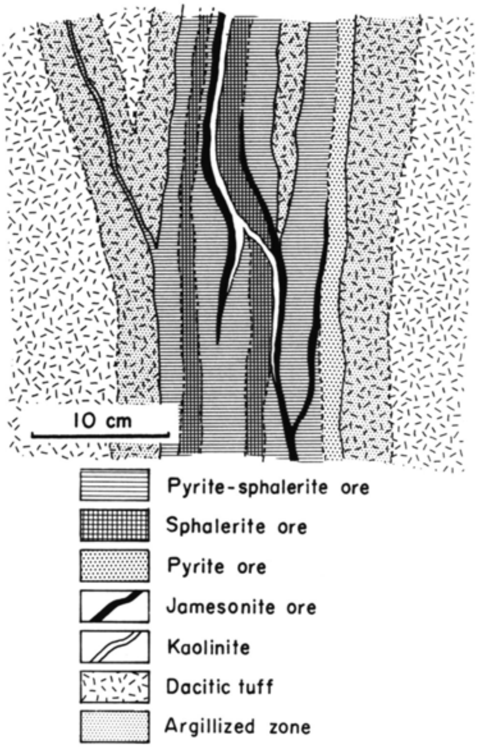

FIGURE 50. SKETCH OF THE SANTO DOMINGO VEIN, THE −70 GUADALUPE LEVEL, TATASI MINE.
Vertical section of the vein looking from east.

fissure pattern. The scales of the principal veins are given in Table 6. The veins of San Francisco, Alcira, Jampatituyoc, Angeles, Santo Domingo, Tusti and Santo Tullu etc. belong to the E-W system. Meanwhile such veins as Chicharrona, Candelaria, Cochinoca and western part of Angeles etc. belong to N60°-70°E system, and the veins of San Gregorio and western part of Tusti are of N60°-70° W system. Among them the San Gregorio vein found in the western part of the area is the longest one having scale of 1,000 m long, 140 m deep and 0.6 m wide. Eastern part of the San Gregorio vein changes its strike to the E-W direction and continues to Tusti vein. Total length of San Gregorio and Tusti veins is over 3,000 m. Dip of the veins vary from 60°N to 70°S as seen in Table 6 and Figure 46. Among them, such veins as San Francisco, Alcira, Chicharrona, Candelaria and the northern part of Cochinoca are embedded in dacite, meanwhile the southern veins such as Jampatituyoc, Angeles, Santo Domingo and Tusti etc. develop in tuff breccia as shown in the geological map and section. The vein arrangement of the 0 Alcira level and the 0 Guadalupe level of the eastern part in the area is shown in Figure 47.

The Candelaria, Cochinoca and Santo Domingo veins in the eastern part of the Tatasi mine consist of pyrite essential and sphalerite-galena dominant parts. Among them, the Candelaria vein, 10 cm in width, is mainly composed of pyrite, sphalerite and galena (Figure 48-B). Pyrite occurs in two types of massive form with a lot of druse and intense dissemination. Sphalerite, 2 to 3 cm wide, runs as a band or veinlet adjacent to dacite of the hanging wall of the vein, and associates with franckeite, cassiterite, quartz and small amount of hocartite. It also appears as black powder band of 5 cm wide as aggregate of very fine grained crystals with marcasite and jamesonite in massive pyrite. Jamesonite occasionally fills up druse in pyrite.

The Cochinoca vein, 15 to 100 cm in width, consists essentially of pyrite, sphalerite and galena etc. (Figure 48-A). Pyrite is the most principal mineral of the vein and generally appears as massive form of its aggregate. It also commonly occurs as strong dissemination in dacite, about 10 to 50 cm in width, adjacent to the vein (Figure 49). Meanwhile sphalerite and galena occur as band of 5 to 15 cm wide along boundary between massive pyrite and dacite of country rock and associate with franckeite as stringer 1 to 2 mm wide. They sometimes cut pyrite band in the vein. Sphalerite is often found as druse mineral in vug of the massive pyrite zone. Sulfosalt minerals such as semseyite, jamesonite, pyrargyrite, stephanite, fizelyite and diaphorite appear as a fine grained compact band or veinlet, 1 to 2 cm in width, in central part of galena and sphalerite zone in the vein. Breccia of dacite is frequently enclosed in the vein. Dacite adjoining to the vein is intensely altered by sericitization and pyritization. Pyrite also runs as veinlets in dacite.

The Santo Domingo vein consists mainly of bands of pyrite, 5 to 15 cm wide, and sphalerite, 2 to 3 cm wide as seen in Figure 50. They are sometimes cut by jamesonite veinlet with 2 to 3 cm wide. The central part of the vein is filled up by kaolinite which sometimes cut the sphalerite band in pyrite. Dacitic tuff adjacent to the vein suffers sericitization in range of 5 cm wide along both the outsides of the vein.

Meanwhile in the central to northeastern part of the mine, the veins such as Cienguillas, Inesperada, Ramo Pioner, Alcira, Angeles and Chicharrona are found. They which have generally widths of 5 to 15 cm are essentially composed of sphalerite and galena showing crustified banding (Figure 48-C and D). The outer part of the vein commonly is rich in sphalerite, while the central part of the vein becomes dominant in galena as aggregate of crystals, 0.5 to 1.0 cm in size. Galena has a druse in the central part of the vein, and siderite and quartz fills up the druse. Veinlets of stibnite, 1 to 2 mm in width, cut whole the vein at the Angeles vein.

As mentioned above, pyrite rich ores of the veins in the Tatasi mine are in general formed at the early stage of the mineralization in association with small

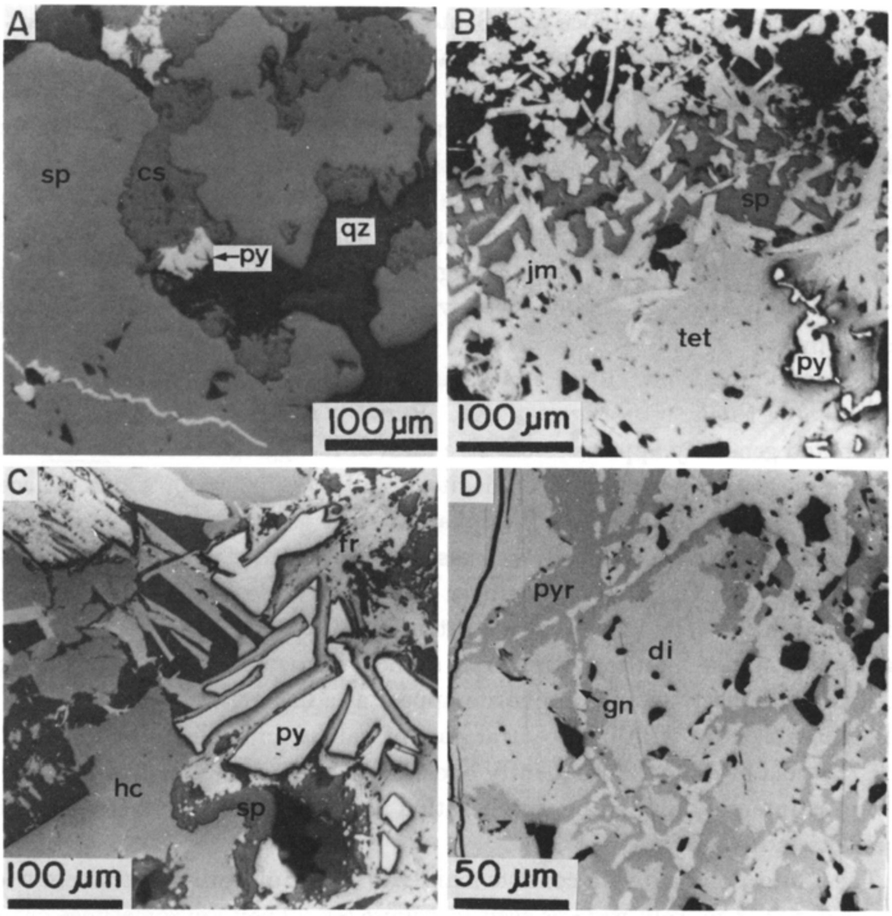

FIGURE 51. PHOTOMICROGRAPHS OF ORES FROM THE TATASI MINE.
A : Cassiterite (cs) and pyrite (py) in sphalerite (sp) with quartz (qz), Angeles vein, −70 Guadalupe level (Sample No. 8181504). B : Tetrahedrite (tet), jamesonite (jm), sphalerite (sp) and pyrite (py), Santo Domingo vein, −70 Guadalupe level (8181512). C : Hocartite (hc) associated with franckeite (fr), sphalerite (sp) and pyrite (py), Candelaria vein, −110 Guadalupe level (8371473). D : Diaphorite (di) being replaced partly by pyrargyrite (pyr) and galena (gn), Cochinoca vein, +35 Guadalupe level (83071210).

amounts of arsenopyrite and pyrrhotite. Meanwhile sphalerite and galena are mainly crystallized during the middle stage of the mineralization assembled with pyrite, arsenopyrite, wurtzite, stannite, kesterite, franckeite and hocartite etc. On the other hand, sulfosalt minerals such as pyrargyrite, stephanite, fizelyite, diaphorite, argyrodite, jamesonite, semseyite etc. are produced in association with galena occasionally at the late stage of the mineralization. Siderite, kaolinite and sericite occur in the fissure or vug of the central part of the veins as filling products at the latest stage of the mineralization. Among these minerals as above, pyrrhotite sometimes appears as inclusion in pyrite under microscope. Cassiterite occurs as aggregate of 5 to 30 μm in grain size, associates with pyrite, sphalerite and quartz (Figure 51-A). Stannite intimately associates with sphalerite usually showing crustified banding. It contains indium of about 5 wt%. Small amounts of kesterite occurs with stannite occasionally. Tetrahedrite occurs as irregular or granular forms accompanied by galena, jamesonite, sphalerite, pyrite and bournonite (Figure 51-B) or as a minute inclusion in galena microscopically. According to analytical data by EPMA, tetrahedrite which has the compositional value Sb : (Sb+As) in atomic ratio of 0.95 to 1.00 contains 18.0 to 30.3 wt % Ag. Jamesonite, franckeite and semseyite intimately associate each other, and also appear in association with galena. Hocartite found in sphalerite rich ores from the Angeles and Candelaria veins occurs as granular form, 0.1 to 1 mm in size, associated with franckeite, sphalerite, pyrite and marcasite, and sometimes con-

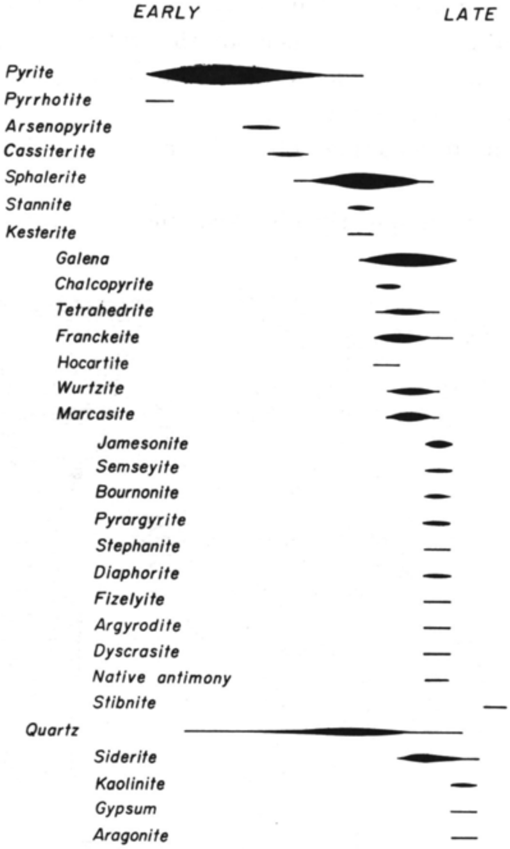

FIGURE 52. MINERALIZATION SEQUENCE OF MINERALS FROM THE TATASI MINE.

tains lath-shaped crystals of franckeite under microscope as seen in Figure 51-C. Silver minerals such as pyrargyrite, stephanite, fizelyite, diaphorite, argyrodite occur in druse of sphalerite and pyrite of the vein or intimately associate with galena, jamesonite, and semseyite filling up the central part of the veins as veinlet. Pyrargyrite found in ores from the Alcira, Candelaria, Cochinoca, Angeles and Animas veins occurs as irregular grain, 10 to 50 μm in size, accompanied by galena, sphalerite and tetrahedrite etc. in the druse. Stephanite showing irregular form assembles with sphalerite, tetrahedrite, pyrargyrite, diaphorite, and fizelyite etc. Diaphorite and fizelyite which are found in the ore from the Cochinoca vein show irregular and granular forms in intimate association with each other or sometimes pyrargyrite, stephanite, tetrahedrite, semseyite and sphalerite in the druse. They are also rimmed by pyrargyrite and stephanite in the case assembling with galena (Figure 51-D). Lamellae of pyrargyrite are rarely observed in diaphorite under microscope. Argyrodite found in the ore from the Animas vein occurs along the crack in galena. Native antimony and dyscrasite are occasionally observed in galena, but some of them are thought to be a secondary product from pyrargyrite. Quartz and siderite are dominant as gangue minerals. The latter appears at latest stage of the mineralization. Idiomorphic crystals of aragonite and gypsum are sometimes observed in druse of the vein as the latest stage products.

Fluid inclusions are frequently observed under microscope in quartz and

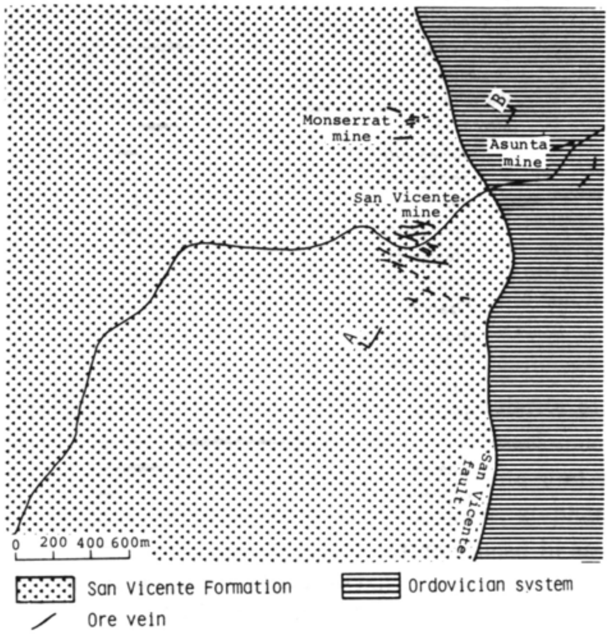

FIGURE 53. GEOLOGICAL MAP AROUND THE SAN VICENTE AND ASUNTA MINES.

sphalerite of the ores from the mine. Homogenization and freezing temperatures of the fluid inclusions in quartz with pyrite from the Cochinoca vein at the −70 Guadalupe level, quartz with sphalerite and galena from the Santo Domingo vein at the −70 Guadalupe level, and sphalerite from Cienguillas vein at the 0 Alcira level were measured using the heating and freezing stage. Homogenization temperatures obtained are 232° to 345°C (mean value 308°C) for quartz from the Cochinoca vein, 180° to 299°C (220°C) for quartz from the Santo Domingo vein, and 217° to 266°C (239°C) for sphalerite from the Cienguillas vein. Salinities obtained from the data of freezing temperutures are 1.5 to 8.9 wt% in equivalent NaCl for inclusions in quartz from the Cochinoca vein, 8.9 to 10.6 wt% for those in quartz from the Santo Domingo vein and 8.2 to 7.2 wt% for sphalerite from the Cienguillas vein. Homogenization temperatures of inclusions in quartz from the Cochinoca vein, accompanied by pyrite formed at early stage of the mineralization are rather higher values in comparison with those in sphalerite.

From the data on mineral assemblage of the vein and occurrence, assemblage and paragenesis of minerals, the sequence of the mineralization formed the ore and gangue minerals from the mine is considered as shown in Figure 52. Pyrite, pyrrhotite and some quartz were crystallized at the early stage of the mineraliza-

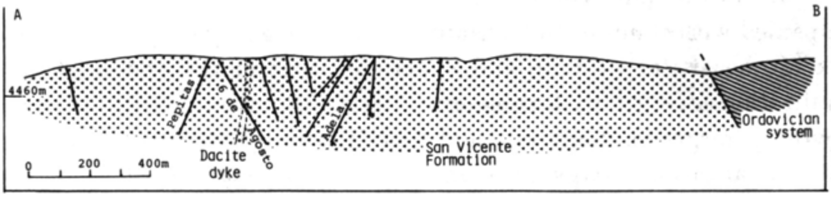

FIGURE 54. GEOLOGICAL CROSS SECTION OF THE SAN VICENTE MINE ALONG THE LINE CONNECTING A AND B IN FIGURE 53.

TABLE 7. SCALES OF PRINCIPAL VEINS IN THE SAN VICENTE MINE.

Vein	Strike	Dip	Length (m)	Depth (m)	Width (m)
Guernica	N70°W	74°-83°N	550	85	0.6
Adela	N60°W	58°S	440	150	1.2
Jesus Maria	N80°W	70°S	280	30+	0.3-0.6
Disputada	N80°W	80°N	240	65+	0.3
San Jose	N50°W	68°N	650	100	0.8
Cantera	N50°W	64°-75°S	420	90	0.8
Artola	N55°E	75°S	210	30+	0.1
6 de Agosto	N80°W	58°N	1500	100	1.2
Ramo 6 de Agosto	N65°E	60°N	160	65+	0.2
Litoral	N60°E	70°S	220	65+	2.5
San Lorenzo	EW	60°N	190	30+	0.3
Deseada	N75°W	58°N	1250	100	1.0
Arturo	N65°W	62°N	1130	80	0.3

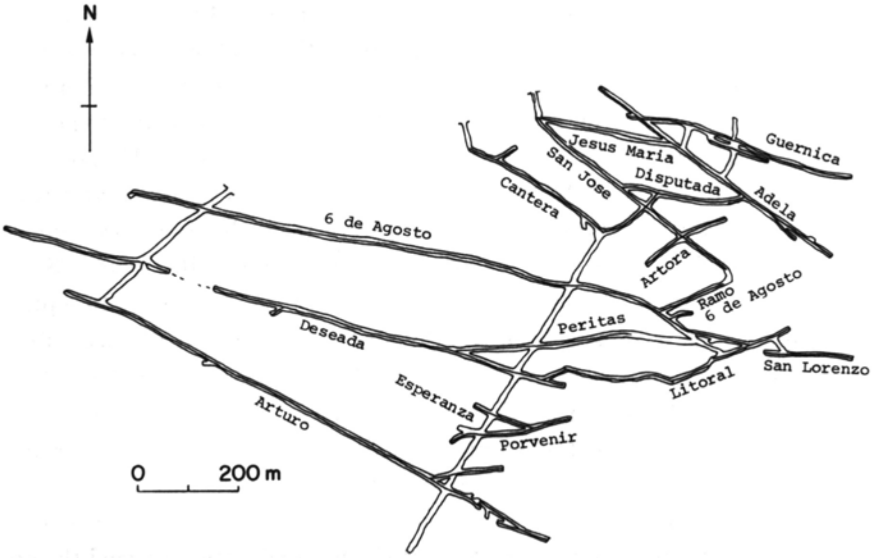

FIGURE 55. VEINS AT THE 0 LEVEL OF THE SAN VICENTE MINE.

tion and arsenopyrite and cassiterite were produced nearly at the end of the early stage. Meanwhile sphalerite was formed at the middle stage of the mineralization accompanied with stannite and kesterite. Also galena, chalcopyrite, tetrahedrite, franckeite, hocartite, wurtzite and marcasite occur in the middle stage of the mineralization together with sphalerite. Sulfosalt minerals such as jamesonite, semseyite, pyrargyrite, diaphorite and fizelyite were crystallized at the late stage of the mineralization. Argyrodite and dyscrasite were also produced at the same stage with sulfosalt minerals as above. Siderite, kaolinite, gypsum and aragonite appear in a veinlet as product at latest stage of the mineralization or as filling up the center of the veins. Finally, veinlets of stibnite cuts whole the vein.

9. *San Vicente mine*

The San Vicente mine belonging to COMIBOL is situated at the southwest part of the Quechisla district and 60 km south of Atocha (Figure 56-A). The monthly production is 9,882 tons as silver and zinc crude ore containing 370 g/ton Ag, and 4.08% Zn in July of 1983. Mining is done at 5 levels from the +45 level (4,505 m above the sea level) to the −70 level (4,390 m).

Geology and ore deposits of the mine has been already described by Ahlfeld and Schneider-Scherbina (1964), and JICA and MMAJ (1977, 1978). Geology of the San Vicente mine area is composed of the Ordovician system and the San Vicente Formation of the Tertiary system. Geological map and its section are shown in Figures 53 and 54, respectively. The Ordovician system is exposed in

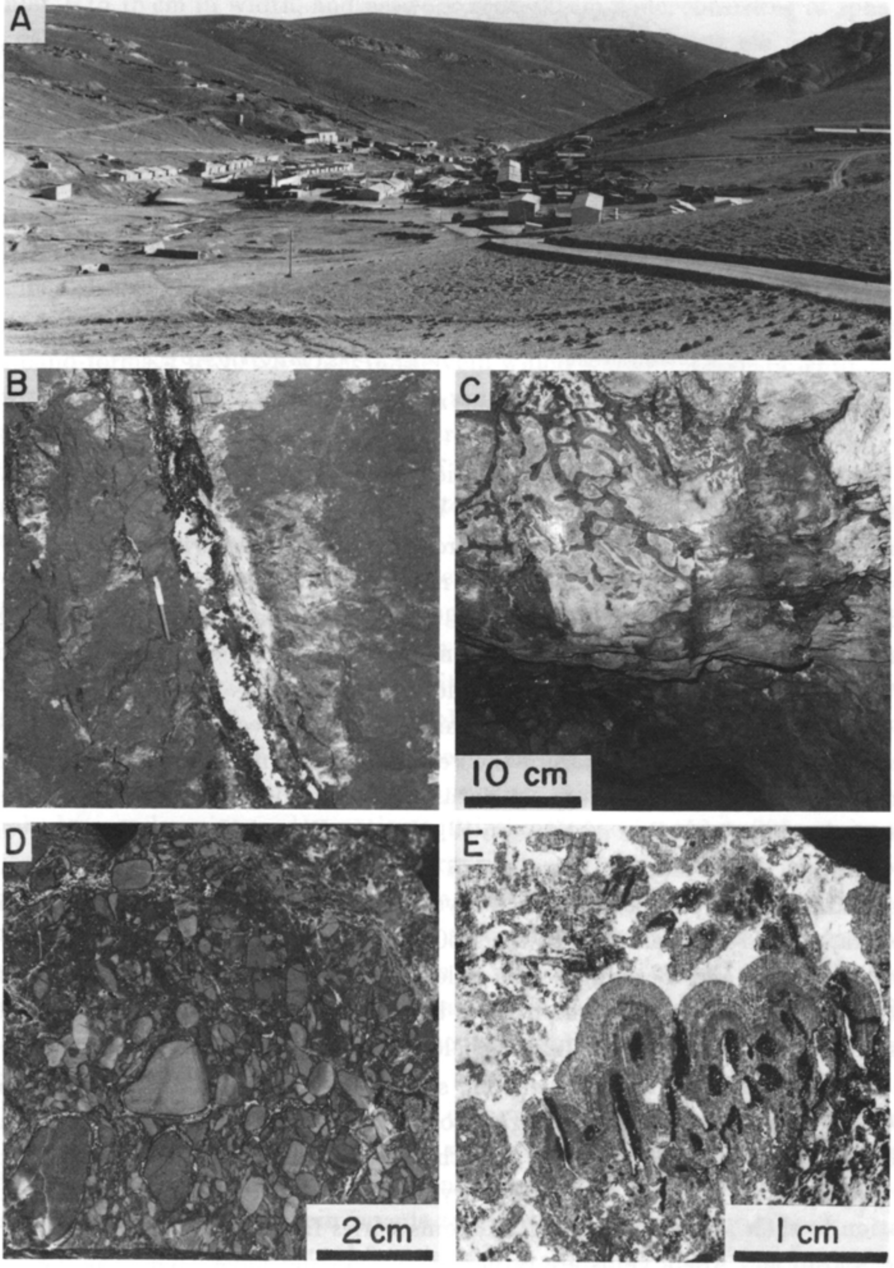

FIGURE 56. PHOTOGRAPHS OF THE SAN VICENTE MINE.
A : The San Vicente mine viewed from the northeast. B : Sphalerite-tetrahedrite-chalcopyrite (dark gray) and barite (white) vein in conglomerate (light gray), 6 de Agosto vein, −30 level. C : Veinlets of tetrahedrite, chalcopyrite and sphalerite (dark gray) in conglomerate (light gray), Jesus Maria vein, −30 level. D : Pyrite network (light gray) in the vein with pebble of conglomerate, Adela vein, −30 level. (Sample No. 8173117). E : Oolitic sphalerite (gray) with wurtzite (dark gray) and barite (white), Arturo vein, −30 level (8181713).

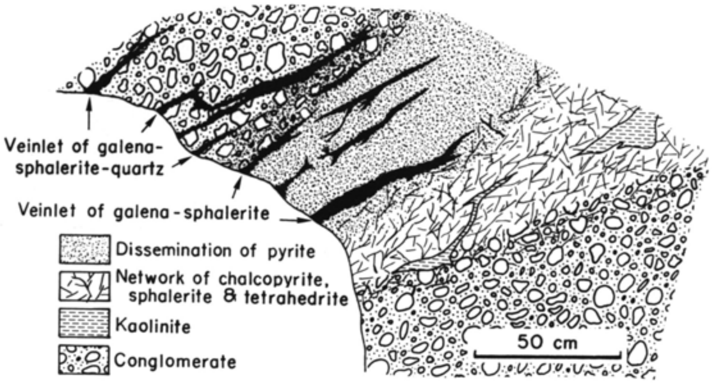

FIGURE 57. SKETCH OF THE ADELA VEIN, THE 0 LEVEL, SAN VICENTE MINE.

the eastern area, and consists of alternation of sandstone and slate. Folding and small faults are common in it. The San Vicente Formation is exposed around the San Vicente mine, and adjoins to the Ordovician formation with reverse fault as shown in Figure 54. It is composed of reddish color conglomerate with pebbles and rarely cobbles of Ordovician rocks. It is poorly stratified, but its bedding is relatively flat. The dacite dyke of 10 m in width which strikes EW and dips vertically is observed at both surface and underground.

The ore veins of the San Vicente mine develop in conglomerate of the San Vicente Formation. The scales of the veins are given in Table 7. The distribution of veins at the 0 level are shown as in Figure 55 and there are three vein systems having the strikes of N70°-85°W, N50°-65°W and N55°-65°E. The veins of Guernica, Jesus Maria, Disputada, 6 de Agosto, Deseada, San Lorenzo and Esperanza belong to the N70°-85°W system, meanwhile the Adela, San Jose, Cantera, and Arturo veins are of the N50°-65°W system, and Artola, Ramo 6 de Agosto, Litoral and Porvenir veins belong to the N55°-65°E system. Among them, the 6 de Agosto vein which has a length of 1,500 m, is the longest and the Deseada vein whose length is 1,250 m belong to the N70°-85°W system. Veins of the N50°-65°W system have rather long scale from 420 to 1,130 m in their strike extension. While the veins belonging to N50°-65°E system are on a small scale. These veins have a general feature that their strikes do not change distinctly, and are continuous. Dips of the veins vary from 60°N to 60°S, and have no any relation to their strike. Width of the veins varies from 0.2 to 2.5 m, but Litoral, 6 de Agosto and Adela veins are rather wide scale and have 2.5 m, 1 to 2 m, and 1 to 2 m, respectively.

All of the veins such as 6 de Agosto, Deseada, Jesus Maria and Adela in the mine develop in conglomerate of the San Vicente Formation. Among them, the Adela vein, about 1.0 m in width is composed of sphalerite, tetrahedrite, pyrite, chalcopyrite, galena, barite and quartz etc. There are generally found band or veinlet, 5 to 15 cm in width, and network zone, 30 cm wide, consisting of sphalerite, galena, pyrite, chalcopyrite, tetrahedrite, barite and quartz etc. in the vein. Also, dissemination zone of pyrite, 30 to 60 cm in width, often develops in the vein (Figure 57). Sometimes some of minerals as above coat as rim on gravel of conglomerate which exists as gangue rock in the vein (Figure 56-D). Kaolinite and sericite appear as veinlet cutting the vein and a product of the latest stage of the mineralization. Conglomerate of the country rock adjoining to the vein suffers silicification.

The Jesus Maria vein with a lot of druses and vug consists of pyrite, chalcopyrite, tetrahedrite, sphalerite and barite. They occur as stringers, veinlets and band-forms, 1 to 10 cm wide, in the vein which is fracture zone of 30 to 50 cm in wide (Figure 56-C). They sometimes appear as crustified band with vug in the fissure developing in conglomerate. Tetrahedrite showing tetrahedral form, 0.5 to 1.0 cm in size, is formed in the druse of the vein. Barite with quartz occurs as veinlet of aggregate of platy crystal, 1 to 3 cm in size, and sometimes associates with tetrahedrite, sphalerite and pyrite. It often has druse or vug. Conglomerate of the country rock adjacent to the vein is remarkably altered by silicification, but pyrite dissemination is weak in conglomerate.

The 6 de Agosto vein, 1.0 to 1.5 m in width, is composed of galena, sphalerite, pyrite, wurtzite, chalcopyrite, tetrahedrite, barite and quartz etc. which occur in dissemination, network or veinlet developed in the mineralized fracture zone inside the vein (Figure 56-B). Galena occurs as aggregate of granular crystals, 0.5 to 1 mm in size, in intimate associations with sphalerite, pyrite, chalcopyrite, tetrahedrite and pyrite, and sometimes includes fine grains, 10 to 200 μm in size, of tetrahedrite, bournonite and pyrargyrite under microscope. Tetrahedrite appears as irregular forms in assemblage with sphalerite, galena and pyrite, and sometimes bournonite. Barite which is a principal mineral of the vein generally appears as a band-like form, about 30 cm in width, in the central part of the vein, and also associates with pyrite usually, and tetrahedrite and galena occasionally. Kaolinite and sericite, 2 to 8 cm wide, occur as veinlet in most outside of the vein, adjoining to conglomerate at footwall side. The country rock is altered by sericitization, and suffers dissemination of pyrite and barite. At the −30 level, dacite dyke with about 10 m in width, which runs roughly parallel to the vein, suffers partly mineralization. Pyrite and quartz veinlets, 1 to 5 cm wide, of a branch of the 6 de Agosto vein invade to the dacite dyke.

The Deseada vein, 0.2 to 1.0 m in width, consists of sphalerite, wurtzite, galena, pyrite, marcasite and barite etc. and occurs as veinlet or band-like form, 2 to 5 cm wide, and network in the vein fracture. The ores of the band-like form as above are composed of pyrite, sphalerite, galena and barite. Galena associates with chalcopyrite and tetrahedrite. Barite is accompanied by pyrite and galena. Conglomerate of country rock is altered by silicification.

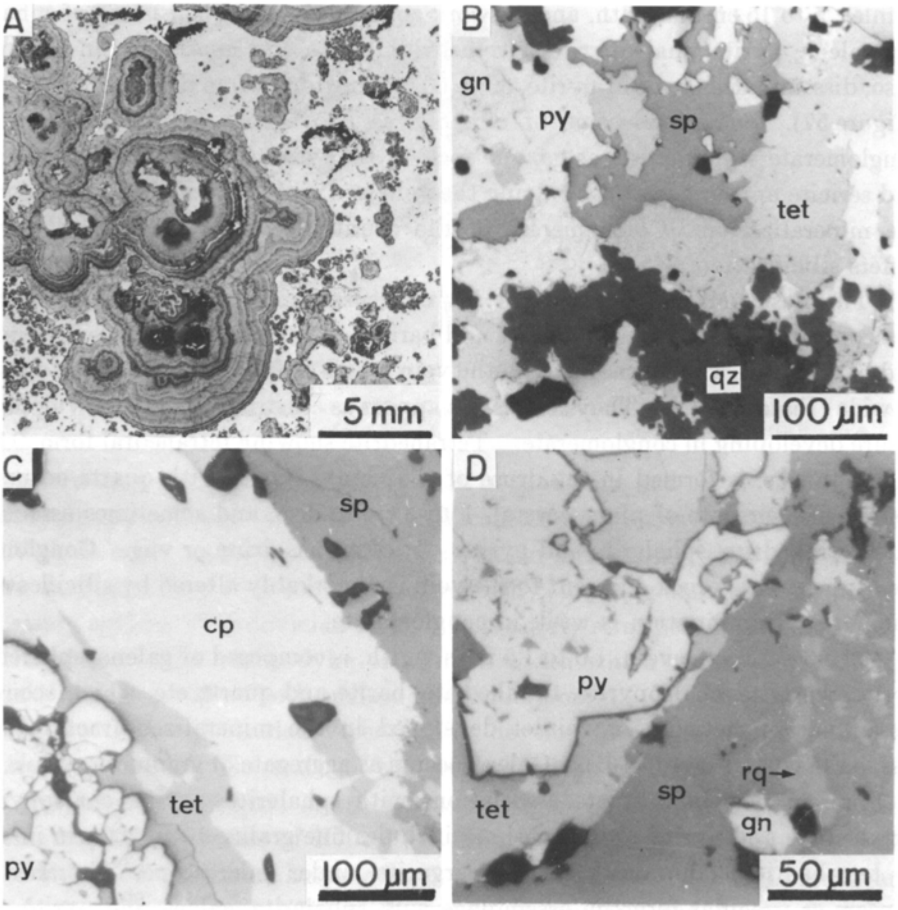

FIGURE 58. PHOTOMICROGRAPHS OF ORES FROM THE SAN VICENTE MINE.
A ; transmitted light. B, C, and D ; reflected light. A : Oolitic sphalerite (dark gray) in quartz (white), Arturo vein, −30 level (Sample No. 8181711). B : Aggregate of tetrahedrite (tet), sphalerite (sp), galena (gn) and pyrite (py), Arturo vein, −30 level (8181710). C : Association of tetrahedrite (tet), Chalcopyrite (cp), sphalerite (sp) and pyrite (py), 6 de Agosto Ramo C vein, −30 level (8173118). D : Tetrahedrite (tet) in interspaces of sphalerite (sp) and euhedral pyrite (py). Roquesite (rq) is found in sphalerite with galena (gn). Deseada vein, −30 level (8181721).

The Arturo vein, 40 to 60 cm in width, consists of sphalerite, galena, pyrite, wurtzite, quartz and barite. They occur in veinlet, 1 to 7 cm wide, and dissemination in the vein. Sphalerite of the dissemination zone in the vein appears as oolitic form, 0.5 to 2.0 cm in size (Figures 56-E and 58-A), and shows a colloform consisting of sphalerite, wurtzite, galena and chalcopyrite microscopically. The veinlet of galena, 3 to 5 cm wide, appears in association with chalcopyrite and tetrahedrite. Barite and quartz are sometimes found as druse minerals in the vein.

From the data on structure of the veins and occurrence, assemblage of minerals, pyrite, sphalerite and quartz were formed at early stage of the mineralization, although sphalerite was produced for rather long period of crystallization than that of pyrite. Sphalerite commonly shows crustified and oolitic structures as observed well in the Arturo vein (Figures 56-E and 58-A). Fibrous aggregate of wurtzite is sometimes observed in the sphalerite band. Tetrahedrite and galena crystallized slightly later than pyrite and sphalerite (Figure 58-B). Overgrowth of tetrahedrite and galena on euhedral or subhedral pyrite is commonly recognized (Figure 58-D). Tetrahedrite is a principal silver mineral from the

TABLE 8. ORE AND GANGUE MINERALS OCCURRING FROM THE MINES IN THE QUECHISLA DISTRICT.

Mineral name	Chemical formula	Mineral name	Chemical formula
Pyrite	FeS_2	Bournonite	$CuPbSbS_3$
Marcasite	FeS_2	Jamesonite	$FePb_4Sb_6S_{14}$
Arsenopyrite	$FeAsS$	Boulangerite	$Pb_5Sb_4S_{11}$
Pyrrhotite	$Fe_{1-x}S$	Semseyite	$Pb_9Sb_8S_{21}$
Chalcopyrite	$CuFeS_2$	Aramayoite	$Ag_6Sb_5BiS_{12}$
Galena	PbS		
Sphalerite	ZnS	Cassiterite	SnO_2
Wurtzite	ZnS	Hydrocassiterite	$(Sn,Fe)(O,OH)$
Stannite	Cu_2FeSnS	Hematite	Fe_2O_3
Kesterite	Cu_2ZnSnS	Wolframite	$(Fe,Mn)WO_4$
Hocartite	Ag_2FeSnS		
Canfieldite	Ag_8SnS_6	Quartz	SiO_2
Argyrodite	Ag_8GeS_6	Corundum	Al_2O_3
Roquesite	$CuInS_2$	Diaspore	$AlO(OH)$
Luzonite	Cu_3AsS_4	Gibbsite	$Al_2O_3 \cdot 3H_2O$
Tetrahedrite	$(Cu,Ag,Fe,Zn)_{12}(Sb,As)_4S_{13}$	Siderite	$FeCO_3$
Bismuthinite	Bi_2S_3	Calcite	$CaCO_3$
Stibnite	Sb_2S_3	Aragonite	$CaCO_3$
Native bismuth	Bi	Smithsonite	$ZnCO_3$
Native antimony	Sb	Barite	$BaSO_4$
Dyscrasite	Ag_3Sb	Gypsum	$CaSO_4 \cdot 2H_2O$
Hessite	Ag_2Te	Alunite	$(K,Na)Al_3(SO_4)_2(OH)_6$
Tetradymite	Bi_2Te_2S	Natroalunite	$(Na,K)Al_3(SO_4)_2(OH)_6$
Electrum	(Au,Ag)	Minamiite	$Ca_{0.5}Al_3(SO_4)_2(OH)_6$
Franckeite	$FePb_6Sb_2Sn_2S_{14}$	Jarosite	$KFe_3(SO_4)_2(OH)_6$
Aikinite	$CuPbBiS_3$	Scorodite	$Fe(AsO_4) \cdot 2H_2O$
Cosalite	$CuPb_7Bi_8S_{20}$	Apatite	$Ca_{10}(F,OH)_2(PO_4)_2$
Gustavite	$Ag_3Pb_5Bi_{11}S_{24}$	Monazite	$(Ce,La,Nd)(PO_4)$
Stephanite	Ag_5SbS_4	Vivianite	$Fe_3(PO_4)_2 \cdot 8H_2O$
Pyrargyrite	Ag_3SbS_3	Variscite	$Al(PO_4) \cdot 2H_2O$
Miargyrite	$AgSbS_2$	Strengite	$Fe(PO_4) \cdot 2H_2O$
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	Wavellite	$Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$
Andorite	$AgPbSb_3S_6$	Crandallite	$CaAl_3(PO_4)_2(OH)_6$
Ramdohrite	$AgPb_2Sb_3S_7$		
Fizelyite	$Ag_2Pb_5Sb_8S_{18}$	Tourmaline	$NaFe_3Al_6B_3Si_6O_{27}(F,OH)_4$
Diaphorite	$Ag_3Pb_2Sb_3S_8$	Dumortierite	$(Al,Fe)_7BSi_3O_{18}$
		Kaolinite	$Al_2Si_2O_5(OH)_2$
		Sericite	$KAlSi_3AlO_{10}(OH)_2$
		Chlorite	$(Mg,Fe,Al)_{12}(Si,Al)_8O_{20}(OH)_{16}$

mine, although pyrargyrite occurs occasionally as granular form of 10 to 200 μm in galena only. The silver content of tetrahedrite is from 0.6 to 15.4 wt%. Chalcopyrite also assembles commonly with galena, tetrahedrite and sphalerite (Figure 58-C). Galena occasionally contains grains of tetrahedrite, pyrargyrite and bournonite, 10 to 200 μm in size, as inclusions. Aikinite also appears as lath shape crystals, 0.1 to 0.3 mm in size, in association with galena and chalcopyrite. Luzonite occasionally occurs as irregular form, 0.1 to 0.3 mm in size, in association with galena, sphalerite, tetrahedrite and chalcopyrite. Roquesite is rarely found as small irregular grain of 0.1 mm or less in size in sphalerite as seen in Figure 58-D.

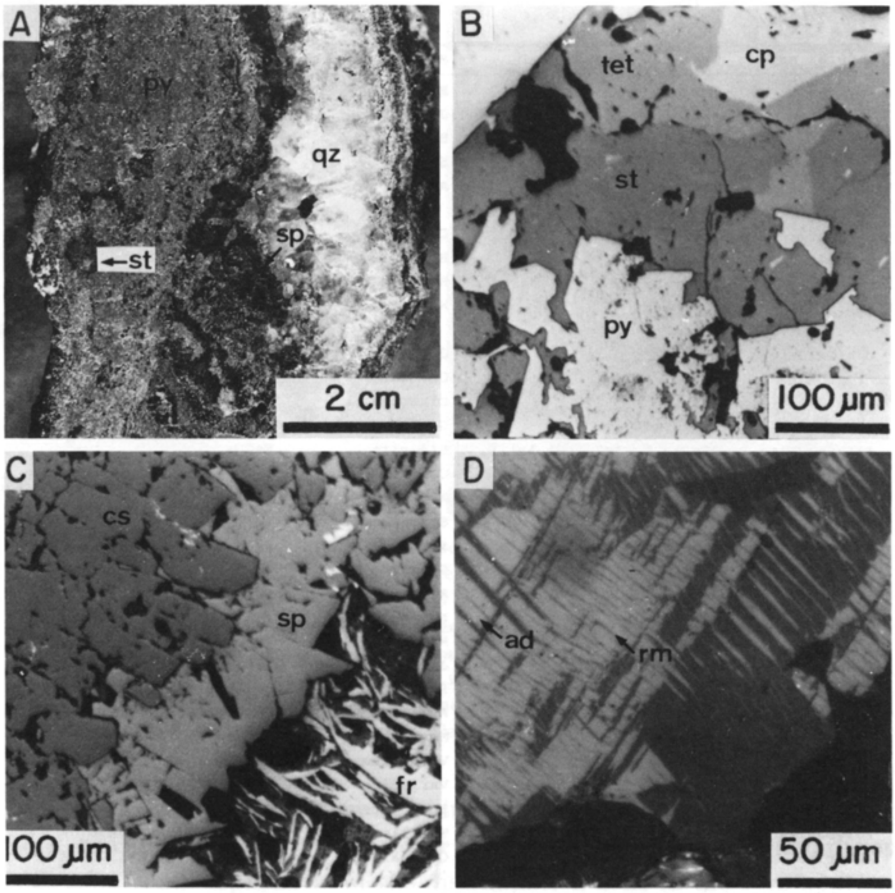

FIGURE 59. ORE AND ORE MINERALS OF THE MONSERRAT AND ASUNTA MINES.
A: Banding of pyrite (py), stannite (st), sphalerite (sp) and quartz (qz) in ore, Monserrat mine (Sample No. 8380101). B: Stannite (st) associated with tetrahedrite (tet), chalcopyrite (cp) and pyrite (py), Monserrat mine (8380101). C: Assemblage of cassiterite (cs), sphalerite (sp) and franckeite (fr), Asunta mine (8173151). D: Lamellar twinned andorite (ad) including ramdohrite (rm) lamellae under crossed nicols, Asunta mine (8173151).

Although tin minerals such as cassiterite, stannite and franckeite are commonly found from the mines in Quechisla district, they are not yet recognized in the ores from the San Vicente mine. However small amounts of kesterite are observed in the ores from the Adela vein as very rare case.

TABLE 9. ORE MINERALS AND THEIR AMOUNTS OCCURRING FROM EACH MINE IN THE QUECHISLA DISTRICT.

	Tasna	Chorolque	Siete Suyos	Animas	Gran Chocaya	Tatasi	San Vicente
Pyrite	◯	○	◯	◯	◯	◯	○
Marcasite	○	∘	○	○	○	∘	∘
Arsenopyrite	◯	○	∘	○	∘	∘	
Pyrrhotite	∘	∘	∘	∘	∘	∘	
Chalcopyrite	◯	○	∘	∘		∘	○
Galena		∘	○	◯	◯	◯	◯
Sphalerite	○	∘	◯	◯	◯	◯	◯
Wurtzite			○	○	○	∘	∘
Stannite	○	○	○	◯	∘	∘	∘
Kesterite						∘	∘
Hocartite			○	∘		○	
Canfieldite				∘			
Argyrodite						∘	
Roquesite							∘
Luzonite							∘
Tetrahedrite		∘		∘		○	◯
Bismuthinite	◯	○		∘			
Stibnite						∘	
Native bismuth	∘			∘			
Native antimony						∘	
Dyscrasite						∘	
Hessite		∘					
Tetradymite		∘					
Electrum		∘					∘
Franckeite	∘		○	○	∘	○	
Aikinite							∘
Cosalite	○	∘					
Gustavite	∘						
Stephanite					○	○	
Pyrargyrite			∘	∘	○	○	∘
Miargyrite			∘	∘	∘		
Polybasite				∘	∘		
Andorite				∘			
Fizelyite						○	
Diaphorite						○	
Bournonite				○		○	∘
Jamesonite	∘			○	∘	○	○
Boulangerite	∘			∘	∘	∘	
Semseyite						○	
Aramayoite				∘			
Cassiterite	○	○	○	○	∘	○	
Hematite		∘			∘		
Wolframite	◯	○		∘			

Size of circles indicates relative quantities of minerals.

Monserrat mine: The Monserrat mine which is a branch of the San Vicente mine is situated at 3 km north of it. The mine was operated by the Chilian private company, but it is now under the juridiction of the San Vicente mine, and underground prospection is being done at the 0 and 40 levels. According to JICA and MMAJ (1977, 1978), ore deposits of this mine are composed of such veins as P, M, San Martin, A, Salvadora and Soniselma from north to south. Geology and ore deposit of the Monserrat mine are not clear, but veins develop in conglomerate of the San Vicente Formation. Conglomerate suffers intensely sericitization and its color changes to white. The ores from the mine consist mainly of pyrite, stannite, cassiterite, sphalerite, galena, tetrahedrite associating with small amounts of marcasite, chalcopyrite, franckeite and electrum (Figure 59-A). Quartz is dominant as a gangue mineral. Tin minerals such as stannite, cassiterite and franckeite are characteristic in comparison with ores from the San Vicente mine. Stannite is found in intimate association with cassiterite, tetrahedrite, chalcopyrite and pyrite (Figure 59-B). Tin sulfide minerals are thought to have been formed by the mineralization as produced the ore of the tin-silver zone described in the Siete Suyos and Animas mines. While the mineralization of the San Vicente mine corresponds to that formed the ores of the silver-lead-zinc zone

TABLE 10. GANGUE MINERALS AND THEIR QUANTITIES FROM EACH MINE IN THE QUECHISLA DISTRICT.

	Tasna	Chorolaque	Siete Suyos	Animas	Gran Chocaya	Tatasi	San Vicente
Quartz	◯	◯	◯	○	○	○	○
Gibbsite			○	○			
Siderite	○	∘	○	○	∘	∘	∘
Calcite					∘		
Aragonite				∘		∘	
Smithsonite				∘			
Barite	∘	○					◯
Gypsum			○	○		∘	
Alunite		○					
Natroalunite	○	○					
Minamiite		○					
Jarosite	∘	◯					
Scorodite	∘						
Apatite	◯		∘	∘	∘		
Monazite	∘						
Vivianite				∘			
Variscite		∘					
Strengite		∘					
Wavellite	∘						
Crandallite	∘						
Tourmaline	◯	◯					
Kaolinite	◯		○	○		○	
Sericite	○	∘	∘	∘			
Chlorite		∘					

of the Gran Chocaya mine.

10. *Asunta mine*

The Asunta mine which belongs to Empresa Minera Unificada Sud Americano (EMUSA) is situated about 4 km northeast of the San Vicente mine. This mine had been under exploitation for tin and silver ores, but has been closed in August, 1981. The ore veins occur in Ordovician sandstone and slate which generally strike from N-S to N40°W, and dip to north. According to Ahlfeld and Scherbina (1964), there are three principal veins such as El Hueco, Chica and Ancha in the mine. Among them, the El Hueco vein of which another name is La Caldera has breccia pipe, 20 to 50 m in diameter, cemented by quartz and limonite.

The ore minerals from the mine consist mainly of pyrite, sphalerite and franckeite associated with minor amounts of cassiterite, hocartite, stannite, canfieldite, andorite and tetrahedrite. Quartz and barite also occur as gangue minerals. Cassiterite appears as aggregate of fine crystals, 10 to 50 μm in size, and is associated with sphalerite, pyrite and quartz (Figure 59-C). Tin bearing sulfides such as hocartite, stannite, franckeite and canfieldite are found in intimate association with each other. Andorite assembles with pyrite, sphalerite and fizelyite, and includes fine lamellae of ramdohrite as seen in Figure 59-D. Barite appears in the vug of the central part of the vein, and sometimes occurs as large platy crystal of about 5 cm in size.

ORE MINERALS

Many ore and gangue minerals from the ore veins of the Tasna, Chorolque, Siete Suyos, Animas, Gran Chocaya, Tatasi, Asunta and San Vicente mines in the Quechisla district as listed in Table 8 occur. Also the kinds and amounts of ore and gangue minerals are shown in Tables 9 and 10, respectively. In the tables, size of open circles indicates the amount of the minerals. Among them, hessite, tetradymite, gustavite, diaphorite, natroalunite, minamiite, diaspore and dumortierite have been first found from Bolivia by this study. Cassiterite occurs as a principal tin mineral from all of the mines in the district except the San Vicente mine. Base metal sulfide minerals such as pyrite, marcasite, galena, sphalerite and chalcopyrite also are found from all of the mines. Wolframite occurs from the Tasna, Chorolque and Animas mines.

Tin bearing minerals such as cassiterite, stannite, kesterite, hocartite, canfieldite and franckeite, silver bearing minerals such as native silver, electrum, dyscrasite, hessite, andorite, fizelyite, diaphorite, pyrargyrite, stephanite, miargyrite, polybasite, tetrahedrite, gustavite, and aramayoite, and lead antimony sulfosalts such as boulangerite, jamesonite and bournonite are found in the district.

Cassiterite occurs in the tin-quartz, tin-pyrite and tin-silver zones as mentioned before. It formed in the tin-quartz zone of the Chorolque mine appears as a band, 1 to 3 mm wide, in quartz vein as aggregate of euhedral or subhedral crystals, 0.1 to 3.0 mm in size, showing growth zoning, and commonly assembles with quartz and tourmaline. Also, in the tin-pyrite zone cassiterite generally occurs as a band, 1 to 3 mm wide, in quartz-pyrite vein in association with quartz, pyrite, arsenopyrite and small amounts of stannite. According to the analytical data obtained by an elecron probe microanalyser (EPMA) for cassiterite which is formed in both the zones, some amounts of iron from 2.6 to 3.6 wt% FeO (4.3 to 6.0 mole% FeO) and from 0.3 to 4.3 wt% FeO (0.6 to 8.8 mole% FeO) are included in it from the Chorolque and Siete Suyos mines, respectively. Cassiterite also occurs in the sulfide veins of the tin-silver zone, as microscopic grains, 5 to 100 μm in size, in association with pyrite, stannite, chalcopyrite, galena, sphalerite, arsenopyrite and quartz etc. Cassiterite from the veins of the tin-silver zone of the Siete Suyos mine has up to 0.3 wt% FeO. Its iron contents in general are less than those of cassiterite from the veins in the tin-quartz and tin-pyrite zones of the Chorolque and Siete Suyos mines.

Wolframite from all the veins in the Rosario and Farellon Nuevo sections of the Tasna mine usually occurs as prismatic crystals of euhedral form, up to 5 cm in size, in association with tourmaline, bismuthinite, chalcopyrite, arsenopyrite and quartz. It has compositions from 5.0 to 8.0 mole% in $MnWO_4$. It from the Chorolque and the Rosario vein of the Animas mines appears as platy crystal, 0.1 to 0.5 mm in size, accompanied by pyrite, stannite, arsenopyrite and quartz microscopically. Wolframite from the Chorolque mine contains $MnWO_4$ from 4.1 to 7.5 mole%, while it from the Animas mine has two different compositions, one is 2.4 mole% or less in $MnWO_4$ and another, 93.4 to 96.9 mole% $MnWO_4$ near pure huebnerite.

Stannite also is an essential tin mineral from the sulfide veins formed in the tin-silver zone, and is generally found as aggregate of granular crystals, 0.5 to 3.0 mm in size, assembled with pyrite, arsenopyrite, sphalerite, galena, franckeite and quartz etc. macroscopically. It sometimes associates with small amounts of cassiterite, hocartite, bismuthinite, tetrahedrite and wolframite under the microscope. Also stannite occurs as a tetrahedral crystal, 1 to 3 mm in size, in druse of the veins together with quartz, pyrite, sphalerite, galena, lead-antimony sulfosalt and silver sulfosalt minerals. Small amounts of stannite sometimes occur in the veins of the tungsten-bismuth and tin-pyrite zones in the Tasna mine. The compositions of stannite analysed by EPMA have 6.7 to 13.1 (W-Bi zone, Tasna), 3.0 to 18.0 (Sn-py zone, Siete Suyos and Animas), 7.1 to 30.6 (Sn-Ag zone, Animas), and 12.3 to 90.7 (Sn-Ag zone, Tatasi), mole% in Cu_2ZnSnS_4 (kesterite) as solid solution. It also contains small amounts of indium as described below.

As an indium bearing mineral, roquesite occurs from the Deseada vein of the

San Vicente mine. It is only found as minute grains, 20 to 40 μm in size, enclosed in sphalerite microscopically. Its chemical composition is $Cu_{1.96-2.00}Fe_{0.00-0.01}Zn_{0.00-0.06}Sn_{0.00-0.01}In_{1.97-2.01}S_{3.98-4.03}$ and very close to the stoichiometric composition. Some stannite, sphalerite and cassiterite contain some amounts of indium. Stannite from some veins of the Tatasi and Siete Suyos mines has 0.1 to 1.2 wt% (0.1 to 1.6 at %) and 0.1 to 5.8 wt% (0.1 to 2.7 at %) In, respectively. Sphalerite from the Tatasi and San Vicente mines also contains 0.5 to 1.1 wt% (0.2 to 0.4 at %) and 0.4 to 2.0 wt% (0.2 to 0.9 at %) In, respectively. Also, cassiterite from the Siete Suyos mine has 0.2 to 0.3 wt% In_2O_3. Therefore, indium is one of characteristic elements in the Quechisla mining district.

Franckeite is one of the characteristic minerals of the veins occurring in the tin-silver zone, and usually found as aggregate of foliate or platy crystals accompanied by stannite, sphalerite, galena and quartz from the Siete Suyos, Animas, Tatasi and Asunta mines, and rarely Tasna mine. Composition of franckeite from the Siete Suyos mine obtained by EPMA is $Fe_{0.85-1.30}Pb_{5.82-6.03}Sb_{1.78-2.10}Sn_{2.03-2.25}In_{0.00-0.10}S_{13.83-13.98}$.

Hocartite also is one of the characteristic minerals from the veins in the tin-silver zone, and in general occurs as minute grains, 10 to 300 μm in size, assembled with franckeite, stannite, galena, sphalerite, pyrite and quartz from the Animas, Site Suyos, Tatasi and Asunta mines. Chemical composition of hocartite from the Salvadora vein of the Siete Suyos mine is $Cu_{0.01-0.02}Ag_{1.98-2.03}Fe_{0.78-0.83}Zn_{0.17-0.21}S_{3.97-4.01}$.

Tetrahedrite occurs from the Animas, Tatasi and San Vicente mines. It is found as irregular form, 0.1 to 0.5 mm in size, associated with chalcopyrite, sphalerite, pyrite, arsenopyrite and quartz, and also appears often as euhedral crystals of tetrahedral forms, 1 to 10 mm in size, in druse of the central part of the veins. Tetrahedrite from the Sn-Ag rich veins in the Tatasi mine closely associates with silver bearing sulfosalts such as pyrargyrite, miargyrite, stephanite and fizelyite. Tetrahedrite from the Animas, Tatasi and San Vicente mines contains large amounts of silver from 11.4 to 20.5 wt%, 18.0 to 32.9 wt% and 0.6 to 15.4 wt %, respectively.

Pyrargyrite occurs in the Sn-Ag and Ag-Pb-Zn zones as seen in the Siete Suyos, Animas, Gran Chocaya, Tatasi and San Vicente mines. It from the Siete Suyos, Animas and Gran Chocaya mining area is an irregular form, 0.1 to 1.0 mm in size, or sometimes hexagonally prismatic crystal assembled with polybasite, miargyrite, galena, sphalerite, pyrite, wurtzite and marcasite etc. in the druse of the central part of the veins. Its chemical composition from the Nueva vein of the Gran Chocaya mine is $Cu_{0.02-0.05}Ag_{2.98}Sb_{0.99-1.00}S_{2.97-3.00}$ which corresponds to mostly stoichiometric composition of pyrargyrite. Pyrargyrite is also found in druse or sulfosalt veinlet of the central portion of some veins in the Tatasi mine, as irregular form, 0.01 to 0.05 mm in size, accompanied by galena, sphalerite, tetrahedrite and sometimes stephanite, diaphorite and fizelyite microscopically. It rarely appears as fine exsolution lamellae in diaphorite from the Cochinoca vein of the Tatasi mine. In the San Vicente mine, pyrargyrite is usually enclosed in galena assembled with tetrahedrite and bournonite as a minor mineral under microscepe.

Miargyrite is only recognized under microscope as granular form,30 to 70 μm in size, from the Siete Suyos, Animas and Gran Chocaya mines. It is enclosed by pyrargyrite or associated with polybasite, galena, sphalerite and pyrite in the druse. Miargyrite from the Nueva vein of the Gran Chocaya mine has composition of $Cu_{0.00-0.01}Ag_{0.98-1.00}Sb_{1.00}S_{2.00-2.01}$ which is stoichiometric.

Polybasite appears as granular crystals, 50 to 100 μm in size, accompanied by pyrargyrite, miargyrite, galena, sphalerite, wurtzite and quartz in the druse of the sulfide vein in the Siete Suyos, Animas and Gran Chocaya mines. The composition of polybasite from the Nueva vein of the Gran Chocaya mine is $Cu_{0.90-0.98}Ag_{15.02-15.21}Sb_{1.89-2.15}S_{10.61-11.22}$.

Stephanite is found in the Nueva vein of the Gran Chocaya mine and the Cochinoca vein of the Tatasi mine. It is occasionally found as granular crystal, 50 to 200 μm in size, in the druse of the Nueva vein, and enclosed in pyrargyrite and galena or sometimes accompanied by polybasite, sphalerite and quartz. Its composition is $Ag_{4.90-4.97}Sb_{1.02-1.10}S_{3.96-4.03}$. Stephanite from the Cochinoca vein of the Tatasi mine is recognized microscopically as veinlet or lenticular form in diaphorite and fizelyite associated with pyrargyrite, galena, tetrahedrite and pyrite.

Argyrodite and dyscrasite are only found in the Animas vein of the Tatasi mine. Argyrodite occurs along the cleavage of galena, crystallized at late stage of the mineralization. Dyscrasite appears as granular form, 0.05 to 0.1 mm in size, enclosed in galena, and occasionally associates with native antimony. It also sometimes assembles with pyrargyrite and sphalerite.

Andorite is rarely found in the ore from the Animas and Asunta mines. It from the Burton Ramo A vein of the Animas mine appears as short prismatic form, 0.1 to 0.3 mm in size, associating with bournonite, jamesonite and pyrite in the druse of the central part of the vein, and has composition of $Cu_{0.02-0.03}Ag_{0.95-0.97}Pb_{1.02-1.05}Sb_{1.03-1.10}S_{2.97-3.01}$. Andorite from the Asunta mine shows granular form, 0.1 to 2 mm in size, and includes fine lamellae of ramdohrite microscopically in close association with pyrite, sphalerite, franckeite, hocartite and quartz etc.

Diaphorite and fizelyite appear as principal silver minerals of the Cochinoca vein in the Tatasi mine. Both minerals are in intimate association with each other or semseyite, jamesonite, tetrahedrite, pyrargyrite, stephanite and galena. They are partly replaced by veinlets of stephanite, pyrargyrite and galena microscopically. Rarely, diaphorite has lamellae of pyrargyrite. X-ray powder data for diaphorite and fizelyite from the Cochinoca vein are in good accordance with those given by JCPDS (1974).

Aramayoite occurs as a very rare mineral from the Burton Ramo A vein of the Animas mine. Under microscope, it appears as granular and prismatic forms, 20 to 50 μm in size, enclosed by stannite and pyrite in the druse of the vein. Its composition is $Ag_{0.95-1.02}Sb_{0.78-0.87}Bi_{0.11-0.20}S_{1.98-2.00}$.

Electrum is only found under microscope in the ores from the Chorolque and Monserrat mines. It occurs as irregular form, 0.05 to 0.3 mm in size, assembled with quartz, goethite and jarosite in the Fanny Ramo vein of the Chorolque mine. Its chemical composition is $Au_{0.77-0.80}Ag_{0.20-0.23}$. Electrum is also found from the Sin Nombre vein in the Sagrario section of the Chorolque mine as granular form, 2 to 20 μm in size, enclosed by arsenopyrite and chalcopyrite in intimate association with tetradymite and hessite etc. It also appears as minute grains, 0.03 to 0. 1 mm in size, assembled with tetrahedrite, stannite, pyrite and quartz in the ore from the Monserrat mine.

Very small quantities of hessite is only recognized in the ore from the Sin Nombre vein of the Sagrario section in the Chorolque mine. Under microscope, it shows fine granular from, 0.02 to 0.05 mm in size, enclosed in arsenopyrite and chalcopyrite in association with electrum and tetradymite.

Jamesonite commonly occurs in druse of the veins in the Tasna, Siete Suyos, Animas and Tatasi mines. It from veins of the Acero and Pando sections belonging to the Sn-Ag zone in the Tasna mine appears as aggregate of acicular crystal, 0.1 to 1 mm in length, and microscopically associates with stannite, chalcopyrite, sphalerite and quartz, and sometimes franckeite in the vein of the

TABLE 11. PRINCIPAL MINERALIZATIONS AND THEIR CHARACTERISTIC MINERALS FOUND IN THE QUECHISLA DISTRICT.

Mineralization type	Principal minerals
Sn-qz	Cassiterite + quartz + tourmaline (pyrite, stannite)
W-Bi	Wolframite + bismuthinite + quartz (chalcopyrite, pyrite, arsenopyrite, pyrrhotite, sphalerite, stannite, cassiterite, tourmaline)
Sn-py	Cassiterite + pyrite + quartz (arsenopyrite, sphalerite, stannite)
Sn-Ag	Sn sulfide + Ag sulfosalt + pyrite (galena, sphalerite, marcasite, wurtzite, arsenopyrite, Pb-Sb sulfosalt, quartz)
Ag-Pb-Zn	Ag sulfosalt + galena + sphalerite (marcasite, wurtzite, pyrite, quartz, barite)

Minerals in parenthesis are in association with the principal or characteristic minerals of the mineralization.

TABLE 12. THE KINDS OF MINERALIZATION FOUND IN EACH MINE OF THE QUECHISLA DISTRICT.

Mineralization type	Characteristic minerals	Tasna	Chrolque	Siete Suyos	Animas	Gran Chocaya	Tatasi	San Vicente
Sn-qz	Cassiterite + quartz + tourmaline	∘	◯					
W-Bi	Wolframite + bismuthinite + quartz	◯*	○					
Sn-py	Cassiterite + pyrite + quartz	○		◯	○		∘	
Sn-Ag	Sn sulfide + Ag sulfosalt + pyrite	∘	∘	○	◯	∘	◯	∘
Ag-Pb-Zn	Ag sulfosalt + galena + sphalerite	∘		∘	∘	◯	∘	◯

* indicates a possibility that the age of the W-Bi mineralization found in the Tasna mine may be not Miocene, and may be more older, probably Jurassic.

Pando section. It also occurs in the druse of sulfide vein of the Siete Suyos and Animas mines as acicular form, 0.05 to 2 mm in length, in close association with boulangerite, bournonite, stannite, sphalerite, galena, marcasite and quartz. Jamesonite commonly appears in the central part of the Cochinoca vein in the Tatasi mine, and shows acicular forms, 0.01 to 1 mm in length, assembled with galena, sphalerite, bournonite, semseyite and silver bearing sulfosalt minerals such as pyrargyrite, stephanite, fizelyite and diaphorite microscopically.

Bournonite is usually found in the druse of the sulfide veins of the Siete Suyos and Animas mines and the Cochinoca vein of the Tatasi mine. It is also recognized microscopically in the ore from the San Vicente mine. Bournonite occurring from the Siete Suyos and Animas mines shows granular from, 0.1 to 0.5 mm in size, and sometimes appears as euhedral crystal of polyhedral form, up to 3 mm in size, in the druse. It is accompanied with stannite, tetrahedrite, galena, jamesonite, boulangerite, pyrargyrite, miargyrite and quartz etc. It from the Tatasi mine assembles with pyrargyrite, tetrahedrite, jamesonite, fizelyite, diaphorite and quartz etc. From the San Vicente mine, bournonite is usually found microscopically as granular form, 5 to 50 μm in size, associating with tetrahedrite enclosed in galena.

Boulangerite is rarely found in the druse of the veins of Tasna, Siete Suyos and Animas mines. That from the veins of the Veneros sections in the Tasna mine appears as aggregate of fine acicular crystal, 5 to 10 μm in length, assembled with jamesonite, franckeite ane quartz. Boulangerite also appears in the druse of the some sulfide veins in the Siete Suyos and Animas mines in association with jamesonite, bournonite, stannite and quartz. Semseyite is only found from the Cochinoca vein of the Tatasi mine. It appears as aggregate of granular form, 0.1 to 0.3 mm in size, in close association with fizelyite, diaphorite, bournonite, jamesonite and quartz microscopically.

MINERALIZATION

From the data of the mineral assemblages and parageneses for ore and gangue minerals by macroscopic and microscopic observations, the mineralizations found in the mines of the Quechisla district are mainly classified into five types such as tin-quartz (Sn-qz), tungsten-bismuth (W-Bi), tin-pyrite (Sn-py), tin-silver (Sn-Ag) and silver-lead-zinc (Ag-Pb-Zn) as given in Table 11 in the order as above from the early to late stages. The Sn-qz mineralization is essentially recognized at the Chorolque mine. The W-Bi mineralization is found in the Tasna and Chorolque mines. The mineralization of Sn-py mainly occurs in the Animas and Siete Suyos mines and the Sn-Ag mineralization is commonly observed all of the mines in the district investigated except the San Vicente mine. Ore veins formed by the Ag-Pb-Zn mineralization mainly appear in the Gran Chocaya and San Vicente mines. The kinds of mineralization observed in these mines are shown in Table 12.

The tin-quartz mineralization is characterized by coarse grained cassiterite, quartz and tourmaline accompanied by small amounts of pyrite, stannite, arsenopyrite and wolframite. It is mainly found in the veins developed in the dacite stock at the Chorolque mine. Country rocks of the mine are usually affected by hydrothermal alterations of tourmalinization, silicification and sericitization. At the latest stage of this mineralization, sulfate and phosphate minerals such as jarosite, alunite, natroalunite, minamiite, strengite and variscite are crystallized.

The tungsten-bismuth (W-Bi) mineralization is found in the veins of the Chorolque and Tasna mines. Ores formed by this W-Bi mineralization are mainly composed of wolframite, bismuthinite and quartz in intimate association with chalcopyrite, pyrite, pyrrhotite, sphalerite, arsenopyrite, stannite, tourmaline and small amounts of cassiterite and cosalite. Country rocks of dacite stock and dacite pyroclastics and Ordovician slate are usually altered by tourmalinization and silicification. At the Chorolque mine, wolframite occurs as fine grains, 2 to 5 mm in size, associated with bismuthinite, chalcopyrite, arsenopyrite, pyrite, pyrrhotite, sphalerite, stannite, and very slight amounts of electrum, tetradymite and hessite microscopically. Meanwhile wolframite from the Tasna mine appear as large crystals, sometimes up to 5 cm in size, assembling with arsenopyrite, tourmaline, pyrite, chalcopyrite, bismuthinite and quartz. Small amounts of phosphate minerals such as apatite, wavellite, crandallite and monazite, and sulfate minerals such as natroalunite, jarosite and barite are found in the veins of the Tasna mine as products at the late stage of the mineralization. As mentioned above, the W-Bi mineralization found in both the mines are not always same.

Cassiterite-pyrite-quartz veins formed by the Sn-py mineralization occur in the Tasna and Siete Suyos mines. They consist of cassiterite, pyrite and quartz

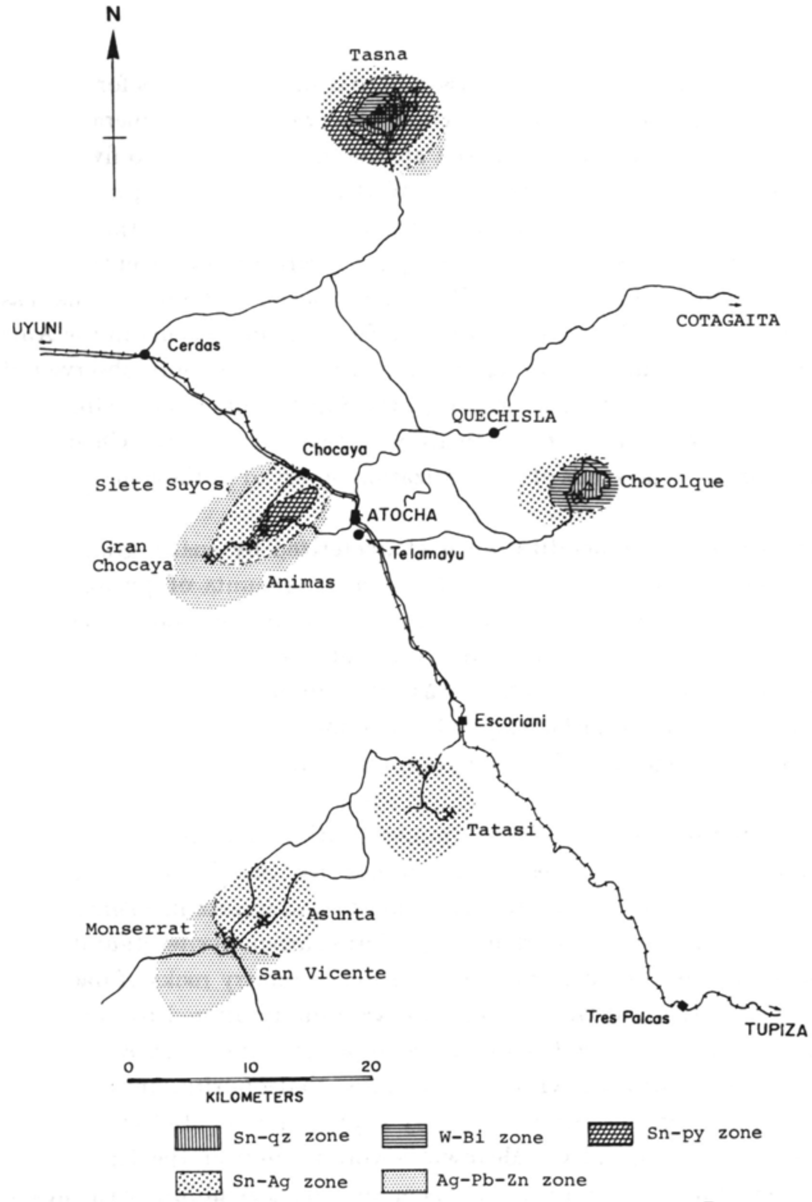

FIGURE 60. MINERAL ZONINGS FOUND IN THE MINES OF THE QUECHISLA DISTRICT.

associating with small amounts of stannite, arsenopyrite and sphalerite, and usually shows crustified banding structure. Cassiterite is always found as a fine grained essential mineral with quartz and pyrite.

The Sn-Ag mineralization mainly appears in the veins of the Siete Suyos, Animas, Tatasi and Asunta mines. From the veins, many ore minerals of tin bearing sulfide minerals such as stannite, hocartite, kesterite, canfieldite and franckeite, and silver bearing sulfosalt minerals such as stephanite, pyrargyrite, miargyrite, polybasite, andorite, fizelyite, diaphorite, aramayoite and tetrahedrite, and Pb-Sb sulfosalt minerals such as bournonite, jamesonite and boulangerite occur in association with pyrite, sphalerite, galena, arsenopyrite, marcasite, wurtzite, chalcopyrite and quartz etc. Besides tin bearing sulfides as above, cassiterite also occurs as fine grained crystals, less than 30 μm in size, included in pyrite, stannite and quartz. Small amounts of wolframite associating with pyrite stannite and quartz appear occasionally. Gangue minerals such as siderite, calcite, aragonite, smithsonite, gypsum, gibbsite, apatite, vivianite, sericite and kaolinite occur in the central part of the veins as final products of the mineralization.

The Ag-Pb-Zn mineralization is found mainly in the veins of the Gran Chocaya and San Vicente mines, and partly in a few veins of the Tasna mine, crystallizing sphalerite, galena, pyrite, chalcopyrite, tetrahedrite and silver sulfosalt minerals such as stephanite, pyrargyrite, miargyrite and polybasite. At the San Vicente mine, tetrahedrite is a principal silver mineral, meanwhile at the Gran Chocaya mine, silver sulfosalts are common. Tin bearing minerals such as stannite, franckeite and cassiterite are not found.

By such mineralizations as mentioned above, zonal arrangements of ore and gangue minerals are recognized at each mine as seen in Figure 60. At the Chorolque mine, cassiterite-tourmaline-quartz veins formed by the Sn-qz mineralization, wolframite and bismuthinite bearing sulfide vein produced by the W-Bi mineralization, and silver bearing sulfide veins formed by the Sn-Ag mineralization are arranged zonally from the center of Mt. Chorolque toward the outside of

TABLE 13. RANGES OF HOMOGENIZATION TEMPERATURES AND SALINITIES (NaCl EQUIVALENT CONCENTRATION) OF FLUID INCLUSIONS IN QUARTZ and BARITE FORMED BY DIFFERENT KINDS OF MINERALIZATIONS IN THE MINES OF THE QUECHISLA DISTRICT.

Mine	Mineralization type	Mineral	Homogenization temp. (°C)	Salinity (NaCl eq. wt%)
Tasna	W-Bi	Quartz	250 ∿ 499	24.6 ∿ 50.4
	Sn-Ag	Quartz	213 ∿ 422	9.9 ∿ 20.2
	Ag-Pb-Zn	Quartz	202 ∿ 328	7.4 ∿ 8.6
Chorolque	Sn-qz	Quartz	261 ∿ 500	24.9 ∿ 53.2
	W-Bi	Quartz	268 ∿ 493	33.2 ∿ 48.2
Siete Suyos	Sn-Ag	Quartz	178 ∿ 251	3.8 ∿ 4.1
Animas	Sn-py	Quartz	228 ∿ 379	4.6 ∿ 11.9
	Sn-Ag	Quartz	210 ∿ 277	3.9 ∿ 4.9
Gran Chocaya	Ag-Pb-Zn	Quartz	176 ∿ 268	4.6 ∿ 5.2
Tatasi	Sn-py	Quartz	232 ∿ 345	1.5 ∿ 8.9
	Sn-Ag	Quartz	180 ∿ 299	8.2 ∿ 10.6
Asunta	Sn-Ag	Barite	205 ∿ 385	0.4 ∿ 5.2
Monserrat	Sn-Ag	Quartz	184 ∿ 342	2.2 ∿ 7.7
San Vicente	Ag-Pb-Zn	Barite	172 ∿ 359	1.5 ∿ 8.9

TABLE 14. SULFUR ISOTOPE DATA OF PYRITE, GALENA AND SPHALERITE FROM THE MINES IN THE QUECHISLA DISTRICT.

Mine	Mineralization type	Mineral	$\delta^{34}S$
Tasna	W-Bi	Pyrite	-4.1 ∿ -2.9
Chorolque	Sn-qz	Pyrite	-2.1 ∿ -1.6
Siete Suyos	Sn-Ag	Pyrite	-0.4 ∿ +3.5
		Sphalerite	-4.7 ∿ +1.4
		Galena	-0.8 ∿ 0.0
Animas	Sn-Ag	Pyrite	+2.6 ∿ +6.4
		Galena	+0.4 ∿ +3.1
Gran Chocaya	Ag-Pb-Zn	Pyrite	+2.5
		Sphalerite	+0.4 ∿ +1.4
		Galena	-6.2 ∿ -1.8
Tatasi	Sn-Ag	Sphalerite	-3.2 ∿ +2.0
		Galena	-3.3 ∿ +0.5
San Vicente	Ag-Pb-Zn	Sphalerite	-4.1 ∿ +0.9
		Galena	-2.6 ∿ -0.6

the mine as shown in Figure 60. At the Siete Suyos, Animas and Gran Chocaya mining area, cassiterite-pyrite-quartz veins formed by the Sn-py mineralization, sulfide veins consisting of pyrite, galena, sphalerite, stannite, franckeite, quartz and silver sulfosalts produced by the Sn-Ag mineralization, and veins composed of galena, sphalerite, quartz, silver sulfosalts and lead-antimony sulfosalts crystallized by the Ag-Pb-Zn mineralization distribute as zonal arrangement as shown in Figure 60, from the Colorada vein of the Siete Suyos mine as a mineralization center toward the veins of the Gran Chocaya mine of the outside via the veins of the Animas mine. Such zonal arrangement is also recognized at the Tatasi, Asunta and San Vicente mining areas. That is, the Sn-Ag mineralization is mainly found in the Tatasi, Asunta and Monserrat mines, and cassiterite, stannite, hocartite and franckeite etc. as tin bearing minerals and sulfosalts of andorite, ramdohrite, fizelyite, diaphorite, pyrargyrite, stephanite, tetrahedrite and argyrodite etc. as silver minerals occur in association with galena, sphalerite, pyrite and quartz. Meanwhile, most of the veins in the San Vicente mine are formed by the Ag-Pb-Zn mineralization, and are composed of galena, sphalerite, tetrahedrite, chalcopyrite, pyrite, wurtzite and barite. No tin bearing minerals such as cassiterite, stannite or franckeite are found, and tetrahedrite is only a silver bearing mineral in the mine.

As mentioned before, it is noticeable that high temperature minerals such as cassiterite, wolframite, tourmaline and pyrrhotite coexist with low temperature minerals such as silver bearing sulfosalts, lead-antimony sulfosalts, wurtzite, marcasite, alunite, natroalunite, minamiite, kaolinite, sericite and siderite in the same vein. These facts suggest that the ore deposits in the Quechisla district were formed under the xenothermal condition similar to the polymetallic deposits in the Oruro and Potosi districts (Sugaki *et al.*, 1981a, b, 1983a, b).

To obtain the data on the formation condition of the veins formed by such mineralizations as mentioned above, homogenization temperature of fluid inclusions in quartz, sphalerite and barite was measured by using the heating stage. Also the salinity in NaCl equivalent concentration of same inclusions was obtained from the freezing temperature for two phase inclusions of gas and liquid, or disappearing temperature of solid phase for polyphase inclusions of some solids, gas and liquid. The data of homogenization temperature and salinity for fluid inclusion in quartz and barite formed by each mineralization observed in the mines of the district are listed in Table 13. It shows a fact that homogenization temperature and salinity of inclusions in quartz from the Sn-qz mineralization found in the Chorolque mine are 261° to 500°C and 24.9 to 53.2 wt%, respectively, which are higher than those of other mineralizations and about same range as those of the porphyry copper deposits as described by Nash (1976). Both the values of homogenization temperature and salinity of fluid inclusion in quartz formed by the W-Bi mineralization in the Tasna and Chorolque mines are 250° to 499°C and 24.6 to 50.4 wt%, and 268° to 493°C and 33.2 to 48.2 wt%, respectively which are more or less lower values than those of the Sn-qz mineralization. Meanwhile the homogenization temperature and salinity of liquid inclusions in quartz and sphalerite crystallized by the Ag-Sn mineralization found in the Siete Suyos, Animas, Tatasi, Asunta and Monserrat mines are 178° to 385°C and 0.4 to 10.6 wt%. Both the values are lower than those formed by the Sn-qz and W-Bi mineralizations. The homogenization temperature and salinity of the inclusions in quartz and barite produced by the Ag-Pb-Zn mineralization are 172° to 359°C and 1.5 to 8.9 wt%, and slightly lower than those of quartz crystallized by the Sn-Ag mineralization. As mentioned above, there is a tendency that these values decrease in order from the Sn-qz to Ag-Pb-Zn mineralizations via the Sn-py and Sn-Ag mineralizations in the district.

Some sulfur isotope date have been obtained about pyrite, sphalerite, galena and wurtzite from all of the mines in the district as given in Table 14. The values of $\delta^{34}S$ for pyrite from the Chorolque and Tasna mines corresponding to the Sn-qz and the W-Bi mineralizations, are from -4.1 to -2.9 ‰ and -2.1 to -1.6 ‰, respectively. All the $\delta^{34}S$ values show the negative values. The value of $\delta^{34}S$ for pyrite, sphalerite and galena crystallized by the Sn-Ag mineralization in the Siete Suyos, Animas and Tatasi mines are -4.7 to $+3.5$‰, $+0.4$ to $+6.4$‰ and -3.3 to $+2.0$‰, respectively. These values are slightly higher than those for pyrite from the Tasna and Chorolque mines. The $\delta^{34}S$ values for sphalerite, galena or pyrite from the veins of the Gran Chocaya and San Vicente mines formed by the Ag-Pb-Zn mineralization are -6.2 to $+2.5$‰ and -4.1 to $+0.9$‰, respectively.

The $\delta^{34}S$ values for pyrite formed by the Sn-qz and W-Bi mineralizations in the Chorolque and Tasna mines are principally negative. Meanwhile those for pyrite crystallized by the Sn-Ag or Ag-Pb-Zn mineralizations in the Siete Suyos and Animas or Gran Chocaya mines show positive values in general. From these facts and the data on salinity of fluid inclusions in quartz, it has been clarified that the $\delta^{34}S$ values for pyrite associated with quartz having high salinity inclusions (24.6 to 53.3 wt%) are negative and that on the other hand those for pyrite assembled with quartz having low salinity inclusions (0.4 to 10.6 wt%) show positive generally.

SUMMARY

1. Geology of the Quechisla district investigated consists of the Ordovician, Cretaceous and Tertiary systems, and intrusive rocks such as dyke and stock of quartz porphyry and dacite. The Ordovician system is mostly composed of alternation of slate and sandstone, but quartzite appears locally with slate instead of sandstone of the alternation. Its thickness is over 2,000 m. The Ordovician system is distinctly folded to repeat anticline and syncline structures with axes of the NW-SE direction. It also is frequently cut by many faults among which principal ones are parallel to the folding axes, but some faults and fissures cutting folding axes at right angle are important as fracture system of the ore veins.

The Cretaceous system mainly consists of alternation of dark red mudstone and brownish red sandstone with conglomerate as a basal sediment on the Ordovician rocks.

The Tertiary system in the district is composed of the San Vicente Formation, Quehua Formation and volcanic complex in ascending order. The first mostly consists of reddish colored conglomerate. The ore veins of the San Vicente mine occur in the formation. Meanwhile the Quehua Formation is composed of white fine tuff, dacitic tuff breccia and alternation of coarse grained dacitic tuff and massive tuff or tuff breccia. The volcanic complex consists mostly of dacitic tuff breccia, massive tuff and dacite lava, and becomes to country rocks of the veins in the Siete Suyos, Animas, Gran Chocaya and Tatasi mines etc. It often suffers hydrothermal alterations such as tourmalinization, silicification and sericitization.

2. Stocks and dykes of quartz porphyry and dacite occur often in the district, but in small scale except the Chorolque stock. Quartz porphyry intrudes into Ordovician slate and sandstone at Mt. Tasna as stock and dyke. It in general is hydrothermally altered by sericitization, silicification and tourmalinization. Meanwhile dacite stock intrudes into Ordovician rocks and Tertiary volcanic complex in the Chorolque mining area. It forms a central body of Mt. Chorolque, and distinctly suffers hydrothermal alterations of silicification, tourmalinization and sericitization. A lot of the ore veins in the Chorolque mine occur in the stock. Also dacite dyke, 10 m wide, intrudes into conglomerate of the San Vicente Formation at the San Vicente mine. The ore vein of this mine occurs along the boundary between the dyke and conglomerate, and sometimes invades to inside of the dyke. The ore deposits in the district are considered to have

intimate relationship with such igneous activities as quartz porphyry and dacite stocks.

3. The K-Ar ages of biotite from rhyodacite and dacitic tuff of the Quehua Formation are 16.8 to 17.1 Ma and 17.0 to 22.9 Ma, respectively. Also those for biotite, whole rocks and altered whole rocks of the volcanic complex are 13.4 to 16.6 Ma, 11.2 to 22.8 Ma and 12.5 to 18.4 Ma, respectively. The K-Ar ages for biotite from dacite dyke of the San Vicente mine is 13.4 to 18.5 Ma, meanwhile that for its whole rock is 18.5 Ma.

4. In the district, there are many metallic mines such as Tasna (tungsten and tin), Chorolque (tin and tungsten), Siete Suyos (tin, silver, lead and zinc), Animas (tin, silver, lead and zinc), Gran Chocaya (silver, lead and zinc), Tatasi (tin, silver, lead and zinc) and San Vicente (silver, lead and zinc) all of which belong to COMIBOL and are now working. The ore deposits of them are of fissure filling type formed by polymetallic mineralizations and as the result, a lot of minerals as given in Table 8 occur from the mines. That is, ore minerals such as cassiterite, wolframite, stannite, pyrite, sphalerite, galena, chalcopyrite, pyrrhotite, bismuthinite, wurtzite, marcasite, hocartite, franckeite, canfieldite, jamesonite, bournonite, boulangerite, stephanite, pyrargyrite, miargyrite and aramayoite, with gangue minerals such as quartz, tourmaline, apatite, alunite, jarosite, natroalunite, variscite, strengite, sericite, kaolinite and siderite are found from the mines. High temperature minerals such as cassiterite, tourmaline, wolframite, arsenopyrite and pyrrhotite coexist with low temperature minerals such as marcasite, wurtzite, some silver sulfosalts, alunite, siderite and jarosite within the limited zone. On the other hand, the distinct mineral zoning around igneous body, telescoped ores and polymetallic crystallization are recognized in the district. These facts suggest that the ore deposits in the Quechisla district really belong to typical xenothermal type.

5. The ore deposits of the Tasna mine consist of hydrothermal veins filling up many fissures in Ordovician slate and sandstone. These veins commonly have 0.1 to 0.5 m in width. Ordovician rocks are affected by hydrothermal alterations of tourmalinization, silicification and sericitization. Around Mt. Tasna, network or veinlets composed of diaspore, dumortierite and corundum are formed. Ore minerals such as wolframite, cassiterite, arsenopyrite, pyrite, chalcopyrite, bismuthinite, sphalerite and marcasite, and small amounts of wurtzite, stannite, jamesonite, galena, cosalite, gustavite, native bismuth, franckeite and boulangerite occur in association with tourmaline, quartz, kaolinite, sericite, gibbsite, siderite, barite, apatite, scorodite, jarosite, natroalunite, monazite, wavellite and crandallite. Among them principal minerals are wolframite, pyrite, cassiterite, arsenopyrite, bismuthinite and chalcopyrite. Wolframite usually shows idiomorphic crystals, 1 to 3 cm, sometimes up to 5 cm in size associating with arsenopyrite, bismuthinite, pyrite, chalcopyrite, tourmaline and quartz. Mineralizations found in the Tasna mine are divided into five types, that is tungsten-bismuth, tin-quartz,

tin-pyrite, tin-silver and silver-lead-zinc mineralizations. Zonal arrangement of minerals formed by these mineralizations is found from Mt. Tasna as central zone toward its outer side.

6. Ore veins in the Chorolque mine mainly develop in the dacite stock, but some of them occur in Miocene dacitic volcanic complex and Ordovician slate and sandstone. Dacite intrusive is distinctly suffered by hydrothermal alterations such as tourmalinization, silicification and sericitization. Mineralizations of the mine are mainly divided into three types of tin-quartz, tungsten-bismuth and tin-silver mineralizations. The tin-quartz mineralization is found in dacite intrusive, and cassiterite, quartz and small amounts of wolframite, pyrite, arsenopyrite, stannite occur by it. Sulfate minerals such as jarosite, alunite, natroalunite, minamiite, variscite and strengite are also found in the central part of the veins, filling up in their vug. Ore veins formed by the tungsten-bismuth mineralization in the Ordovician rocks and Miocene volcanic complex are composed of arsenopyrite, pyrite, pyrrhotite, bismuthinite, wolframite, chalcopyrite, sphalerite, stannite and marcasite accompanied with small amounts of cassiterite, electrum, tetradymite and hessite. The tin-silver mineralization found in the veins in the Ordovician rocks and Miocene volcanic complex crystallizes galena, chalcopyrite, bismuthinite, sphalerite, and small amounts of stannite. As a silver bearing mineral, tetrahedrite appears in association with chalcopyrite and galena. Ore veins formed by the mineralization mentioned above are arranged zonally from the central tin-quartz zone in dacite stock to the tin-silver zone via the tungsten-bismuth zone.

7. The ore veins of the Siete Suyos mine working about two kinds of tin-silver and silver-lead-zinc ores occur in Ordovician slate and sandstone mainly, and dacite and its tuff breccia partly. They are usually divided into two types, cassiterite-quartz-pyrite veins of the tin-pyrite zone such as Colorada, Inca 1 and Nueva, and sulfide veins of the tin-silver zone such as Esperanza, Salvadora, Arturo and Diez. The sulfide veins consist principally of pyrite, sphalerite, stannite and galena with small amounts of marcasite, arsenopyrite, chalcopyrite, wurtzite, tetrahedrite, franckeite, hocartite, boulangerite, jamesonite, quartz, kaolinite, gibbsite and siderite. They show distinctly crustified banding and often have durse in the central portion of the vein. As tin minerals, cassiterite from the quartz-pyrite vein of the tin-pyrite zone, and stannite, franckeite and hocartite from the sulfide veins of the tin-silver zone are recognized. Cassiterite appears as band, 1 to 2 mm wide in the quartz-pyrite vein. Meanwhile, stannite occurs in intimate association with pyrite, sphalerite, galena, cassiterite, franckeite and quartz. Franckeite usually appears as aggregate of platy crystals assembled with pyrite, sphalerite, galena, stannite and hocartite in the central part of the veins. Hocartite is only found microscopically and accompanied by franckeite and stannite.

8. The ore veins of the Animas mines belong to the sulfide type formed by the tin-silver mineralization except the Colorada vein of the cassiterite-quartz-pyrite type by the tin-pyrite mineralization. They develop mostly in Ordovician slate and sandstone as well as these of the Siete Suyos mine, but partly occur in Miocene pyroclastics. The sulfide veins such as San Juan, Rosario, Rafael, Animas, Burton, Inca 6 and Dejada generally consist of pyrite, sphalerite, wurtzite, galena, arsenopyrite, marcasite stannite, franckeite and quartz associated with small amounts of tetrahedrite, chalcopyrite, bismuthinite, cassiterite, hocartite, andorite, pyrargyrite, miargyrite, polybasite, aramayoite, bournonite, jamesonite, boulangerite, wolframite, siderite, aragonite, smithsonite, gypsum, vivianite, sericite, gibbsite and kaolinite etc. They also show distinctly crustified banding structure of sphalerite, galena and pyrite etc. Stannite appears as band, 1 to 5 mm wide, near the central part of the vein and microscopically associates with cassiterite and chalcopyrite. Silver bearing sulfosalt and lead-antimony sulfosalt minerals crystallize in the druse or vug of the veins in closely association with each other. Gibbsite, kaolinite and sericite fill up the fissure or vug of the central part of the veins.

9. The veins which correspond to the southwest extension of the veins in the Animas mine are now mined at the Gran Chocaya mine located at 2.5 km southwest of the Animas mine. They occur in Ordovician slate and Miocene dacitic pyroclastics. Principal veins such as Nueva, San Bartolome, Candelaria and Inocentes belong to the zone of the silver-lead-zinc mineralization, and have general strikes parallel to the direction of the veins in the Animas mine. The ores from this mine are principally composed of sphalerite, galena, wurtzite and quartz in assemblage with some amounts of marcasite, arsenopyrite, jamesonite, silver bearing minerals, siderite, calcite and apatite. The silver minerals from the mine are mainly silver-antimony sulfosalts such as pyrargyrite, miargyrite, polybasite and stephanite, and occur as durse minerals in association with galena, sphalerite and pyrite. Tin bearing minerals such as stannite, franckeite and hocartite are found only at limited northeast part of the Nueva vein near the boundary with the Animas mine, but cassiterite does not appear from the veins of the mine.

10. The ore veins of the Tatasi mine occur in Miocene dacite or dacitic tuff. These veins, commonly 10 to 100 cm in width, consist of pyrite, sphalerite, galena, wurtzite, marcasite, franckeite, jamesonite and small amounts of pyrrhotite, arsenopyrite, cassiterite, stannite, kesterite, chalcopyrite, tetrahedrite, hocartite, argyrodite, semseyite, pyrargyrite, stephanite, diaphorite, fizelyite, dyscrasite, native antimony and stibnite. Quartz, siderite, kaolinite, gypsum and aragonite are also formed as gangue minerals. The veins are divided into three types of pyrite, sphalerite-galena and sulfosalt veins according to its constituent minerals. Pyrite vein of the Cochinoca vein has a rather simple mineral assemblage with small amounts of pyrrhotite, arsenopyrite and cassiterite. Sphalerite-galena vein

is composed of sphalerite, galena, stannite, kesterite, chalcopyrite, tetrahedrite, franckeite, hocartite, wurtzite and marcasite etc. Sulfosalt vein consists of galena, franckeite, tetrahedrite, wurtzite, marcasite, jamesonite, semseyite, stibnite, native antimony and silver minerals such as pyrargyrite, stephanite, diaphorite, fizelyite and dyscrasite. The pyrite vein was formed at the early stage of the mineralization, and sphalerite-galena vein was produced at the middle stage of the mineralization. The late stage of the mineralization is characterized by the crystallization of sulfosalt minerals. Quartz occurs as a dominant gangue mineral from the early to late stages of the mineralization. While siderite, kaolinite, gypsum and aragonite were formed in the latest stage of the mineralization.

11. The ore deposits of the San Vicente mine are composed of veins which fill up fissures developed in conglomerate of the San Vicente Formation. The ore veins consist of pyrite, galena, sphalerite, wurtzite, tetrahedrite, chalcopyrite, marcasite, pyrrhotite, kesterite, luzonite, pyrargyrite, aikinite, bournonite and roquesite as ore minerals, and quartz, barite and siderite as gangue minerals. Ore minerals generally appear as veinlet or network, and dissemination in the vein. Matrix of the conglomerate is often replaced by ore minerals. Pyrite, sphalerite and quartz are formed at early stage of the mineralization. Sphalerite is crystallized at the middle stage of the mineralization associating with galena and shows crustified banding and sometimes forms oolitic or colloform structures, and usually accompanies by needle shaped wurtzite in it. Galena and tetrahedrite which is a principal silver mineral from the mine were produced at slightly later stage than that of sphalerite. Large amounts of barite also occur in the late stage of the mineralization. Tin minerals are not found in the ores from the San Vicente mine. But, the Monserrat mine, barnch of the San Vicente mine, which is situated at about 4 km north of it, produces ores consisting of pyrite, stannite, cassiterite, sphalerite, tetrahedrite, and small amounts of marcasite, chalcopyrite, franckeite and electrum.

12. From the data of the occurrence, mineral assemblage and paragenesis for ore and gangue minerals obtained by macroscopic and microscopic observations, the mineralizations recognized in the mines of the Quechisla district are classified into five types as follows: tin-quartz (cassiterite, quartz and tourmaline), tungsten-bismuth (wolframite, bismuthinite and quartz), tin-pyrite (cassiterite, pyrite and quartz), tin-silver (stannite, silver bearing sulfosalts, galena and sphalerite) and silver-lead-zinc (silver sulfosalts, galena and sphalerite) mineralizations in order from early to late stages. Among them, the tin-quartz mineralization is found as most principal one in the Chorolque mine. The tungsten-bismuth mineralization appears mainly in the veins of the Rosario section of the Tasna mine, and partly in the veins of the Chorolque mine. Both the tin-pyrite and tin-silver mineralizations are recognized in the Siete Suyos and Animas mines, and while in the Gran Chocaya mine the silver-lead-zinc mineralization is

principal. The ore deposits of the Tatasi, Asunta and Monserrat mines are mainly formed by the tin-silver mineralization. The ore veins of the San Vicente mine are principally prdouced by the silver-lead-zinc mineralization. By such minerulizations as described above, there is formed zonal arrangement of minerals as seen in the Chorolque area ; Tasna area ; Siete Suyos, Animas and Gran Chocaya mining area ; and Tatasi, Asunta and San Vicente mining area.

13. The homogenization temperatures and salinities in NaCl equivalent concentration of fluid inclusions in quartz, sphalerite and barite crystallized by the tin-quartz, tungsten-bismuth, tin-pyrite, tin-silver and silver-lead-zinc mineralizations were measured. The values for the tin-quartz and tungsten-bismuth mineralizations are 261° to 500°C and 24.9 to 53.2 wt% and 250° to 499° C and 24.6 to 50.4 wt%, respectively. Those for the tin-pyrite mineralization are 232° to 379°C and 1.5 to 11.9 wt%. The values for the tin-silver and silver-lead-zinc mineralizations are 184° to 342°C and 0.4 to 10.6 wt%, and 172° to 359°C and 1.5 to 8.9 wt%, respectively.

14. Some sulfur isotope values $\delta^{34}S$ obtained for common sulfide minerals such as pyrite, sphalerite and galena from the mines in the Quechisla district are from -4.1 to $-2.9‰$ for pyrite formed by the tungsten-bismuth mineralization, from -2.1 to $-1.6‰$ for pyrite produced by the tin-quartz mineralization, from -4.7 to $+3.5‰$ for pyrite, galena and sphalerite crystallized by the tin-silver mineralization and from -4.1 to $+0.9‰$ for pyrite, galena and sphalerite formed by the silver-lead-zinc mineralization.

ACKNOWLEDGEMENTS

The financial support of the Grant-in-Aid for Overseas Scientific Survey by the Ministry of Education, Science and Culture, Japan for our field and laboratory studies is sincerely acknowledged by authors.

We are very grateful to the staff of Facultad de Ciencias Puras y Naturales, Universidad Mayor de San Andres at La Paz, Bolivia for their kind cooperations and valuable discussions. We are also indebted to Ing. Ivan Pedrazas of COMIBOL, La Paz for his favorable consideration to visit the mines of COMIBOL, and to Ings. Julio Frentes, Antonio Cortes, Roberto Merida and Manuel Arandia of the Quechisla organization office of COMIBOL, and also Ing. Jorge Claros of the Oruro division of COMIBOL. We would like to express thanks to geologists of the Tasna, Siete Suyos, Animas, Chorolque, Tatasi and San Vicente mines for their kind guidance and useful advise during our field survey, and to Messrs. Hiroji Kuronuma and Toshiya Itoh of Dowa Engineering Co. for their useful suggestions and informations on our filed survey. We want to express heartily our appreciation to Mr. Tooru Yoshimizu, the ambassador and his staff of Japanese Embassy in Bolivia and the staff of the La Paz office of Japan International Cooperation Agency (JICA) for the kindness and sincerity to support our study.

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