

THESIS

**GEOLOGY, HYDROTHERMAL ALTERATION, PARAGENETIC SEQUENCE
AND FLUID INCLUSION ANALYSIS OF LA MARUJA LEVEL, MARMATO
DISTRICT, CALDAS DEPARTMENT, COLOMBIA.**

Submitted by

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In Partial fulfillment of the requirements

for the Degree of Master of Science

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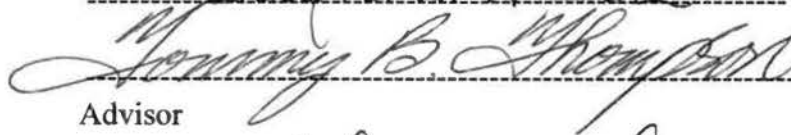
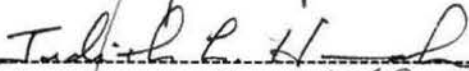
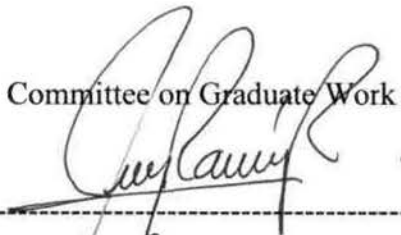
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY OSCAR GEOVANY BEDOYA SANMIGUEL ENTITLED "GEOLOGY, HYDROTHERMAL ALTERATION, PARAGENETIC SEQUENCE AND FLUID INCLUSION ANALYSIS OF LA MARUJA LEVEL, MARMATO DISTRICT, CALDAS DEPARTMENT, COLOMBIA" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

GEOLOGY, HYDROTHERMAL ALTERATION, PARAGENETIC SEQUENCE AND FLUID INCLUSION ANALYSIS OF LA MARUJA LEVEL, MARMATO DISTRICT, CALDAS DEPARTMENT, COLOMBIA

The Marmato goldfield is located in the Department of Caldas in the western Cordillera of Colombia. The area is topographically characterized by steep hills of abrupt relief. Rocks that range in age from the Cretaceous to the present appear in the area. Confined to the northeast of the area, the oldest units consist of sedimentary and volcanic rocks that have been metamorphosed to mid-amphibolite facies to amphibolites, hornblende schist and quartz-sericite schist. The metamorphic rocks form pendants within younger porphyry intrusions (Marmato Stock) and occur intermittently in a north-south belt along the Rio Cauca.

The ore host at La Maruja level consists of dacite porphyry. A Late Miocene age has been assigned for this unit. This body has been affected by a tectonic event and it exhibits faulting, shearing and joint features. Structure is the primary control of ore mineralization. The fault surfaces are usually curved or arched and have a predominantly northwestern orientation with high dip angle. Sin Nombre, Porvenir, Santa Ines and Mucura are the veins

at La Maruja level. The thickness of these veins can range from 0.30 to 2.5 m.

The ore minerals of La Maruja level listed according to their relative abundance are: pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, gold, galena, marcasite and polybasite. The gangue minerals present are calcite, chlorite and quartz. Deposition of ore and gangue minerals in this level occurs in three stages. The early stage is characterized by abundant deposition of coarse euhedral pyrite crystals. The intermediate stage is characterized by abundant deposition of sphalerite and minor amounts of chalcopyrite and gold. A tectonic event occurred at the end of this stage. The late stage is a short period of fine-grained pyrite deposition which ended with great amounts of calcite and chlorite deposition.

Silicic, sericitic, propylitic and albitic hydrothermal alteration assemblages occur at La Maruja level. Fluid inclusion homogenization temperatures, assumed to represent minimum ore fluid temperatures, range between 250°C and 350°C with mean values of about 310°C for Sin Nombre vein and 330°C for other veins; no evidence for boiling is present. The ore fluid salinity ranges from 3.7 to 10.3 equiv. wt% NaCl. Characteristics of the hydrothermal fluid in this level are: a relatively high temperature, moderate salinity and high in reduced sulfur.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
PURPOSE OF STUDY	1
LOCATION, ACCESSIBILITY AND CLIMATE	3
PREVIOUS INVESTIGATIONS	3
METHOD OF INVESTIGATION	7
REGIONAL GEOLOGY	8
AMPHIBOLITE	8
SCHISTS	9
ULTRAMAFIC ROCK	11
GABBRO	12
BASALT	12
TERTIARY SEDIMENTARY ROCKS	13
HYPABYSSAL PORPHYRY ROCKS	13
RECENT DEPOSITS	14
LOCAL GEOLOGY	15
LITHOLOGY	15
STRUCTURAL FEATURES	17
FAULTS AND SHEAR ZONES	18
JOINTS	29
MINERALIZATION PROCESSES	33
VEINS	33
SPATIAL RELATIONSHIPS BETWEEN VEINS	37
MINERALIZATION OF ORE BODIES	38
PYRITE	38
PYRRHOTITE	42

	Page
ARSENOPYRITE	47
CHALCOPYRITE	54
GOLD	54
SPHALERITE	59
GALENA	62
POLYBASITE	62
MARCASITE	67
CALCITE	67
QUARTZ	70
CHLORITE	70
PARAGENETIC SEQUENCE	73
HYDROTHERMAL ALTERATION	76
SILICIC ALTERATION	77
STRONG SERICITIC ALTERATION	78
SERICITE-QUARTZ association	81
SERICITE association	91
SERICITE-CARBONATE association	97
MODERATE SERICITIC ALTERATION	105
SERICITE association	108
SERICITE-CARBONATE association	112
SERICITE-carbonate association	116
WEAK SERICITE ALTERATION	118
SERICITE association	118
SERICITE-CARBONATE association	119
PROPYLITIC ALTERATION	122
CHLORITE-CALCITE association	122
EPIDOTE-CHLORITE association	124
EPIDOTE-($\pm$ CHLORITE-CALCITE) association	129
ALBITIC ALTERATION	130
SUMMARY	130
FLUID INCLUSION	136
INTRODUCTION	136
ORE FLUID TEMPERATURE	147
ORE FLUID SALINITY	147
THE HYDROTHERMAL FLUID AT LA MARUJA LEVEL	150

	Page
CONCLUSION	153
RECOMMENDATION	157
REFERENCES CITED	158

LIST OF TABLES

	Page
Table 3.1 Mineralized joints at La Maruja level	130
Table 6.1 Fluid inclusion data	137

LIST OF FIGURES

		Page
Figure 1.1	Location map of Marmato gold field and La Maruja level	2
Figure 2.1	Regional geology surrounding the Marmato area	9
Figure 3.1	Photomicrograph showing zone of high shear	20
Figure 3.2	Photomicrograph showing zone of intense shear and development of secondary quartz	22
Figure 3.3	Photomicrograph showing folded biotite	22
Figure 3.4	Photomicrograph showing right lateral microfaulting of quartz crystals	24
Figure 3.5	Photomicrograph showing high degree of deformation	26
Figure 3.6	Plot of poles to joints in La Maruja level. Schmidt Stereonet	32
Figure 4.1	Generalized paragenetic diagram for La Maruja level	39
Figure 4.2	Photomicrograph showing fractured early pyrite crystals	40
Figure 4.3	Photomicrograph showing tabular late pyrite crystals in a tabular texture inherited from precursor marcasite	43
Figure 4.4	Photomicrograph showing fine-grained late pyrite crystals with colloform texture	43
Figure 4.5	Photomicrograph showing late pyrite associated with calcite and chlorite filling the interstitial spaces of early pyrite	45
Figure 4.6	Photomicrograph sample showing medium to coarse-grained early pyrite replacing pyrrhotite crystals	48
Figure 4.7	Photomicrograph showing pyrrhotite crystals 90% replaced by early pyrite	48

	Page
Figure 4.8 Photomicrograph showing euhedral rhombic arsenopyrite crystals in sphalerite	50
Figure 4.9 Photomicrograph showing arsenopyrite with atoll texture in sphalerite	50
Figure 4.10 Photomicrograph showing arsenopyrite crystals growing within calcite	52
Figure 4.11 Photomicrograph showing chalcopyrite between early pyrite and arsenopyrite crystals	55
Figure 4.12 Photomicrograph showing a globular chalcopyrite crystals within sphalerite as “chalcopyrite disease.”	55
Figure 4.13 Photomicrograph showing chalcopyrite filling microfractures in sphalerite	57
Figure 4.14 Photomicrograph showing subhedral gold crystal within early pyrite	57
Figure 4.15 Photomicrograph showing gold crystal associated with calcite and chlorite filling open spaces in sphalerite	60
Figure 4.16 Photomicrograph showing calcite replaces galena along cleavage plane	63
Figure 4.17 Photomicrograph showing polybasite replacing early pyrite along cleavage plane	63
Figure 4.18 Photomicrograph showing polybasite filling intragranular spaces between early pyrite crystals	65
Figure 4.19 Photomicrograph showing marcasite development along cleavage plane of early pyrite	68
Figure 4.20 Photomicrograph showing fine-grained marcasite filling interstitial spaces between early pyrite	68

	Page
Figure 4.21	Photomicrograph showing late pyrite filling spaces between early to intermediated euhedral quartz crystals
	71
Figure 5.1	Photomicrograph showing subhedral secondary quartz in a reticulate texture within the matrix
	79
Figure 5.2	Photomicrograph showing quartz-sericite vein in silicified zone
	79
Figure 5.3	Photomicrograph showing sericite replacement of a plagioclase phenocryst in a random orientation
	83
Figure 5.4	Photomicrograph showing sericite associated with chlorite and pyrite developed in a biotite phenocryst along cleavage planes
	85
Figure 5.5	Photomicrograph showing sericite in the interstitial spaces between quartz grains, generating a crisscross quartz-sericite texture
	87
Figure 5.6	Photomicrograph showing sericite associated with chlorite in a nest texture within the matrix
	89
Figure 5.7	Photomicrograph showing a quartz-pyrite veinlet with a sericite selvage in the wallrock
	92
Figure 5.8	Photomicrograph showing more than 95% sericite replacing a plagioclase phenocryst
	95
Figure 5.9	Photomicrograph showing a veinlet of quartz-sphalerite-pyrite-chlorite
	98
Figure 5.10	Photomicrograph of sericite associated with chlorite, calcite and pyrite replacing a plagioclase phenocryst
	101
Figure 5.11	Photomicrograph showing mass of calcite associated with chlorite and replacing matrix
	103
Figure 5.12	Photomicrograph showing quartz-sericite-pyrite-calcite veinlet
	106
Figure 5.13	Photomicrograph showing sericite replacement of a plagioclase phenocryst
	110

	Page
Figure 5.14 Photomicrograph showing calcite associated with chlorite in ferromagnesian phenocrysts	114
Figure 5.15 Photomicrograph showing plagioclase phenocryst partially replaced by sericite	120
Figure 5.16 Photomicrograph showing strong epidotization in matrix and phenocrysts	125
Figure 5.17 Photomicrograph showing epidote and zoisite-clinozoisite and minor amounts of sericite in a nest texture within plagioclase phenocrysts	127
Figure 5.18 Photomicrograph showing unaltered euhedral albite crystals associated with pyrite in a vein	131
Figure 5.19 Photomicrograph showing albite associated with fine leaves of chlorite and pyrite replacing a phenocryst	133
Figure 6.1 Frequency distribution of fluid inclusion homogenization temperature, La Maruja level	144
Figure 6.2 Plot of homogenization temperatures and salinity of four vein at La Maruja level	145
Figure 6.3 Photomicrograph showing primary fluid inclusions in the early to intermediate quartz from Santa Ines vein	146
Figure 7.1 Idealized sketch of La Maruja level	152

LIST OF MAPS

Map 1 Structural features at La Maruja level.

Map 2 Hydrothermal alteration type.

INTRODUCTION

The Marmato goldfield, which is located in the Department of Caldas in the western Cordillera of Colombia, has been worked since pre-colonial time. Formerly mined on quite a large scale during the initial decades of this century, mining at Marmato is now confined to small operations. Gold grades range from 6 to 12 g/t; silver grades are generally substantially higher with Au:Ag ratios in the order of 1:5 to 1:10. Porphyry dacite and andesite are the ore host of the vein deposits at the Marmato district. The veins are controlled by high-angle faults and exhibit a range of mineralization over a vertical interval of 500 m. This study was done in a single level, La Maruja, which is 1.160 m above sea level and cuts the Sin Nombre, Porvenir, Santa Inès and Múcura veins.

PURPOSE OF STUDY

The main objectives of the present project are to determinate the type and extent of hydrothermal alteration, and to define the paragenesis of ore and gangue minerals along the Sin Nombre, Porvenir, Santa Inès and Múcura veins at La Maruja level. Also included is a study of fluid inclusions in gangue minerals from these mineralized structures. From these data some physical-chemical characteristics of the ore forming fluid of these veins may be ascertained.

LOCATION, ACCESSIBILITY AND CLIMATE

The Marmato gold field is located in the Western cordillera of Colombia (Fig. 1.1).

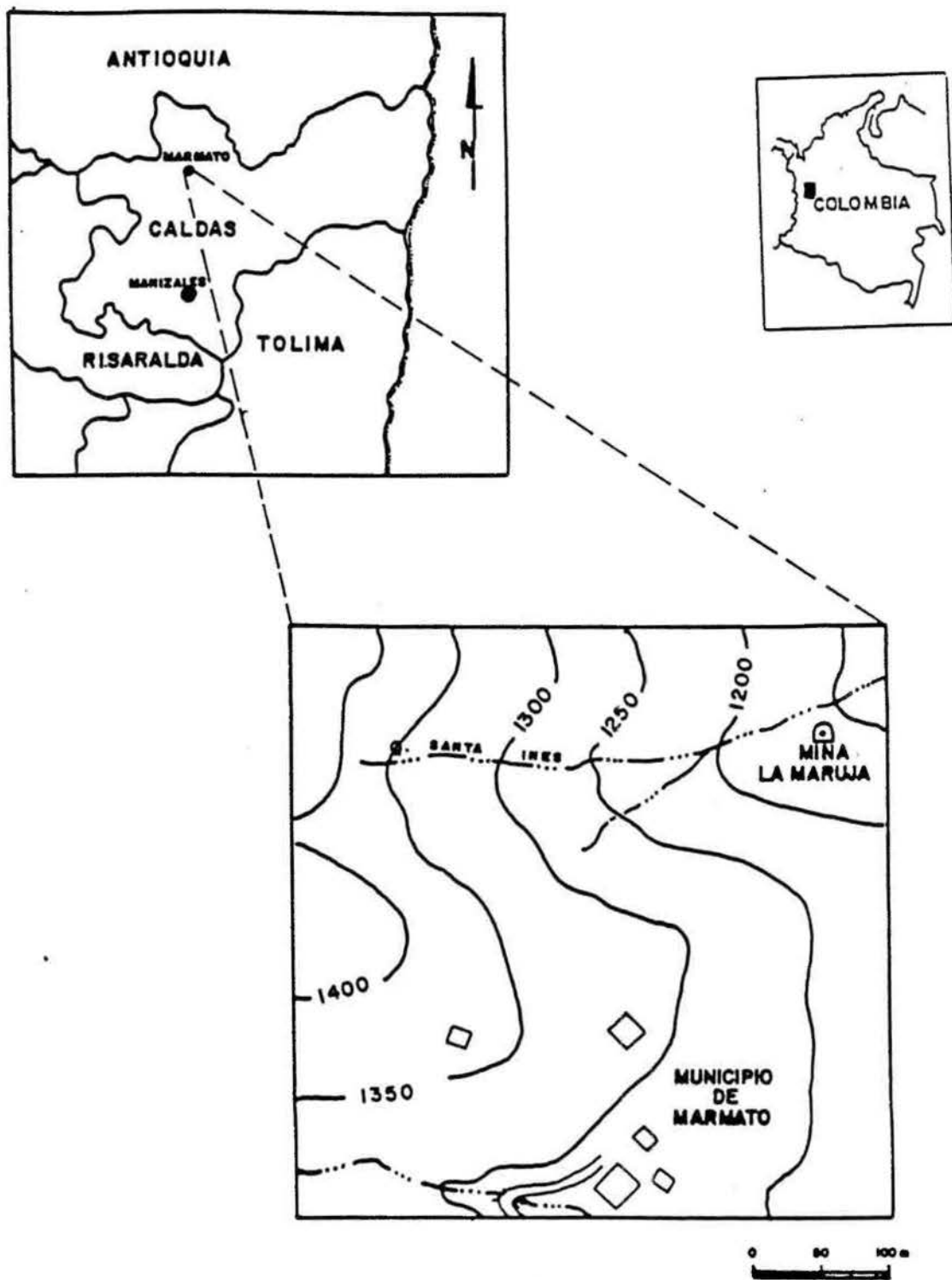


Figure 1.1 Location map of the Marmato gold field and La Maruja level.

110 km of paved road (Troncal Occidental) from Medellin city which in turn is connected by 7 km gravel road provide access to the Marmato town. The Marmato area is topographically characterized by steep hills of abrupt relief. Elevations in the district range from 600 m above sea level at the Cauca River to 1,650 m above sea level at El Burro Hill. In general, the district is sparsely vegetated with various range grasses and trees. Annual climatic variations in Colombia include two rainy and two dry periods. Relatively dry periods do not always occur during the same months but usually fall in November-January and May-June. The mean annual rainfall at the Marmato town is about 2,100 mm, and the average temperature is 20°C.

PREVIOUS INVESTIGATIONS

Lleras-Codazzi (1929), Scheibe (1933) and Jimenez-Jaramillo and Scheibe (1934) called “Corcovadita” the porphyry ore host at the Marmato area because the Marmato ore host was similar in composition and texture to the rocks present in the Corcovado hills, which are located northwestern of Marmato region. According to these authors, the “corcovadita” is composed of hornblende, plagioclase and minor amounts of quartz and biotite. Magnetite, apatite and sphene are accessories minerals. These authors also found some masses of granite bodies within the “corcovadita” rock.

Radelli (1962; 1965), Pagnacco and Radelli (1962) and Pagnacco (1962) describe the general mineralogic composition of the ore host in the Marmato mine which they classified as porphyry micro-diorite, formed during the Late Tertiary and composed of large zoned andesine crystals, prismatic hornblende, and minor amounts of quartz. The quartz is

bipyramidal and the amounts of it increase toward to the veins. Morer and Nicholls (1959), Hall et al.(1971), Alvarez and Arias (1970), and Cuellar and Mora (1985) classify the Marmato stock as a quartz-diorite porphyry, quartz-monzonite porphyry, diorite porphyry, and dacite porphyry, respectively.

Alvarez and Arias (1970) established the petrographic variation of the hypabyssal rock of the Marmato District, and they identified the dacite and andesite porphyry facies within the Marmato stock. According to these authors, the Marmato stock was formed from a diorite to quartz-diorite magma. Also, these authors describe the regional geology of Marmato and the surrounding area (e.g schists, mafic rocks, hypabyssal rocks, Tertiary sedimentary rocks and Recent deposits).

The reported K/Ar age date by Restrepo et al. (1981) for the Marmato stock is 6.3 ± 0.7 Ma. This age is different from other porphyry bodies which were assumed to have formed concomitantly. For example, MacDonald (1980) determined K/Ar age dates for the porphyry rock from the Corcovado hills of 8.0 ± 0.9 Ma; Jaramillo (1978) determined age dates by fission track in zircon for andesite porphyry from the “Corcovado” hill of 9.5 ± 0.9 Ma and 10.6 ± 1.2 Ma. In addition, a sample from the 6 km (Pintada Road) yielded a K/Ar age of 8.0 ± 0.4 Ma (Restrepo et al., 1981).

Hernandez and Molano (1989), Alvarez and Arias (1970), Mora and Cuellar (1982), Gomez-Villalba and Rodriguez-Gomez (1988), Cordova and Martinez-Silva (1989), Lopez-Rendon (1989), Navarro-Puentes (1989) described the regional structure features of Marmato and the surrounding area. According to Hernandez and Molano (1989), the Marmato area

is part of the Cauca-Romeral block whose borders are the Rio Arquia fault to the north, Rio Supia fault to the south, Romeral fault system to the east and the Marmato fault to the west. The other authors described the general NW orientation of the fault system and discuss the mean strike of the joints at the Marmato area.

According to Garces-Gonzalez (1940, 1975), Gonzalez (1980), Cuellar and Mora (1985) the mineralization of the Marmato district is dominated by pyrite, iron-rich sphalerite, chalcopyrite, minor amounts of galena, arsenopyrite, chalcopyrite, free gold and pyrrhotite. Quartz and calcite are present as gangue minerals. Gonzalez (1980) described all the above minerals and also found cinnabar at the Echandia level (400 m above La Maruja level). Other minerals that have been described at the Marmato district include mackinawite, cubanite II and melnicovite (Rubiano, 1986).

Different types of hydrothermal alterations have been described at the Marmato district. Gonzalez (1980) presented the propylitic ($\pm$ epidote), sericitic (quartz, sericite, pyrite association), potassic (biotite), and silicic alterations within the Marmato stock as regional scale. For this author the sericitic alteration is the most prevalent alteration and it is present in both mineralized and non-mineralized zones. Similar regional scale alteration types are described by Cuellar and Mora (1985). Phyllic and propylitic alterations are the most common at the Marmato area (Hernandez and Molano, 1989). Previous work done at a different mine in the Marmato district (local scale) described propylitic, phyllic, argillic and silicic alteration. For example, Alvarez-Betancut (1989), Lopez-Rendon and Bedoya (1989), Medina-Gallego (1989), Monsalve-Bedoya (1989), Restrepo-Nieto (1989), Blanco -Saint

Sorny (1991), Lopez-Rendon (1991), Molina (1991), Zapata-Montoya and Pelaez- Jimenez (1991) described the hydrothermal alteration in different levels in La Maruja area.

Fetzer (1938), Garces-Gonzalez (1940), Morer and Nicholls (1959), Radelli and Pagnacco (1962) presented the principal group of veins (e.g North, Central, and South) and their spatial position in the Marmato district. The north group includes the Porvenir and Santa Inès veins which strike N70°W. The central group includes the Mellizos and Santa Inès veins which strike N86°W and the south group includes the Aguaceral, Morenos and Carrancho veins. All of these groups of veins exhibit steep dips and are hosted by porphyry hypabyssal rock.

Some authors outline the evolution of the Marmato district and also classify the deposit as a mesothermal-hypothermal type. Jimenez-Jaramillo and Scheibe (1934) say that the veins were formed when the host rock cooled and hydrothermal fluids from residual magmatic fluids moved through tension fractures. A similar hypothesis is proposed by Hall et al.(1971), and Alvarez and Arias (1970). Pagnacco (1962) classified the Marmato deposits as sub-volcanic type and he affirms that the mineralization is related to the magma which formed the host rock. The Marmato deposit has mesothermal characteristics, but the Echandia mineralization shows clear epithermal characteristics.

Fetzer (1938), Garces-Gonzalez (1975), Gonzalez (1980), and Rubiano (1986) describe two periods of mineralization in the Marmato gold field, the first having a high temperature (mesothermal) and the second with lower temperatures (epithermal).

Phelps Dodge (1985) and Lakefield Research (1984) present results of mineral

exploration and geologic mapping completed at La Maruja level. In this research, several core holes were drilled to establish the grade, reserve and the possibility of benefit from ore mineral at La Maruja level.

METHOD OF INVESTIGATION

The project was broadly divided into field and laboratory work. It consisted of following parts: (1) Literature research consisted of compiling a series of plan maps and previous references on La Maruja Level; (2) Mapping of structures and vein features, lithology, and hydrothermal alteration in mine working that were accessible at the time of study (mine base maps to scale 1:2000 were used); (3) A large number of samples were studied as hand specimens prior to the final selection for later studies; (4) Petrographic studies of thin sections to determine the mineralogic and textural variation, as well the mineral alteration assemblages of the veins and host rock were carried out; (5) Ore microscopy studies of polished sections were conducted to determine the paragenetic sequence of the minerals involved during the mineralizing episodes; and (6) Analysis of fluid inclusions were carried out utilizing a heating and freezing stage involving measurement of homogenization and freezing temperatures. Prior to heating-freezing stage analysis, a visual study of fluid inclusion was carried out to determine their genetic nature.

REGIONAL GEOLOGY

In the surroundings of Marmato, rocks range in age from the Cretaceous to the present. (Fig. 2.1)

Amphibolite: (Pae in Fig 2.1) These rocks are located to the east and to the north of Marmato. They occur as lens-shaped, discontinuous, isolated bodies. In some places such as along the Arquia River, the amphibolite is associated with schists (green and sericitic with graphite schists) and serpentine, in a sequence that has been recognized as the Arquia Group by Restrepo and Toussaint (1976).

The amphibolite is dark green to dark green-gray. Alternating white bands of plagioclase, dark bands of hornblende, and milky quartz veins and lenses dominate its gneissic to schistose structure (Alvarez and Arias, 1980). Hornblende is the dominant mineral in the amphibolite, followed by plagioclase. Quartz occurs in small amounts. Secondary minerals consist of epidote, calcite and chlorite. Accessory minerals include pyrite, pyrrhotite, and sphene. Chalcopyrite is also associated with pyrite and pyrrhotite. These sulfides occur in disseminated form and along joints (Gonzalez, 1980).

Restrepo and Toussaint (1976) describe the garnet-amphibolite of Arquia River as a dark, foliated, dense rock composed of green hornblende, plagioclase, almandite garnet and sphene. They date these amphibolites at 110 Ma (Aptian-Albian). According to these authors, the development of almandite garnet, and the presence of abundant chlorite in the

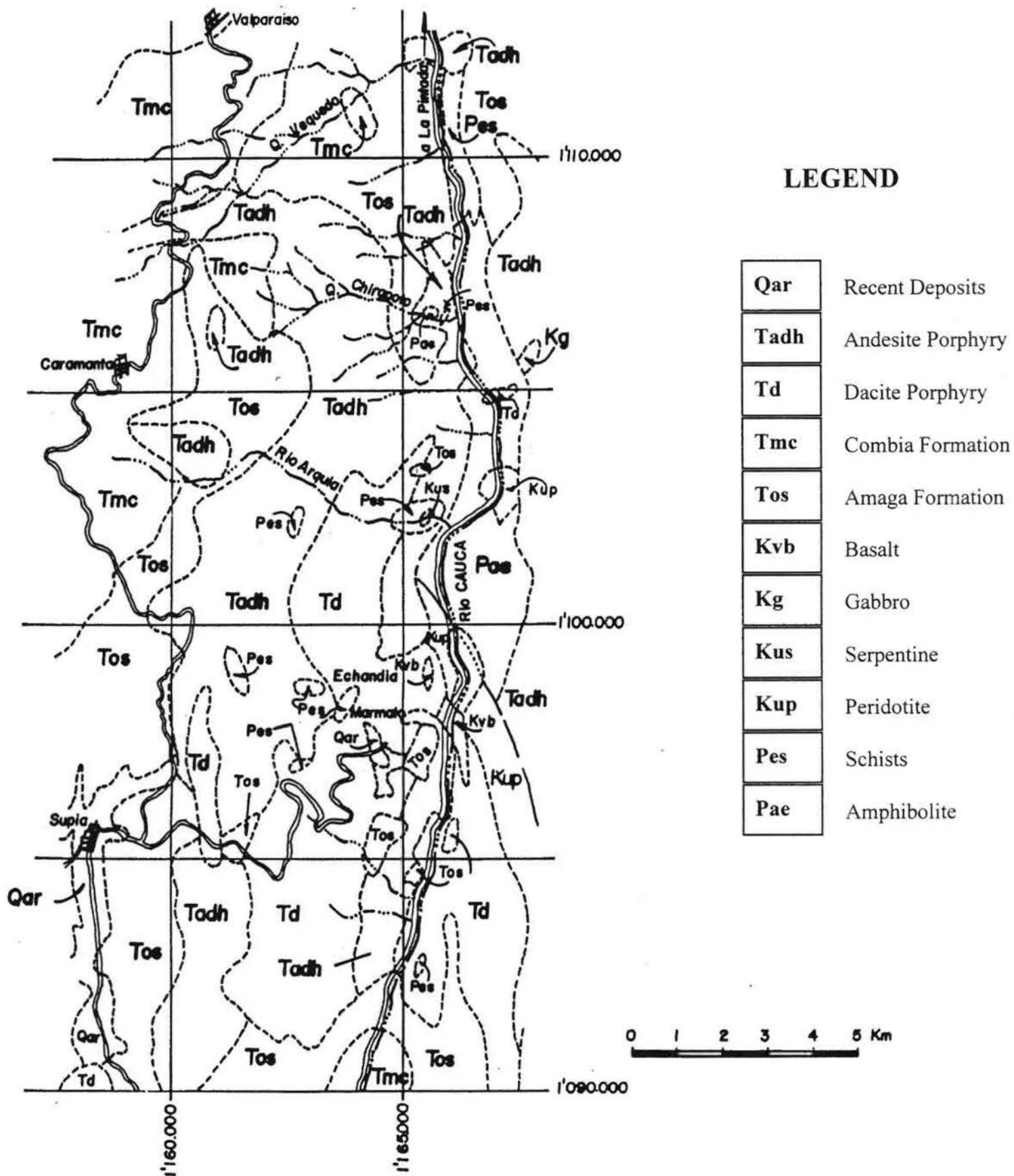


Figure 2.1 Regional geology surrounding the Marmato area

associated amphibolitic metasedimentary rocks indicates a medium pressure metamorphic grade (Barrovian). This event probably occurred during Albian time as a result of obduction of oceanic crust upon what is now the Central Cordillera.

Schists: (**Pes** in Fig 2.1). Three varieties of schists can be differentiated: sericitic-quartz with graphite, biotitic- quartz, and green schists.

Sericitic- quartz with graphite schist: This unit has been classified many times in the field as a black schist due to its color. The rocks are very finely laminated in layers of 3 to 5 mm of thickness. Elongated veins of milky quartz, 0.1 to 10 cm thick (locally up to 2 m) and generally parallel to the foliation, are commonly found in these units (Gonzalez, 1980). The color ranges from dark gray to black. The rocks show a silky luster due to the presence of micaceous minerals and a banded structure that is due to alternating layers of graphite-mica and quartz-plagioclase.

Quartz and sericite are the dominant minerals in these schists. Plagioclase, chlorite, biotite, and muscovite are present in minor amounts. Accessory minerals are graphite, zircon, apatite, and opaque minerals. According to Ortiz et al. (1987), these rocks have a structure that ranges from schistose, locally brecciated, to gneissic. These characteristics are clearly exposed along the Chirapoto Creek. Where the gneissic structure occurs, it is common to find sulfide-bearing veins that are parallel to the foliation. These are exposed at the confluence of Chirapoto Creek to Cauca River. The origin of these veins has not yet been clearly defined. Two hypothesis should be considered: 1) Lateral secretion during a regional metamorphic event, and 2) The formation of the veins is genetically related to the

mineralization of the Marmato zone.

Biotitic-quartz schists: This unit occurs as lens-shaped, discontinuous, isolated bodies. The color range from gray to dark green. Quartz and biotite are the dominant minerals in this schist. Plagioclase, chlorite, sericite, and opaque minerals are present in minor amounts. Elongated veins of milky quartz and dark biotite bands parallel with the foliation, are common. This unit is very clearly exposed around the Echandia village.

Green schists: These are rocks white to dark green, with alternating bands of plagioclase-quartz and bands of mafic minerals (Ortiz et al., 1987). In general, these rocks are composed of chlorite, quartz, plagioclase, calcite, actinolite, and minerals of the epidote group. Sphene, zircon, apatite, biotite and opaque minerals are accessory minerals. When one of the major minerals dominates, various schist groups can be described: chlorite schists, composed of chlorite and plagioclase; actinolite schists, composed of actinolite and plagioclase; and green calcareous schists composed of calcite, albite and epidote (Samudio and Zapata, 1984).

Manifestations of disseminated sulfides are common in these schists. Pyrite, chalcopyrite, and molybdenite are the dominant sulfide minerals. In some places the green schists alternate with sericitic-quartz schists, and together may correspond to an original volcano-sedimentary sequence. The green schists may represent basic volcanic rocks, while the sericitic-quartz schists may have been derived from intercalated pelitic sediments (Alvarez and Arias, 1970).

Ultramafic Rocks: (**Kup, Kus** in Fig 2.1) They are isolated lens-shaped bodies

with tectonic contacts having a N-S trend along the plane of the Romeral fault system. They appear to define the contact between oceanic crust to the west and continental crust to the east. Essentially they are peridotites that have been slightly to highly serpentinized. The age assigned to these rocks is early Cretaceous (Calle, 1980).

The serpentine is dark green, massive, and highly fractured locally. In regions that are particularly close to the fault zone it exhibits a schistose structure. This unit is composed of antigorite, olivine, magnetite, talc, chromite and carbonate. Antigorite and talc may comprise as much as 90% of the rock (Alvarez and Arias, 1970). The structure ranges from schistose to gneissic and, in zones with more intense deformation, mylonite is present (Gonzalez, 1980).

Gabbro: (Kg in Fig 2.1) Some small bodies of gabbro are exposed to the northeast of the Marmato district, on the eastern bank of the Cauca River. They are medium-grained, composed of plagioclase and hornblende, with alteration products of zoisite-clinozoisite, chlorite, calcite, and epidote. Accessory minerals include biotite, sphene, apatite, and magnetite-ilmenite. An early Cretaceous age has been postulated for these units (Calle, 1980).

Basalt: (Kvb in Fig 2.1) The basalt is dark green, aphanitic and dense, and occurs toward the lower downhill portion of the Marmato district. This rock is composed of plagioclase and pyroxene with chlorite, calcite, sphene, magnetite and pyrite as accessory minerals. This basalt may represent an equivalent to the volcanic flows described in the Quebrada Grande Formation of the late Cretaceous. However, Calle (1980) assigns an early

Cretaceous age to this basalt unit because it is intruded SE of Marmato by the Mistrato pluton, whose postulated age is middle Cretaceous.

Tertiary sedimentary rocks: (Td and Tadh in Fig 2.1) Two sedimentary formations have been described in the Marmato zone.

Amaga Formation: This unit is composed of conglomerates, siltstones, and shales. These are immature sedimentary rocks generally composed of rock fragments and clay minerals. Van der Hammen (1958) reported an age of early Oligocene-Miocene assigned to this formation.

Combia Formation: Miocene in age and discordant with the Amaga Formation, this unit is about 600 meters thick. Gonzalez (1980) recognizes two members. The upper member is dominated by poorly consolidated sedimentary rock and recent volcanic ash. The lower member is predominantly volcanic, and includes tuffs, tuff breccias, lapilli tuffs, welded and unwelded tuff, agglomerates, and basaltic and andesitic flows.

Hypabyssal Porphyry Rocks: (Td and Tadh in Fig 2.1) These rock units include both dacite porphyry and andesite in the Marmato area. The contact between them is gradational. This unit, designated the stock of Marmato, is an intrusive body with a dacite composition in the nucleus and andesite at the border. The area exposed is 20 km² of which 8 km² corresponds to the dacite facies and 12 km² to the andesite facies. It is elongated parallel to the regional Romeral structure. K/Ar dating of hornblende, from porphyry dacite samples of the stock of Marmato indicate an age of 6.3 ± 0.7 Ma or late Miocene (Restrepo, 1981). The Stock of Marmato intrudes the sericitic-quartz with graphite

schists in the Echandia village.

Recent Deposits : (Qar in Fig. 2.1) Deposits resulting from mass movements are present in the area. They include mud flow, debris flow, alluvial, and colluvial deposits. These deposits range in thickness and are composed of the surrounding material.

LOCAL GEOLOGY

LITHOLOGY

The work done at La Maruja level took place between the entrance and the exploitation fronts, which were accessible for the present research (Map 1). This work was done in porphyritic rock classified as Porphyry Dacitic. The host rock is late Miocene (Restrepo et al., 1981) and may be part of the Marmato stock (Alvarez and Arias, 1970).

In almost all thin sections studied hydrothermal alteration products range from abundant to sparsely present. No fresh samples were available; for this reason, only samples with weak hydrothermal alteration were analyzed to define the type of rock that hosts ore. This information was added to observations from samples of hydrothermally altered rock, in order to get an estimate of the percentages of phenocrysts in the rock. Through very detailed observation of the phenocryst edges and the minerals formed or altered in them, conclusions were made regarding the possible mineralogy of the original non-altered phenocrysts. In the case of ferromagnesian phenocrysts with partial alteration, it was possible to identify the original mineral (e.g. hornblende) located in a preserved part of the host rock. In the case of partially altered plagioclase, it was possible to identify the type present in the host rock.

The macroscopic image of the porphyry rock is compact, with a color ranging between several shades of gray and green. It is composed of phenocrysts of plagioclase,

quartz, and ferromagnesian minerals, with a quartz feldspathic matrix. Plagioclase is present as subhedral or euhedral 3-10 mm crystals with common zoning and twinning (albite, carlsbad, and pericline twins). The multiple extinction measurements on plagioclase crystals done on albite twins and carlsbad- albite twins show that there is a general compositional interval of An_{23} - An_{40} . However, the majority of the measurements were found within the narrow interval An_{26} - An_{33} , which indicates that the composition is in the border line of the solid solution series oligoclase-andesine. Alteration minerals found are sericite, calcite, epidote, zoisite-clinozoisite, quartz, and chlorite.

Biotite and hornblende represent the ferromagnesian phenocrysts, and are present in almost equal amounts in the host rock. Hornblende occurs as subhedral or euhedral, generally elongated, prismatic crystals. Their average size is 1mm (seldom 7mm). Relatively fresh hornblende exhibits pleochroism on X=light green, Y=green, Z=yellowish green. Biotite is present as sheet-like aggregates, with subhedral or euhedral sheets whose size ranges from 1.5 to 3mm. The primary mineral formed by the alteration of ferromagnesian minerals is chlorite, with calcite, sericite, epidote, quartz, fine-grained pyrite, and in some places, apatite as secondary minerals.

Quartz phenocrysts are subhedral or anhedral. The latter present round edges and a maximum size of 5 mm. In thin section, they may exhibit deeply embayed shapes interpreted by Alvarez and Arias (1970) to be the result of corrosion during magmatic re-melting or dissolution. In places where moderate to intense shearing of the porphyritic rock occurs, quartz phenocrysts are fractured and show undulatory extinction. Near hydrothermal

veins, these microfractures serve as channels of access by the altering and mineralizing fluids. Microfractures also serve as sites for mineral deposition, including quartz, sericite, pyrite, sphalerite, chlorite and albite. This deposition occurs simultaneously with phenocryst alteration, which moves from the microfractures towards the interior of the phenocrysts.

The porphyritic rock matrix is relatively fine-grained, composed of anhedral quartz microcrystals and plagioclase crystals. The proportion of phenocrysts to rock matrix is 1:1. However, in places of intense shearing, extensive phenocrysts pulverization produces an apparent increase in the portion of matrix.

Besides plagioclase, hornblende, biotite and quartz as major minerals, there are accessory minerals such as apatite. Apatite occurs as hexagonal crystals with a 1st order gray interference color, with random distribution in matrix as well as in phenocrysts. Apatite is found as an accessory phenocrysts mineral adjacent to biotite and hornblende. Apatite was almost never found within plagioclase or quartz phenocrysts.

Fine-grained pyrite stays within the category of opaque accessory minerals. However, most of this mineral's occurrences might have been located at hydrothermal fluid zones.

The estimated modal mineralogy defined by several thin sections indicates an average phenocrysts population of 32% plagioclase, 12% ferromagnesian minerals, and 8% quartz.

STRUCTURAL FEATURES

The main structural features found at La Maruja level were faults and joints. Both have predominantly northwestern orientations with a relatively steep dip.

FAULTS AND SHEAR ZONES

The exposures in the underground studies carried on at La Maruja level showed several faulting surfaces located mainly parallel to the length of the vein's walls (Map 1).

From the observations made in Map 1 at the veins it can be concluded that: a) The south part of the Sin Nombre vein seems to be controlled by a fault whose strike may range from N25°W to N35°W, in some places (not on the map), to N40°W. The dip ranges from 64° to 76°SW; b) The Porvenir vein was identified in the southernmost part of the zone that was accessible for study, and it is localized along a fault with a strike N50°W and a dip of 53°SW. West of the Santa Inès vein, there is a faulted segment with a strike N87°W (almost E-W), and a dip of 80°NE and d) Another fault was found at the vein called Múcura or Zanco (a branch from Santa Inès vein) with a strike ranging from N25°W to N70°W and dipping between 68° - 78° NW (locally it is vertical).

After detailed observations, it was concluded that the fault surfaces are usually curved or arched, with a NW general orientation tendency, close to E-W orientation locally, and exhibiting a steep dips. Moreover, the faulted structures that are located in or related to the Santa Inès and Múcura veins have a NE inclination, while the ones located in the Porvenir and Sin Nombre veins have a SW inclination. Therefore, the Santa Inès and Múcura veins are thought to intersect the Porvenir vein deep under the floor of La Maruja level. This interpretation had already been proposed in previous studies by Garcés and Gonzáles (1940, 1975) and Phelps Dodge (1985).

The spatial distribution of the relative shearing intensity observed in the surrounding

rock immediately adjacent to the veins, confirms the above observations (Map. 1). There is an existing structural control mainly located in the veins' faults of La Maruja level. Thin section samples from the surrounding rock, provided valuable information to establish a classification of the shear zones according to their relative intensities (from strong, to moderate, and weak intensities). In thin sections taken from zones of strong shear, the quartz phenocrysts are highly pulverized and exhibit undulatory extinction (Figs 3.1 and 3.2). Intergrown crystals of secondary quartz fill spaces between individual fragments of the original quartz phenocrysts. Plagioclase phenocrysts in zones of strong shear show moderate pulverization, and folded or curved crystal habit, along with curved twins. Most of the ferromagnesian phenocrysts show folds and cracks (Fig 3.3). There is also microfaulting of quartz (Fig 3.4), plagioclase, and ferromagnesian phenocrysts. The fragments are randomly or chaotically distributed within the matrix. Thin sections of the host rock reveal a high degree of deformation that appears to be a microbreccia (Fig 3.5). This texture is visible in macroscopic samples, especially where they have been cut by a diamond saw. Most of the rock samples show some alteration or partial destruction of the rock's porphyritic texture. This is partially caused by intense or moderate sericitization, which is typical in regions of intense shearing.

In zones of moderate shearing it is less common to find folding, arching, or microfaulting in ferromagnesian and plagioclase phenocrysts. However, quartz phenocrysts still have strong recrystallization and exhibit undulatory extinction. Microbreccia and chaotic spatial settings among phenocrysts within the matrix are less frequent. In these

Figure 3.1 Photomicrograph of sample number 100539 showing zone of high shear. The quartz phenocryst is recrystallized and exhibits undulatory extinction. There are also fine crystals of pyrite filling microfractures in quartz. Crossed nicols and plane light. Field of view 2.75 mm.

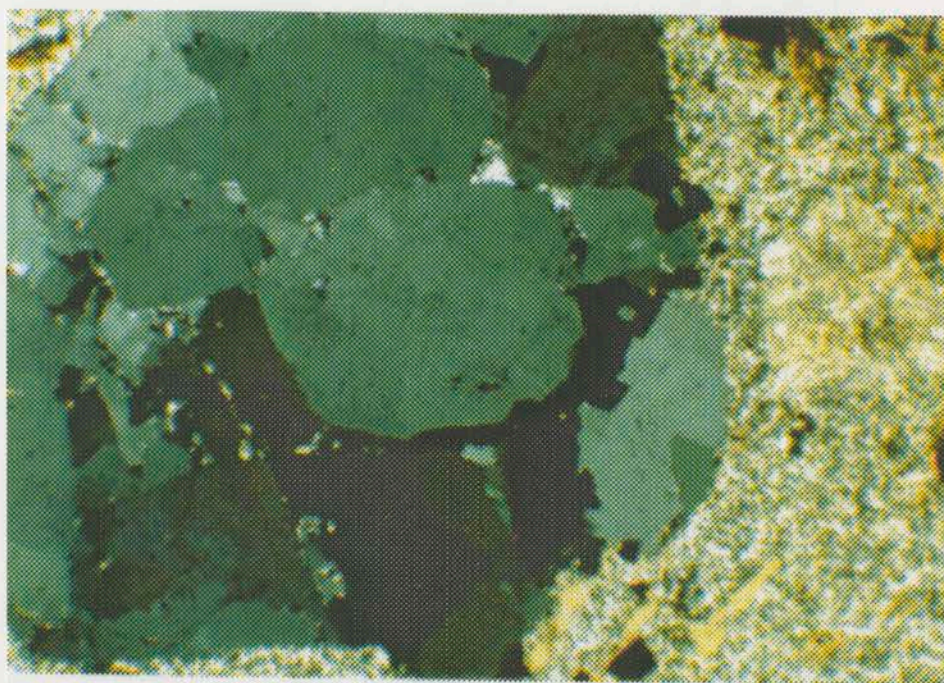


Figure 3.2 Photomicrograph of sample number 100520 showing zone of intense shear and development of secondary quartz (Qz). Crossed nicols. Field of view 2.75 mm.

Figure 3.3 Photomicrograph of sample number 100932 showing folded biotite. Crossed nicols. Field of view 1.1 mm.

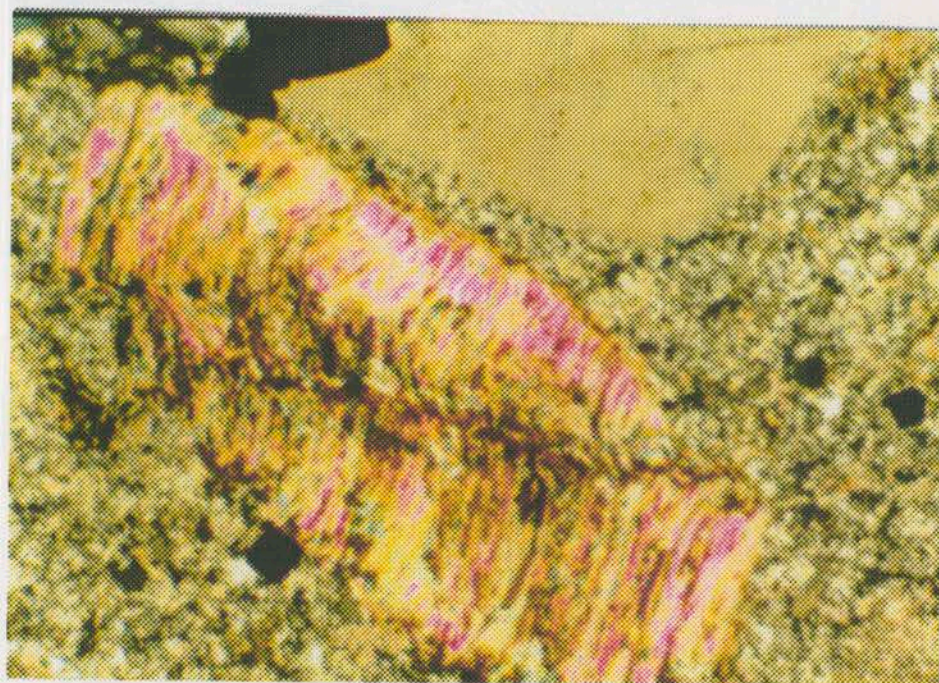


Figure 3.4 Photomicrograph of sample number 100812 showing right lateral microfaulting of quartz crystals (Qz_1 , Qz_2). Crossed nicols. Field of view 2.7 mm.

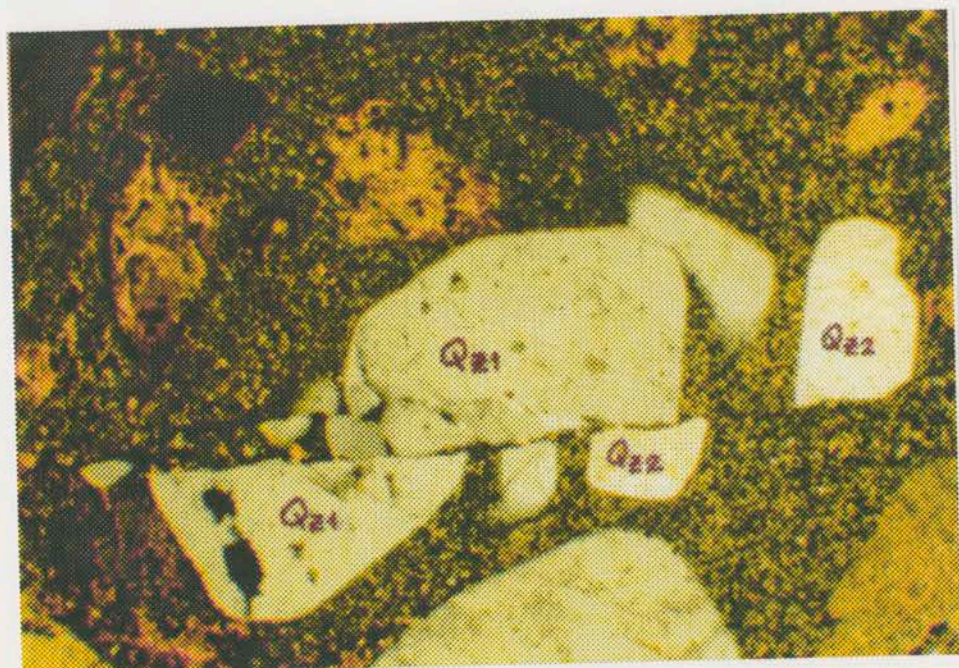
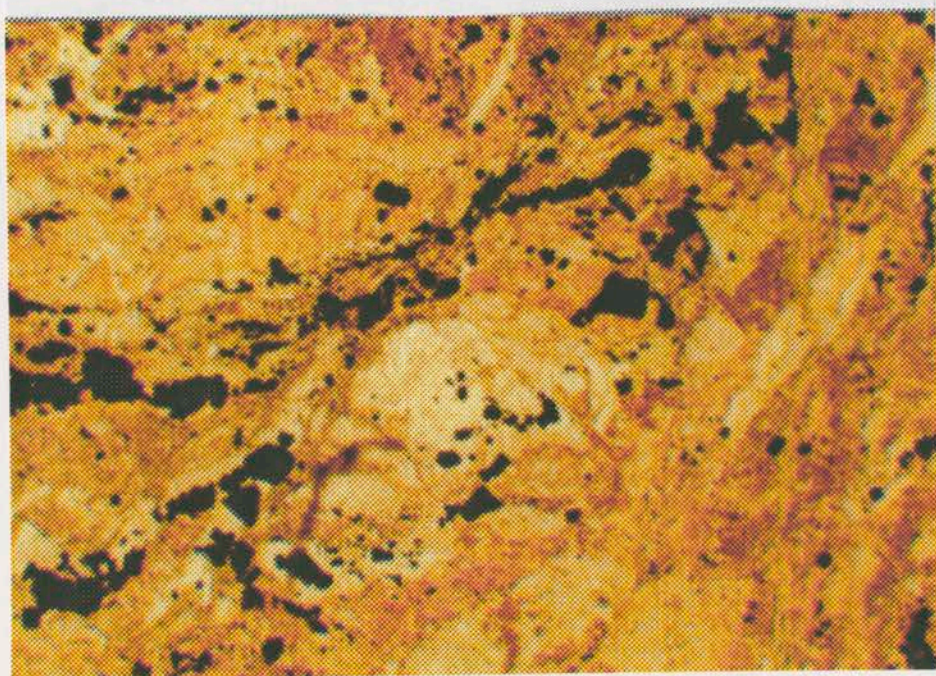


Figure 3.5 Photomicrograph of sample number 100917 showing high degree of deformation. It appears to be a microbreccia, that has flow textures. Crossed nicols and plane light. Field of view 2.75 mm.



zones, the rock's porphyritic texture is often visible in thin section, as well as in macroscopic samples. In outcrop it is more difficult to identify the presence of shearing striations. Nevertheless, they are present, but at a lower density than those in zones of strong shear.

In zones of weak shear, the microbrecciated texture is almost absent in porphyritic rock. However, quartz phenocrysts still exhibit undulatory extinction. Recrystallization is present but rare, and there is local folding and arching of ferromagnesian phenocrysts. The host rock shows high preservation, with the exception of places where there is intense hydrothermal alteration.

Evaluating the evidence of the interaction of faults with location of the veins and the presence of shearing in thin sections of the wallrock, it is evident that there is a direct spatial connection between intensity of shearing in sites of veins. Furthermore, when examining Map. 1, it is evident that the east section of La Maruja level might have experienced higher tectonic activity than the west.

Fault traces were also detected in three different places along the veins and La Maruja tunnel. There is a fault located in La Maruja crosscut, and east of the Sin Nombre vein, which has a strike of N34°W, and a dip of 47°SW. This orientation matches the orientation of the Sin Nombre vein and the direction of the mineralization from the "Veta de Entrada" named by Phelps Dodge (1985). Fifteen meters before the intersection of the Porvenir vein, along La Maruja crosscut, there is a second fault surface with a strike of N70°E, and a dip of 72° N. This orientation matches the one from the Santa Inés vein, located west of the Sin Nombre vein. This faulted surface might be an easterly projection of

the structure that controls the Santa Inès vein. The third faulted surface is visible in the lateral tunnel which connects La Maruja crosscut with the south part of the Porvenir vein. The strike here is N15°E, and the dip is 68°SW.

JOINTS

The distinction between mineralized and non-mineralized joints is evident in the present study. The first are filled with sulfides and gangue minerals. The thickness of these minerals may be greater than 2 cm. The latter locally have surfaces covered by sulfides (e.g. pyrite and/or sphalerite) which form thin crusts whose thickness is less than 0.5 mm.

Table 3.1 shows the orientation of mineralized joints at the tunnel's entrance through the intersection with the Sin Nombre vein, and also the ones between the Sin Nombre and the Porvenir vein. The great majority of mineralized joints located along the main excavation tunnel exhibit a characteristic northwesterly orientation with a dip range between 54°-90°. There were only two measurements taken through La Maruja crosscut where the joints exhibited a northeast orientation. Some mineralized joints were found within the two tunnels perpendicular to the main one. They connect La Maruja crosscut with the south side of the Porvenir vein (3 measurements). Their strikes range between N60°W and E-W. The dips range from 65°-75° mainly northeast (2 measurements). The joints located at the tunnel that connects La Maruja crosscut with the Porvenir vein (4 measurements) typically have a east-west direction. The strikes in this location are approximately N60°W and the dips range from 70°-86°. The mineralized joints observed in the walls of the Múcura and Sin Nombre vein (3 measurements at Múcura and 1 at the vein

TABLE 3.1 Mineralized joins at La Maruja level.

Axis N	Axis E	Localization	Strike/dip
97684	53967	Main excavation, between entrance and Sin Nombre.	N55°E/vertical
97684	63937	”	N60°W/54°SW
97682	63915	”	N82°E/55°NW
97680	63903	”	N10°W/71°SW
97678	63872	”	N45°W/vertical
97683	63815	”	N70°W/70°S
97681	63788	”	N33°W/73°E
97682	63750	”	N45°W/58°SW
97669	63741	Tunnel that connects the main excavation with south portion of Porvenir vein	N80°W/75°NE
97673	63737	”	N60°W/75°NE
97668	63737	”	E-W/65°S
97691	63720	Tunnel that connects the main excavation with north portion of Porvenir vein	E-W/76°S
97698	63703	”	E-W/76°S
97703	63699	”	E-W/84°S
97703	63699	”	N60°W/70°NE
97667	63824	Sin Nombre vein	N25°W/75°SW
97726	63824	Múcura vein	N45°W/vertical
97755	63460	”	N65°W/65°NE
97756	63453	”	N60°W/73°NE

Sin Nombre), are oriented northwest and their dips range from 65° to 90°.

Non-mineralized and mineralized joints occur in both, La Maruja tunnel and veins. The general joint orientation at La Maruja level is northwest. Dips do not exhibit a characteristic tendency. There are dips toward the west, as well as towards the east. However, most of the dip measurements are greater than 50° (commonly 90°) (Fig. 3.6). The joint measurements for La Maruja level, are similar to those described previously by other scientists. Alvarez and Arias (1970) established two joint main orientations for the Marmato

District: N55°W and N65°W. Cuellar and Mora (1985) describe one direction at N58°W with a dip of 86°E, and a second at N40°W with a 76°W dip. Moreover, López-Rendón and Bedoya (1989) in their study of the area of Echandía, found strikes ranging from N40°W-N60°W, and variable steepdips.

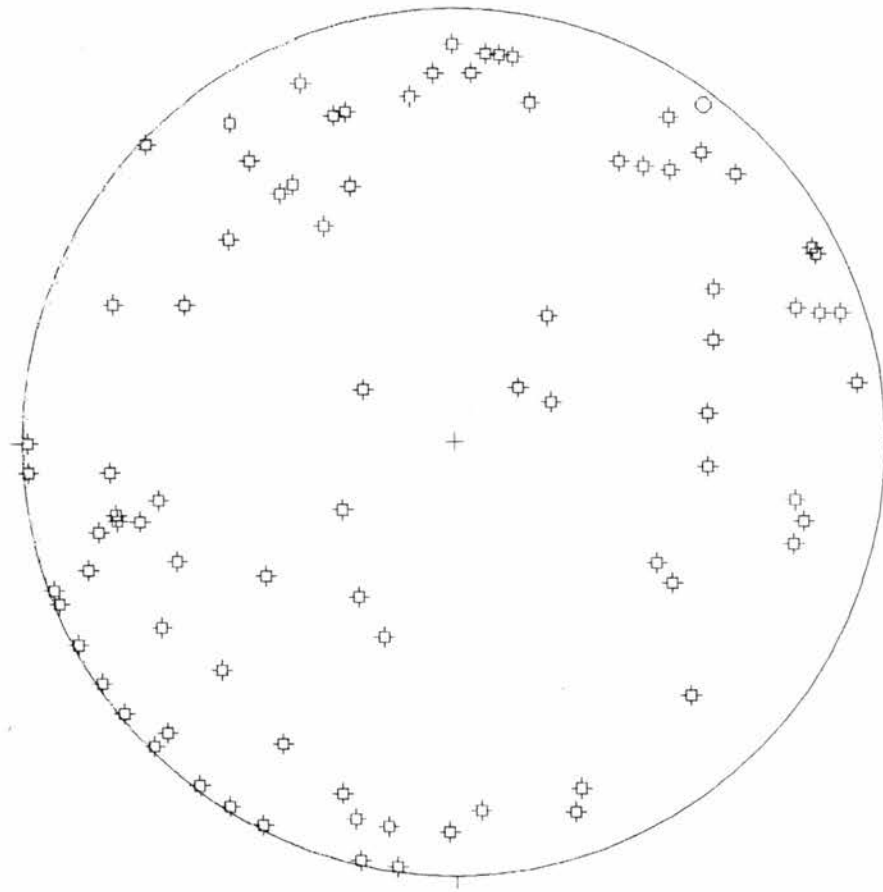


Figure 3.6 Plot of poles to joints in La Maruja level. Schmidt Stereonet. Number of sample points 104. x = mineralized joints, □ = unmineralized joints.

MINERALIZATION PROCESSES

OCCURRENCES

VEINS

The veins located at La Maruja level (Map. 2) were assigned to the Grupo Norte Inferior by the Mining District of Marmato years ago. The veins are as follows: Sin Nombre, Porvenir, Santa Inès and Múcura (Garcés and González (1940); see also article No 461 of March 5, 1940, ruled by law 72 of 1939, which establishes the groups of mines owned by the nation located at the region of Marmato).

In previous maps, the Veta Rica was included in La Maruja level (Radelli and Pagnacco, 1962). This vein appeared to intersect La Maruja crosscut at 85 m from the entrance, going west. The Veta Rica seems to belong to the system established by Phelps Dodge (1985), which they called "Filon de Entrada." In the present study, a thin vein (35 mm thick), composed of sulfides and clays was found at this location.

The "Filon Entrada" has a well-defined wall, with strike N20°W and a dip of 71°SW at the place of observation. Due to its thickness, shape, and lack of lateral and vertical continuity, this vein does not have much economical value for mining.

The Sin Nombre, Porvenir, Santa Inès, and Múcura veins are fracture fillings, which formed due to tectonic activity affecting the surrounding porphyritic rock. These fractures

are lens-shaped, characterized by sinuosity and smaller veins splay off the larger ones.

The veins are controlled mainly by high-angle faults, which follow curved or sinuous paths and whose orientation and inclination angles vary along La Maruja level. In some places, the veins do not occur on the fault surfaces themselves, but concentrate in the host rock, following smaller fractures more or less parallel to the surface of the main fault. They locally generate stockwork features, which are known locally as "horse tail" structures. In this particular case, what is interpreted as vein is the rock being traversed by multiple regular and smaller veins. In some other places, the density of sulfide deposition can increase enormously to the point of massive deposition.

Depending on the occurrence, the thickness of the veins can range from 0.30 to 1.80 m regionally, and from 0.30 to 2.50 m locally (Map 1). The strike length also ranges; the maximum length can be as great as 500 m, as found on maps from old quarries. Nevertheless, it is important to mention that the maximum length found in a vein for the present study was 260 m (Santa Inès vein, Map.1). Moreover, lateral branches of these veins were not included in the present study because of poor access and rock and mudslides.

The **Sin Nombre** vein (Map.1), which intersects La Maruja crosscut east of La Maruja level is a longitudinal-sinusoidal one. It has a strike range between N30°W and N40°W, a dip range between 64° and 76° towards the southwest, with thickness ranging from 0.25 to 1.20 m. The structure of this vein is controlled by a fault zone. Evidence of intense or moderate shearing between faults can be observed in thin sections from surrounding rock samples taken on both sides of the vein. According to Phelps Dodge

(1985), this specific vein could have an average content of 5.5 g/ton of gold and 30 g/ton of silver. The vein could extend vertically a few meters above Level 17 or Nivel Zancudero, whose approximate elevation is 1,200 meters. For all the reasons mentioned, it would be suitable to start exploring this vein laterally as well as vertically from La Maruja level.

The **Porvenir** vein runs almost parallel to the Sin Nombre vein (Map. 1). Its strike ranges from N40°W to N55°W, its dip angle oscillates between 53° and 75° to the SW, and its thickness ranges from 0.35 m to 1.60 m, to 2.20 m locally (e.g. at the intersection with La Maruja crosscut). This vein's shape is apparently controlled by a fault in the host rock characterized by moderate shearing intensity. The main structure of the Porvenir vein is accompanied by isolated occurrences of parallel mineralized fractures, located approximately a maximum of 5m away from it.

Due to such restrictions as lack of ground access, the Porvenir vein was not studied thoroughly. However, previous studies reveal that samples were taken over lateral lengths greater than 300 m (e.g. Phelps Dodge, 1985). This vein is well known for its relatively large vertical extent. According to studies carried out by Phelps Dodge (1985), the potential grade of gold and silver produced from Porvenir vein could be as high as 8.5 g/ton, and 24 g/ton, respectively. This is in agreement with previous studies of the vein at La Maruja level. Analyses done in the past at the Planta Metalurgica Nacional revealed values of 7 g/ton for gold, and 21 g/ton for silver, in samples take from the northernmost part of the Porvenir vein which had 6.3% total sulfide content (Garcés-González, 1940).

Following the same nomenclature used by Phelps Dodge (1985), it was found that

the **Santa Inès** vein has a strike which ranges from N60°W to a general E-W orientation, with dips ranging from 60° to 80° N and NE, and vein thickness between 0.30 and 1.50 m (Map 1). In some places, this vein seems to be controlled by faulting. This is specifically characteristic of the zone west of the place where the vein Múcura branches out. Slickensides are very commonly found in this vein, along moderate to intense shear zones. Maps created by the Planta Metalurgica Nacional in the past indicate that this vein might extend laterally as far as 500 m to the west. Vertically from La Maruja level, the vein can be found at levels as high as Level 14 or San Pedro (altitude: 1290 m).

Below La Maruja level, and following a vertical orientation, the Santa Inès vein seems to intersect the south branch of the Porvenir vein at an approximate elevation of 1,060 m. This is equivalent to 35 m below level 20 or La Palma. This is based on the exploration done by Phelps Dodge (1985) and their relatively high-angle dips, which are opposed to each other. The Porvenir vein dips south and southwest, while Santa Inès vein dips north and northeast. Some drilling done by the Planta Metalurgica Nacional starting at La Maruja level has also provided supporting evidence for how these two veins intersect each other as well.

The portions of the Santa Inès vein that have been accessed and studied have gold and silver average contents of 7.0 g/ton and 24 g/ton, respectively (Phelps Dodge, 1985). These values match the information from previous studies. For instance, the research done by the Planta Metalurgica Nacional between the years of 1938 and 1940, reports that gold and silver contents at the Santa Inès vein range from 5.02 g/ton to 9.25g/ton and from 23.8

g/ton to 57.17g/ton, respectively, from samples that had sulfide contents ranging between 26.8% and 56.8%, Garcés-González, (1940).

The **Múcura** vein is a branch of the Santa Inès vein (Map 1). The strike of this vein fluctuates between N55°W and N75°W, and in some places it could even be E-W. The dip range from 55° to 80° towards the N, with isolated cases of vertical inclination. The vein's thickness ranges from 0.20 to 1.70 m (Map 1) and its length is 140 m, running 120 m vertically from La Maruja level (Map 1). This vein's structural control is indicated by its alignment with the fault system. Thin section analysis of host rock surrounding the vein reveals moderate to high shearing of the porphyritic rock. Average gold and silver contents are similar to those found for the Santa Inès vein.

SPATIAL RELATIONSHIPS BETWEEN VEINS

A sequence of cuts taken from La Maruja level are directly related to the interpretation of Phelps Dodge(1985). The findings inferred from these cuts show that the veins from the Grupo Norte are wedged within high dip angle rock structures, which have a tendency to have lower dips with increasing depth (e.g., Porvenir vein). The veins also tend to get closer to each other with increasing depth below La Maruja level, and these three veins seem to be derived from a single structure, at some depth below La Palma level.

If it is true that the veins join and change in inclination at depth, then these conditions might cause a change in the hydraulic nature of the fluids. According to Berger and Eimon (1983), a variation of this kind, might control ore deposition. It also favors the formation of precious metal deposits called "bonanza." It is important to focus the exploratory work on

finding the possible projection of the veins at depth, including La Palma level and below.

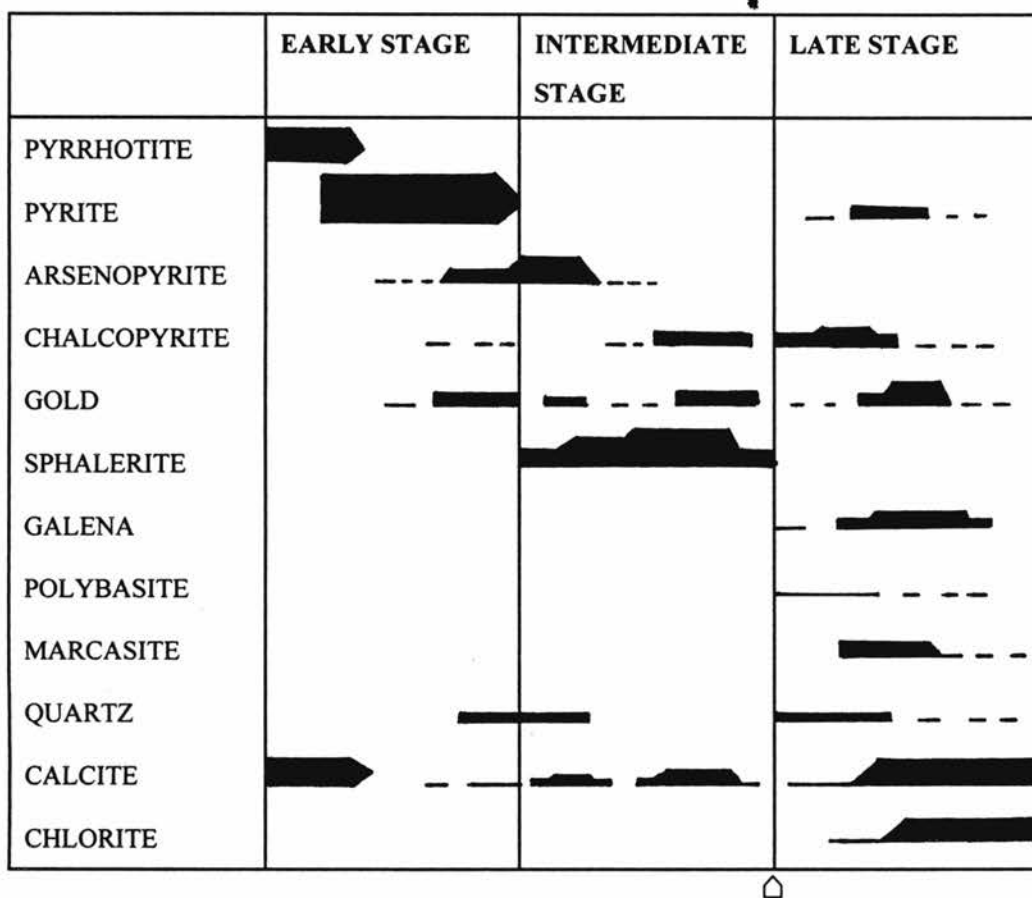
MINERALIZATION OF OREBODIES

The ore minerals identified in the present study include pyrite, pyrrhotite, sphalerite, arsenopyrite, chalcopyrite, gold, galena, marcasite, polybasite. They have been listed in order of their relative abundances. The gangue minerals present are calcite, chlorite and quartz (Fig. 4.1).

Pyrite: This is the most abundant ore mineral in all the veins, constituting more than 80% of the sulfides present. Locally, this percentage might be lower, especially where pyrrhotite and sphalerite are abundant. Two varieties of pyrite were identified. Each was deposited at different points in time. These two varieties are distinguished as Py1 and Py2, respectively.

The pyrite deposited earlier in time (Py1) replaces pyrrhotite, the first stage of sulfide deposition. and occurring in the outermost part of the veins. In many places, pyrite penetrates into the host rock, where pyritization takes place. This is the case where the contact between the vein and the host rock is irregular. Py1 develops relatively large crystals (maximum 10 mm), mostly cube-shaped. These crystals are distributed in irregular masses which may acquire comb textures. The interstitial spaces among pyrite are filled by minerals formed later in the paragenetic sequence.

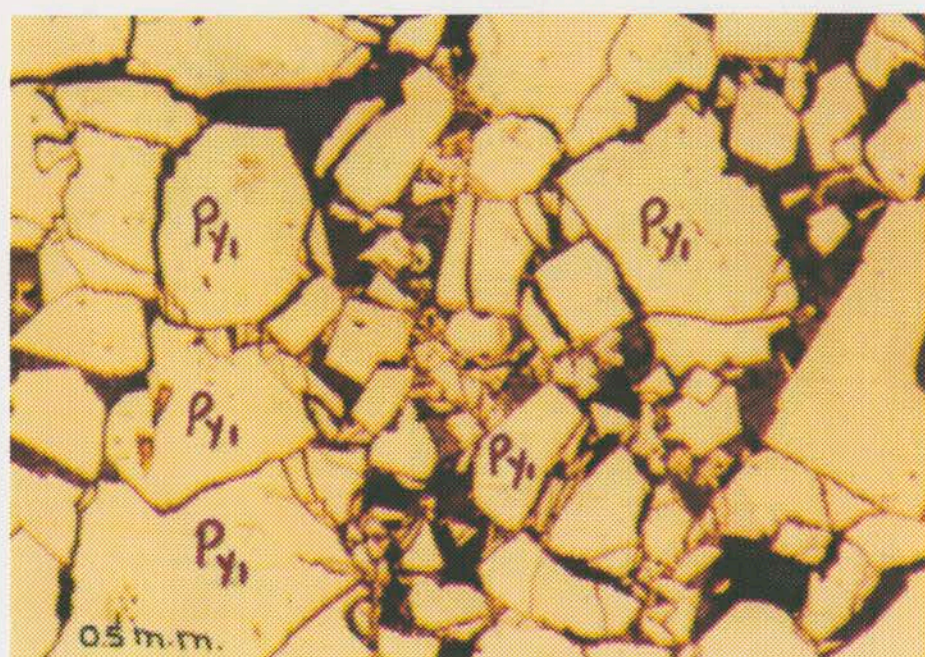
Early Pyrite deposition can generate triple junction due to slow cooling (Craig and Vaughan, 1981). Py1 is replaced by almost all ore minerals present in veins. Fractures in Py1 suggest a subsequent deformational event (Fig 4.2).



Tectonic event.

Figure 4.1 Generalized paragenetic diagram for the La Maruja level. Line width indicate the relative abundance of minerals.

Figure 4.2 Photomicrograph of 100786 sample showing fractured early pyrite crystals (Py1). Field of view 0.5 mm.



Py2 is characterized by fine-grained, euhedral and subhedral crystals. It exhibits elongated crystals with interstitial spaces occupied by gangue minerals. In this case, pyrite exhibits an acicular texture inherited by the replacement of precursor marcasite (Fig. 4.3). Fine-grained pyrite crystals that show colloform textures intergrown with gangue minerals are indicators of rapid Py2 deposition (Ramdohr, 1980) (Fig. 4.4).

Py2 associated with calcite and chlorite fill up the interstitial spaces of Py1, with development of minerals exhibiting micro-comb textures (Fig. 4.5). On the other hand, Py2 associated with euhedral quartz, calcite, and chlorite fills interstitial spaces in Py1 where the latter is massive. Fine-grained marcasite and gangue minerals fill the interstitial spaces between Py1 and Py2. In other cases, Py2 is directly related to calcite without marcasite or other gangue minerals.

Py2 surrounds and replaces arsenopyrite crystals, and fills interstitial spaces between sphalerite crystals. It is located along contacts between sphalerite crystals. In addition, some amounts of Py2 are replaced by galena and chalcopyrite.

Py2 was apparently deposited after a tectonic event, which affected the sphalerite crystals present. This is evident in the presence of Py2 directly associated with gangue minerals, cementing sphalerite fragments. It is also evident in the presence of Py2 associated with calcite, and filling microfractures within sphalerite crystals.

Pyrrhotite: This mineral is second in relative abundance, after coarse early pyrite. Locally, it can be more abundant than coarse pyrite. Pyrrhotite forms medium- to coarse-grained euhedral crystals, forms very early in the paragenetic sequence, and constitutes the

Figure 4.3 Photomicrograph of 100851-A-3 sample showing tabular late pyrite crystals (Py2) in a tabular texture inherited from precursor marcasite. The dark mineral is calcite. Field of view 0.2 mm.

Figure 4.4 Photomicrograph of 100851-B-2 sample showing fine-grained late pyrite crystals (Py2) with colloform texture. Field of view 0.5 mm.

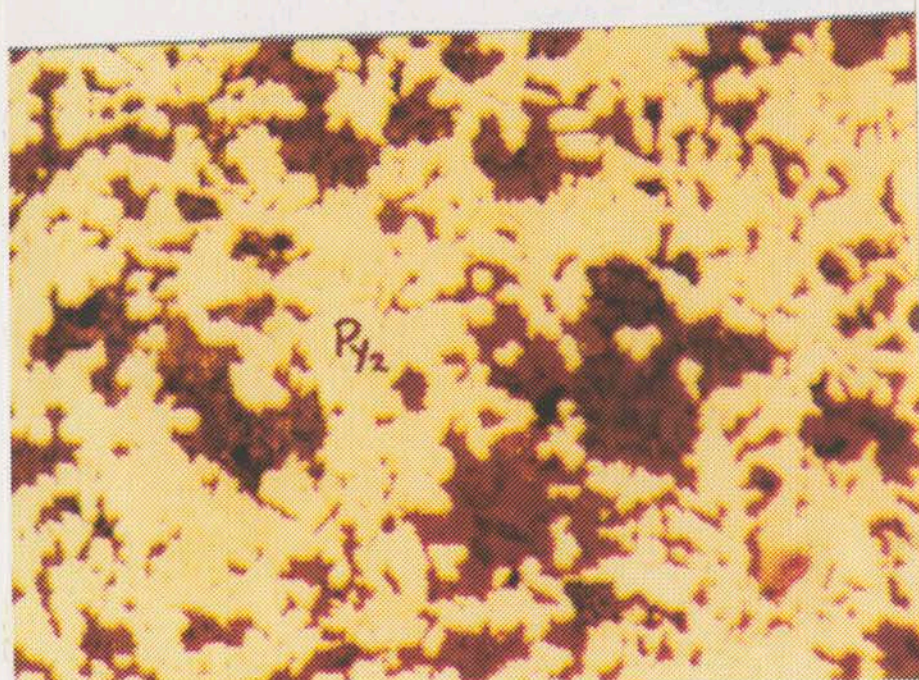
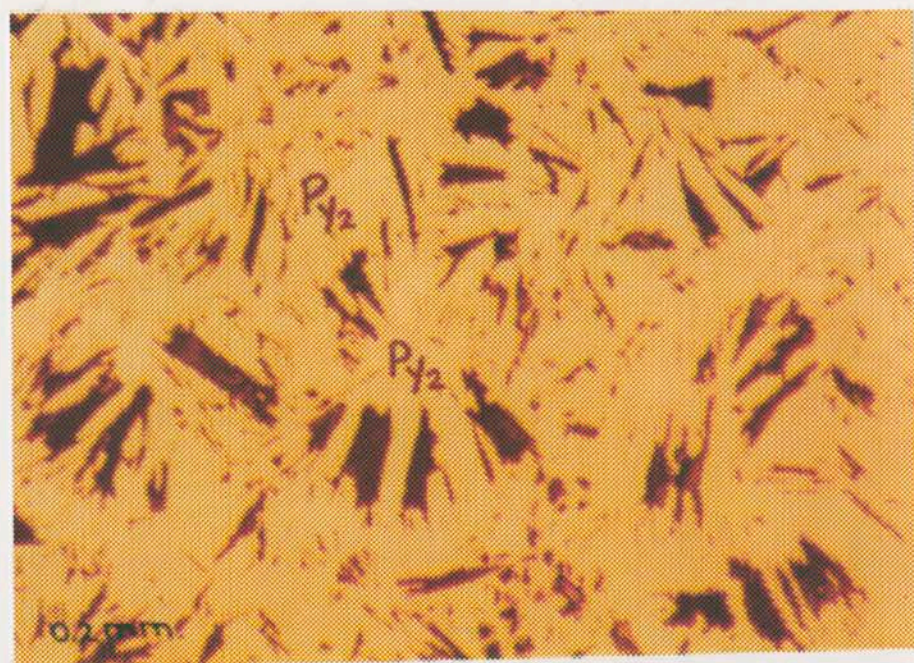
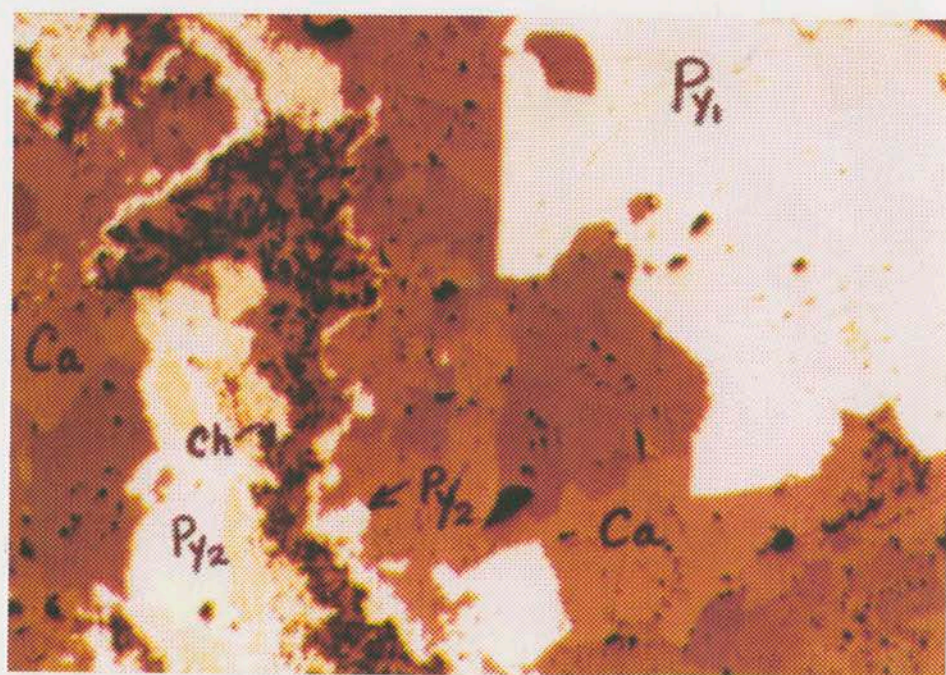


Figure 4.5 Photomicrograph of 100851-B-2 sample showing late pyrite (Py2) associated with calcite (Ca) and chlorite filling the interstitial spaces of early pyrite (Py1). Field of view 2.0 mm.



first stage of sulfide deposition. Pyrrhotite is replaced by all ore minerals present in veins.

Medium-to coarse-grained Py1 replaces pyrrhotite crystals. The highest degree of replacement concentrates along cleavage plains of pyrrhotite. Total or near total replacement is apparent in some places where Py1 pseudomorphs pyrrhotite crystals (Figs. 4.6 and 4.7). In other instances, sphalerite replaces pyrrhotite. There is also pyrrhotite associated with calcite, and thick pyrrhotite cut through by calcite veins.

Arsenopyrite: In the scale of relative abundances, arsenopyrite follows immediately after Py1 and pyrrhotite. This mineral and its comb texture are visible with the naked eye in hand samples. The texture is characterized by the sequential presence of pyrite, arsenopyrite and sphalerite.

Some arsenopyrite precipitates simultaneously with Py1, creating net contacts between the two. Arsenopyrite may also replace Py1, or it may fill spaces between Py1 crystals. This mineral may be deposited along Py1 crystal grain contacts. Euhedral rhombic crystals of arsenopyrite occur within sphalerite showing net contacts or intergrowing with sphalerite (Fig 4.8). On the other hand, in some places arsenopyrite crystals shows an atoll texture in sphalerite (Fig. 4.9). Arsenopyrite may also grow inside calcite (Fig 4.10) or be surrounded by chalcopyrite.

Figure 4.6 Photomicrograph of 100644-C-2 sample showing medium-to grained-coarse-early pyrite (Py1) replacing pyrrhotite crystals (Po). Field of view 0.5 mm.

Figure 4.7 Photomicrograph of 100622-A sample showing pyrrhotite crystals (Po) 90% replaced by early pyrite (Py1). Field of view 0.2 mm.

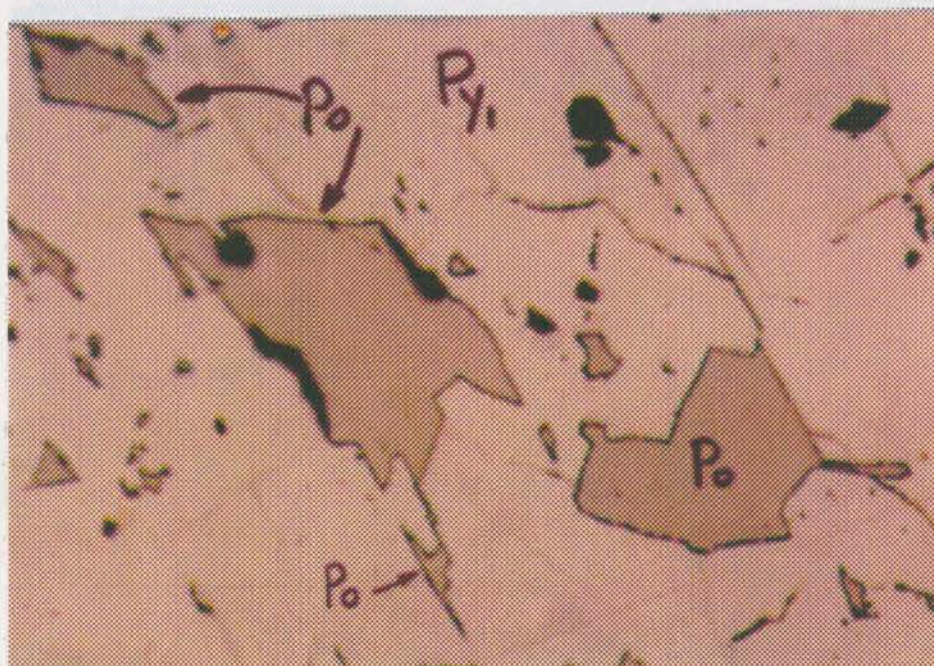
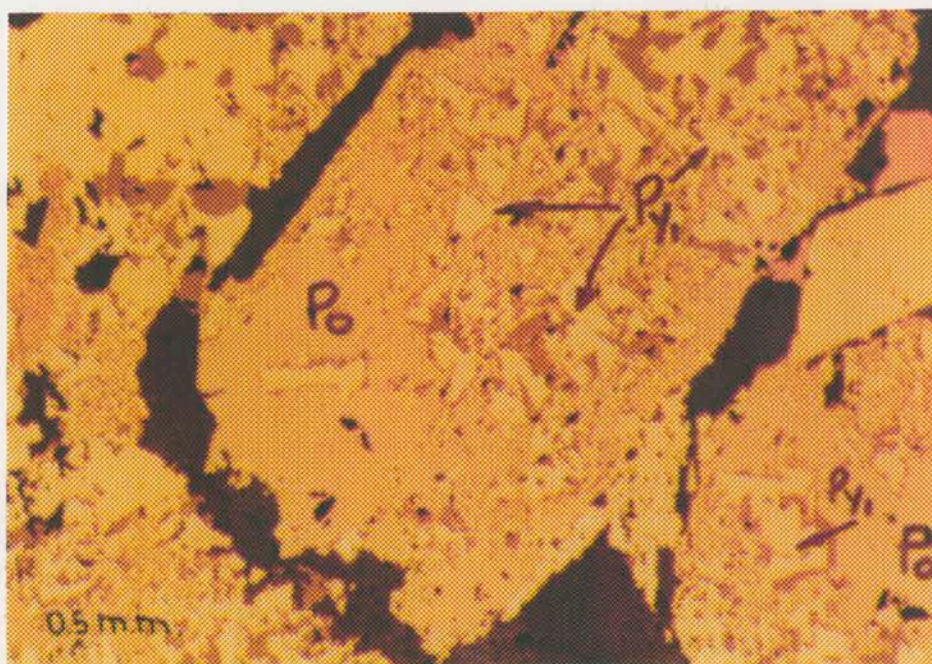


Figure 4.8 Photomicrograph of 100849-B sample showing euhedral rhombic arsenopyrite crystals (apy) in sphalerite ((Sph). Field of view 0.2 mm.

Figure 4.9 Photomicrograph of 100852-D sample showing arsenopyrite with atoll texture in sphalerite. Field of view 0.5 mm.

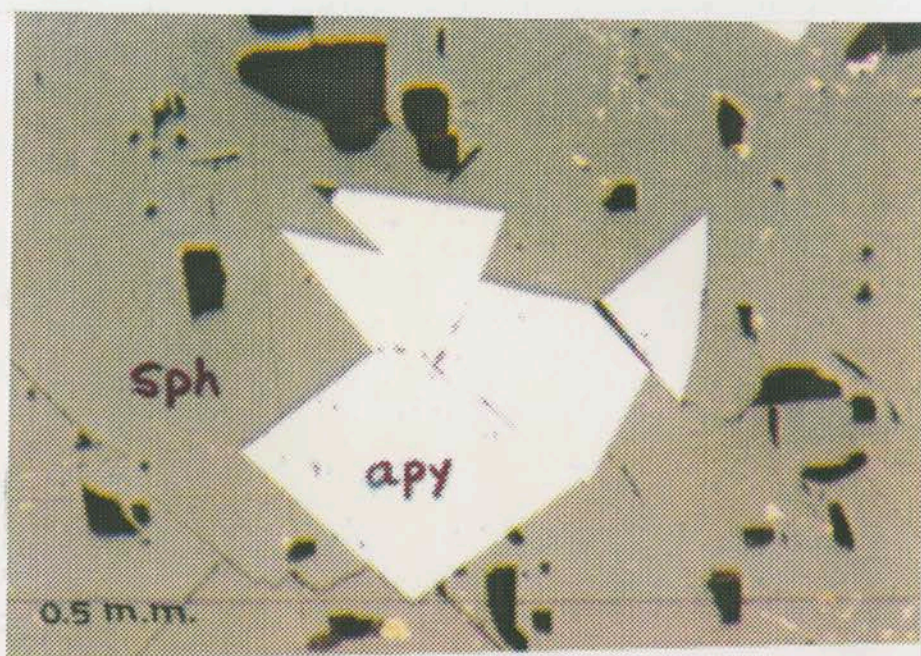
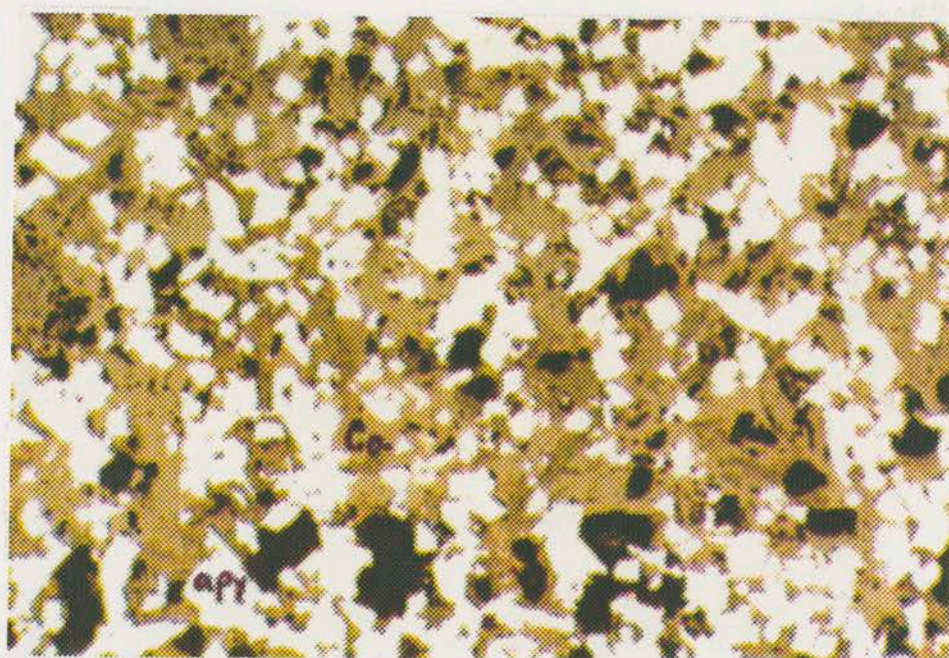


Figure 4.10 Photomicrograph of 100852-D sample showing arsenopyrite crystals (apy) growing within calcite (Ca). Field of view 0.5 mm.



Chalcopyrite: This mineral occurs in small quantities, and as an accessory mineral. Its crystals are usually anhedral and mixed with gangue minerals. Chalcopyrite associated with gangue minerals commonly occurs around Py1 crystals. It replaces Py1 crystals and occupies interstitial spaces. In addition, this mineral may occur along intra-grain contacts within Py1 and pyrrhotite crystals (Fig. 4.11).

Chalcopyrite replaces arsenopyrite, and fills interstices between arsenopyrite crystals. It penetrates sphalerite and thick pyrrhotite crystals. When associated with calcite, it replaces sphalerite, and fills interstitial spaces among euhedral quartz crystals. This mineral may also be intergrown with chlorite.

Other occurrences of chalcopyrite exhibit grains and rods of chalcopyrite within sphalerite. The former may sometimes be concentrated in nuclei of sphalerite crystals. Chalcopyrite may occur as strings oriented along cleavage inside sphalerite. This type of occurrence is called “chalcopyrite Disease” Craig and Vaughan (1994). In this specific case chalcopyrite occurs as a replacement event subsequent to sphalerite formation (Fig. 4.12). Chalcopyrite fills spaces within microfractures of Py1 and sphalerite caused by tectonic activity (Fig. 4.13).

Gold: Gold occurs in amounts smaller than the accessory minerals. It may occur within gangue minerals. Its crystals may be anhedral, or with irregular round edges (Fig 4.14).

There are a variety of occurrences for this native mineral: as a replacement of Py1, as a replacement of Py1 on its cleavage planes; associated with polybasite and as a

Figure 4.11 Photomicrograph of 100869-A sample showing chalcopyrite between early pyrite (Py1) and pyrrhotite (Po) crystals (apy). Also, chalcopyrite replacing early pyrite. Field of view 1.0 mm.

Figure 4.12 Photomicrograph of 100644-C-1 sample showing a globular chalcopyrite crystals (Cpy) within sphalerite (Sph) as “chalcopyrite disease.” Field of view 1.0 mm.

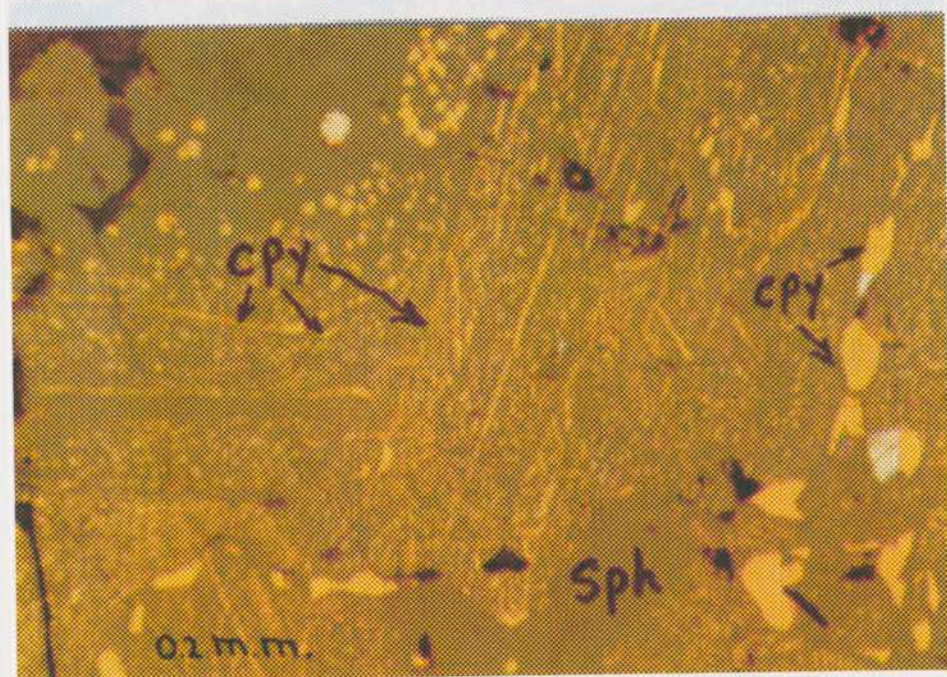
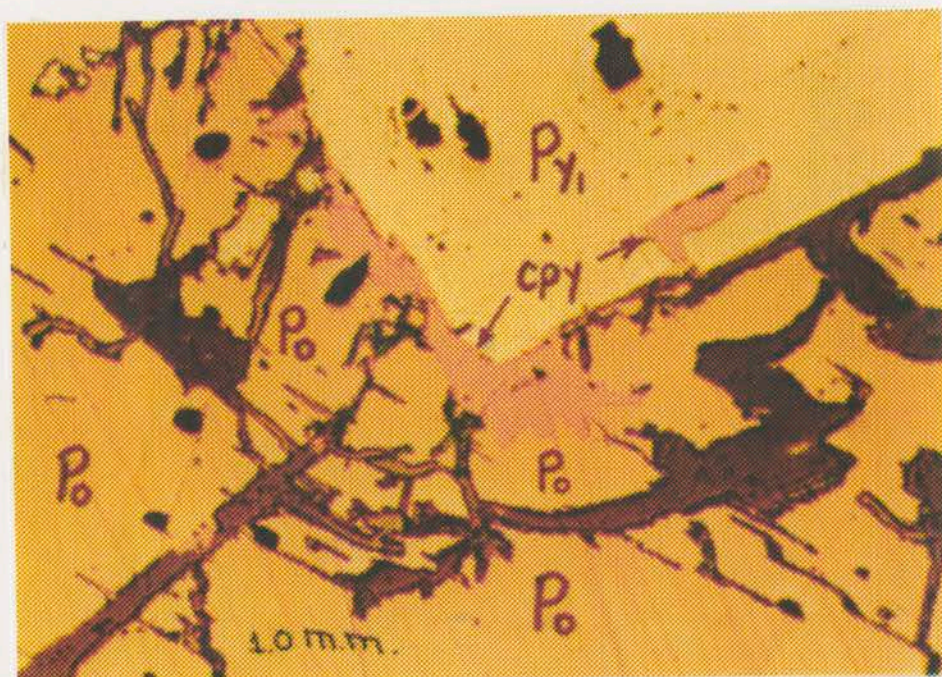
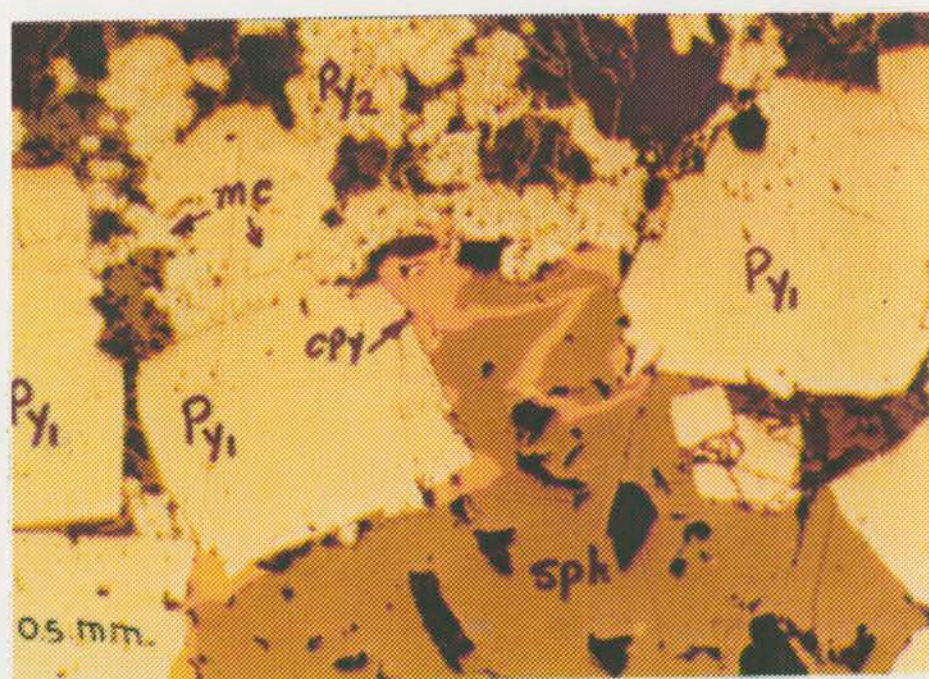


Figure 4.13 Photomicrograph of 100612-B sample showing chalcopyrite (Cpy) filling microfractures in sphalerite. Field of view 0.2 mm.

Figure 4.14 Photomicrograph of 100540-A sample showing subhedral gold crystal (Au) within early pyrite (Py1). Field of view 0.5 mm.

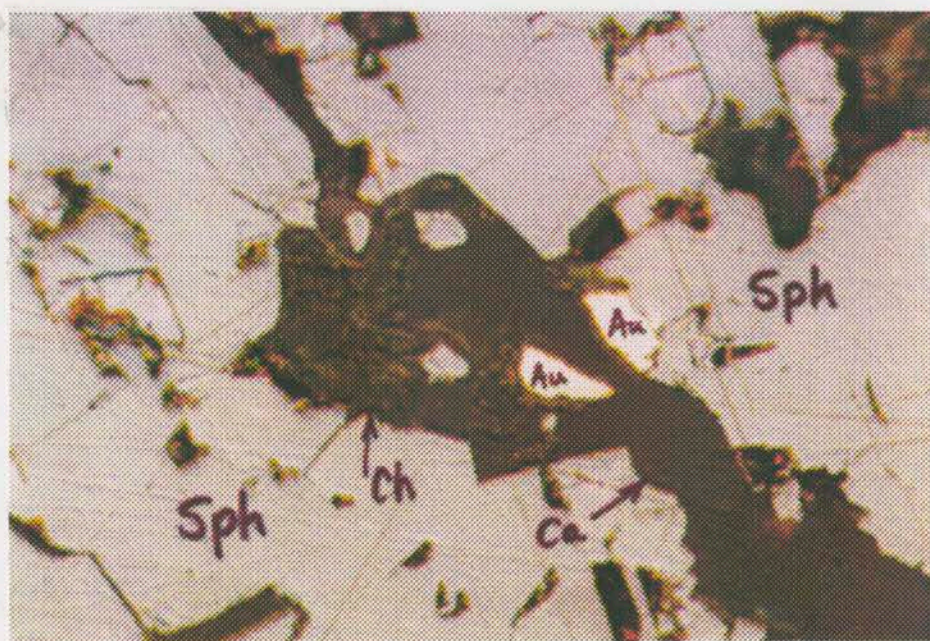


replacement of Py1; as a replacement along intra-granular contacts between Py1 crystals, where this occurs, gold may or may not be associated with polybasite; filling up spaces between Py1 and sphalerite contacts; inside interstitial spaces within Py1 crystals; associated with calcite, and replacing some Py1; associated with chalcopryite; within Py1 crystals, and as a replacement for Py1 crystals; associated with chalcopryite, and along Py1 crystals' contacts; filling up spaces between sphalerite and Py2; inside sphalerite crystals; associated with chlorite; penetrating sphalerite within crystals; inside calcite crystals; associated with quartz, within small cavities of Py1; associated with gangue minerals, within arsenopyrite crystals; associated with Py1 crystals that may have been affected by tectonic events in several ways; associated with calcite filling open spaces in sphalerite (Fig. 4.15); associated with thick pyrrhotite and calcite intergrown crystals coming from the first depositional event; associated with galena, within Py1 crystals. where present within Py1 crystals, gold exhibits round grains.

All of the above observations indicate that the gold was deposited at La Maruja level during all three stages. However, this mineral is particularly abundant in between the intermediate and late stages of deposition.

Sphalerite: This mineral is subordinate to Py1 in abundance. Sphalerite is abundant locally, and it exhibits comb textures typically banded by sphalerite and Py1 crystals. Sphalerite bands may reach a thickness of 3 cm. In many places sphalerite is relatively free of spherical chalcopryite inclusions. Nevertheless, it may occur with abundant inclusions of chalcopryite as “chalcopryite disease”(Fig. 4.12).

Figure 4.15 Photomicrograph of 100740-B sample showing gold crystal (Au) associated with calcite (Ca) and chlorite (Ch) filling open spaces in sphalerite (Sph). Field of view 0.2 mm.



Sphalerite in polished section shows the following relations and textures: occurs as a replacement of Py1, replaces coarse pyrrhotite, replaces arsenopyrite where arsenopyrite shows atoll texture (Fig. 4.9), fills up interstitial spaces between arsenopyrite crystals, develops mutual spatial relationships with chalcopyrite. It is replaced by chalcopyrite, and traversed by gangue minerals.

Galena: This mineral usually occurs as an accessory on La Maruja level. Its characteristic fine-grained texture makes it almost impossible to identify with certainty in hand sample.

Galena in polished section shows the following features: occupies interstitial spaces between P1 crystals; adapts to Py1 skeletal structure, shows coarse globular habit along intra-granular contacts between Py1 crystals. Where galena replaces sphalerite crystals, it may be associated with chalcopyrite. It replaces chalcopyrite, pyrrhotite and euhedral crystals of arsenopyrite. Galena is replaced by calcite and supergene minerals (Fig. 4.16).

The above observations indicate that Galena was deposited late in the sequence of deposition on La Maruja level.

Polybasite: A small amount of this mineral is present on La Maruja level.

In polished section polybasite shows the following features: replaces Py1 (Fig. 4.17), pyrrhotite, arsenopyrite, and sphalerite. When associated with galena, polybasite replaces Py1. Polybasite is associated with chalcopyrite and quartz. In some places polybasite invades Py1 crystals along cleavage and intragranular contacts (Fig. 4.18) and may be associated with gold. Where it is associated with calcite, it fills interstitial spaces between Py1 crystals. In

Figure 4.16 Photomicrograph of 100867-B sample showing calcite (Ca) replacing galena (Ga) along cleavage plane. Field of view 1.0 mm.

Figure 4.17 Photomicrograph of 100747-A sample showing polybasite (Pb) replacing early pyrite along cleavage plane. Also, calcite (Ca) replaces polybasite. Field of view 0.5 mm.

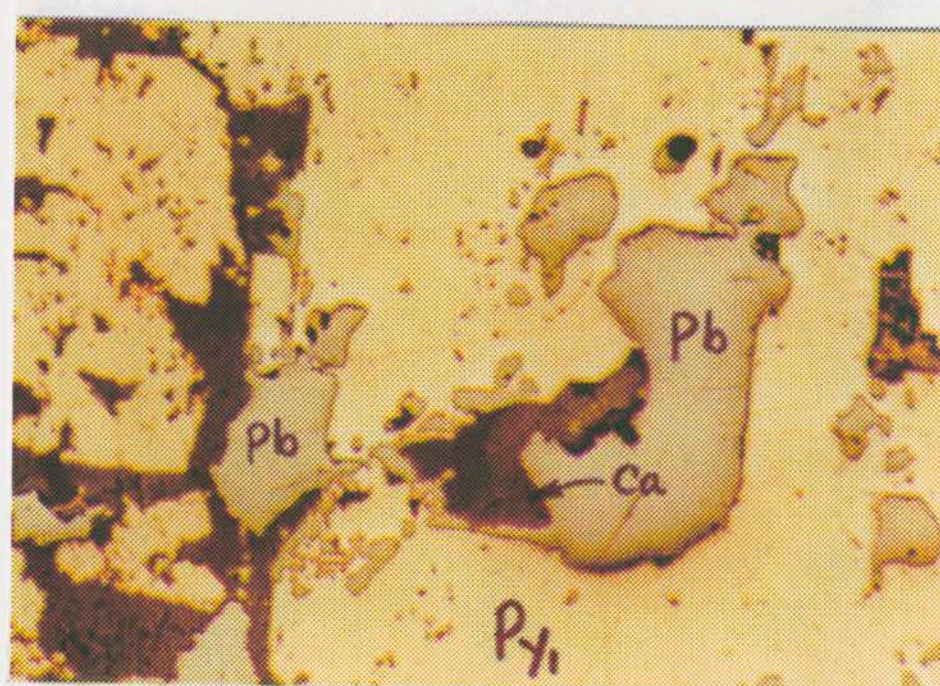
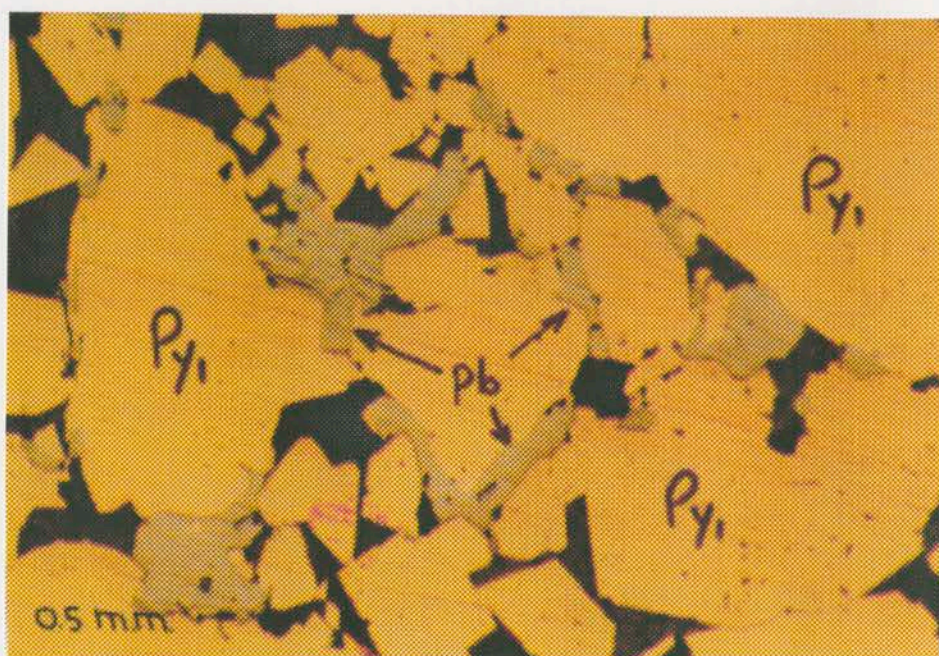


Figure 4.18 Photomicrograph of 100855-A-1 sample showing polybasite (Pb) filling intragranular spaces between early pyrite crystals (Py1). Field of view 0.5 mm.



this case, polybasite may have been deposited before Py2.

All of the above observations indicate that polybasite was deposited somewhat late within the paragenetic sequence.

Marcasite: It is a minor accessory mineral at La Maruja level, commonly present in fine-grained euhedral crystals.

In polished sections marcasite exhibits the following features: occurs along cleavage planes of Py1 crystals (Fig. 4.19) and as a crystal intergrowth with Py2. Marcasite fills interstitial spaces between Py1 crystals and also it penetrates Py1 crystals (Fig 4.20). In some places, marcasite replaces pyrrhotite and rhombic arsenopyrite. It is deposited within calcite crystals, filling fractures in sphalerite.

All of the above observations indicate that marcasite was deposited somewhat late within the paragenetic sequence.

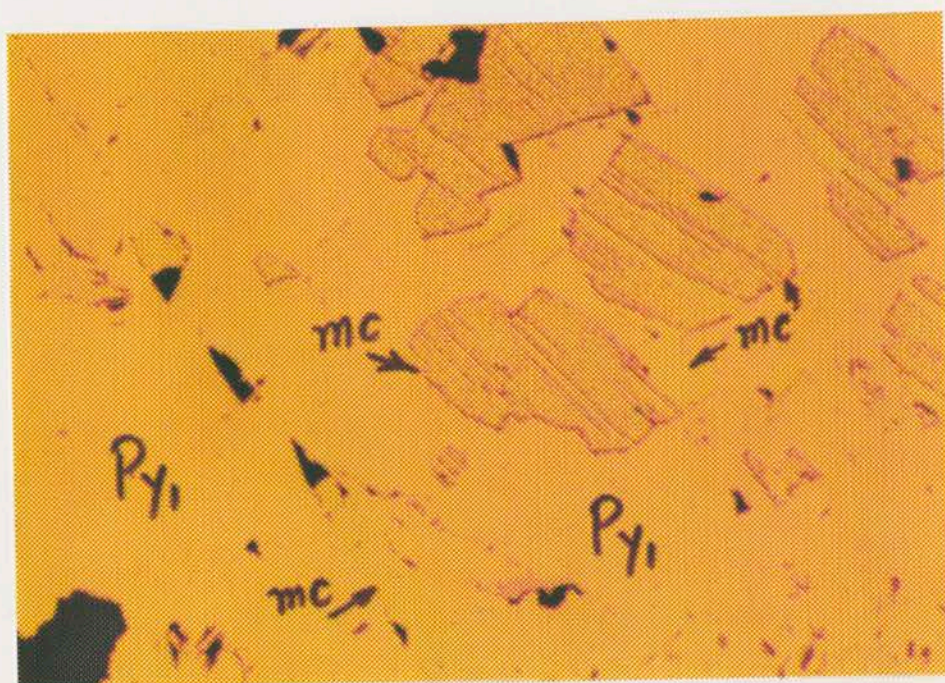
Gangue Minerals: the principal gangue minerals identified on La Maruja level include calcite, quartz and chlorite.

Calcite was deposited from the early to late stages of mineralization on la Maruja level. Early calcite is directly related to Py1. This association may have occurred simultaneously with veinlets that travel through the host rock. These veins are described in the section related to hydrothermal alteration.

Early to intermediate calcite fills interstitial spaces between Py1 crystals intergrown with arsenopyrite. At intermediate to late stages calcite replaces Py1, pyrrhotite, sphalerite and galena. It fills microfractures in chalcopyrite and replaces it. Also, it fills microfractures

Figure 4.19 Photomicrograph of 100856-B-2 sample showing marcasite (mc) development along cleavage plane of early pyrite (Py1). Field of view 0.5 mm.

Figure 4.20 Photomicrograph of 100851-A-2 sample showing finegrained marcasite (mc) filling interstitial spaces between early pyrite (Py1), and also replaces it. Field of view 0.2 mm.



in sphalerite. In some places, calcite associated with Py1 or Py2 fill interstitial spaces between early, euhedral quartz crystals.

Quartz: Its distribution is much like calcite but in minor amounts, quartz has been deposited from the early to late stages of mineralization on La Maruja Level.

In hand samples, polished sections and thin sections, quartz shows the following features: euhedral quartz crystals replace and are replaced by almost all the minerals present in the paragenetic sequence (Fig. 4.21). It invades sphalerite and in some places is associated with calcite and chlorite. When associated with calcite, quartz grows on Py1 crystals, fills spaces between P1, and fills microfractures in Py1 aggregates.

Chlorite: Chlorite and some calcite grow in the latest stages of gangue minerals. In hand samples, polished sections and thin sections, chlorite shows the following features: where associated with late calcite, chlorite replaces arsenopyrite. It replaces intermediate to late calcite. It fills interstitial spaces between intermediate and late stage quartz crystals and replaces it. Vermiform chlorite fills microfractures in sphalerite.

Figure 4.21 Photomicrograph of 100849-A sample showing late pyrite (Py2) filling spaces between early to intermediated euhedral quartz crystals. Field of view 0.5 mm.



Paragenetic Sequence

The paragenetic diagram for La Maruja level was deduced from observations taken from polished sections, hand sample analysis, and direct analysis from the main excavation tunnel and veins (Fig. 4.1). Deposition of ore and gangue minerals in this level occurred in three different stages: early, intermediate, and late.

The early stage is characterized by abundant deposition of coarse euhedral Py1 crystals. Py1 associated with calcite is not only deposited within the vein, but also penetrates the host rock resulting in pyritization. The host rock exhibits pyritization with masses of pyrite cubic crystals precipitated along joint planes, forming veins, veinlets, and micro-veins. Py1 is preceded by pyrrhotite deposition. Evidence of this fact is the presence of early pyrite replacing pyrrhotite along cleavage, and also in some places as random distribution within pyrrhotite. Deposition of coarse pyrrhotite ends by the middle early stage.

At the end of the early stage, deposition of coarse arsenopyrite occurs, exhibiting in some places net contacts with Py1, indicating co-precipitation of these two minerals. Small amounts of chalcopyrite appear to be directly associated with Py1. Gold is present in early pyrite, and fills open spaces or occurs along cleavage, indicating that it was deposited during the early stage of the paragenetic sequence. Moreover, gold was not observed in polished sections taken from the surrounding rock.

There is a transition between early and late pyrite stages represented by increasing amounts of associated coarse arsenopyrite. Sphalerite appears also in this intermediate

stage, and coarse pyrite occurrence decreases. In addition, this stage does not show evidence of simultaneous deposition of early pyrite and sphalerite. Sphalerite seems to replace Py1 in all samples collected. The boundary between early and intermediate stages is represented by the presence of sphalerite and the end of Py1 deposition. Great amounts of coarse arsenopyrite were deposited at the beginning of the intermediate stage.

Chalcopyrite associated with arsenopyrite is basically absent in the intermediate stage. Chalcopyrite occurs as “chalcopyrite disease” in sphalerite. This fact indicates that this particular occurrence of chalcopyrite takes place in the later part of the Intermediate stage. Sphalerite associated with arsenopyrite does not contain any included or any exsolved globular chalcopyrite. Furthermore, deposition of gold occurs also at the end of the intermediate stage and is associated with all minerals present.

Quartz is detected in all of stages and is associated with arsenopyrite, sphalerite, and coarse pyrite. Calcite deposition occurs throughout the intermediate stage. Tectonic activity ends the intermediate stage, having an effect on the minerals deposited during early and intermediate stages. The effect is shown through fragmentation, microfractures, and microbrecciated textures, along with the end of deposition of sphalerite.

Deposition of most gangue minerals with sulfides, and gold occurs during the late stage of the paragenetic sequence. Chalcopyrite deposition increases in this stage and fills microfractures caused by tectonic activity and replaces pre-existing minerals. Its predominance is evident over fine-grained pyrite, galena, gold, polybasite, and marcasite. Mineralization of the late stage is driven by a hydrothermal fluid rich in copper; this is

different from the previous stages where it was driven by a hydrothermal fluid which deposited mostly pyrite, arsenopyrite, and pyrrhotite.

The late stage is characterized by a short period of fine-grained pyrite deposition which ends with great amounts of calcite and chlorite deposition at the middle part of this stage. Marcasite deposition occurs in association with fine-grained pyrite, at the end of the stage. Chalcopyrite, gold, galena, polybasite, and quartz deposition occur during the first and middle parts of this stage. They end their deposition a little before the end of this stage. Chlorite and calcite deposition occurs at the end of the late stage in greater amounts.

In short, La Maruja level seems to have had three stages of mineralization. The early stage is characterized by abundant deposition of pyrrhotite, pyrite and arsenopyrite. The intermediated stage is characterized by abundant deposition of sphalerite. Fine-grained pyrite, galena, polybasite, marcasite, gold, some quartz and minor amounts of calcite and chlorite were deposited in the late stage. Tectonic activity ends the intermediate stage, having an effect on the minerals deposited during early and intermediate stages. Gold was deposited in all of stages.

HYDROTHERMAL ALTERATION

La Maruja level contains several types of hydrothermal alterations (Map. 2). Mineralogy, textures, and relative intensity of phenocryst and matrix replacements have been the parameters of classification of the alteration type. The suggestions of Rose and Burt (1979) were utilized to define of the various alteration classes.

Alteration products of plagioclase and ferromagnesian phenocrysts are enumerated in order of abundance. Terms describing the major alteration products that are used include “sericitic” and “propylitic”. The modifiers strong, moderate and weak are used to indicate the relative intensities of hydrothermal alteration.

When the essential minerals are written in uppcase, it means that such minerals are approximately equal in abundance; if one of the minerals is written in lowercase it indicates that it is essential to the association of alteration products but that its relative abundance to the other mineral is minor.

The alteration types in La Maruja level include (Map 2): Silicic, Strong Sericitic (SERICITE-QUARTZ associations, SERICITE associations, SERICITE- CARBONATE association), Moderate Sericitic (SERICITE associations, SERICITE-CARBONATE association, SERICITE- Carbonate association), Weak Sericitic (SERICITE associations, SERICITE-CARBONATE association), Propylitic (CHLORITE-CALCITE associations,

EPIDOTE-CHLORITE, EPIDOTE [$\pm$ CHLORITE- CALCITE] association), Albitic.

SILICIC ALTERATION

This association was observed adjacent to the Porvenir, Santa Inés and Múcura veins and also in some places along La Maruja crosscut. In all these cases, the silicification is intimately related to a zone of strong sericitic alteration (SERICITE-QUARTZ association), which is described below. Silicification extends for a few tens of centimeters along the veins and locally along La Maruja crosscut for 3 or 4 meters

This type of alteration is distinguished where about 70% or more of plagioclase phenocrysts are altered to quartz-sericite and 90% or more of ferromagnesian minerals are altered to sericite-quartz-chlorite, and abundant secondary quartz associated with sericite is developed in the matrix. The silicified rock is white to white-grey, very hard, heavy, and the original porphyry texture has been completely destroyed. In some places this rock looks like some varieties of chert.

This type of alteration is characterized by the development of secondary quartz, and lesser amounts of sericite and pyrite. Chlorite and calcite are not common minerals in this association. Where the amount of secondary quartz decreased the alteration is defined by the SERICITE- QUARTZ association in the strong sericitic alteration.

Secondary quartz replaces plagioclase phenocrysts, occurring along grain boundaries and in their interiors. In ferromagnesian phenocrysts the secondary quartz forms nets that generally are located along cleavage. In the matrix, secondary quartz occurs as anhedral to subhedral crystals, in some places with prismatic form and in variety of textures like

mosaic, reticular, mesh, and xenomorphic (Fig. 5.1).

In this alteration sericite replaces plagioclase and ferromagnesian phenocrysts. In the latter, sericite is located along cleavage and also around the border or nucleus of the crystals. In the matrix, leaves of sericite between secondary and primary quartz are commonly found. Also, sericite replaces microcrysts of plagioclase and with secondary quartz forms nets textures in the matrix.

Chlorite replaces ferromagnesian phenocrysts. In thin section chlorite shows intense green color, strong pleochroism and anomalous blue interference color, which corresponds to the magnesium-rich variety Saggerson and Turner (1982). Small leaves of chlorite commonly are associated with sericite replacing plagioclase. On other hand, nets of quartz-sericite-pyrite-chlorite or pyrite-chlorite are found in the matrix.

Disseminated cubes and aggregates of pyrite crystals are found within both phenocrysts and matrix. Fine-grained subhedral pyrite occurs along the cleavage of ferromagnesian minerals and is locally present around the border of biotite and hornblende.

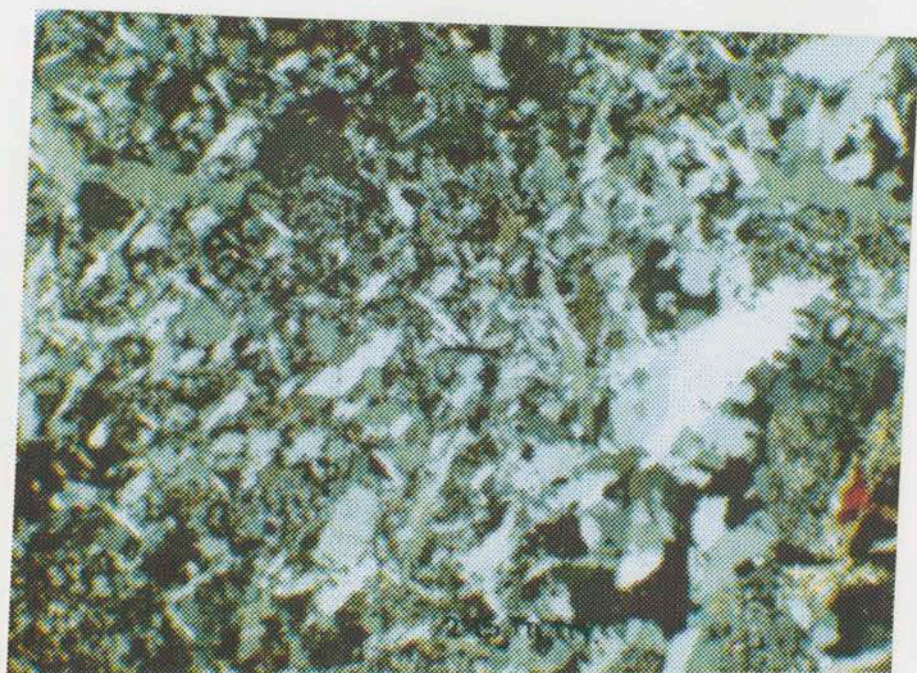
In the silicic alteration it is common to find veins, veinlets and nets with the following composition: quartz-pyrite-sphalerite $\pm$ sericite $\pm$ calcite, quartz-sericite, quartz-chlorite $\pm$ sericite-pyrite, quartz-pyrite $\pm$ albite and calcite-pyrite $\pm$ quartz. Some of these veins and veinlets exhibit very sharp contact with the host rock, and they may have formed after silicification took place (Fig. 5.2).

STRONG SERICITIC ALTERATION

Strong sericitic alteration (strong seritization) is denominated when 70% or more of

Figure 5.1 Photomicrograph of sample number 100722 showing subhedral secondary quartz in a reticulate texture within the matrix. Crossed nicols. Field of view 2.75 mm.

Figure 5.2 Photomicrograph of sample number 100583 showing quartz-sericite vein in silicified zone. Crossed nicols. Field of view 2.75 mm.



plagioclase phenocrysts have been replaced by sericite, and ferromagnesian minerals show a weak to moderate sericitization.

SERICITE- QUARTZ association.

This association was observed in several places along the La Maruja crosscut, and inside all veins of La Maruja level (Map 2). This type of alteration is characterized by the development of abundant sericite associated with quartz and minor amounts of carbonate.

Where the amount of secondary quartz increases the SERICITE-QUARTZ association grades to silicification, and where the amount of secondary quartz decreases, this association grades to SERICITIC association in the strong sericitic alteration. Also, if the intensity of alteration decreases, the alteration grades laterally to a weak sericite alteration.

The length of exposure of SERICITIC-QUARTZ association in the strong sericitic alteration was not determined in all the study places where it was present. However, in some areas along La Maruja crosscut the length of exposure extends along the wall rock to distances as much as 1.5 meters. There is a special case in La Maruja crosscut between the portal and the Sin Nombre vein where the SERICITIC-QUARTZ association has a exposure of 5 meters.

The SERICITIC-QUARTZ association rock is gray, and the original porphyry texture is partially preserved. In some places, where there is a transition from SERICITIC-QUARTZ association to silicic alteration, or where the association of alteration is located in a strong shear zone, the phenocrysts are no longer recognized and the rock is massive.

Sericite and quartz are the most common minerals in this association of alteration. Lesser amounts of chlorite and pyrite are also present. Calcite is not a common mineral in this association. Sericite replaces ferromagnesian and plagioclase phenocrysts and also occurs mixed within the matrix. When sericite replaces plagioclase or ferromagnesian phenocrysts it shows a random distribution. In a strongly sericitized zone, up to 100% of the phenocrysts are replaced by sericite (Fig. 5.3).

In some places, where sericite associated with chlorite replaces ferromagnesian crystals they show a net texture or are located along the cleavage or the replacement extends from the border toward the nucleus and vice versa (Fig. 5.4). In the matrix, sericite occupies the interstitial spaces between quartz grains, generating a crisscross quartz-sericite texture, and also replacing original microcrysts of plagioclase and quartz (Fig. 5.5). In cases of stronger sericitization, sericite develops nets of sericite or sericite-quartz within the matrix.

Secondary quartz occurs as aggregates and anhedral grains within sericitized plagioclase phenocrysts and the matrix. Where secondary quartz occurs inside plagioclase and ferromagnesian phenocrysts it can be associated with fine-grained pyrite and sericite. These sericite-quartz-pyrite occurrences are similar to those that Creasy (1966) refers to as QSP alteration.

Chlorite replaces plagioclase and ferromagnesian phenocrysts and is also present in the matrix where it shows a nets texture with secondary quartz, fine-grained cubic pyrite and sericite (Fig. 5.6). Very fine subhedral to anhedral pyrite crystals that are located along cleavage and the border of biotite are observed as alteration products. Medium size

Figure 5.3 Photomicrograph of sample number 100908 showing sericite (Se) replacement of a plagioclase phenocryst in a random orientation. In this case, abundant sericite is present and 100% of the phenocryst is replaced by sericite. Crossed nicols and plane light. Field of view 0.440 mm.

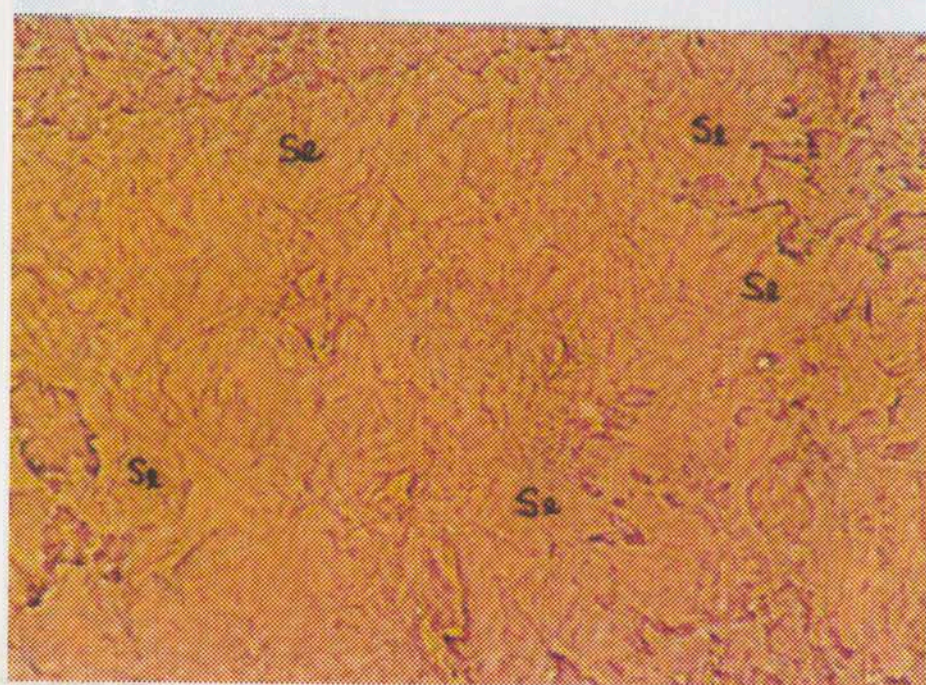
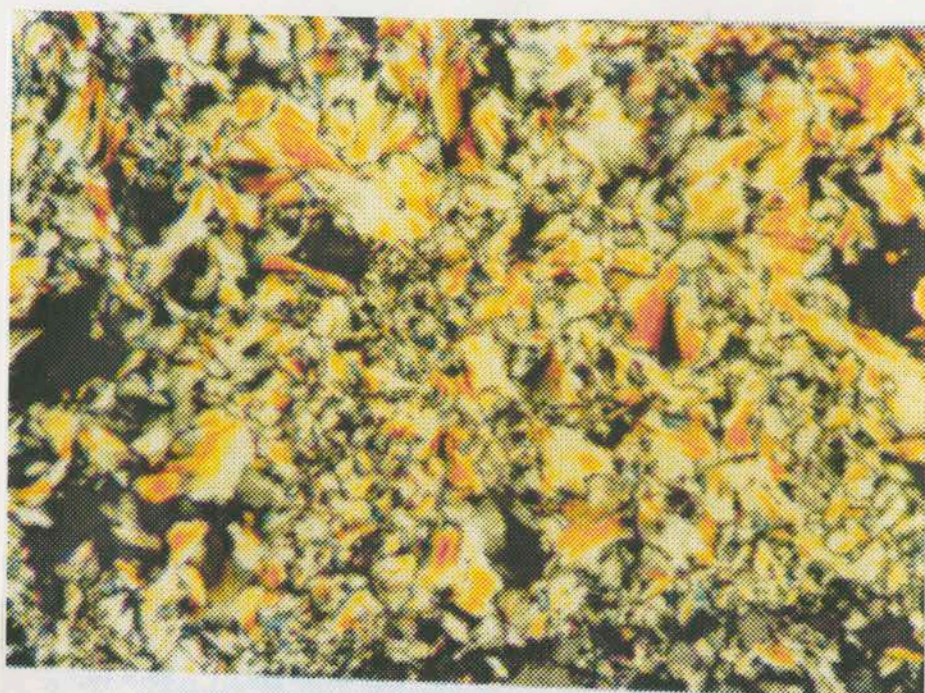


Figure 5.4 Photomicrograph of sample number 100904 showing sericite (Se) associated with chlorite (Ch) and pyrite (Py) developed in a biotite phenocryst along cleavage planes. Crossed nicols and plane light. Field of view 1.1 mm.

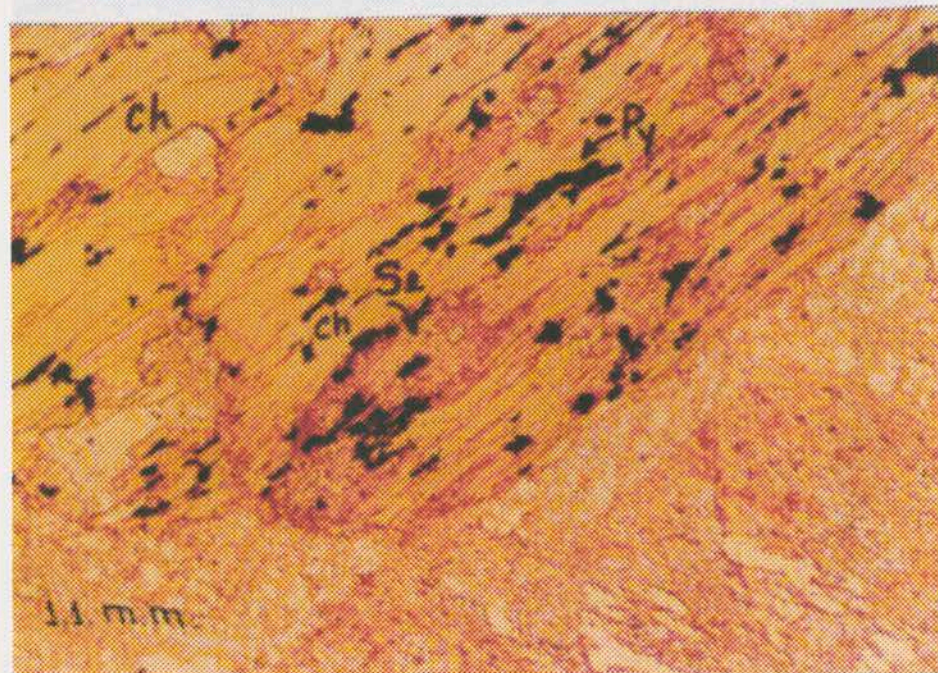
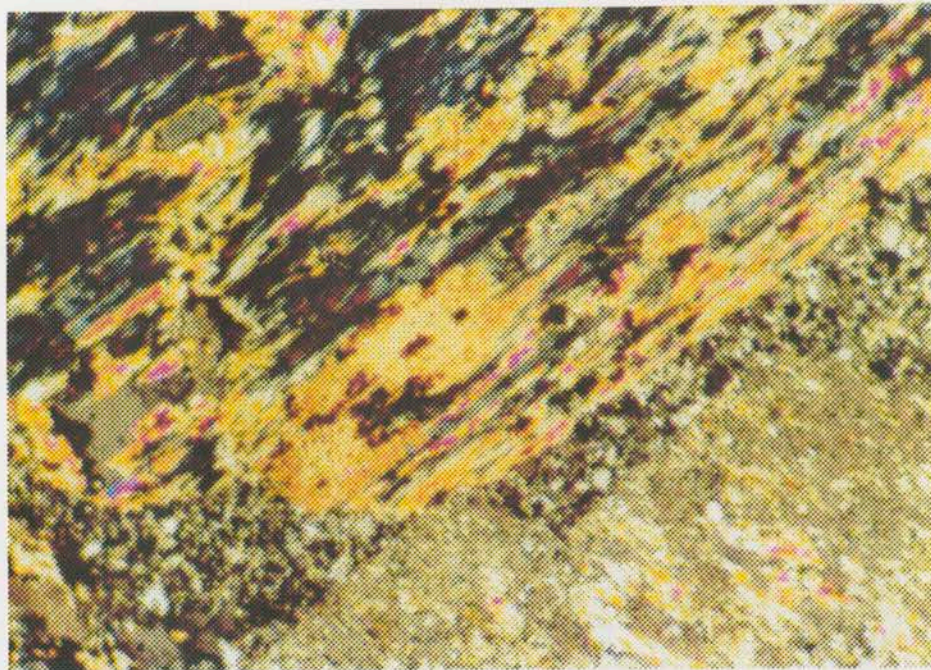


Figure 5.5 Photomicrograph of sample number 100909 showing sericite (Se) in the interstitial spaces between quartz grains (Q), generating a crisscross quartz-sericite texture, and also it is replacing original microcrysts of quartz. Crossed nicols. Field of view 0.44 mm.

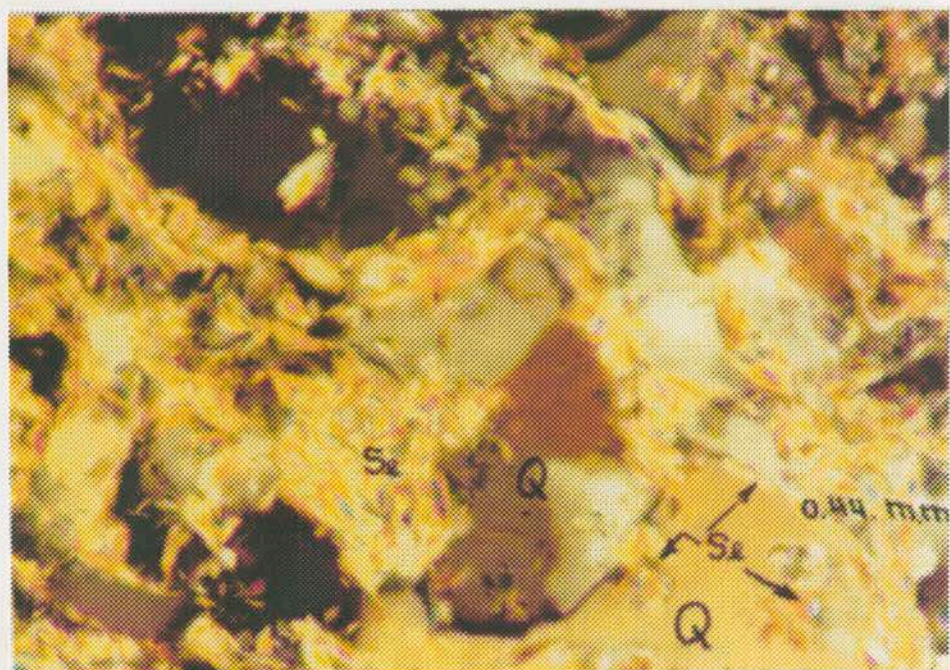
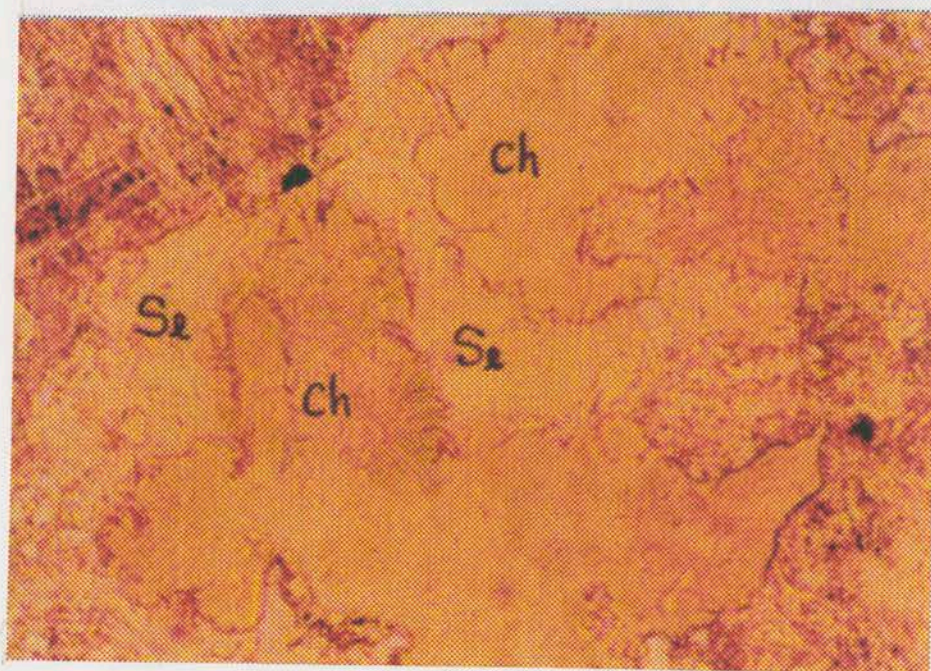
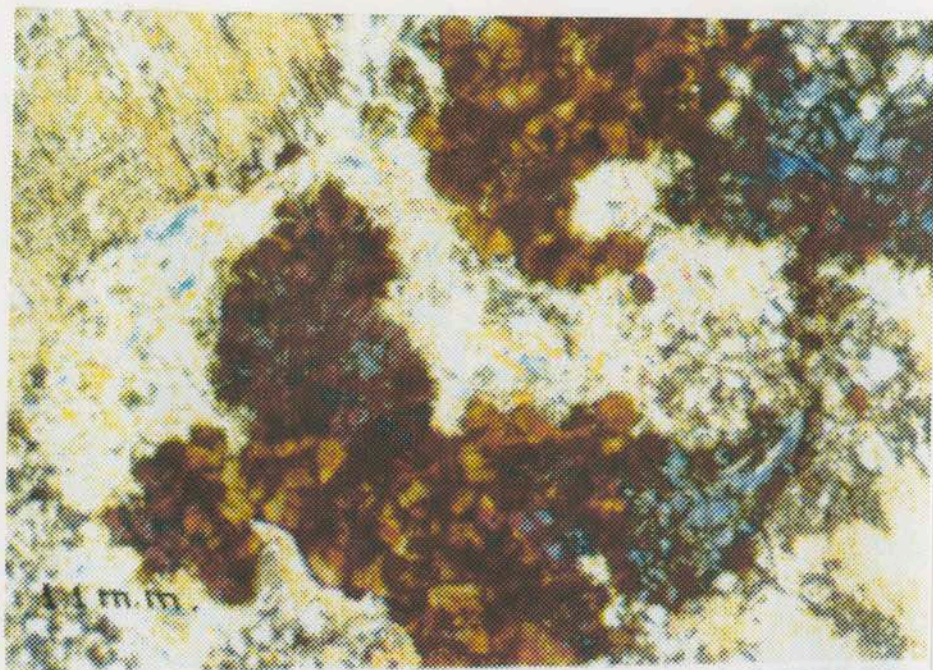


Figure 5.6 Photomicrograph of sample number 100904 showing sericite (Se) associated with chlorite (Ch) in a nest texture within the matrix. Crossed nicols and plane light . Field of view 1.1 mm.



grains of pyrite are commonly found within phenocrysts and matrix. In some places quartz phenocrysts are replaced by the pyrite grains. The intensities of this pyritization is strong to moderate (approximately 5% to 7%). Where pyritization is present in the matrix it shows a nets texture of pyrite and/or pyrite- secondary quartz. In hand samples from pyritized zones it is common to find pyrite crystals that range in size from 5 to 7 mm.

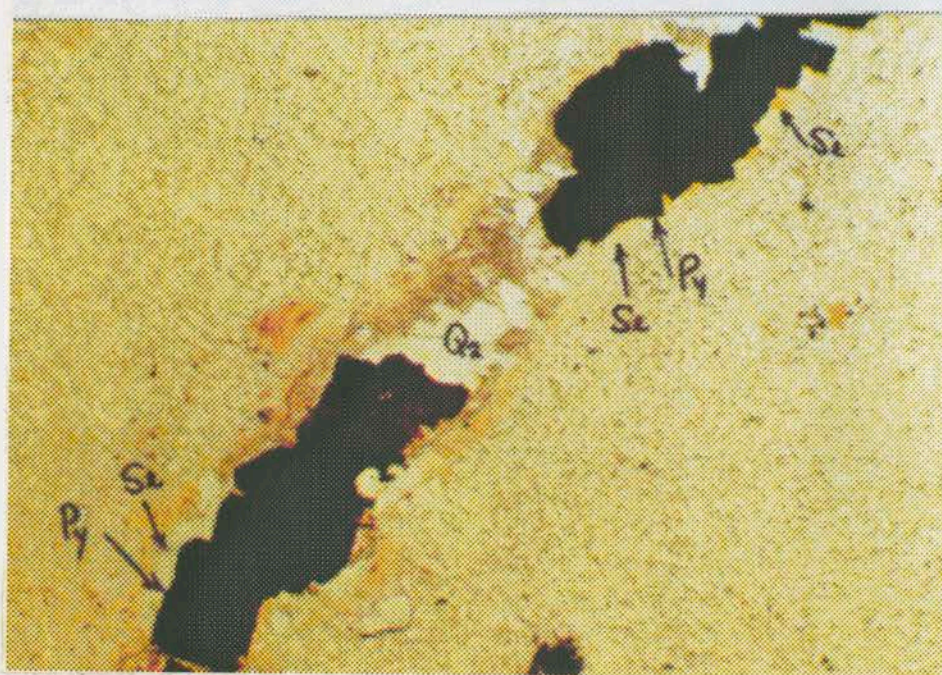
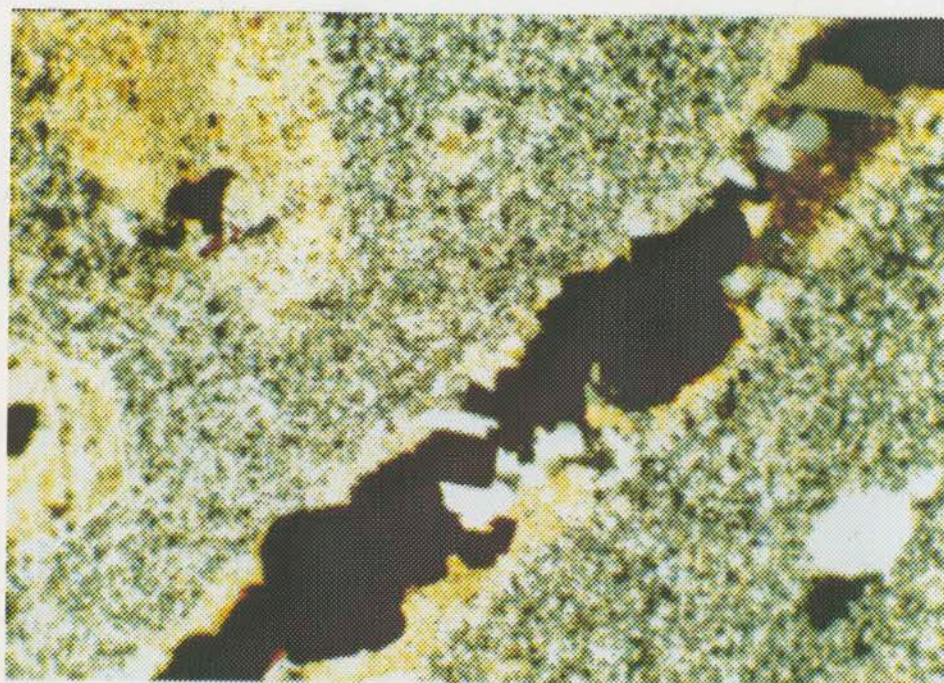
In the SERICITE-QUARTZ association it is common to find veins and veinlets with the following composition: quartz- pyrite $\pm$ sericite, quartz-sericite, and quartz (Fig. 5.7). In some places these veins and veinlets show a gradational contact with the quartz-sericitic matrix. On the other hand, there are veins and veinlets composed of calcite-quartz-pyrite $\pm$ sphalerite, quartz-pyrite $\pm$ calcite $\pm$ chlorite $\pm$ sericite, calcite-pyrite, chlorite-pyrite-quartz-sericite $\pm$ calcite, quartz-pyrite-sphalerite-sericite, and quartz-sericite-pyrite-albite $\pm$ chlorite that cut the matrix and phenocrysts and exhibit a sharp contact with surrounding rock. The sharp contact indicates that the veins and veinlets were probably formed after hydrothermal alteration occurred.

SERICITE association

This association is a variation of the SERICITE-QUARTZ association within the strong sericitic alteration. If these two associations are compared, both are characterized by the development of abundant sericite. However, secondary quartz and chlorite are more abundant in SERICITE-QUARTZ association than in the SERICITE association.

This association is present in La Maruja crosscut as well as in Santa Inès, and in minor amounts in Porvenir, Sin Nombre and Múcura veins. In the Santa Inès vein this

Figure 5.7 Photomicrograph of sample number 100815 showing a quartz (Q)-pyrite (Py) veinlet with a sericite (Se) selvage in the wallrock. Crossed nicols and plane light . Field of view 1.1 mm.



association is more abundant than the SERICITE-QUARTZ association (Map 2). Where the amount of secondary quartz increases, the SERICITE association passes to the SERICITE-QUARTZ association. If there is a decrease in the amount of sericite, the association passes to moderate sericitization without carbonate.

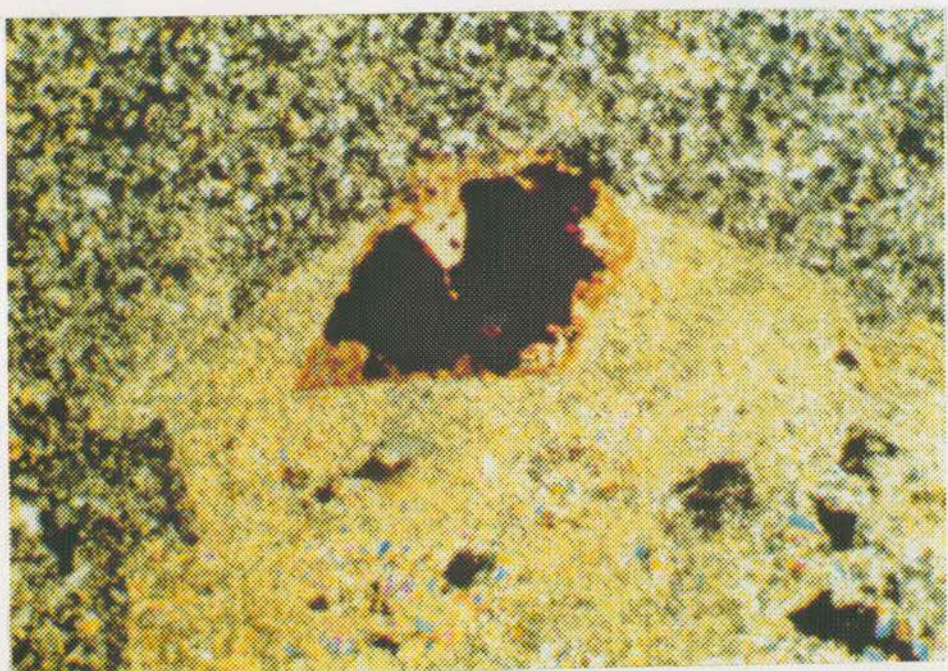
SERICITE association takes place where about 70% or more of plagioclase and ferromagnesian phenocrysts are altered to sericite. The length of exposure of the SERICITE association along the veins range from a few centimeters to 1.2 meters. The sericitized rock is massive and gray to gray-white in color.

Sericite and chlorite are the most common minerals in this association. Quartz and pyrite are present in minor amounts and calcite is an accessory mineral. The sericite replaces phenocrysts of plagioclase and ferromagnesian as well as the matrix in a random distribution. Next to the veins this replacement can be more than 95% (Fig. 5.8), and plagioclase phenocrysts exhibit minor amounts of fine secondary quartz crystals which are associated with fine-grain pyrite. In some thin sections, sericite replaces and is associated with secondary chlorite inside of ferromagnesian phenocrysts. These replacements occur on the grain boundaries and in their interior and indicate that chlorite replacement preceded sericite.

In the matrix, sericite is located between quartz crystals and has also replaced microcrystals of plagioclase and quartz. In some places, where sericitization is as much as 95% of the rock the sericite-quartz association shows a nest texture inside of the matrix.

Chlorite replaces ferromagnesian phenocrysts. In the matrix chlorite occurs as clots, and in some places it replaces phenocrysts and fine grains of primary and secondary quartz

Figure 5.8 Photomicrograph of sample number 100585 showing more than 95% sericite replacing a plagioclase phenocryst. Crossed nicols. Field of view 1.1 mm.



In these clots, chlorite is associated with quartz and quartz-sericite-pyrite.

The pyritization in this association is moderate. Pyrite occurs as isolated or aggregate cubes that in some places are associated with quartz and/or calcite. Fine-grained euhedral pyrite occurs along the cleavage of ferromagnesian crystals and is locally present around the borders of biotite. In this case pyrite is formed from the mix of Fe from biotite and S from hydrothermal fluid. Fine-grained pyrite fills fractures in quartz crystals. Rutile is present as an alteration product of biotite. Where present it exhibits a prismatic, sagenetic habit.

In the SERICITIC association it is common to find veins and veinlets with the following composition: quartz-pyrite-sericite±chlorite, quartz-pyrite, quartz, quartz-pyrite-chlorite-calcite, calcite, quartz-pyrite-sphalerite-chlorite, and calcite-sphalerite (Fig. 5.9). Some of these associations are also developed as nets in the matrix: for example, quartz, quartz-pyrite, quartz-chlorite-pyrite, chlorite-sphalerite, chlorite-pyrite-sphalerite, calcite-pyrite, quartz-sericite-pyrite-chlorite.

SERICITE-CARBONATE association

This association is characterized by sericite and calcite as essential alteration minerals. The SERICITE-CARBONATE association in the strong alteration is present in the east zone of La Maruja level. This association is almost absent in the Santa Inés and Múcura veins (Map 2). In some places, the SERICITE-CARBONATE association seems to overlap a previous propylitic altered rock. This is indicated by the persistent remains of epidote/zoisite within plagioclase and ferromagnesian phenocrysts.

This type of alteration takes place where 70% or more of plagioclase phenocrysts

Figure 5.9 Photomicrograph of sample number 100781 showing a veinlet of quartz (Q₂)-sphalerite (Sph)-pyrite (Py)-chlorite (Ch). Plane light. Field of view 1.1 mm.



are altered to sericite-calcite, sericite and calcite are abundant in the matrix, and ferromagnesian crystals show a moderate to strong alteration to sericite-calcite.

Where the amount of calcite decreases this association grades to the SERICITE association. If there is a simultaneous decrease in the amounts of sericite and calcite, it is able to grade to a SERICITE-CARBONATE association in the weak sericitic alteration. Along La Maruja crosscut the length of exposure of this association can measure up to 5 meters.

The altered rock is dense, and has a gray to white-gray color. Sericite, calcite and chlorite are the most common minerals. Pyrite and quartz are present in small amounts. Sericite associated with calcite replace plagioclase phenocrysts (Fig. 5.10). In some places up to 80% of the plagioclase phenocrysts are replaced by calcite, and between 15%-20% by sericite. In all cases this replacement occurs along cleavage or from the nucleus to the borders of the crystals or vice versa. In ferromagnesian sites, sericite is associated with chlorite and they can show elongated aggregates with a random distribution or may be located along cleavage. Fine and coarse sericite are abundant within the matrix. They occur between quartz crystals and as replacement of plagioclase.

In the SERICITE-CARBONATE association, small elongated aggregates of calcite can be found along cleavage or in a random distribution within phenocrysts of plagioclase and ferromagnesian minerals. In the matrix, anhedral to subhedral masses of calcite are common (Fig. 5.11). They are associated with chlorite and/or sericite and exhibit a acicular radial or rosette texture.

Figure 5.10 Photomicrograph of sample number 100781 showing sericite (Se) associated with chlorite (Ch), calcite (Ca) and pyrite (Py) replacing a plagioclase phenocryst. Crossed nicols and plane light. Field of view 1.1 mm.

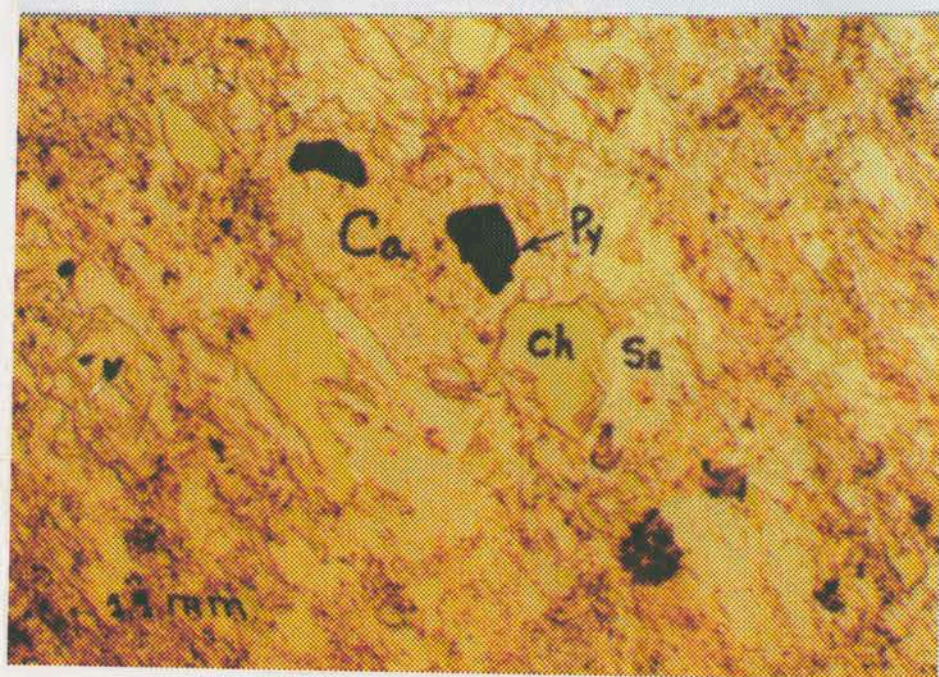
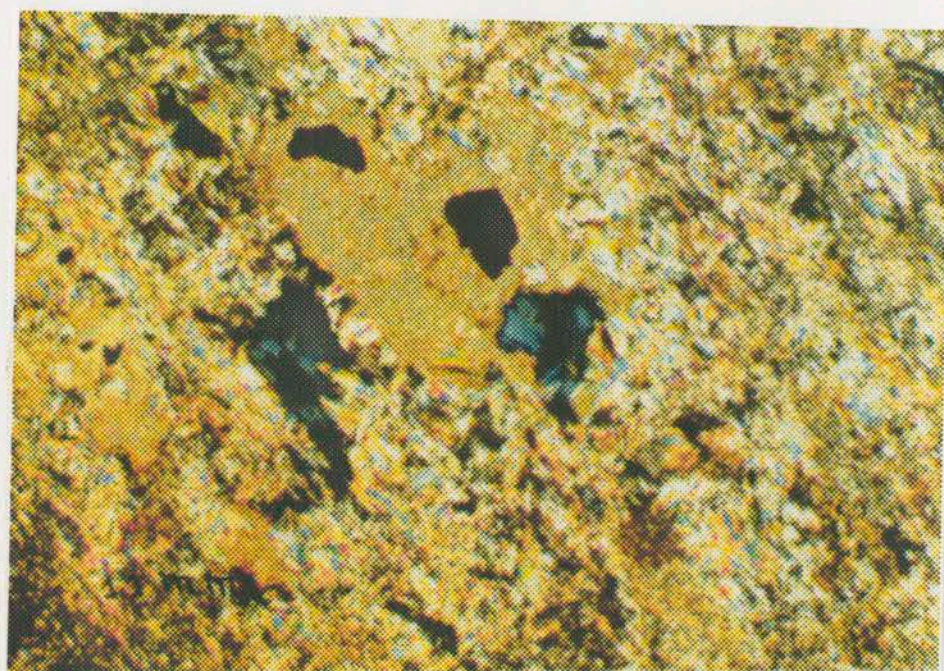
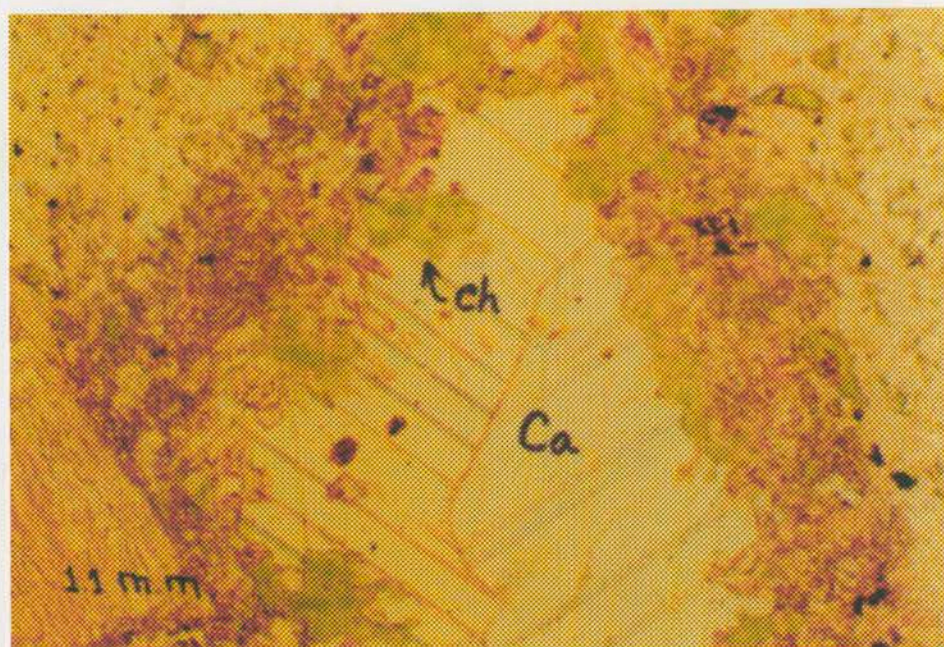


Figure 5.11 Photomicrograph of sample number 100532 showing mass of calcite (Ca) associated with chlorite (ch) and replacing matrix. Plane light. Field of view 1.1 mm.



Chlorite is produced as an alteration product of phenocrysts and matrix. In the SERICITE-CARBONATE association the chlorite is the Mg-rich variety. In the matrix, chlorite appear as specks, random in size and with an irregular external contour.

It is common to find fine cubic grains of pyrite along the cleavage of ferromagnesian phenocrysts in the SERICITE-CARBONATE association. Also, medium grains of cubic pyrite are present as disseminated crystals in the matrix. This pyrite can form irregular strong to weak pyritized zones in the wall rock. In the matrix pyrite can be associated with calcite, chlorite and secondary quartz. Where this occurs it show a nets texture in the matrix.

Secondary quartz occurs in the matrix as nest in form. Anhedral to subhedral secondary quartz which is intergrown with calcite, and associated with sericite, are present in the plagioclase phenocrysts.

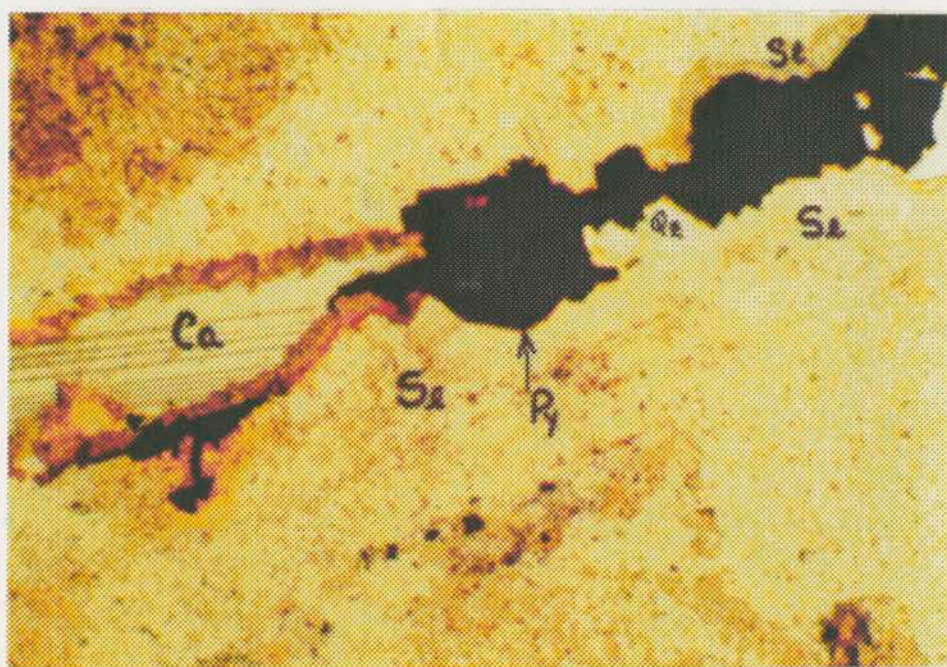
Rutile is present as an alteration product of biotite. Where present it exhibits a prismatic habit that ranges from acicular to reticular in form.

In the CARBONATE-SERICITE alteration it is common to find veins and veinlets with the following composition: calcite-sericite-pyrite $\pm$ quartz (Fig. 5.12), quartz-sericite-pyrite, calcite-pyrite, and calcite-sericite-sphalerite-pyre $\pm$ quartz, and calcite. All these veins and veinlets cut the matrix and/or phenocrysts and show sharp contact with surrounding rock. The sharp contact indicates that the veins and veinlets were probably formed after hydrothermal alteration occurred.

MODERATE SERICITIC ALTERATION

This alteration take place where altered plagioclase phenocrysts contain 40% to 70%

Figure 5.12 Photomicrograph of sample number 100821 showing quartz (Q)-sericite (Se)-pyrite (Py)-calcite (Ca) veinlet. Plane light. Field of view 1.1 mm.



sericite and ferromagnesian minerals show a weak replacement by sericite.

SERICITE association

This association is characterized by the presence of sericite and chlorite as essential minerals. Quartz and pyrite are present in lesser amounts and calcite is not a common mineral in this association.

The SERICITE association was especially observed adjacent to the Santa Inés and Múcura veins, and also along La Maruja crosscut that connects the Santa Inés and Porvenir veins. In these places SERICITE association is dominant over all the other types of associations present. In a minor extension, the SERICITE association was detected in the Porvenir vein and the tunnel that connects the Sin Nombre and Porvenir veins (Map 2).

Where the amount of sericite decreases the SERICITE association grades to a weak sericite alteration without carbonate. If the amount of sericite increases, this association grades to the SERICITE association within the strong sericitic alteration.

SERICITE association takes place where 40-50% of the plagioclase phenocrysts are altered to sericite, and ferromagnesian minerals exhibit a weak replacement by sericite. In this alteration it is common to find unaltered plagioclase microcrysts within the matrix.

The length of exposure of the SERICITE association extends along the wallrock to distances of as much as 1.2 meters. Locally, it can reach a total exposure of about 8 meters. This occurs where the wall rock is intensely fractured. The altered rock is dense, gray in color, and shows its original porphyry texture.

Sericite and chlorite are the most common minerals in this type of association.

Quartz and pyrite occur in lesser amounts.

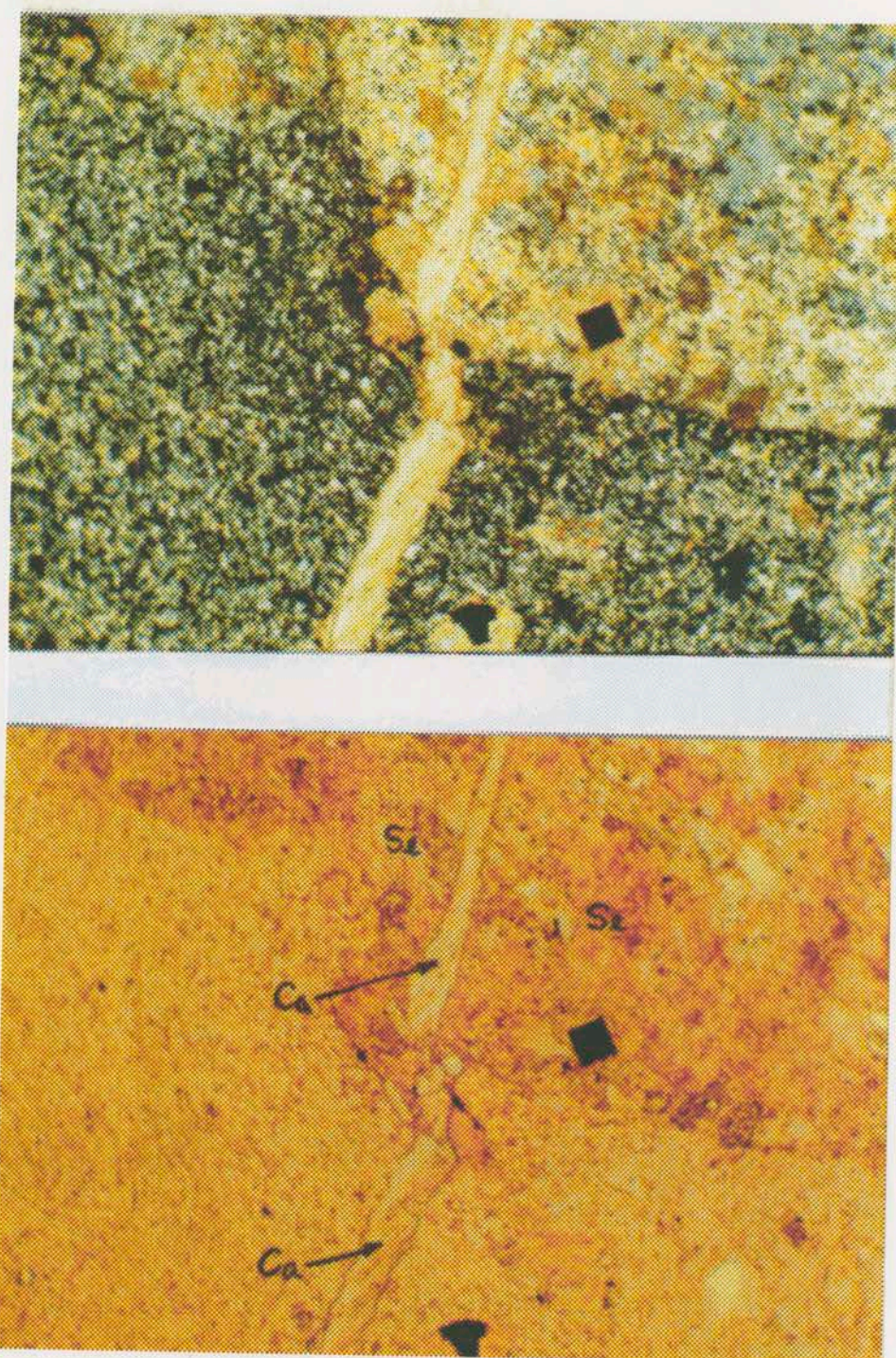
Sericite replaces plagioclase phenocrysts. In some places, the sericite occurs in association with cubic pyrite, small platy chlorite, and aggregates of secondary quartz. In ferromagnesian minerals sericite is present in small amounts, or it can be completely absent. Sericite is also present in minor amounts in the matrix. Where it is present, it is located between quartz grains, or surrounding plagioclase crystals. Also, sericite can be found within the matrix as veins and veinlets.

It is common to find Mg-rich chlorite in the SERICITE association. Where it occurs it has replaced ferromagnesian crystals along the cleavage and/or in a random distribution. In some places chlorite is associated with fine grains of cubic pyrite and secondary quartz. In the matrix, chlorite is found filling open spaces between secondary quartz and/or is associated with secondary quartz±pyrite. Where this appears it exhibits a net texture within the matrix.

Secondary quartz occurs as aggregates of anhedral crystals in plagioclase phenocrysts. Secondary quartz associated with chlorite is common in the ferromagnesian phenocrysts, and to a smaller extent in plagioclase and the matrix.

In the SERICITE association it is common to find veins and veinlets of the following composition: quartz-pyre±sericite, chlorite-pyrite-quartz, quartz-pyrite and quartz. These veins and veinlets show a gradational contact with the matrix. The gradational contact indicates that the veins and veinlets were probably formed when the hydrothermal alteration occurred. On the other hand, veins and veinlets of calcite (Fig. 5.13), sphalerite-pyrite-quartz,

Figure 5.13 Photomicrograph of sample number 100803 showing sericite (Se) replacement of a plagioclase phenocryst . Note late calcite veinlet (Ca) with sharp contact cutting matrix and phenocrysts. Crossed nicols and plane light. Field of view 1.1 mm.



calcite-chlorite-pyrite-quartz, and albite-chlorite-pyrite $\pm$ quartz $\pm$ sericite show a sharp contact with the surrounding rock. The sharp contact indicates that the veins and veinlets were probably formed after hydrothermal alteration occurred.

SERICITE-CARBONATE association

Sericite, calcite and chlorite are common in moderate amounts in this association. Quartz and pyrite are present in smaller amounts as accessory minerals.

The SERICITE-CARBONATE association was observed in several places along La Maruja crosscut and in the Sin Nombre and Porvenir veins. On the other hand, in the Santa Inès and Múcura veins this association has a very restricted distribution, and is generally absent (Map 2). This indicates that moderate sericitization in the SERICITE-CARBONATE association could be an external halo (not adjacent) to the veins in La Maruja level, and it particularly began between the Porvenir and Santa Inès veins.

This association grades to a moderate sericitic and propylitic alteration with an increase or decrease of sericite or calcite, respectively. This association takes place where 40-70% of the plagioclase phenocrysts are altered to sericite-calcite. Also, the ferromagnesian phenocrysts show a weak alteration to chlorite-calcite. In this alteration, the matrix shows minor amounts of calcite with an irregular form and sericite occurs as an accessory mineral between quartz crystals.

The altered rock is hard, massive, gray to a greenish-gray in color, and the porphyritic original texture is preserved. Sericite, calcite and chlorite are the most abundant minerals in this association. Pyrite and minor amount of secondary quartz are also present.

Sericite occurs as an alteration product of plagioclase phenocrysts. In general where it occurs, sericite shows a random distribution and is associated with calcite. In ferromagnesian phenocrysts sericite occurs as small leaves along cleavage planes. Fine grains of sericite occurs in minor amounts in the matrix filling the interstitial spaces between quartz crystals.

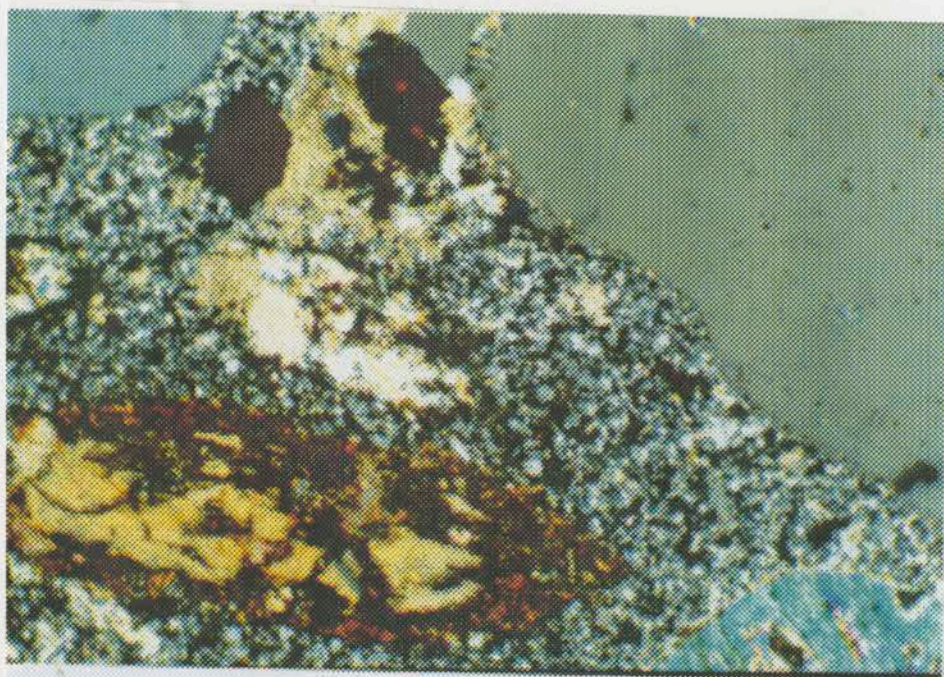
Calcite associated with sericite and chlorite occurs within the plagioclase and ferromagnesian phenocrysts (Fig 5.14). In some places it shows a nets texture inside of phenocrysts. In the matrix, calcite occurs in moderate to minor amounts as irregular fills in interstitial spaces between primary and secondary quartz. In some places calcite is associated with chlorite± pyrite and sericite that form irregular mass within the matrix.

In general, chlorite replaces 50-70% of ferromagnesian phenocrysts. Locally, it appears within plagioclase phenocrysts as small aggregates of fine leaves associated with sericite. In the matrix, it is common to find small specks or thick irregular masses of chlorite associated with quartz-sericite-pyrite with a random distribution.

Fine anhedral to subhedral pyrite crystals are common within ferromagnesian phenocrysts. Where it occurs, pyrite is located along cleavage planes and in the borders of the crystals (Fig. 5.14). The pyritization in this association is weak. Secondary quartz is present in minor amounts in phenocrysts and in the matrix. It is most commonly found in veins and veinlets, where it is associated with other minerals.

In the SERICITE-CARBONATE association it is common to find veins and veinlets which exhibit a gradational contact with the wallrock and have the following composition:

Figure 5.14 Photomicrograph of sample number 100537 showing calcite (Ca) associated with chlorite (Ch) in ferromagnesian phenocrysts. Also, pyrite (Py) is located along cleavage planes and in the borders of hornblende phenocrysts. Crossed nicols and plane light. Field of view 1.1 mm.



calcite, chlorite-calcite, chlorite $\pm$ pyrite, quartz $\pm$ calcite, quartz-sericite and calcite-pyrite. On the other hand, in the SERICITE-CARBONATE association there are veins and veinlets that exhibit a sharp contact with the wallrock and have the following composition: quartz-pyrite-sphalerite $\pm$ chlorite $\pm$ calcite $\pm$ sericite, sphalerite-calcite, pyrite-calcite, calcite-sphalerite-pyrite $\pm$ sericite.

SERICITE-carbonate association

This association is characterized by the development of moderate amounts of sericite and chlorite and minor amounts of calcite. Quartz and pyrite are accessory non-essential minerals.

The SERICITE-carbonate association occurs along La Maruja crosscut that connects the Sin Nombre and Porvenir veins. It is also present in some places along Múcura vein and locally adjacent to the Sin Nombre and Santa Inés veins (Map 2). Where the amounts of sericite decrease, the SERICITE-carbonate association grades to SERICITE-CARBONATE association in the weak sericitic alteration. If calcite is absent, it grades to a SERICITE association in the moderate sericitic alteration.

SERICITE association takes place where the plagioclase phenocrysts are altered to sericite-calcite, and ferromagnesian minerals are altered to chlorite-sericite-calcite by 40-70% and 50-60%, respectively. Also in the matrix, sericite, calcite and secondary quartz occur in minor amounts and as accessory minerals.

SERICITE-carbonate association is present as isolated zones adjacent to the veins. The length of exposure in this association can extend up to 30 meter along the vein. The

altered rock is a greenish-gray to dark gray color, dense, and the porphyritic texture is somewhat preserved.

Sericite, chlorite and calcite are common minerals in this association. Quartz and pyrite are present in minor amounts as accessory minerals.

In this association sericite is associated with minor amounts of chlorite and calcite replacing plagioclase phenocrysts. When sericite replaces ferromagnesian phenocrysts it is always present in lesser amounts than chlorite, and it is located along the cleavage planes (especially in biotite crystals). In the matrix, sericite occurs in minor amounts and is generally found between grains of primary quartz.

Magnesium-rich chlorite is the most common alteration mineral in the ferromagnesian phenocrysts. In some places, minor specks of chlorite are associated with calcite and pyrite within the matrix.

Minor amounts of calcite are within plagioclase and ferromagnesian phenocrysts. Calcite, in association with pyrite, is located on the border of the phenocrysts and shows a clear rim texture. A small amount of calcite is present in the matrix in small and irregular masses.

The degree of pyritization in this association of alteration is generally weak. In the SERICITE-carbonate association pyrite occurs in cube form as dissemination, that are usually surrounded by a thin halo of calcite. Fine subhedral to anhedral pyrite crystals associated with chlorite are present along the cleavage planes of the ferromagnesian phenocrysts.

Secondary quartz is locally observed as small nets inside of plagioclase phenocrysts and the matrix. Small veinlets of secondary quartz are also present in the host rock.

In the SERICITE-carbonate association it is common to find veins and veinlets near to the mineralized zones with the following composition: sericite-quartz $\pm$ pyrite $\pm$ chlorite $\pm$ calcite, and pyrite-calcite.

WEAK SERICITIC ALTERATION

This alteration takes place where 40% or less of the plagioclase phenocrysts are altered to sericite, and 40-50% of the ferromagnesian minerals are altered to chlorite.

SERICITE association

In this association sericite occurs in minor amounts. Chlorite is present in moderate amounts and pyrite and secondary quartz are accessory minerals. Calcite is practically absent, and where it appears, it is an accessory mineral.

This association was observed only in some places adjacent to the Múcura and Santa Inés veins. Only one occurrence was noticed in La Maruja crosscut (Map 2). Where the amounts of sericite decrease, this association grades into propylitic alteration with chlorite $\pm$ sericite. This association takes place where 40% or less of plagioclase phenocrysts are altered to sericite, as 40% to 50% of ferromagnesian are altered to chlorite, and the matrix exhibit a very weak alteration.

The length of exposure of this association can measure as much as 2 meters wide. A special case is located in the western zone of the Múcura vein, where the SERICITE association exhibit a length of exposure along the vein of 20 meters. The altered rock is a

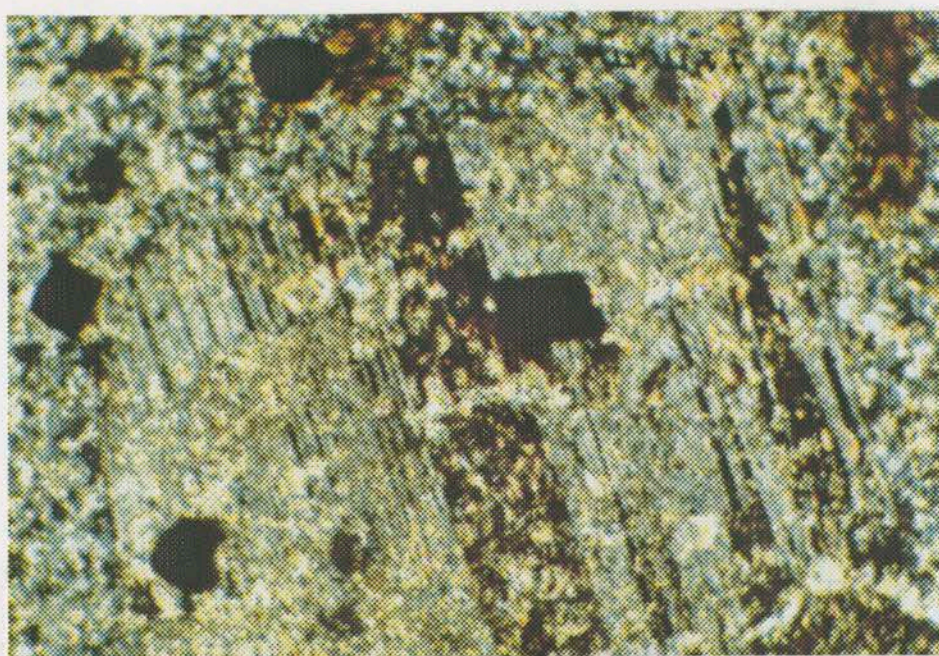
dark green to gray color, dense, and the porphyry texture is preserved. Chlorite and sericite are essential minerals in this association of alteration, and quartz and pyrite are non-essential accessories.

Sericite partially replaces plagioclase phenocrysts (Fig. 5.15), and in some places it is present in minor amounts within ferromagnesian minerals. In the matrix, sericite occurs as fine crystals that are located between grains of primary quartz and/or as stains on plagioclase microcrysts. Magnesium-rich chlorite partially replaces ferromagnesian phenocrysts. In some places, where it occurs, chlorite is associated with minor amounts of fine sericite and cubic pyrite that are localized along cleavage planes. Chlorite associated with pyrite also appears as specks in the matrix. In this association the pyrite grade is weak to absent. Minor veins and veinlets can be found in this association which are composed of quartz±pyrite±sericite and quartz-pyrite.

SERICITE-CARBONATE association

This association is characterized by minor amounts of sericite and calcite, and by moderate amounts of chlorite. Pyrite and quartz are present as accessory minerals. This association was only observed in three samples from the Sin Nombre, Santa Inés and Múcura veins. The SERICITE-CARBONATE association is located in the most distal positions from the veins (Map 2). Where the amounts of calcite decrease, this association grades to the SERICITE association in weak sericitic alteration. Where the amounts of sericite decrease and a simultaneous increment in calcite content appears, this association grades to a propylitic alteration.

Figure 5.15 Photomicrograph of sample number 100844 showing plagioclase phenocryst partially replaced by sericite. Crossed nicols. Field of view 1.1 mm.



This association takes place where less than 30%-40% of plagioclase phenocrysts are altered to sericite-calcite, about 60%-70% of ferromagnesian minerals are altered to chlorite, and the matrix shows a very weak alteration. Because the three studied samples are from three different places, one can not define the length of exposure of alteration. The altered rock conserves all the characteristics of the unaltered dacite.

Sericite, calcite and chlorite are the most common minerals in this association. Pyrite and quartz are present in minor amounts.

Sericite associated with calcite replaces plagioclase phenocrysts. In ferromagnesian minerals and the matrix, sericite is present in minor amounts. In the matrix it is common to find sericite associated with secondary quartz that is located between interstitial spaces of primary quartz.

Fine grains and irregular forms of calcite are present in phenocrysts and in the matrix. The pyrite content is low to absent. Where pyrite is present, it shows a cubic form as dissemination. On some localities, veins and veinlets of pyrite-sericite±chlorite±quartz and pyrite-calcite±quartz form a nets texture within the matrix.

PROPYLITIC ALTERATION

CHLORITE-CALCITE association.

This propylitic alteration is characterized by the development of large amounts of chlorite and calcite, with the absence of epidote and zoisite-clinzoisite. Pyrite and quartz can be found in minor amounts as accessory mineral.

This association was only detected in the western part of La Maruja level, and in La

Maruja crosscut, 100 meters to the east of the Sin Nombre vein (Map 2).

Where the epidote-zoisite minerals are presented this association changes to EPIDOTE association with $\pm$ chlorite $\pm$ calcite.

This alteration takes place where 40%-60% of plagioclase phenocrysts are altered to calcite with minor amounts of sericite and, where 60%-70% of ferromagnesian minerals are altered to chlorite or chlorite-calcite $\pm$ pyrite. Also, specks or nests of chlorite and/or chlorite-calcite $\pm$ quartz are present in the matrix.

The length of exposure of this association could not be established, but the spatial position of the studied samples and their classification in this association allows one to propose that CHLORITE-CALCITE association is a regional alteration that has spread along all of the eastern zone of La Maruja level.

The altered rock is dark gray, dense, and the porphyry texture of original rock is preserved. Chlorite and calcite are common minerals in this association. Quartz and pyrite appear as accessory minerals.

Magnesium-rich chlorite replaces the ferromagnesian phenocrysts. In the matrix, specks and leaves of chlorite $\pm$ calcite are common.

Calcite is an abundant alteration product in plagioclase phenocrysts. In ferromagnesian minerals calcite is associated with chlorite. In the matrix calcite occurs in large accumulations of thick masses that show very clear rhombohedral cleavage planes.

The pyritization is very weak in this association. Where pyrite occurs, it occurs as fine cubic crystals that are located along cleavage planes and/or in the borders of biotite.

Minor amounts of calcite-chlorite veins and veinlets are present in this association.

EPIDOTE-CHLORITE association

This association was observed only in one sample. The sample was derived from a location in La Maruja crosscut, 70 meters to the east of the Sin Nombre vein (Map 2). It shows that the EPIDOTE-CHLORITE association is a type of alteration that appears in distal positions from the mineralized zones. This alteration is characterized by abundant epidote (in both phenocrysts and matrix) and chlorite. Quartz and pyrite are present in minor amounts. Calcite is absent in this association.

This association takes place where 20%-40% of rock is altered to epidote±zoisite±clinozoisite (Fig 5.16). In some places the epidote can be as much as 90% of the rock and can be observed in hand sample. The altered rock is dark green to gray, hard, dense, and the original porphyry texture is preserved.

Displaying a random distribution and showing a nets texture, epidote and zoisite-clinozoisite±sericite have replaced the plagioclase phenocrysts (Fig. 5.17). In ferromagnesian phenocrysts it is common to find epidote-zoisite-clinozoisite±chlorite as alteration products. The association epidote, epidote-zoisite, epidote-quartz±pyrite and chlorite-epidote are commonly within the matrix. The intensity of replacement in plagioclase and ferromagnesian minerals can be so complete, that in some places it is very difficult to specify which was the original mineral. The abundance of pyrite in this association is low, and in some places, it is common to find veinlets of epidote-quartz.

Figure 5.16 Photomicrograph of sample number 100810 showing strong epidotization (epidote and zoisite (Zo)) in matrix and phenocrysts. Crossed nicols. Field of view 2.750 mm.

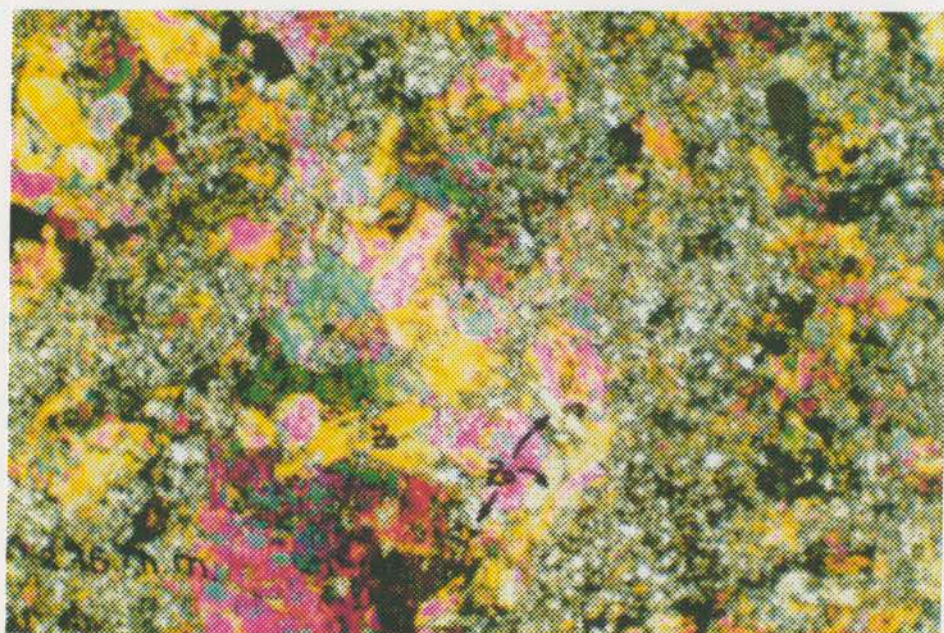
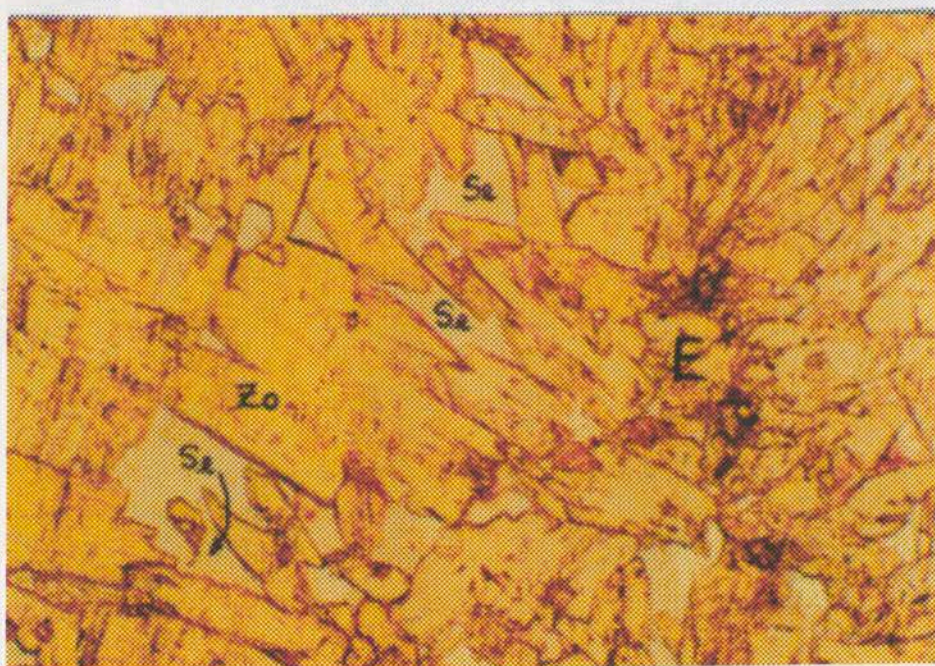
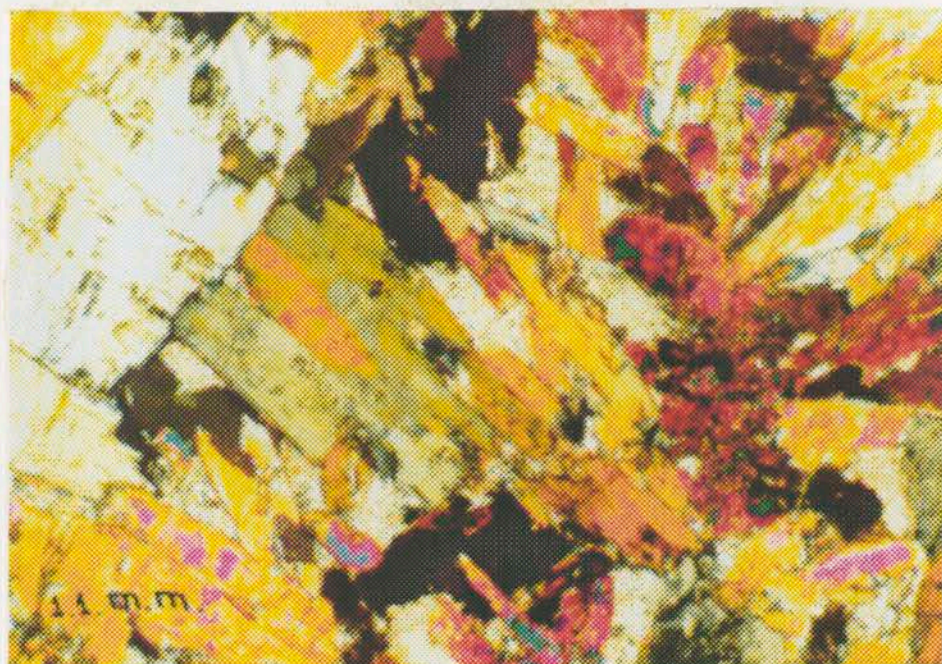


Figure 5.17 Photomicrograph of sample number 100810 showing epidote (E) and zoisite-clinozoisite (Zo) and minor amounts of sericite (Se) in a nest texture within plagioclase phenocrysts. Crossed nicols and plane light. Field of view 1.1 mm.



EPIDOTE- ($\pm$ CHLORITE-CALCITE) association

This association is characterized by the presence by abundant epidote, zoisite-clinozoisite, chlorite and calcite. Quartz and pyrite occur in minor amounts as accessory minerals. This association appears in some places of the outer boundaries of the Sin Nombre, Porvenir and Múcura veins (Map 2). Where the amount of calcite decreases, this association grades to the EPIDOTE-CHLORITE association.

Strong epidotization (epidote+ zoisite-clinozoisite) ranging from 20% to 40% is present in hand samples. Some thin sections exhibit 90%, to 100% of plagioclase phenocrysts that have been replaced by epidote, chlorite and calcite.

The length of exposure of this association extend along the veins to distances of up to 8 meters. The altered rock is greenish to gray, porphyritic, dense, and exhibit epidote nets that can be 5 mm in diameter.

Epidote, zoisite and calcite replace plagioclase. Where they occur, the alteration products exhibit a nest texture of thick euhedral crystals that are located within plagioclase.

Abundant magnesium chlorite associated with epidote and/or epidote-calcite replaces ferromagnesian minerals. Where this occurs in certain locations, the alteration products are located along cleavage planes. In some places, the ferromagnesian minerals are altered to chlorite+acicular rutile crystals.

In the matrix, it is common to find nest, disseminated bodies, veins and veinlets of epidote, calcite, quartz-epidote $\pm$ pyrite, calcite-chlorite, epidote-zoisite.

ALBITIC ALTERATION

Albite in minor amounts occurs within the above described alteration. This alteration occurs along the Santa Inés, Múcura, and Porvenir veins, and in La Maruja crosscut between the Sin Nombre and Porvenir veins (Map 2).

Albite is associated with almost all the ore minerals in veins and veinlets in the host rock (Fig. 5.18). The albite crystals are euhedral and do not show any type of alteration. In some places, albite replaced plagioclase phenocrysts. In ferromagnesian sites albite replaces it and is associated with fine cube pyrite and leaves of chlorite (Fig. 5.19). Albite is associated with sphalerite, chlorite, and secondary quartz replacing quartz phenocrysts from the border to the nucleus. In the matrix, albite can be present as a disseminated mineral. In some places albite is associated with chlorite, sphalerite-pyrite, chlorite-pyrite-quartz, sphalerite, and pyrite-calcite in the form of nets within the matrix.

SUMMARY

In short, at La Maruja level there is a zonal distribution of hydrothermal alteration minerals, particularly for the alteration assemblages where calcite is an essential mineral and present from moderate to abundant amounts (Map 5). The SERICITE-CARBONATE association in the strong and moderate sericitic alteration dominates in the eastern part of La Maruja level, where most of the rock samples contain calcite in moderate to abundant amounts. On the other hand to the west of the Porvenir vein the altered rock exhibits minor amounts of calcite. Nevertheless, calcite is an abundant gangue mineral in all four veins.

SERICITE association in the moderate sericitic alteration assemblage dominates at

Figure 5.18 Photomicrograph of sample number 100610 showing unaltered euhedral albite crystals (Ab) associated with pyrite (Py) in a vein. Crossed nicols and plane light. Field of view 1.1 mm.

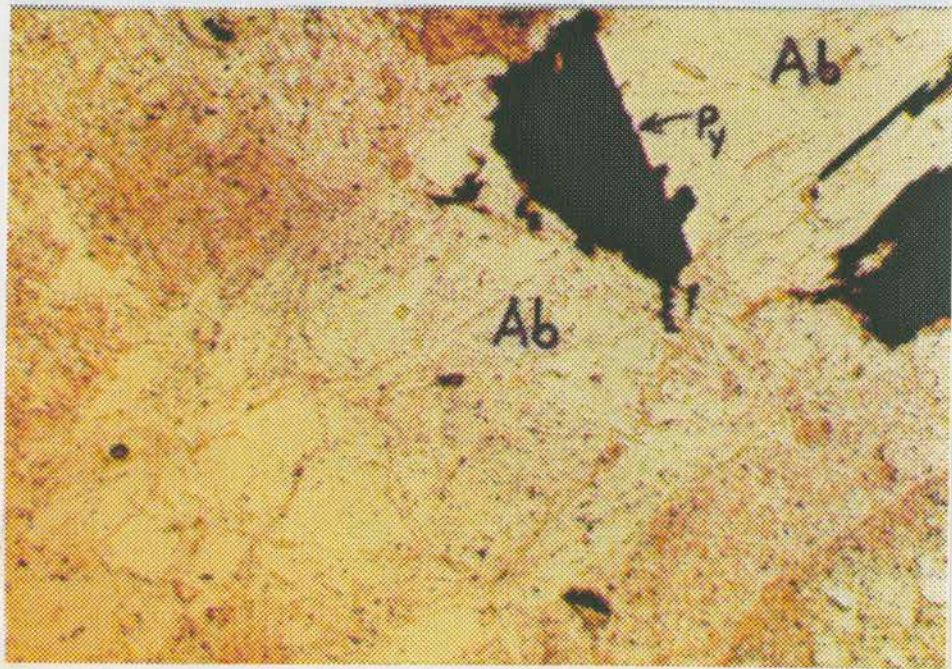
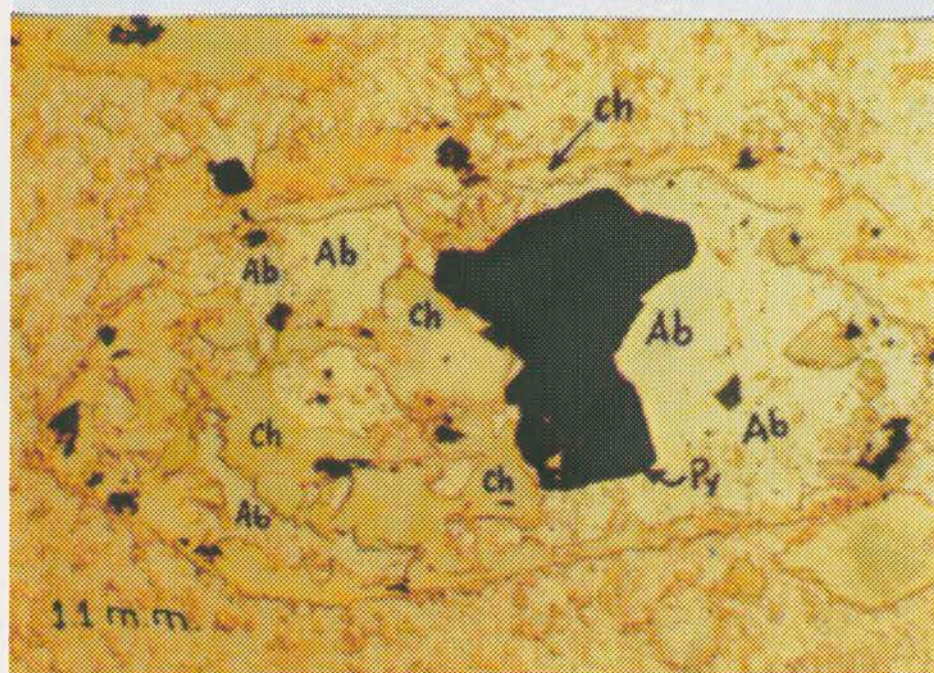
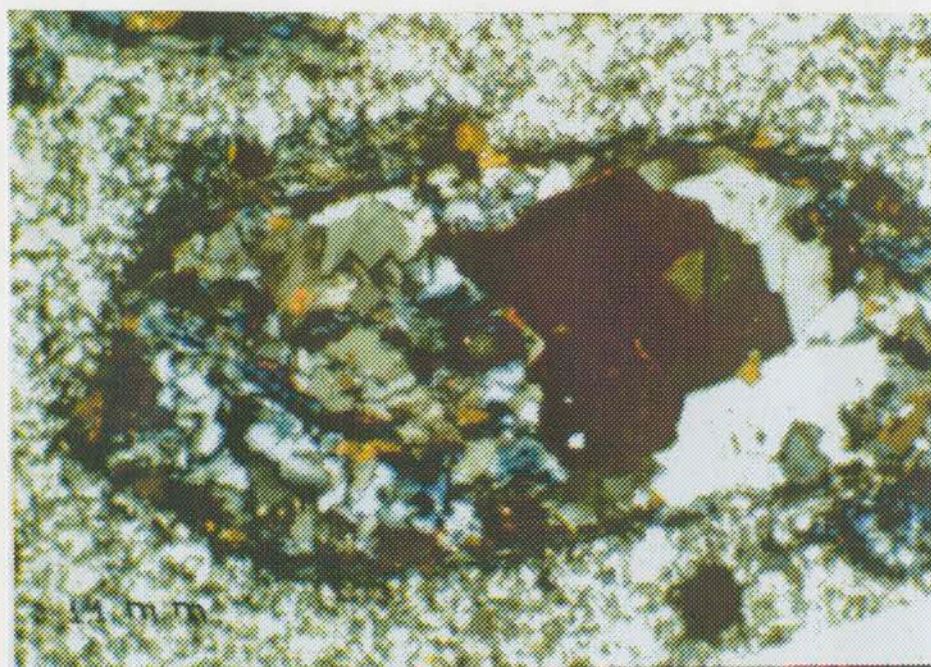


Figure 5.19 Photomicrograph of sample number 100597 showing albite (Ab) associated with fine leaves of chlorite (Ch) and pyrite (Py) replacing a phenocryst. Crossed nicols and plane light. Field of view 1.1 mm.



the Santa Inès and Múcura veins, while the SERICITE-QUARTZ And SERICITE-CARBONATE association in the strong sericitic alteration assemblage dominate at the Sin Nombre vein. The Porvenir vein exhibit a random hydrothermal alteration distribution.

FLUID INCLUSIONS

INTRODUCTION

Heating and freezing determinations were made on fluid inclusions in doubly polished sections of gangue minerals. The gangue minerals used include quartz from the early to late stages from all the veins and late calcite from Santa Inès vein .

The fluid inclusion data are presented in Table 6.1 and summarized in Fig.6.1 and 6.2. Only primary fluid inclusions were used in the study (Fig. 6.3). Fluid inclusions range from about 3 to 21 microns in long dimension. The fluid inclusions are round or elongate. All inclusions observed are simple, two-phase, liquid-vapor inclusions with no daughter minerals. Liquid/vapor ratios are consistent in quartz. Vapor bubbles make up 20-40% of the volume with an average of 30%. Vapor bubbles are slightly smaller in calcite, making up approximately 20-30% of the volume.

Heating runs were completed before freezing runs in almost all cases to avoid stretching of inclusions. Duplicate heating and freezing temperatures were determined in 173 inclusions by heating the fluid inclusion until the vapor bubble disappeared. Freezing temperatures were measured by cooling the inclusion to -80°C to ensure formation of ice, then raising the temperature slowly and noting the temperature at which the last crystal melted. No clathrate or other evidence of CO₂ were observed during freezing runs.

Table 6.1 Fluid inclusion data, La Maruja level. Th = homogenization temperature; Tm= melting temperature. W% NaCl equivalent calculated from fluid inclusion freezing point depression using the equation of Potter et al.(1997).

Sample II , Late calcite stage, Santa Inés vein.

	Th °C	Tm °C	W% NaCl
1	311.9	-3.1	5.4
2	314.0		
3	311.2		
4	302.8		
5	317.1		
6	305.0		

Sample 1000852-A, Late calcite stage, Santa Inés vein

	Th °C	Tm °C	W% NaCl
1	185.4		
2	183.5		
3	198.4		
4	353.3		

Sample 100849-B, Late quartz stage, Santa Inés vein.

	Th °C	Tm °C	W% NaCl
1	311.6	-3.8	6.1
2	319.4		
3	310.8		
4	328.8		
5	325.8		
6	317.2	-3.6	5.6
7	330.0		
8	320.2		
9	307.0		

Sample 100846-A, Early to Intermediate quartz stage, Santa Inés vein.

	Th °C	Tm °C	W% NaCl
1	335.2		
2	330.7	-3.9	6.3
3	308.0		
4	306.3		
5	297.0	-3.4	5.5
6	318.1		
7	318.6		
8	312.0		
9	328.3	-4.6	7.3
10	327.9	-4.8	7.6
11	312.0	-3.6	5.4
12	320.0	-4.2	6.7
13	330.0	-4.9	7.7
14	313.7		
15	313.0		
16	329.7		
17	326.1		
18	311.2		

Sample 100854, Early to Intermediate quartz stage, Santa Inés vein.

	Th °C	Tm °C	W% NaCl
1	353.7		
2	313.5		
3	365.0		
4	315.0		
5	312.8		
6	302.2		

úSample 100776-B, Late quartz stage, Múcura vein.

	Th °C	Tm °C	W% NaCl
1	319.2		
2	296.6		
3	306.8	-6.5	9.8
4	318.0		
5	317.0		
6	332.8		
7	345.1		
8	320.5		
9	305.3		
10	313.1		
11	314.2		
12	313.0		
13	341.7		
14	320.8		
15	332.8	-6.9	10.3
16	317.5	-6.8	10.2
17	308.3	-6.8	10,2

Sample 100776-B, Intermediate quartz stage, Múcura vein.

	Th °C	Tm °C	W% NaCl
1	312.6		
2	322.6		
3	343.4		
4	306.7		
5	316.0		
6	318.1		
7	311.2		
8	326.6		

Sample 100859-B, Intermediate quartz stage, Múcura vein.

	Th °C	Tm °C	W% NaCl
1	254.4		
2	314.2		
3	298.9		
4	296.0		
5	311.6		
6	319.6		
7	345.9		
8	353.4		
9	310.1		
10	324.0		
11	350.6		
12	350.0	-2.7	4.7
13	328.1		
14	372.0		
15	331.2		
16	338.7		
17	363.2		
18	327.4		
19	320.1		
20	333.9		
21	312.7		
22	350.0	-3.5	5.7
23	317.4	-2.4	4.0
24	324.1	-2.2	3.7
25	319.1		

Sample 100551-B, Late quartz stage, Porvenir vein.

	Th °C	Tm °C	W% NaCl
1	350.2		
2	272.4		
3	354.7		
4	297.0		
5	280.7		
6	285.4		
7	328.1		
8	320.0		
9	318.4		
10	301.4		
11	353.8		
12	364.2	-5.7	8.8
13	347.2		
14	310.4		
15	374.8		
16	301.0		
17	342.0		

Sample IV, Intermediate quartz stage, Sin Nombre vein.

	Th °C	Tm °C	W% NaCl
1	270.0		
2	286.4	-4.7	7.4
3	276.2	-5.1	8.0
4	283.5		
5	307.1		
6	278.0		
7	298.0	-4.9	7.7
8	308.0	-5.0	7.8
9	302.6		
10	309.6		
11	268.4		
12	298.0		

	Th °C	Tm °C	W% NaCl
13	283.1	-4.9	7.7
14	274.6	-5.0	7.8
15	291.0		
16	287.0	-4.8	7.5

Sample III, Intermediate quartz stage, Sin Nombre vein.

	Th °C	Tm °C	W% NaCl
1	305.5		
2	335.5		
3	336.8		
4	312.0		
5	325.2		
6	328.2		
7	338.0		
8	279.2		
9	265.2		
10	284.8		
11	270.7		
12	288.2	-5.2	8.1
13	267.4	-4.7	7.4
14	279.0	-5.8	8.9
15	280.0	-5.0	7.8
16	269.0	-4.5	7.1
17	284.7	-5.5	8.5
18	315.7	-5.2	8.1
18	313.2		
20	301.2		
21	306.2		
22	309.0		
23	308.0	-4.0	6.4
24	275.0	-4.2	6.7

Sample V, Intermediate quartz stage, Sin Nombre vein.

	Th °C	Tm °C	W% NaCl
1	298.3		
2	278.5		
3	292.1		
4	299.0		
5	234.2		
6	308.0		
7	291.0		
8	359.0		
9	357.2		
10	322.2		
11	324.5		
12	329.9	-6.2	9.4
13	370.0	-4.8	7.5
14	369.0		
15	357.0	-6.5	9.8
16	352.0	-4.2	6.7

Sample VI, Intermediate quartz stage, Sin Nombre vein.

	Th °C	Tm °C	W% NaCl
1	310.5		
2	314.3	-6.2	9.4
3	271.8		
4	308.0	-6.0	9.2
5	302.0		
6	296.0		
7	281.7		
8	292.4		
9	313.4	-5.0	8.0

FLUID INCLUSION DATA

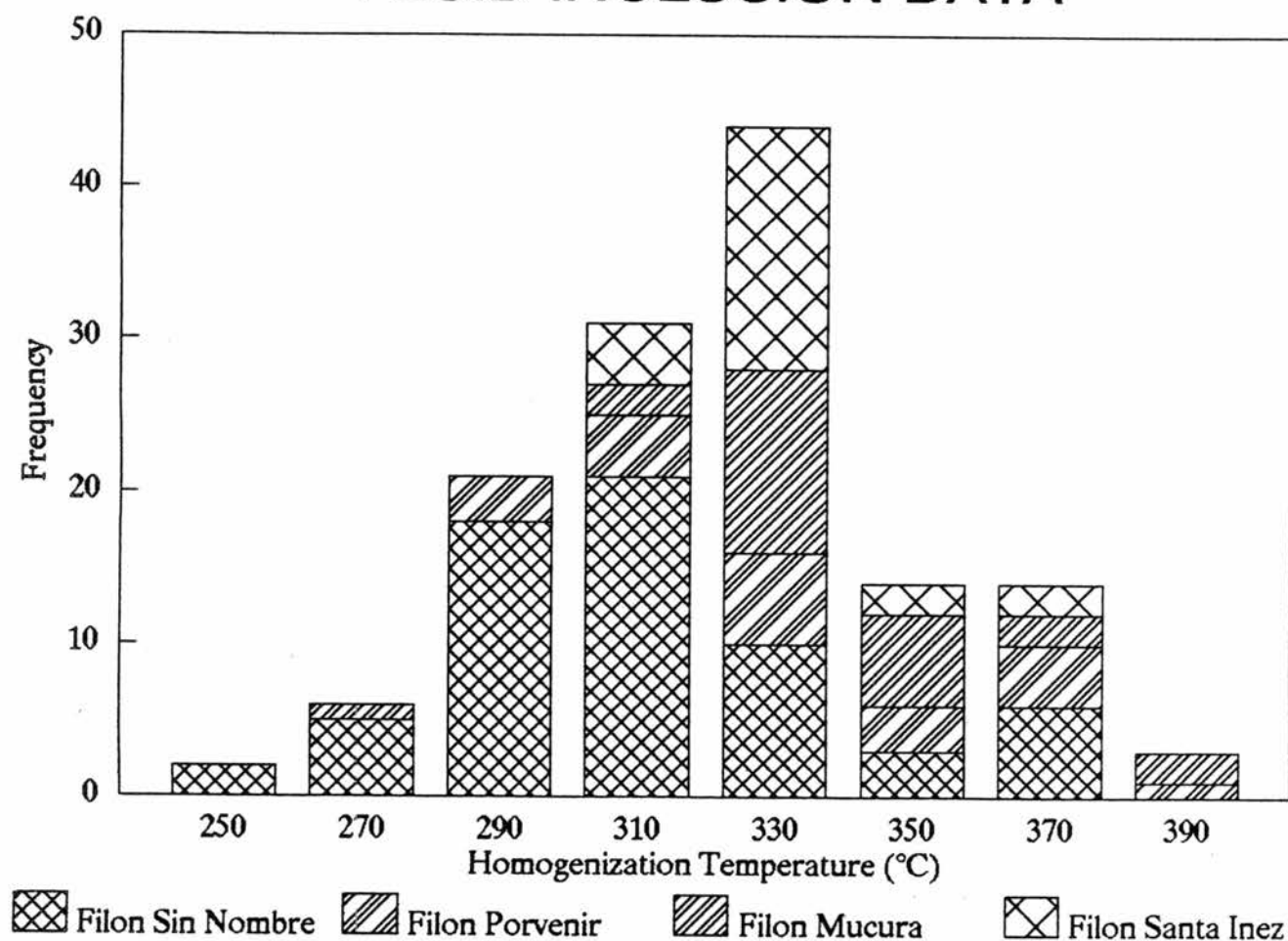


Figure 6.1 Frequency distribution of fluid inclusion homogenization temperature, La Maruja level, showing mean values at about 310°C for Sin Nombre vein and 330°C for the other three veins.

FLUID INCLUSION DATA

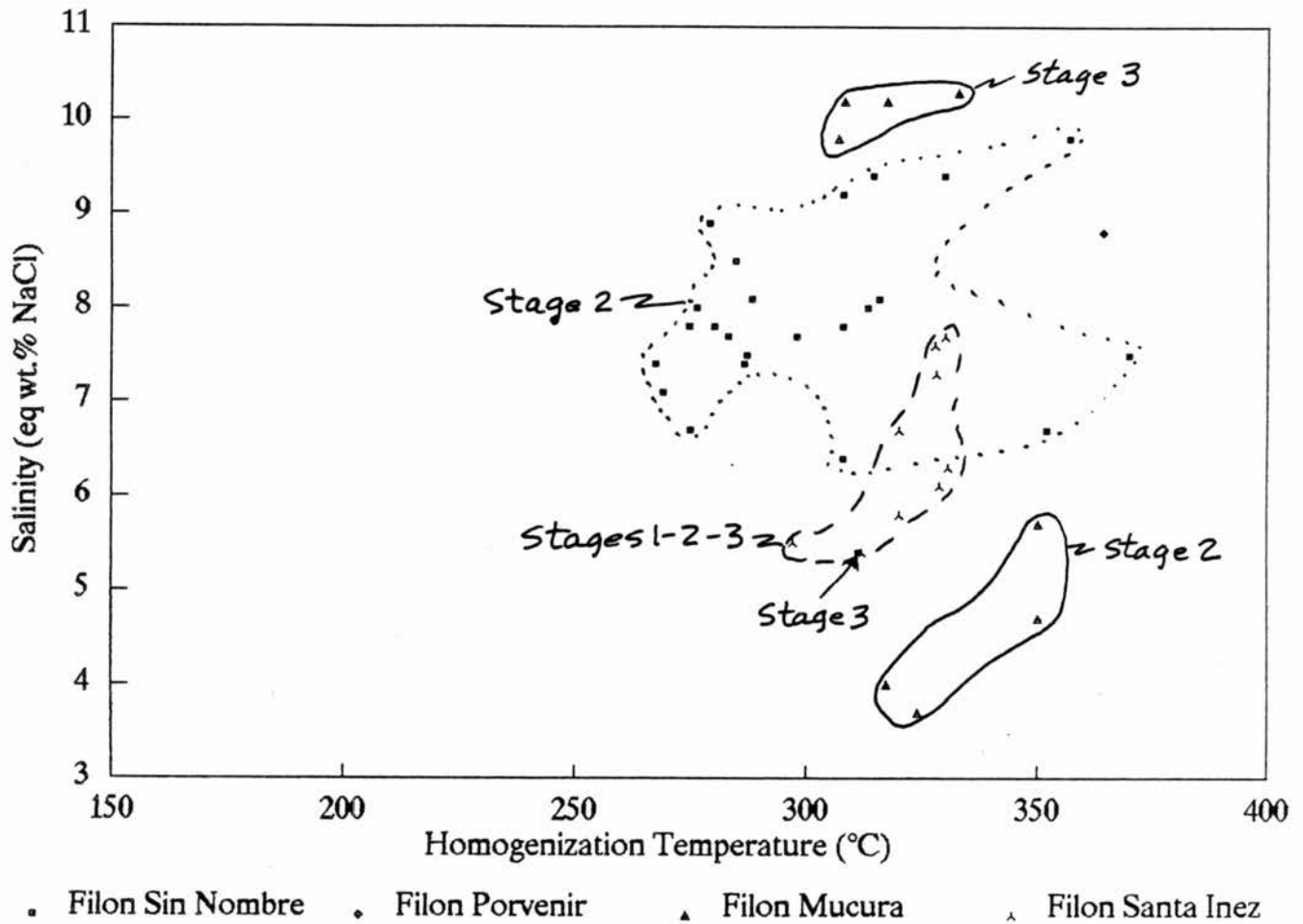


Figure 6.2 Plot of homogenization temperatures and salinity of four vein at La Maruja level, showing an increases in salinity in the Múcura vein from intermediate to late stage.

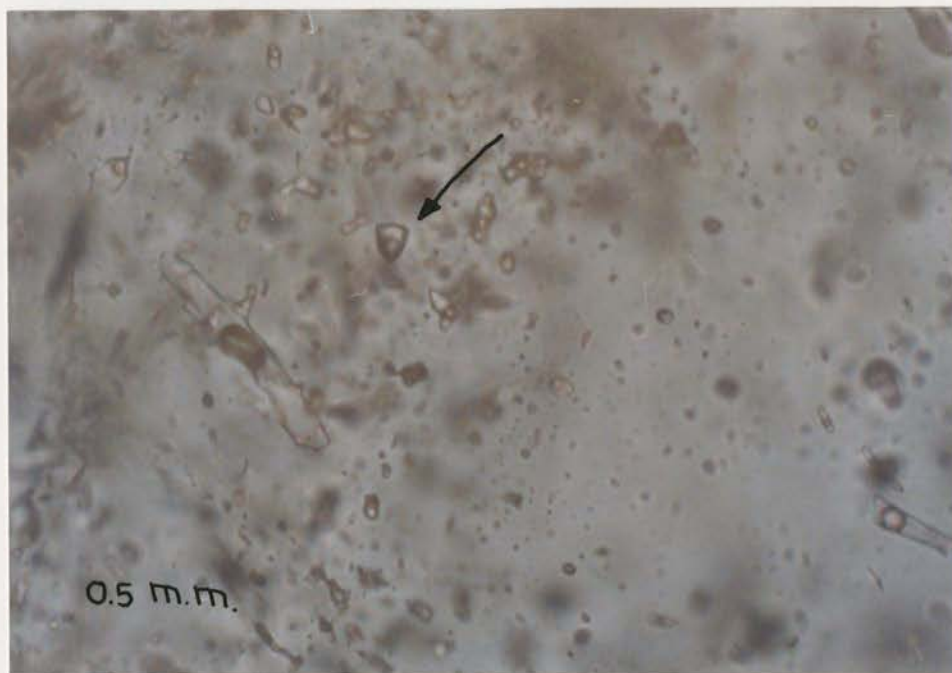


Figure 6.3 Photomicrograph showing primary fluid inclusions in the early to intermediate quartz from Santa Inés vein. Field of view 0.3 mm.

ORE FLUID TEMPERATURES.

Fluid inclusion homogenization temperatures, assumed to represent ore fluid temperatures, range between 250° and 350°C with mean values at about 310°C for the Sin Nombre vein and 330°C for other veins; no evidence for boiling is present.

The average homogenization temperature for fluid inclusions hosted by quartz in each vein at La Maruja level are:

- Santa Inès vein, Early to Intermediate stage 320.8°C.
- Múcura vein, Intermediate stage, 327.6°C.
- Porvenir vein, Intermediate stage, 323.2°C.
- Sin Nombre vein, Intermediate stage, 302.1°C.
- Santa Inès vein, Intermediate to Late stage, 318.9°C.
- Múcura vein, Intermediate to Late stage, 318.9°C.

Thus, there are slight temperature decreases going from the west to the east at greater structural complexities. Intermediate stage fluid inclusion data indicate that the Sin Nombre vein has homogenization temperatures about 20-25°C lower than the other vein systems. In support of thermal zoning, the intermediate and late stages in the Múcura quartz vein exhibit increases in salinity (Fig. 6.2), indicating an expanding hydrothermal system to the west.

ORE FLUID SALINITY

Salinities of the inclusion fluids can be determined from the freezing point depression

of the fluid. These range from -3.1° to -6.9°C and average -4.9°C in La Maruja level. Fluid inclusion salinities were calculated from melting temperatures (T_m) using the equation of Potter et al.(1997).

$$W_s = \{ (0.00 + 1.76959) x \} - \{ (4.2384)(10^{-2}) x^2 \} + \{ (5.2778)(10^{-4}) x^3 \}$$

W_s = equiv. wt % NaCl in aqueous solution.

x = freezing point depression determined from last melting of ice, $T_m(\text{ice})$.

Table 6.1 gives the measured T_m and calculated salinities in equivalent weight percent NaCl (W% NaCl).

Ore fluid salinities for inclusion at La Maruja level are: Santa Inès vein, Intermediate stage, range from 5.4 to 7.7 wt% NaCl and average 6.6 wt% NaCl; Santa Inès vein, Late stage, range from 5.4 to 6.1 wt% NaCl and average 5.7 wt% NaCl; Múcura vein, Intermediate stage range, from 3.7 to 5.7 wt% NaCl and average 4.5 wt% NaCl; Múcura vein, late stage range, from 9.8 to 10.3 wt% NaCl and average 10.2 wt% NaCl; Porvenir vein, late stage 8.8 wt% NaCl (one freezing determination); Sin Nombre vein, Intermediate stage range from, 6.4 to 9.8 wt% NaCl and average 7.9 wt% NaCl.

The initial melting temperature of a fluid inclusion, or the temperature at which ice begins to melt, is also important because it represents the eutectic temperature of the solution. The eutectic temperature is determined by formation of the first liquid in equilibrium with ice as the frozen inclusion is slowly warmed (Roedder, 1984). The eutectic temperature of an aqueous solution differs depending on the type of salt present. The eutectic

temperature for NaCl-H₂O solutions is -21.2 °C, and the eutectic temperature is progressively lower for solutions containing KCl, MgCl₂, and CaCl₂ (Schiffries, 1990).

The initial melting temperature is very difficult to determine in La Maruja level fluid inclusions because of their small size. The first change noted when warming frozen fluid inclusions was the vapor bubble changing shape in recrystallizing ice (Roedder, 1962) at temperatures of -13.2° to -16.8 °C. These temperature are higher than the eutectic temperature for NaCl-H₂O solution (-21.2°C), but the lack of any discernable evidence for ice melting at lower temperatures does not eliminate NaCl as the dominant salt in solution.

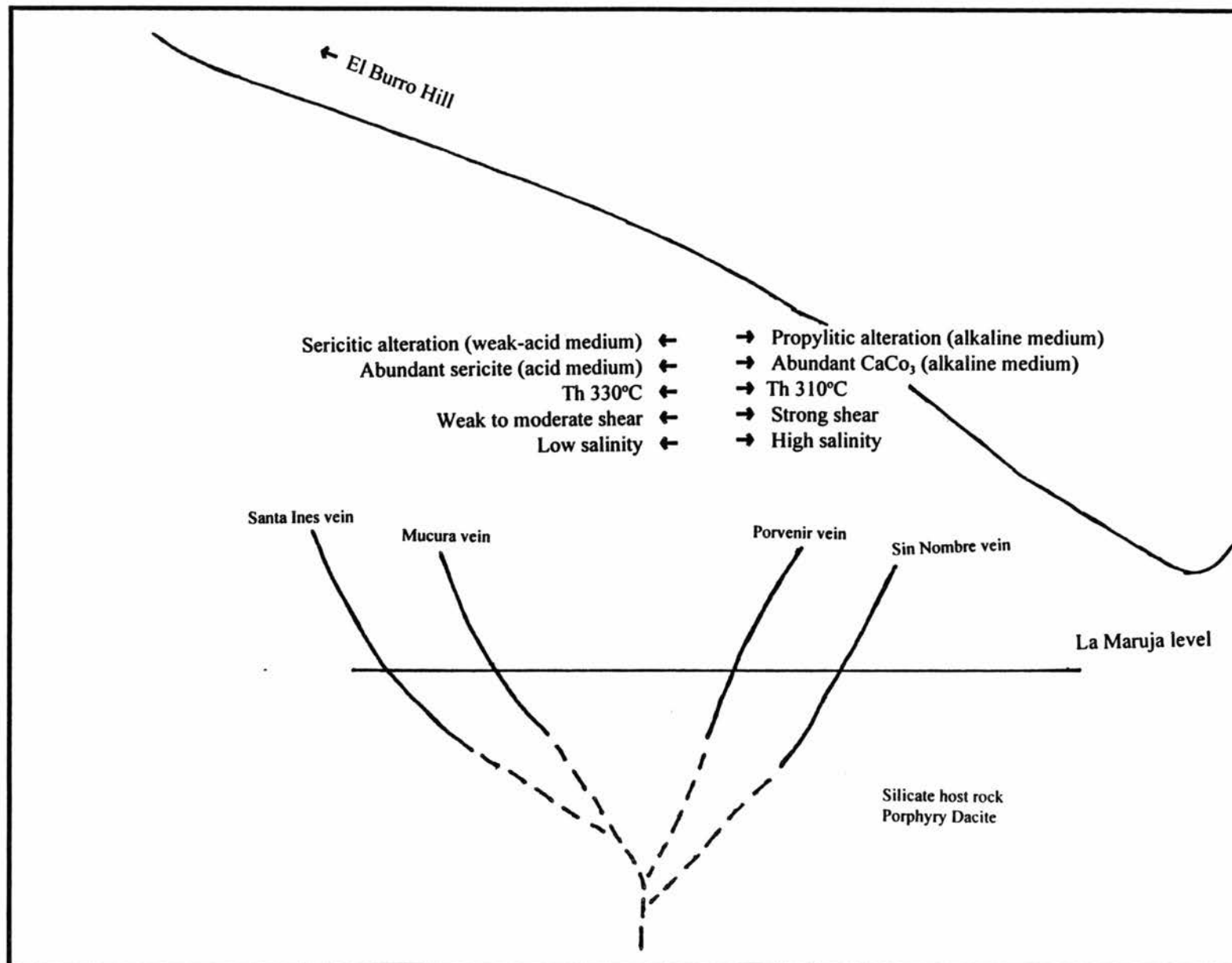
THE HYDROTHERMAL FLUID AT LA MARUJA LEVEL

A preliminary model for the evolution of hydrothermal fluid in La Maruja level is proposed on the basis of hydrothermal alteration association, mineralogy, ore texture, fluid inclusion data and field observations (Fig. 7.1). Supporting isotopic data (sulfur, hydrogen and oxygen) are not yet available.

During the early stage, the hydrothermal fluid reacted with the silicate host rock, creating propylitic type alteration assemblages. This assemblage is characterized as being stable in a moderately alkaline medium (e.g the epidote-chlorite-calcite association) (Creasey, 1966; Montoya and Hemley, 1975). During their formation, Ca cations (for calcite and epidote) were consumed thereby displacing the pH of the fluid toward neutral interval. During this stage, pyritization in the host rock took place. Sulfur was not only removed from the fluid but hydrogen bonds were also broken producing a relatively high H^+ concentration (Huston et al., 1992). At this new stage, the fluid acquired a weakly acidic character, favoring the development of sericite (Seward, 1982). Because species such as kaolinite and alunite were not formed, a low pH was not achieved (i.e. pH lower than 4). That is to say, argillic or advanced argillic alteration did not develop (Seward, 1982).

The hydrothermal fluid became progressively H^+ deficient as the formation of sericite increased. This caused pH values to be displaced toward alkaline values where calcite is

Figure 7.1 Idealizes sketch of La Maruja level



stable (Holland and Malinin, 1979). It is probable that a variation in pH underwent an alternating sequence (alkaline-acidic-alkaline) in which the pH values did not vary more than two units from neutral. Evidence derived from the hydrothermal alteration assemblages (sericitic alteration in particular) indicate almost simultaneous sericite and calcite intergrowths. However, toward the end of the hydrothermal alteration cycle, the dominant pH was probably moderately alkaline. This favored the development of albite (Kishida and Kerrich, 1984), particularly in vein and veinlets where calcite, sulfides, and quartz were also precipitated.

Mineral deposition in the veins is also related to the variation in pH throughout the stages. In the early stage of the paragenetic sequence coarse pyrite, arsenopyrite, and pyrrhotite are deposited in a medium that began to vary between moderately alkaline to neutral pH's (Seward, 1982).

It is possible that the alternating sequence in pH during this stage of sulfide deposition was not severe enough to favor the precipitation of gold within the coarse-grained pyrite (Helgeson and Garrels, 1968). However, as pyritization is initiated in the host rock, and coarse-grained pyrite is precipitated, the quantity of reduced sulfur that is present begins to fall in the hydrothermal fluid, favoring the precipitation of early gold (Weissberg, 1970). Gold deposition is not only favored by the variations in pH but also by a reduction in the total amount of reduced sulfur present in the fluid, and a decrease in temperature throughout the ore stages (Seward, 1973).

A tectonic event occurred at the end of the intermediate stage that fractured the

previously deposited minerals. This event created conduits for a second surge of hydrothermal fluid that was rich in copper and other vein-forming elements. This event also affected the host rock where minerals like calcite, albite, and sulfur were deposited in microfractures that traverse hydrothermally altered zones of previous stages.

The third pulse of hydrothermal fluid was weakly alkaline allowing albite and carbonates to be deposited in the host rock (Crerar and Barner, 1976). Sulfides (chalcopyrite, pyrite, galena, polybasite) along with calcite, chlorite and quartz were deposited in the veins. Acidic conditions were established as the minerals were deposited to allow for deposition of marcasite and late gold (Huston et al., 1992).

Additional aspects to the hydrothermal fluid pulses have to do with the temperature of the fluid, oxygen fugacity and sulfur. As mentioned, early fluid pulses (early to late paragenetic stages) occurred at a relatively high temperature of around 320°C.

Relatively low values of oxygen fugacity appear to have been maintained during all pulses of hydrothermal fluid. The development of minerals such as pyrrhotite and arsenopyrite and the absence of oxidized mineral (alunite, anhydrite, barite, hematite), indicate a reduced medium during early to beginning of the intermediate stage.

Sulfur fugacity, or the total concentration of reduced sulfur, was relatively high as the deposition of metallic minerals was initiated, and decreased throughout the early to intermediate stages.

CONCLUSION

Porphyry Dacite is the ore host of the vein deposits at La Maruja level, Marmato district, Caldas Department. A Late Miocene age has been assigned for this unit. The estimated modal mineralogy indicates an average phenocryst content of 32% plagioclase, 12% ferromagnesian minerals, and 8% quartz. All of them occur within a fine grained-matrix composed of quartz and plagioclase microcrysts. Pyrite and apatite are present in minor amounts as accessory minerals.

The porphyry dacite unit has been affected by a tectonic event and it shows faulting, shearing and joint features. Structure is the primary control of ore localization. All known precious metal mineralization is hosted in or near fissures. The fissures acted both as fluid conduits and as ore receptors. The faults are usually curved and have predominantly northwesterly strikes with steep dips. The shear intensities range from weak to strong and are related to fault zones. Non-mineralized and mineralized joints occur in both La Maruja crosscut and veins. The general joints orientation at La Maruja level is northwest. Most of the joints dip greater than 50°.

The veins located at La Maruja level were assigned to the Grupo Norte Inferior years ago. The veins are Sin Nombre, Porvenir, Santa Inès, and Múcura. They are fracture fillings, which formed due to tectonic activity affecting the surrounding porphyritic rock. The veins are controlled by steep faults, which follow curved paths and whose orientation and

inclination angle vary along La Maruja level.

Depending on the location, the thickness of the veins can range from 0.30 to 1.80 m regionally. The exposed lengths can be as high as 500 m. The ranges of strikes, dips and thickness for each vein are the following: **Sin Nombre vein**; N30°-40° W/64°-76°S; 25-120 cm, **Porvenir vein**; N40°-55°W/53°-75°S; 35-150 cm, **Santa Inès vein**; N60°W-EW/60°-80°N; 30-150 cm, **Múcura vein**; N55°-75°W/55°-80°N; 20-170 cm. Because the strikes of Porvenir and Santa Inès veins are opposite these veins probably intersect below La Maruja level.

The ore minerals of La Maruja level listed according to their relative abundances are: pyrite, pyrrhotite, sphalerite, arsenopyrite, gold, galena, marcasite and polybasite. The gangue minerals present are calcite, chlorite, and quartz.

Pyrite is the most abundant mineral in all the veins. Pyrrhotite can be locally abundant within Santa Inès and Múcura veins. Arsenopyrite is more abundant in the Santa Inès and Múcura veins than in the Porvenir and Sin Nombre veins. Gold occurs with all ore and gangue minerals. Sphalerite characterizes the intermediate stage of deposition.

Deposition of ore and gangue minerals in this level occurs in three stages: Early, intermediate and late stage. The early stage is characterized by abundant deposition of coarse euhedral pyrite crystals after minor amounts of pyrrhotite and calcite. At the end of this stage, deposition of coarse grained arsenopyrite and small amounts of quartz with pyrite occurs. There is a transition between early and intermediate stages. It is represented by changes in the relative proportions of coarse arsenopyrite and large amounts of sphalerite.

The intermediate stage is characterized by abundant deposition of sphalerite and minor amounts of chalcopyrite and gold. Arsenopyrite is only present at the beginning of the intermediate stage. Small amounts of quartz and calcite occur in both at the beginning and at the end of this stage.

The end of the intermediate stage is characterized by tectonic event after which the late state began. The late state is characterized by a short period of fine-grained pyrite deposition which ended with great amounts of calcite and chlorite deposition at the middle part of this stage.

La Maruja level contains several types of hydrothermal alteration and they include silicic, sericitic (strong, moderate and weak), propylitic and albitic assemblages.

Silicic alteration is only present in a few places, and it is characterized by abundant amounts of secondary quartz. Sericite and pyrite occurs in moderate amounts and chlorite and calcite appear in minor amounts or they are absent. The sericitic alteration is closely related to the mineralized zone. This alteration includes SERICITE-QUARTZ, SERICITE, SERICITE-CARBONATE and SERICITE-carbonate associations. The propylitic alteration is characterized by the development of abundant chlorite, calcite, epidote and zoisite-clinozoisite. Quartz and pyrite occur in minor amounts in this alteration. The following associations are present within propylitic alteration: CHLORITE-CALCITE, EPIDOTE-CHLORITE and EPIDOTE{ $\pm$ CHLORITE-CALCITE}. The albitic assemblage is characterized by veins and veinlets of albite associated with ore and gangue minerals.

Ore fluid temperatures ranged between 250° and 350°C with mean values about

310°C for Sin Nombre vein and 330 °C for the other three veins. There is a slight temperature decreasing going from early to late stage in each vein system, but it is evident that Sin Nombre vein was further from the heat engine of the hydrothermal fluid or at higher structure level than the other veins.

The ore fluid salinity at La Maruja level range from 3.4 to 10.3 wt% NaCl and average 7.2 wt% NaCl. The intermediate and late stages in Múcura vein quartz have increasing salinities, indicating an expanding hydrothermal system from the west.

Possible characteristics of the hydrothermal fluid at La Maruja level are a relatively high temperature, moderate salinity, high concentration of reduced sulfur (S^{2-}), a moderate alkaline pH and oxygen deficient. In addition, metallic ore-forming elements along with calcium, potassium, and sodium elements were also present.

RECOMMENDATION

The purpose of this project was to examine in detail the local geology, structural features, ore minerals, hydrothermal alteration, and a study of fluid inclusions at La Maruja level. The information and conclusion of this project allow for several recommendation for future studies as follows.

One of the most important aspects of a mineralization system, the evolution of the ore forming fluid at the Marmato district, could be determined by means of detailed and extensive hydrothermal alteration, ore microscopy and fluid inclusion analyses of different levels in the zone. This investigation would provide invaluable data about the physico-chemical zoning of the mineralizing solution, for temperatures, salinities, and composition.

Investigations of oxygen and hydrogen stable isotopes of fluids and alteration minerals would provide important information about the nature and degree of mixing of the waters involved in the mineralizing even at La Maruja level.

Studies of other isotopes such as sulfur and carbon would definitively answer the question regarding the source of these elements.

Age determinations of the host (porphyry dacite) and related mineralizing events, would provide needed information about the geochronologic evolution of the hydrothermal ore forming system and host rocks at La Maruja level.

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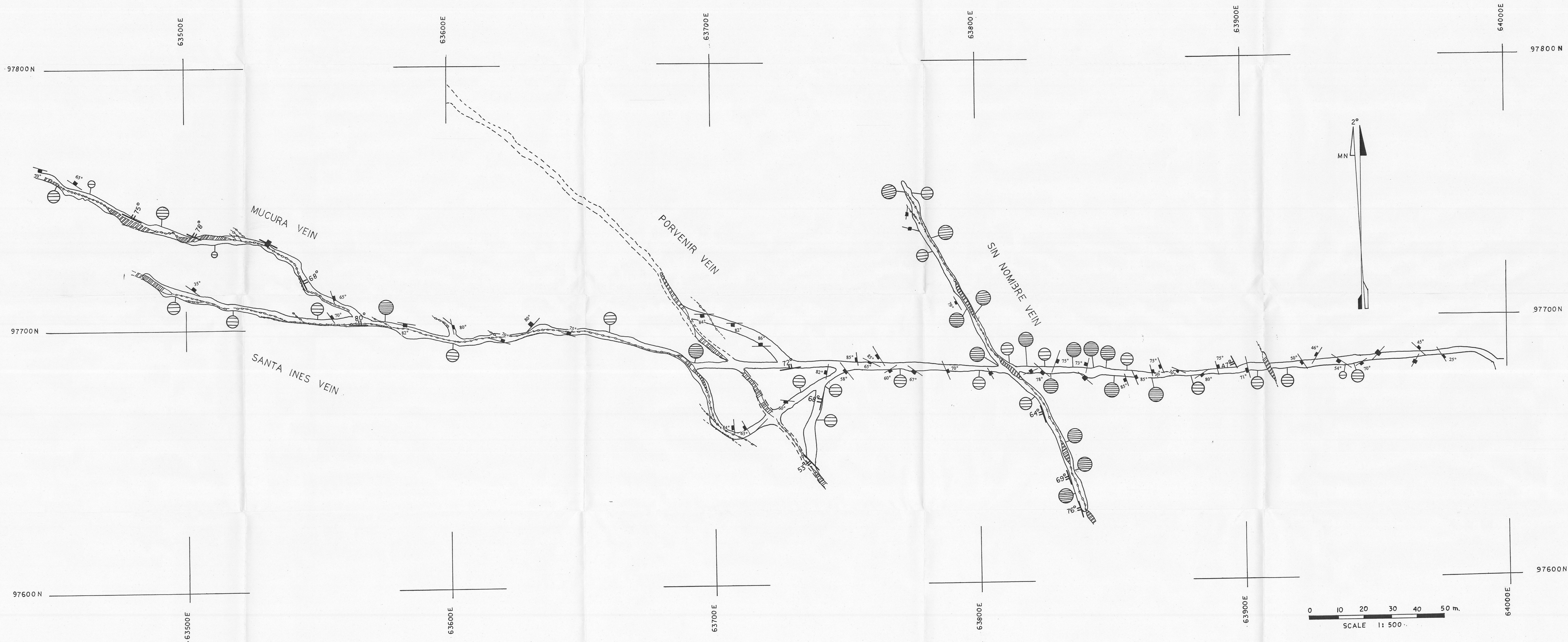
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Plate 1

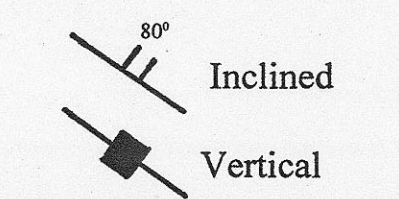
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LA MARUJA LEVEL

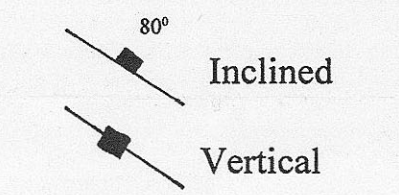
MAP. No 1

SRUCTURAL FEATURES AT LA MARUJA LEVEL

STRIKE AND DIP OF FAULT



STRIKE AND DIP OF JOINT



PYRITE MINERALIZATION

- a. Massive, dense.
b. Soft, with superficial clays.
c. Thickness less than 0.5 m.

SHEAR ZONES

- Strong Shear
Moderate Shear
Weak Shear



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LA MARUJA LEVEL

MAP No 2

HYDROTHERMAL ALTERATION TYPE

- Strong sericitic, SERICITE-QUARTZ association .
- Strong sericitic, SERICITE association .
- Strong sericitic, SERICITE-CARBONATE association .
- Moderate sericitic, SERICITE association .
- Moderate sericitic, SERICITE-CARBONATE association .
- Moderate sericitic, SERICITE-carbonate association .
- Weak sericitic, SERICITE association .
- Weak sericitic SERICITE-CARBONATE association .
- Propylitic, CHLORITE-CALCITE association
- Propylitic, EPIDOTE-CHLORITE association
- Propylitic, EPIDOTE +/- {CHLORITE -CALCITE} association
- Silicic

100850 Sample Location.