# REPORT
# ON
# THE MINERAL EXPLORATION
# IN
# THE BOLIVAR AREA
# REPUBLIC OF ECUADOR

PHASE I

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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## PREFACE

In response to the request of the Government of the Republic of Ecuador, the Japanese Government decided to conduct a Mineral Exploration in the Bolivar Area Project and entrusted the survey to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The JICA and MMAJ sent to the Republic of Ecuador a survey team headed by Dr. Hideo Kuroda from August 2 to December 1, 1988.

The team exchanged views with the officials concerned of the Government of the Republic of Ecuador and conducted a field survey in the Bolivar area. After the team returned to Japan, further studies were made and the present report has been prepared.

We hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

We wish to express our deep appreciation to the officials concerned of the Government of the Republic of Ecuador for their close cooperation extended to the team.

February 1989

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

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Metal Mining Agency of Japan

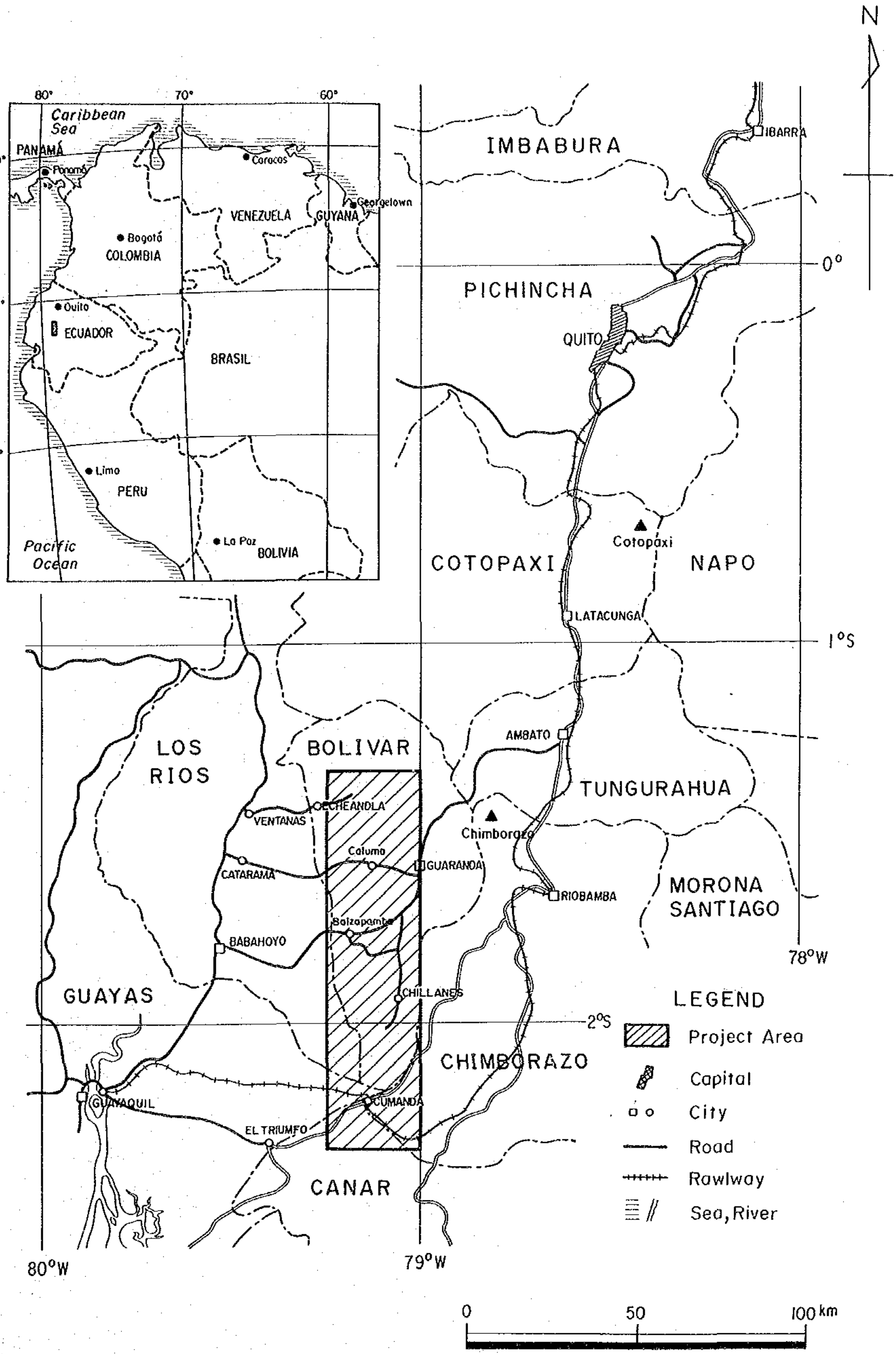


Fig. I Location Map of the Project Area

## ABSTRACT

In accordance with the SCOPE OF WORK for the Mineral Exploration in the Bolivar area, the Republic of Eduador, the Phase 1 work was focused on precise clarification of occurrences and features of mineralizations in the selected prospective areas (Fig. I-1-1) proposed by Ecuador on the basis of their previous undertakings and also on delineation of more potential targets from those areas for the subsequent phase work.

From this context, the detailed geological mapping with magnetic susceptibility measurement, geochemical sampling of rock chips and geophysical survey (CSAMT method) as well as diamond drilling were conducted in the Balzapamba area, and the semi-detailed geological and geochemical surveys in other eleven areas of Chaso Juan, La Industria-Yatubi, Tres Hermanas, Telimbela, San Miguel, Las Guardias, Sicota, Tambillo, Tablas Pamba, Balaron and Chilcales Alto.

The results of the work accomplished can be summarized as follows:

1. Balzapamba Area

The area is underlain by volcanic rocks of the Macuchi Formation dated as Late Cretaceous and granitic rocks emplaced during Oligocene to Miocene time.

Within the area there have been three types of mineralization; porphyry copper type of El Torneado, Osohuayco and Las Juntas mineralized zones formed mainly in granitic rocks and partially in surrounding volcanic rocks, vein type of El Cristal in the Macuchi Formation, and hot spring type of Las Palmas and Cochapamba in the same Formation. The El Torneado mineralized zone, which is the largest in the area, spreads over an extent of 400m x 400m and comprises five NNE-SSW trending principal zones with 20-70m wide consisting of relatively dense dissemination of sulfide minerals and network of sulfides-bearing quartz veinlets (Fig. II-1-38). For ore minerals, pyrite, chalcopyrite, molybdenite, magnetite, scheelite and pyrrhotite are observed. The chemical analyses of the surface samples gave the maximum contents of 0.2 g/t Au, 7.7g/t Ag, 0.66% Cu, and 0.42% Mo.

The magnetic susceptibility measurement detected low magnetic susceptibility anomalous zones consistent with mineralized zones (Fig. II-1-6). These anomalous zones were interpreted to be demagnetization caused by mineralization.

The factor analysis of the geochemical data resulted in detection of the factors related to mineralization and characteristics of host rocks. Particularly, the factors indicating Cu and Mo mineralizations were obtained over the El Torneado, Osohuayco, Las Juntas and El Cristal mineralized zones (Fig. II-1-7).

As the result of the geophysical survey, low resistivity zones were acquired on and around

each mineralized zone or relating alteration zone. Among them, the low resistivity zone of 126∿560 Ωm detected below the El Torneado mineralized zone (Fig. II-1-22) and the zone of 159∿788 Ωm beneath the Osohuayco mineralized zone (Fig. II-1-18), which is about 300m wide and extends for about 500m southeast downward, are remarkably encouraging for further exploration.

The diamond drilling in the El Torneado mineralized zone confirmed that the mineralized zone A, 30∿50m wide at the outcrop and 100m wide at 120m southeast of the outcrop, extends downward with dip of 60° southeast and swells in the depth, and also that another blind network zone with 60m wide occurs 150~200m below the mineralized zone A (Fig. II-1-39). These mineralized zones are generally low in Cu contents with the highest value of 0.36% Cu.

**2. Other Areas**

The eleven semi-detailed survey areas are mostly underlain by Late Cretaceous volcanic rocks of the Macuchi Formation emplaced by Oligocene to Miocene granitic rocks, and partially by Pliocene to Pleistocene Lourdes Volcanic Rocks (Plates II-2-1~11).

Viewed on a broad scale, the mineralizations occurred in these areas can be grouped into three types; porphyry copper type formed in granitic rocks and enclosing volcanics of the Macuchi Formation in the Chaso Juan, Telimbela and Las Guardias areas, vein type occurred in vlcanics of the Lourdes Volcanic Rocks in the San Miguel area, and hot spring type found in granitic rocks cropped out in La Industria-Yatubi and in the Lourdes Volcanic Rocks in the San Miguel areas. Among these mineralized zones, those in Chaso Juan, Telimbela and Las Guardias are remarkably larger in size than those in the remaining areas.

In the Chaso Juan area, a total of 10 mineral showings varying from 10 to 300m in extension occur and form the north, the east, and the south mineralized zones. The analytical results of ore samples showed 1.2 ~ 1.8 g/t Ag and 0.24 ~ 0.44% Cu with the maximum contents of 1.5 g/t Au, 160.9 g/t Ag and 9.03% Cu. The south mineralized zone has high chalcopyrite/pyrite ratio and the occurrence of scheelite was reported by previous workers though not confirmed in this present investigation. In the Telimbela area, four mineralized zones, three of which have extents of 500m x 350m to 450m x 200m and one is 150m wide, were located. The highest value of Cu is 1.60%. The Las Guardias area contained three mineralized zones of 400m x 100m, 350m x 50m, and 50m wide in size. The general trend of the mineralized zones are N-S in Chaso Juan, NE-SW in Telimbela, NW-SE in Las Guardias and NNW-SSE in San Miguel.

The magnetic susceptibility measurement revealed the presence of low magnetic susceptibility anomalous zones with size of 1km x 1km in the Chaso Juan area and of 2km x 0.75km in the Telimbela area (Figs. II-2-3 and 8).

As the result of the factor analysis of the geochemical data, the factors indicating Cu and Mo mineralizations were obtained in the Chaso Juan, Telimbela and Las Guardias areas (Figs. II-2-3, 8 and13).

Based on the comprehensive consideration of the above work results and careful evaluation of ore potential of each mineralized zone, the following are recommended for the Phase II work (Fig. III-2-1, 2).

1. **Balzapamba Area**

    1) Borehole geophysics (IP method) and diamond drilling for more precise delineation and evaluation of the El Torneado mineralized zone.

    2) Detailed geophysical survey (IP or SIP method) for clarification of nature of the CSAMT anomalous zone obtained below the Osohuayco mineralized zone.

2. **Other Areas**

    1) Detailed geological investigation and geophysical survey (IP or SIP method) for clarification and evaluation of porphyry copper mineralizations in the Chaso Juan, Telimbela and Las Guardias areas.

    2) Geochemical survey (soil) for examination of possibility to find out hot spring type gold mineralization in the southwestern part of the La Industria-Yatubi area.

    3) Geophysical survey (SIP) for determination of lateral and vertical extentions of vein type copper mineralization and detailed geological investigation for examination of possibility of hot spring type mineralization in the San Miguel area.

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PART I GENERAL

## PART II DETAILS

# PART I GENERAL

# Chapter 1 Introduction

## 1–1 Background and Purpose of Survey

In the western half of the Occidental (Western) Cordillera, Ecuador, a porphyry copper belt extending from North America to South America traverses, and the Bolivar project area lies on this belt (Fig. 1, I–3–2). Under the San Miguel project, this area and its adjacent areas covering a total of 6,100km$^2$ were surveyed from 1975 to 1982 by DGGM* with British technical cooperation. As a result of this survey, several promising porphyry copper and molybdenum mineralized zones were recommended for further investigation. However, these mineralized zones have been left untapped without follow-up work because of the nation's priority of development of oil resources and difficult economic conditions. Under these circumstances, recently the Ecuadorian Government politically gives a top priority to development of metallic mineral resources for reconstructing the nation's economy through promotion of exports of those commodities. In 1984 the Ecuadorian government requested the Japanese Government to provide technical cooperation for conducting mineral exploration in the Bolivar area. In response to this request, the Japanese Government sent a mission comprising representatives of the Japan International Cooperation Agency (JICA), Metal Mining Agency of Japan (MMAJ), the Ministry of Foreign Affairs, and the Ministry of International Trade and Industry to Ecuador from May 15 to 24, 1988. The mission concluded a SCOPE OF WORK agreement with INEMIN for mineral exploration of the Bolivar area.

The purpose of this survey is to determine the possible occurrence of ore deposits through careful clarification of geology and geological structure in the Bolivar area.

## 1–2 Outline of Survey

The Phase I work covered the Balzapamba and 11 other areas delineated by the past Ecuadorian side undertakings (Fig. I–1–1).

The detailed geological and geochemical surveys, geophycial survey (CSAMT method) and drilling were conducted in the Balzapamba area. The semi-detailed geological and geochemical surveys were made in the other 11 areas (Chaso Juan, La Industria-Yatubi, Tres Hermanas, Telimbela, San Miguel, Las Guardias, Sicota, Tambillo, Tablas Pamba, Balaron and Chilcales Alto) (Tables I–1–1, 2).

*DGGM : Direccion General de Geologia y Minas (the predecessor of present Instituto Ecuatoriano de Minera; INEMIN)

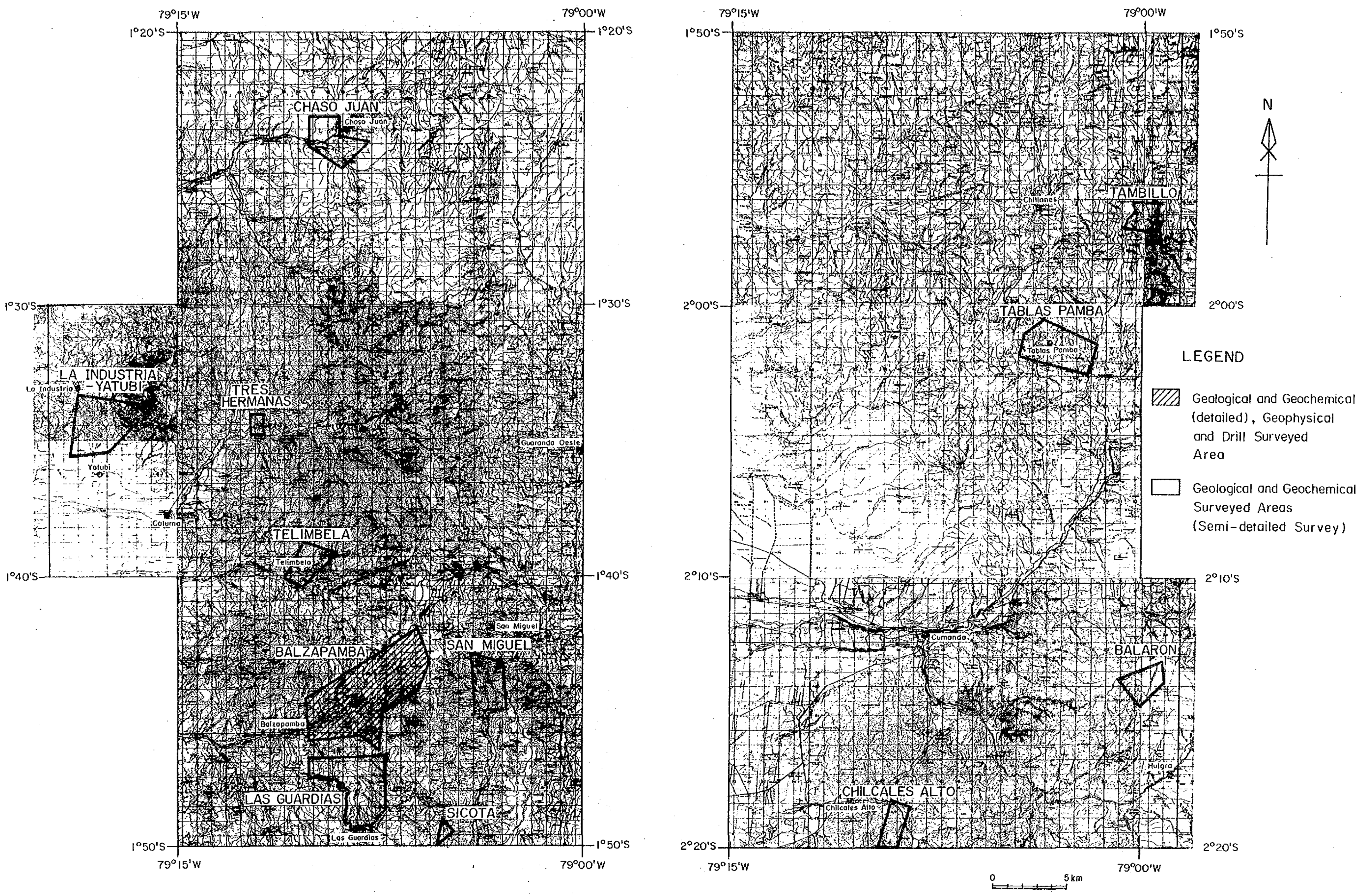


Fig. I－1－1 Location Map of the Surveyed Area

Table I – 1 – 1 List of Survey Amounts

| Item | | Quantity | |
|---|---|---|---|
| 1. Geological Survey ·Geochemical Survey | | | |
| (1) Balzapamba (detail) | | Survey area | 36 $Km^2$ |
| | | Survey route length | 84.8 Km |
| | | Geochemical rock sample number | 33 |
| (2) The others (semi-detail survey) | | Survey area | 80 $Km^2$ |
| | | Survey route length | 157.5 Km |
| | | Geochemical rock sample number | 34 |
| 2. Geophysical Survey (CSAMT) | | Survey area | 36 $Km^2$ |
| Balzapamba | | Measurement points | 104 |
| 3. Drilling | MJE–1 | Depth | 305.40m |
| Balzapamba | | Dip | –90° |
| | MJE–2 | Depth | 305.40m |
| | | Dip | –90° |
| | MJE–3 | Depth | 303.30m |
| | | Dip | –90° |

Table I − 1 − 2 Items Analysed and Numbers

| Method / Area | Thin Section | Polished Section | Dating (K-Ar Method) | Chemical Analysis (Whole Rock) | Ore Analysis (Au,Ag,Cu,Pb, Zn,Mo,W) | Geochemical Analysis (Ag,Cu,Pb,Zn, Mo,Co,Ni) | X-ray Diffractive Analysis | Resistibity Measure-ment |
|---|---|---|---|---|---|---|---|---|
| Balzapamba | 8 | 4 | 1 | 1 | 24 | 33 | 20 | 20 |
| Drill Core | – | 10 | – | – | 42 | – | – | 9 |
| Chaso Juan | 3 | 2 | 1 | 1 | 10 | 5 | 6 | – |
| La Industria –Yatubi | 2 | – | 1 | 1 | 6 | 4 | 4 | – |
| Tres Hermanas | – | – | – | – | 1 | – | – | – |
| Telimbela | 3 | 2 | 1 | 1 | 11 | 6 | 7 | – |
| San Miguel | – | – | – | – | 3 | 4 | 6 | – |
| Las Guardias | 2 | 1 | 1 | 1 | 9 | 6 | 5 | – |
| Sicota | – | – | – | – | 1 | – | 1 | – |
| Tambillo | – | – | – | – | 1 | 3 | 2 | – |
| Tablas Pamba | 2 | – | – | – | 2 | 3 | 2 | – |
| Balaron | – | – | – | – | 1 | 1 | 1 | – |
| Chilcales Alto | – | – | – | – | 1 | 2 | 1 | – |
| Total | 20 | 19 | 5 | 5 | 112 | 67 | 55 | 29 |

The geological and geochemical surveys aim to delineate more promising mineralized zones through clarification of favorable geological environment for mineralization by means of investigation of relationship of mineralization with geological structure and igneous activity, and of integrated interpretation of the present and previous data on geology and geochemistry.

The geophysical survey is planned to pursue lateral and vertical extension of mineralization and to make the best selection of drilling sites.

The drilling is purposed to confirm the vertical extension of the El Torneado mineralized zone in the Balzapamba area.

## 1–3 Organization of Survey Team

The members who participated in the planning and consultations on the survey as well as in the field survey are as follows:

Planning and Consultation

| Japanene counterparts | | Ecuadorian counterparts | |
|---|---|---|---|
| Yoshio Matsukawa | MMAJ | Leonardo Elizalde | INEMIN |
| Yoshiyuki Isoda | the Ministry of Foreign Affairs | Guillermo Bixby Garcia | INEMIN |
| Hideiku Shinokawa | the Ministry of International Trade and Industry (MITI) | Wilson Santamaria Lopez | INEMIN |
| | | Marco Marin | INEMIN |
| Hiroyasu Kainuma | JICA | Edgar Lopez | INEMIN |
| Naotaka Adachi | MMAJ | Luis Quevedo | INEMIN |

Field Survey

| Japanese counterparts | | | Ecuandorian counterparts | | |
|---|---|---|---|---|---|
| Hideo Kuroda | Leaders<br>Geological and geochemical surveys | Bishimetal Exploration Co., Ltd. (BEC) | Vicente Fiallos | Geological and geochemical surveys | INEMIN |
| | | | Guillermo Aguilera | Geological and geochemical surveys | INEMIN |
| | | | Alfredo Zamora | Geological and geochemical surveys | INEMIN |
| Hirofumi Taniguchi | Geological and geochemical survey | BEC | Xavier Bermudez | Geological and geochemical surveys | INEMIN |
| Norio Ikeda | Geological and geochemical survey | BEC | Edgar Lopez | Geophysical survey | INEMIN |
| Toshimasa Tajima | Geophysical survey | BEC | Cesar Cardenas | Drilling | INEMIN |
| Manabu Kaku | Geophysical survey | BEC | Luis de la Torro | Drilling | INEMIN |
| Makoto Tsuchiya | Geophysical survey | BEC | Alfonso Vaca | Drilling | INEMIN |
| Kooji Kudoh | Drilling | BEC | | | |
| Takashi Matsuoka | Drilling | BEC | | | |
| Tsukasa Anbo | Drilling | BEC | | | |

## 1–4 Survey Period

Planning and consultation

May 15 to 24, 1988

Field survey

| | | |
|---|---|---|
| Geological and Geochemical surveys | : | August 2 to September 30, 1988 |
| Geophysical survey | : | August 17 to September 30, 1988 |
| Drilling | : | September 12 to December 1, 1988 |

Preparation of report

October 1, 1988 to February 10, 1989

## Chapter 2 Geography of Survey Area

### 2–1 Location and Access

The project area is situated in the central western part of the Republic of Ecuador and is mostly in Bolivar Stata (Fig. 1). The Balzapamba area lies on the central part of the project area (Fig. I–1–1).

Balzapamba, the base of this survey, is located about 190km to the south-southwest of Quito, the capital of the Republic of Ecuador, accessible in about 7 hours' ride via Ambato and Guaranda, and about 130km northeast of Guayaquil, with 3 hours' traveling via Babahoyo.

In and around the project area, there are two trunk roads; Quito-Guayaquil highway (via Babahoyo) and Quito-Guranda-Guayaquil highway (via San Miguel, Balzapamba and Babahoyo). Each of the survey areas or its nearest villages are served by unpaved feeder roads from the trunk roads. However, due to well developed E-W system drainages, N-S roads are seldom in the project area, therefore during the semi-detailed surveys in the north and south, temporary camps were established in the survey areas. Particularly, the Tambillo, eastern part of the Tablas Pamba and Balaron areas are very poor in access, and only horseback and manual ropeway are available. The road distance and necessary time between Balzapamba and each surveyed area are as follows:

| | |
|---|---|
| Chaso Juan | Car (150km, 3.0 hours) |
| La Industria-Yatubi | Car (125km, 2.5 hours) |
| Tres Hermanas | Car (130km, 2.5 hours) |
| Telimbela | Car (135km, 3.0 hours) |
| San Miguel | Car ( 45km, 1.0 hour) |
| Las Guardias | Car ( 5km, 0.5 hour) |
| Sicota | Car ( 35km, 1.0 hour) |
| Tambillo | Car ( 70km, 2.0 hours),<br>horse and manual ropeway (1.5 hours) |
| Tablas Pamba | Car ( 80km, 2.5 hours),<br>horse (2.0 hours) |
| Balaron | Car (230km, 3.5 hours),<br>horse (3.0 hours) |
| Chilcales Alto | Car (170km, 2.5 hours) |

## 2–2 Topography and Drainage

The project is situated in the western marginal zone of the Occidental (Western) Cordillera as described earlier and individual survey areas are scattered at an altitude of 150m to 3,200m. The highest peak in Ecuador of Mt. Chimborazo (6,267m) rises in the northeastern outside the present survey area. The area is in steep, rugged mountainous terrain, and the relative heights between the highest and lowest altitude in each survey area vary from 500m to 2,000m. Particularly, in the Tambillo and Tablas Pamba areas, the average slope is in as high as 40 degrees, and in the Tablas Pamba, precipitous cliffs from numerous waterfalls, rerely about 400m in head. The differential erosion caused by different underlying lithology is well reflected on topographic features. Generally, granitic rocks make relatively gentle land forms but the Macuchi Formation forms steep, rigged crests and slopes.

Major rivers in the survey area rise in the Occidental (Western) Cordillera and flow down from northeast-east toward southwest to west. Numerous NW-SE and N-S system branches are joined to these major rivers. In the south, Rio Chimbo, the largest river in the survey area, flows southerly.

## 2–3 Climate and Vegetation

According to available records, climate in the survey area is tropical, high humidity in lowlands and temperate, dry in highlands. The rainy season runs from December to April but during the survey for this year temperature was generally low and there were many rainy days. The records show annual temperature veriation is from 15 to 29°C and annual humidity variation, 65% to 85%.

The following table shows recent mean monthly temperature and mean monthly precipitation.

Vegetation mainly consists of dense jungles. Orange, banana, coffee, cacao, and a few other crup plantations exist in places in lowlands while corn fields, ranches, etc. are developed in some highland areas.

| | 1984 | | 1985 | | 1986 | |
|---|---|---|---|---|---|---|
| | Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) |
| January | 20.8 | 101.7 | 19.8 | 155.6 | 20.4 | 4.18 |
| February | 20.9 | 406.4 | 20.4 | 113.6 | 21.2 | 4.42 |
| March | 21.1 | 462.6 | 20.8 | 243.2 | 21.1 | 6.00 |
| April | 20.9 | 370.4 | 20.5 | 124.4 | 22.3 | 1.85 |
| May | 20.6 | 18.6 | 20.4 | 54.3 | 20.9 | 1.65 |
| June | 20.5 | 22.8 | 20.0 | 19.0 | 19.7 | – |
| July | 19.1 | 5.1 | 19.5 | 2.1 | 20.4 | 0.4 |
| August | 20.0 | 4.2 | 19.8 | 13.1 | 20.1 | – |
| September | 20.1 | 33.5 | – | – | 20.6 | – |
| October | 20.4 | 33.1 | 20.1 | 12.5 | 20.4 | 0.5 |
| November | 20.1 | 41.5 | 19.9 | 8.1 | 21.8 | 0.83 |
| December | 20.3 | 117.5 | 20.2 | 151.0 | 20.1 | – |

# Chapter 3 Available Geological Information on Survey Area

## 3–1 Outline of Previous Work

In a period from 1975 to 1982, the San Miguel project was undertaken over an area of 6,100km², which covers the present project area, with British technical cooperation. Of the total survey period, the earlier period of 1975 to 1979 was devoted to a regional geochemical survey. From this survey, 2,500 samples of stream sediments and panned heavy minerals were collected and analyzed for Cu, Pb, Zn, Co and Ni by the atomic absorption method, and for CxCu and CxHm* by the colorimetric cold extraction method. As the results of chemical anlyses of these samples, anomalies of Cu, Pb, Zn and Ni were detected in 38 zones. Of these zones, 17 zones were interpreted to be related to Cu mineralzed zones, six to Pb-Zn, three to Cu-Ni, and one to Zn. While remaining 11 zones reflected geochemical characteristics of host rocks. Depending on progress of the regional geochemical survey, further detailed surveys were conducted in four promising areas of Balzapamba, Chaso Juan, Telimbela and San Miguel from 1976 to 1982 and detailed follow-up surveys were recommended for the above four areas. At the same time, execution of necessary check surveys for other geochemical anomalous zones were also recommended. An outline of the four areas is given in undermentioned table. In the Balzapamba, the regional survey and subsequent detailed survey led to discovery of mineral showings of El Torneado, Osohuayco, Las Juntas, El Cristal, Las Palmas and Cochapamba.

| Area | | Geol. Surv. | Geochem. Surv. | | | | Geophy. Surv. | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Stream Sedi. (sps) | | Soil (sps) | Rock (sps) | IP (km) | MG (km) | SP (km) | EM (km) | |
| | | | Regional | Detail | | | | | | | |
| Balzapamba | El Torneado | D | 189 | – | 759 | 85 | 11.2 | 2.75 | 5.95 | – | 60 pits, 18 trenches |
| | Osohuayco | SD | | – | – | | – | – | – | – | |
| | Las Juntas | SD | | 269 | 379 | | 8.8 | – | – | – | |
| | El Cristal | SD | | – | 444 | | – | – | – | – | |
| | Las Palmas | SD | | – | – | | – | – | – | – | |
| | Cochabamba | SD | 79 | – | 390 | – | 1.05 | * | – | * | HM: 79 sps, Water: 102 sps |
| Chaso Juan | | SD | 241 | 221 | 2,039 | – | 31.4 | * | – | – | |
| Telimbela | | SD | – | 126 | 814 | 85 | 10.2 | 10.2 | – | – | 4 drill holes, 9 short holes |
| San Miguel | | SD | 475 | – | 2,182 | 54<br>38(D/D) | 14.0 | 2.0 | – | * | 1 drill hole |

Abbreviation
D : Detail
SD : Semi-detail
* : Work amounts are anavailable

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* CxCu : cold extraction copper
CxHm : Heavy Metal analyzed by using dithizone

In Balzapamba, Chaso Juan and Telimbela, porphyry copper mineralization was observed mainly in acid to intermediate intrusive rocks emplaced in the Macuchi Formation, and partially in enclosing rocks of the Macuchi Formation. Based on these resutls, recommendations consisting of detailed geological survey, soil geochemical exploration, geophysical exploration were made for these areas. Particularly, drilling (5 holes, 1,125m) was also recommended for the Balzapamba area.

In San Miguel, dissemination and veins of sulfide minerals were noted in hydrothermal alteration zones of the Lourdes Volcanic Rocks. Thus, detailed geological survey and soil geochemical exploration were recommended. However, this area is lower in priority than the three areas mentioned above.

## 3–2 General Geology of Bolivar Area

In terms of geological structure, Ecuador belongs to so-called mobile belt of the Andes geocyncline which has been formed in a narrow strip on the western side of Guiana and Brazil shield. It has complex geological structure accompanied by faults, foldings and intensive volcanic activity characterized by Eugeosyncline. The geology of Ecuador consists of Precambrian system to Quaternary. The important geological structure runs in NNE-SSW ~ NE-SW direction. Tectonically, Ecuador has been divided into three provinces of Coast, Mountainrange and Oriente. All these tectonic provinces are consistent with topographic characteristics.

The Coast province consists of Mesozoic marine sediments (Pinon Formation), Tertiary system and Pleistocene series.

The Mountainrange province is divided, from west to east, into the Occidental (Western) Cordillera, Interandean Depression, and Real Cordillera. The Occidental Cordillera consists of volcanic rocks (Macuchi Formation) of Cretaceous age, but in the southwestern part, Precambrian to Paleozoic basement rocks are exposed. In the Interandean Depression, many sedimentary basins exist accompanied by stream sediments, lake deposits and volcaniclastic materials. The Real Cordillera consists of metamorphic and volcanic rocks of Precambrian to Mesozoic age.

The Oriente province is underlain by Carboniferous to Quaternary rocks.

Ecuador has two major metallogenic provinces: eastern and western metallogenic provinces, and each province is further subdivided into eight metallogenic zones. The interrelation among these tectonic and metallogenic characteristics is shown in following table and Fig. I–3–1.

| Topography | | Geology | Metallogenic Province | Metallogenic Zone | Metallogenic Sub-Province |
|---|---|---|---|---|---|
| Galapagos Islands | | Pliocene ~ Quaternary | | | Cu-Ni-Co Sub-Province of Ocean Floor (Quaternary) |
| Coast | | Pre-Cretaceous ~ Pleistocene (Pinion Formation) | Occidental (Ocean Crust, Eugeosyncline) | VIII. Coastal Zone | Fe-Ti-Pt Sub-Province of Coast (Jura ~ Early Cretaceous) |
| Mountain Range | Occidental Cordillera | Cretaceous ~ Paleocene (flysh) (Macuchi Formation) | | VII. *Anticlinorium-Synclinorium of Occidental Cordillera* | *Cu Sub-Province of* Occidental Cordillera (Cretaceous ~ Miocene) |
| | Interandean Depression | Neogene ~ Holocene | | VI. Catamayo Synclinorium Graben | Polymetalic Sub-Province of High Plateau (Paleocene ~ Quaternary) |
| | | | | V. Azuay Basin | |
| | | | | IV. Quito Graben | |
| | Real Cordillera | Metamorphic Rocks of Paleozoic and Mesozoic | Oriental (Continental Crust, Miogeosyncline) | III. Anticlinorium of Real, Moromoro and Mullepungo Cordillera | Sn-W-U Sub-Province of Real Cordillela (Later Paleozoic) |
| Orient | | Carboniferous ~ Cretaceous | | II. Oriental Pre-Andean Zone | Au Sub-Province of Orient Basin (Mesozoic ~ Cenozoic) |
| | | Tertiary ~ Quaternary | | I. Iquitos Basin | |

The anticlinorium-synclinorim metallogenic zone of the Occidental Cordillera which is an important porphyry copper belt includes the Bolivar area. The metallogenic zone continues to Piedrancha deposit in Colombia in the north (50 Ma, JICA-MMAJ, 1983), Chaucha deposit, Ecuador in the south (Eocene, OMRD, 1972), and further to Michiquillay deposit, Peru (46/21 Ma, Stewart et al, 1974), respectively. In vicinities of Piedrancha deposit, Au mineralization in late period is also concurrently observed. In addition, La Plata and Macuchi massive sulfide deposite occur in the north of the Bolivar area and Portovelo polymetallic veined deposit in the south. The Bolivar area has a high possibility of occurrence of deposits such as porphyry copper ore deposits (Fig. I–3–2).

The geology of the Bolivar area mainly consists of basic-intermediate volcanic rocks of the Macuchi Formation in Late Cretaceous period and its thickness is estimated to be about 5,000m (NRNE/DGGM, 1979, 1982). These rocks are emplaced by acidic-intermediate rocks. Henderson (1979) stated that in the Macuchi Formation in other areas marine fossil fauna (*Inoceramus peruanus*) indicating Late Cretaceous and foraminifer fossils (*Nummulites nummulitiformis* Rutten, *Amphistegina* spp.) indicating Eocene have been identified and that a K-Ar isotopic age of 51.5 ± 2.5 Ma (early Eocene) was obtained. Also, with respect to plutonic association, K-Ar isotopic ages of 19.2 ± 3 Ma and 30.8 ± 1 Ma were obtained from Las Guardias batholith. Principal tectonic line is in NNE-SSW ~ NE-SW direction as represented by Guayaquil Pallatanga fault. Geological correlation in and around this area is shown in Fig. I–3–3.

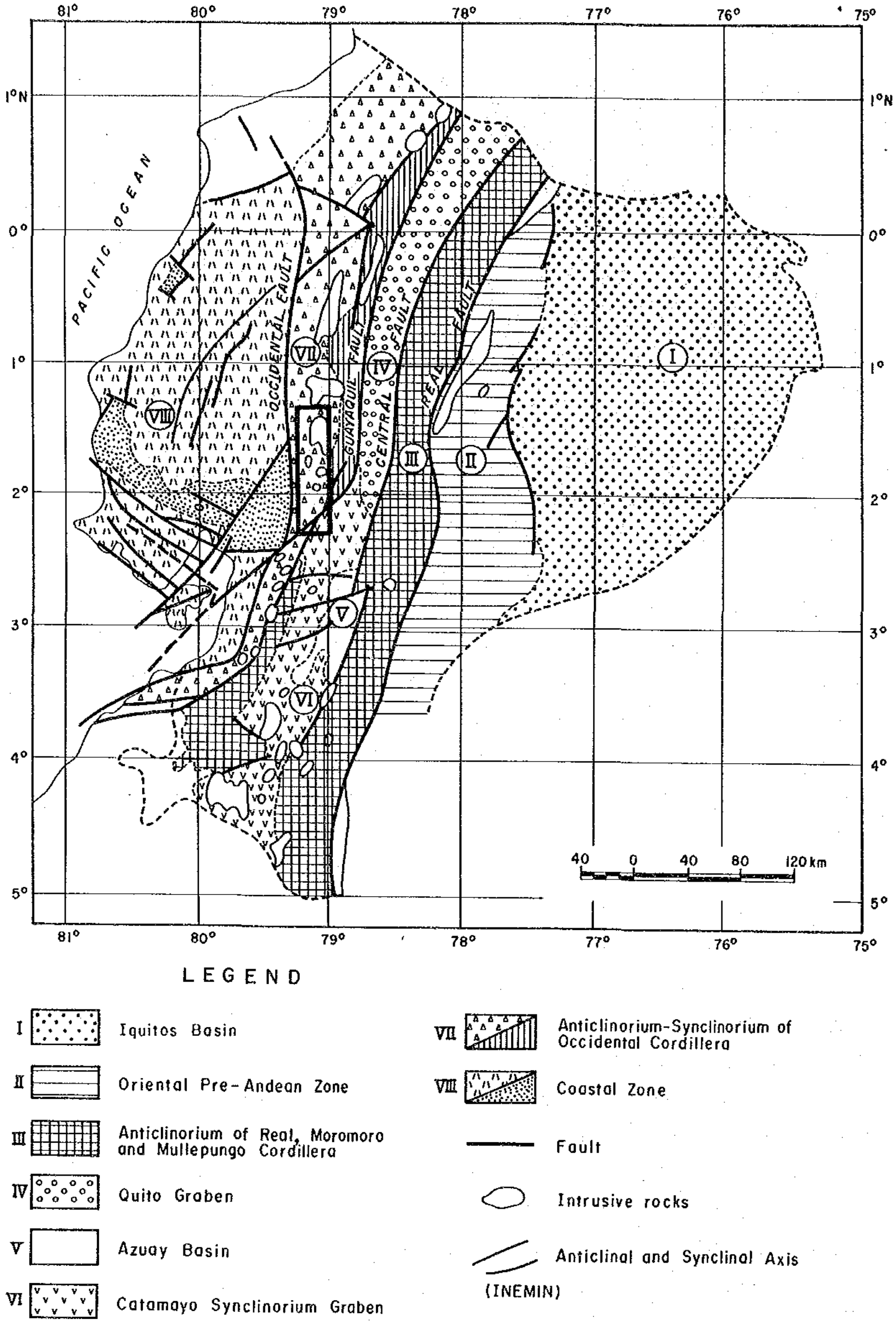
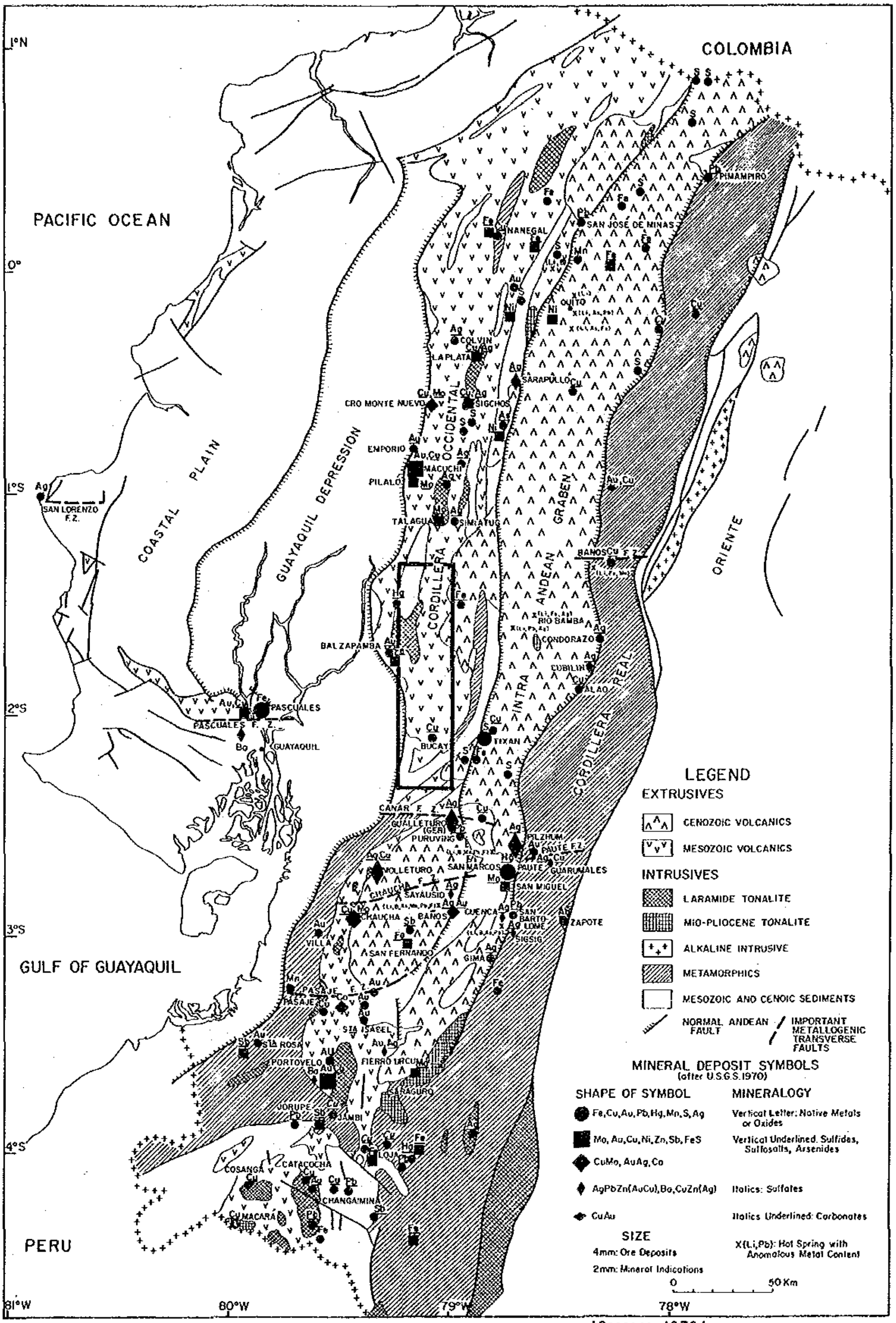



Fig. I − 3 − 1 Geotectonic and Metallogenic Zone Map of Ecuador




(Goosens, 1972)

Fig. I − 3 − 2 Metallogenic Map of Ecuador

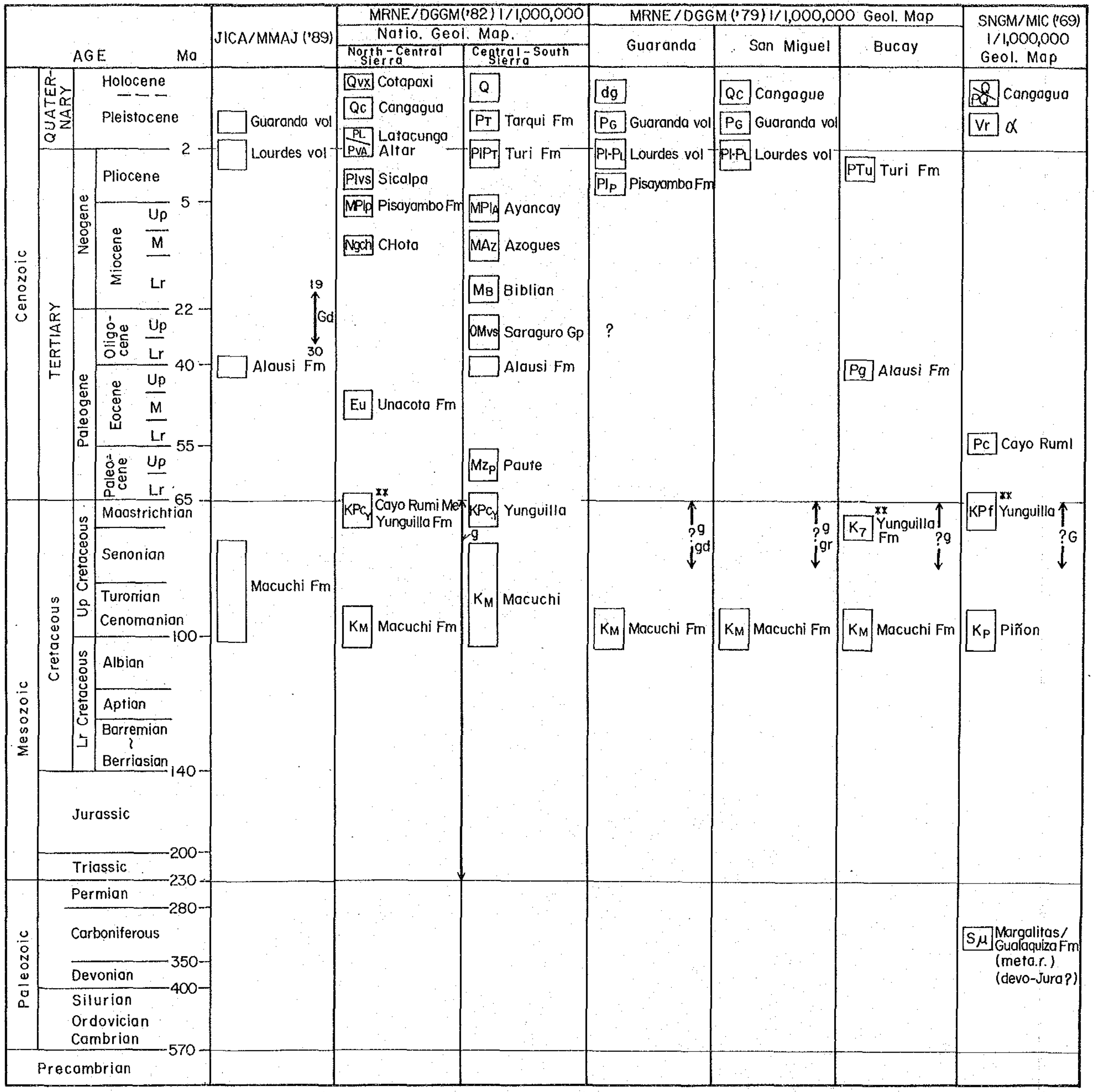



Fig. I – 3 – 3 Stratigraphic Correlation around the Project Area

Mineralization in this area comprises following three types: (1) porphyry copper type Cu-Mo mineralization observed mainly in intrusive rocks and enclosing Macuchi Formation (Balzapamba, Chaso Juan, Telimbela and Las Guardias areas), (2) vein type sulfide minerals - quartz mineralization found in the Macuchi Formation (El Cristal) and in the Lourdes Volcanic Rocks (San Miguel area), and (3) hot spring type mineralization consisting of network of hematite-silica sinter veins accompanied with alteration by acid hydrothermal fluid which are found in the Lourdes Volcanic Rocks (San Miguel area) and hamatite-quartz network zone in plutonic rocks (La Industria-Yatubi area).

## 3–3 Brief History of Mining in Boliver Area

Ecuador has given a high priority mostly to production of petroleum in the eastern and coastal zones, then mineral resources have been left undeveloping, whereas various kinds of metallic and non-metallic mineral resources are considered to occur in many places on the basis of geological environment. Mines developed thus for are virtually limited to Protovelo mine exploiting vein type deposits of gold, copper, lead and zinc and La Plata and Macuchi mines with copper and zinc massive sulfide deposits. All mines are operated on a small scale. The Portovelo mine which was first operated by a private company, produced crude ore of 500t/day until 1950 and more than 800,000t during the period between 1953–1968. It was taken over by the government in 1979 because of the depression. Ore reserves of the Portovelo mine is estimated to be 250,000t at present. The La Plata mine has a estimated reserve of 233,000t with average grades of 4.77% Cu, 2.35% Zn, 2.49g/t Au and 39g/t Ag. The Macuchi mine produced approximately 26,000t of Cu concentrates during 1940 to 1950 and ore reserves of it is estimated to be 139,000t. A mine currently under exploration other than above is Chaucha mine of porphyry copper type deposit. Ore reserves of it is estimated to be 60 million tons with the average contents of 0.40% Cu and 0.03% Mo.

Technical assistance on the field of mineral resources to Ecuador comprises surveys conducted by the United Nations, British, Spain, Belgium, West Germany and Italy. As one of these surveys, geological, geochemical and geophysical surveys and drilling were undertaken in vicinities of this area from 1975 to 1982 under British cooperation.

## Chapter 4 Comprehensive Consideration of Survey Results

### 4–1 Balzapamba Area

#### 4–1–1 Characteristics of Geological Structure and Mineralization

The area is underlain by volcanic rocks belonging to the Macuchi Formation of Late Cretaceous. These rocks have been intruded by granitic rocks and trachyandesite (Fig. I–4–1).

The Macuchi Formation is comprised andesite lava and its pyroclastic rocks, quartz-bearing andesite lava and its pyroclastic rocks, and can be divided into six members.

Intrusive rocks consist of granodiorite batholith, melanocratic diorite, trachyandesite and thin aplite dykes. K-Ar isotopic age of granodiorite was determined as 25.7 ± 0.9 Ma.

Geological structure is emphasized by N-S system folds, NE-SW and NNW-SSE trending faults, and NE-SW trend of mineralized zones and small intrusive rocks.

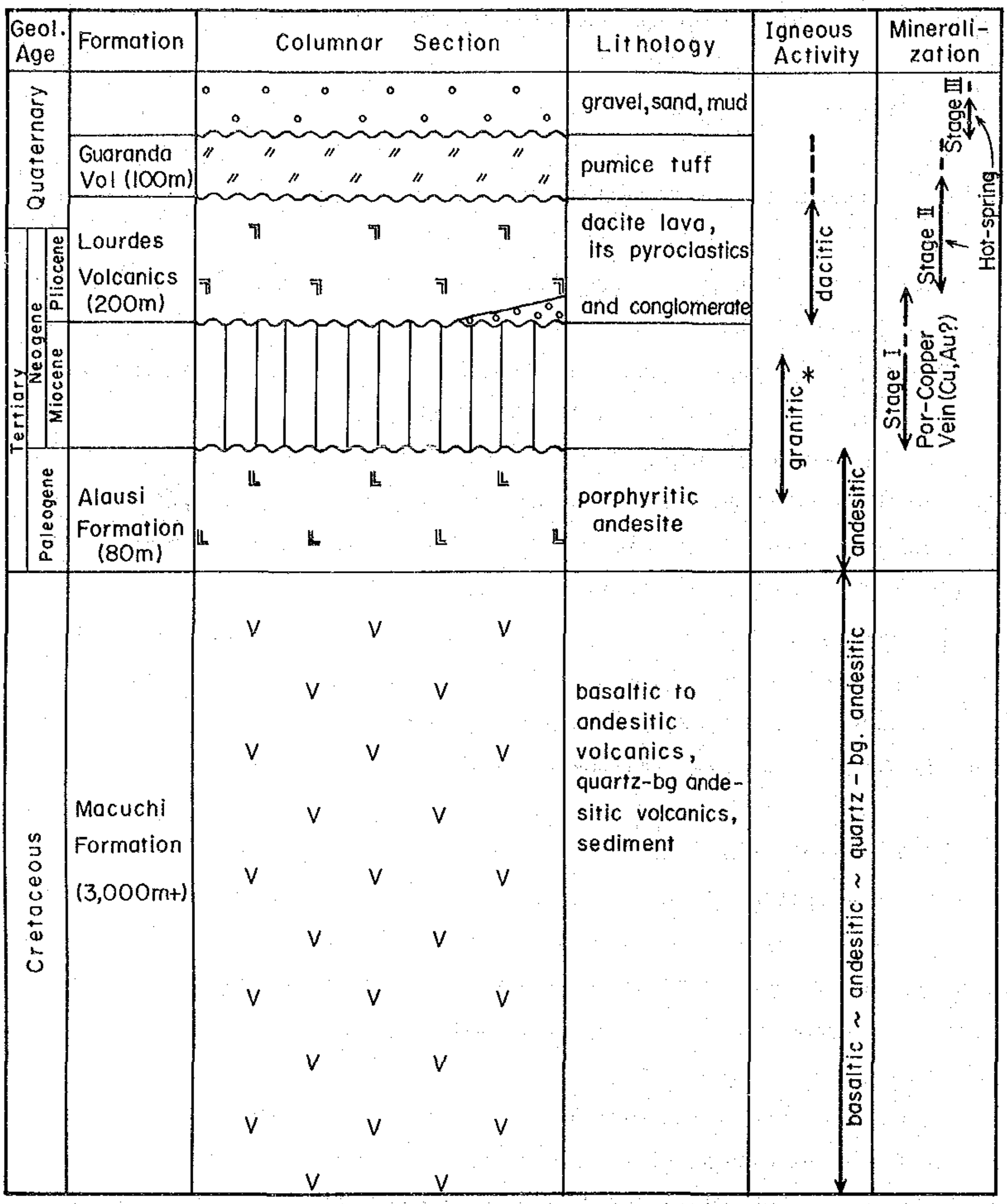
Mineralization in this area can be divided into the three types of porphyry copper, vein and hot spring. Porphyry copper type includes El Torneado, Osohuayco and Las Juntas mineralized zones. El Cristal mineralized zone is grouped as vein type while Las Palmas and Cochapamba alteration zones are hot spring type (Table I–4–1, Fig. II–1–1).

**(1) El Torneado Mineralized Zone**

This mineralized zone is situated in the northeastern edge of granodiorite batholith and spreads over a range of about 400m x 400m (Fig. II–1–38). It mainly consists of five principal zones (A ~ E) extending in NNE-SSW direction. They occur as dissemination/stockwork of chalcopyrite, pyrite, molybdenite, magnetite, scheelite and pyrrhotite, and the dissemination zone is often cut by the stockwork.

In disseminated mineralized zones, pyrite > chalcopyrite-molybdenite occur as dissemination or film in granodiorite. Alteration of host rocks comprise secondary biotitization and weak chloritization. Mineralized zone B falls under this category and chalcopyrite is relatively abundant in part of about 20m along the valley crossing the zone B.

Networked vein mineralized zone consist of ore minerals and gangue minerals filling in irregular patterns mainly brecciated granodiorite and locally the Macuchi Formation. For ore minerals, pyrite > chalcopyrite-molybdenite > magnetite-scheelite- pyrrhotite are observed. Quartz, K- feldspar, sericite, chlorite, secondary biotite, and epidote are present as gangue minerals. Mineralized zones A, C, D and E fall under this category. These mineralized zones are




* Las Guardias batholith (25.7 ± 0.9 Ma) (30.1 ± 1.1 Ma)
Chaso Juan batholith (20.9 ± 0.7 Ma)
La Industria batholith (25.5 ± 0.9 Ma)
Telimbela batholith (19.4 ± 0.6 Ma)

Fig. I − 4 − 1 Generalized Stratigraphic Columnar Section in the Project Area

## Table I – 4 – 1 Summary of Survey Results with Mineral Showings

(1)

| Type of Survey | Name of Area Invesigated | Area (Km2) | Geology | Mineralization: Name of Zone | Type (Occurrence) | Lateral Extension | Ore Minerals | Host Rock | Alteration | Assay Results: Au (g/t) | Ag (g/t) | Cu (%) | Pb (%) | Zn (%) | Mo (%) | W (%) | Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detailed Survey | Balzapamba | 36.0 | Macuchi Formation of andesite, q-andesite and their pyroclastics, minor calcareous sediments; hornfels near granodio<br>Intrusives of: leuco bio-hb-granodio melano dio trachyande | El Torneado | Por. Cu (network) (diss) | 400x400m | Py,Cp, Moly, Po,Mg,Shee, | granodio, hornfels | sil, biotite, argill, chl | 0.2<br>0.1<br>Tr<br>Tr | 2.0<br>7.7<br>Tr<br>1.6 | 0.66<br>0.43<br>0.17<br>0.05 | 0.00<br>0.00<br>0.00<br>0.00 | 0.00<br>0.00<br>0.00<br>0.05 | 0.01<br>0.42<br>0.01<br>0.31 | 0.00<br>0.00<br>0.06<br>0.05 | required further exploration work (geophy, drilling) |
| | | | | Osohuayco | Por. Cu (diss) | 300x100m | Py,Cp,Moly | granodio, hornfels | sil, chl | Tr | Tr | 0.08 | 0.00 | 0.00 | 0.00 | - | required further investigation (geolo, geophy) |
| | | | | | Por.Cu-Skarn (vein) (NE-SW/35°S) | 350m long 10m wide (max) | Cp,Py,Moly Bn | hornfels | sil, skarn | 0.4 | 27.8 | 2.60 | 0.00 | 0.10 | 0.00 | 0.00 | |
| | | | | Las Juntas | Por. Cu? (diss) | very local | Cp,Py, | granodio | sil, argill | | | | | | | | very poor interest (no further work) |
| | | | | | Vein (network) | 10m wide | Py,lim, | hornfels | | 0.1 | 1.1 | 0.11 | 0.00 | 0.03 | 0.00 | - | |
| | | | | El Cristal | Vein (N80°W/86°S) | 30m (+) long, 17m wide | Py,(Cp) | hornfels | sil, argill, chl, | 0.1<br>Tr | 2.1<br>Tr | 0.16<br>0.11 | 0.00<br>0.00 | 0.03<br>0.00 | 0.00<br>0.00 | -<br>0.00 | poor interest (no furter work) |
| | | | | Las Palmas | Hot spring? (diss) (network) | 2km wide | Py with rare Cp | hornfels, volcanics | extensive sil, argill, chl | 0.3 | 7.6 | 0.60 | 0.00 | 0.01 | 0.00 | 0.00 | poor interest (no furter work) |
| | | | | Cochapamba | Hot spring | - | - | volcanics | extensive sil, | | | | | | | | very poor interest (no further work) |
| Semi-detailed Survey | Chazo Juan | | Macuchi Formation of hornfels, andesite<br>Intrusives of: leuco granodio, melano dio | North zone | Por. Cu (network) (diss) | 10 50m x3 pla | | | | Tr | 1.3 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | required further investigation, especially, for Au-qtz network zone (geolo, geochemi, geophy, drilling) |
| | | | | East zone<br>South zone | (network) (diss) (network) (diss) | 150 300m x4 pla 20 200m x3 pla | Cp,Py, Moly,(Shee) | granodio | sil, chl, biotite, argill | 0.1<br>Tr<br>0.2<br>0.1<br>1.5 | 1.7<br>1.2<br>1.8<br>7.6<br>160.0 | 0.26<br>0.24<br>0.44<br>1.46<br>0.93 | 0.00<br>0.00<br>0.00<br>0.00<br>0.00 | 0.00<br>0.01<br>0.00<br>0.03<br>0.03 | 0.00<br>0.01<br>0.00<br>0.02<br>0.01 | 0.00<br>0.00<br>0.00<br>0.00<br>0.00 | |
| | | | | Northern Outside | Vein? (network) | 30x150m (?) | limo,goe | granodio | sil, | Tr | 1.3 | 0.03 | 0.00 | 0.00 | 0.02 | - | |
| | La Industria | | Intrusives of mostly qtz-dio with minor granodio, dio, small area of Macuchi For. | Northeast | Por. Cu (diss) | 100 300m x4 pla | (Cp), Py | qtz-dio | sil, chl, argill | Tr<br>Tr | Tr<br>Tr | 0.05<br>0.01 | 0.00<br>0.00 | 0.01<br>0.02 | 0.00<br>0.00 | -<br>0.00 | required further exploration (geolo, geochemi and geophy) |
| | | | | Southwest | Hot spring? (network) | not defined (600x700m) | gossan floats of hem-lim-goe | qtz-dio | sil | Tr<br>0.3 | 0.8<br>16.3 | 0.03<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.01<br>0.00 | -<br>0.00 | |
| | Tres Hermanas | | Machuchi Formation of basalt, andesite and pyroclastics | | (diss) | very local | | ande | | 0.1 | 4.6 | 0.03 | 0.00 | 0.00 | 0.00 | - | no interest (no further work) |

(2)

| Type of Survey | Name of Area Investigated | Area (Km²) | Geology | Name of Zone | Type | Lateral Extension | Constituent Minerals | Host Rock | Alteration | Au (g/t) | Ag (g/t) | Cu (%) | Pb (%) | Zn (%) | Mo (%) | W (%) | Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mineralization | | | | | | Assay Results | | | | | | | |
| Semi-detailed Survey | Telimbela | | Macuchi Formation of hornfels, basaltic ande, andesite | Zone I (Main) | Por. Cu (network) (diss) | 500x350m | Cp,Py, (Moly), | qtz-dio | | Tr | Tr | 1.60 | 0.00 | 0.02 | 0.04 | 0.00 | required further investigation (with expansion of area) |
| | | | | | | | | | | Tr | Tr | 0.37 | 0.00 | 0.01 | 0.00 | 0.00 | |
| | | | Intrusives of qtz-diorite, dio and qtz-porphyry (later than qtz-dio) | Zone II (E-ext of Main) | (network) (diss) | 200 (?) x400m | Cp,Py,Moly, | qtz-dio, hornfels | sil, chl | Tr | Tr | 0.04 | 0.00 | 0.17 | 0.00 | - | |
| | | | | Zone III | (network) (diss) | 200 (?) x450m | Py, | qtz-dio | | Tr | Tr | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | |
| | | | | Zone IV (SW ext of III ?) | (network) (diss) | 150m wide | Py,Cp,Moly, | qtz-dio | | Tr | Tr | 0.05 | 0.00 | 0.00 | 0.03 | 0.00 | |
| | San Miguel | | Macuchi, Formation of andesite, qtz-andesite | | Vein Hot spring (diss and vein) | local zones along NW-SE fault (within 1.4km) | Cp,Py, | Laurdes Vol | sil, strong argill (kao, pyrophy) | Tr | Tr | 0.01 | 0.00 | 0.06 | 0.00 | - | required further investigation (as hot spring type Au mineralization) |
| | | | Laurdes Volcanics of decite and pyrochastics<br>Guaranda Volcanics of pumice tuff | | | | | | | Tr | Tr | 0.00 | 0.00 | 0.00 | 0.00 | - | |
| | Sicota | | granodio | | (diss) | 30m wide | Py, | granodio | sil, argill | 0.2 | 3.9 | 0.09 | 0.01 | 0.01 | 0.00 | - | no Interest (no further work) |
| | Las Guardias | | Macuchi Formation of hornfels, qtz-andesite, andesitic pyroclastics | North | Por. Cu (diss) (network) | 50x50m | Py,Cp,Moly | granodio with hornfels | | Tr | 0.6 | 0.02 | 0.00 | 0.01 | 0.00 | 0.00 | |
| | | | Intrusives of leuco granodio and melano diorite | Central | (network) (diss) | 500x50m | Cp,Py, | - do - | strong sil | Tr | Tr | 0.09 | 0.00 | 0.01 | 0.00 | 0.00 | required further investigation (geolo, geophy) |
| | | | | South | (diss) | 400 x100m (?) | Cp,Py,Moly | granodio | | Tr | Tr | 0.02 | 0.00 | 0.01 | 0.00 | 0.10 | |
| | Tambillo | | Macuchi Formation of andesite and their pyroclastics, qtz-andesite, granite porphyry dyke | | (diss) | 3 small, localized | Cp,Py | andesite | sil, chl | Tr | Tr | 0.07 | 0.00 | 0.02 | 0.00 | - | poor interest (no further work) |
| | Tablas Pamba | | Macuchi Formation of basalt, basaltic andesite and their pyroclastics partially hornfels | West of Tablas Pamba | (diss) | 300x250m | Cp,Py | | | Tr | Tr | 0.02 | 0.00 | 0.01 | 0.00 | - | poor interest (no further work) |
| | | | Small stock of diorite | Others | (diss)) | verly localized zones | Py,minor,Cp | hornfels, basalt, basaltic ande | sil, chl | | | | | | | | |
| | Balaron | | Macuchi Formation of basalt, basaltic andesite andesite<br>Alausi Formation of por ande | | (diss/vein) | very local | Py, malachite, | basalte, ande | sil, chl | 0.1 | 7.3 | 1.47 | 0.00 | 0.01 | 0.00 | - | no interest (no further work) |
| | Chilcales | | Macuchi Formation of basalt, basaltic ande, andesite and their pyroclastics | | (diss and network) | very local | Py, | andesite | sil, chl | Tr | Tr | 0.01 | 0.00 | 0.03 | 0.00 | - | no interest (no further work) |

20 to 70m in width and about 50 to 300m or more in extension. A maximum content of Cu is 0.66%.

**(2) Osohuayco Mineralized Zone**

This mineralized zone is formed as NE-SW trending three zoned showings in granodiorite and surrounding Macuchi Formation in the southern part of this area. In granodiorite, these showings dominantly occur as chalcopyrite-pyrite-chlorite-quartz network and dissemination, while network of chalcopyrite-pyrite-bornite-chalcocite-grossular-quartz veins are developed in the Macuchi Formation. The size of the showings in granodiorite is about 100m in width and about 200m long. Those in the Macuchi Formation are about 10m wide and about 200m long, with some small intermittent mineralized outcrops.

**(3) Las Juntas Mineralized Zone**

This mineralized zone consists of dissemination of chalcopyrite and pyrite formed in granodiorite and quartz diorite, and network of pyrite-quartz veins in the Macuchi Formation. All are small in scale.

**(4) El Cristal Mineralized Zone**

This mineralized zone is of E-W trending pyrite-dominant vein associated with narrow network zone of quartz-limonite veins in the Macuchi Formation. Within the pyrite-dominant zone, rare amount of chalcopyrite is observed. The vein is 17m wide and is exposed at least 30m along strike.

**(5) Las Palmas and Cochapamba Alteration Zones**

Both alteration zones spread over a wide range of the area, mainly comprising alteration zones (quartz-kaolinite-halloysite) formed by late hot spring activities of acid hydrothermal fluid. Pyrite dissemination related with porphyry copper mineralization or hematite-quartz-clay veins being products of the second stage – hydrothermal activity of the Bolivar area are observed in places.

### 4–1–2 Relationship between Results of Magnetic Susceptibility Measurement and Geochemical and Geophysical Surveys, and Mineralization

Measurement of magnetic susceptibility detected low anomalous zones of magnetic susceptibility caused by demagnetization attributed to mineralization over all the above mineralized zones and alteration zones (Fig. II–1–6). Of these anomalous zones, those found in El Torneado and Osohuayco are wider in scale. In addition, tuffs and sediments of the Macuchi Formation show generally low magnetic susceptibility.

The factor analysis of the geochemical data resulted in detection of the factors related to mineralization and characteristics of host rocks. Particularly, the factors indicating Cu and Mo mineralization were obtained over the El Torneado, Osohuayco and Las Juntas mineralized zones (Fig. II–1–7).

Geophysical survey revealed low resistivity zones over each mineralized or alteration zone (Fig. II–1–33). The resistivity values vary depending on geology. Generally, it is 1,000 to 1,500 Ω·m in the Macuchi Formation and 5,000 to 10,000 Ω·m in granitic rocks. However, it remains only about 100 to 500 Ω·m in the mineralized or alteration zones. In the El Torneado mineralized zone dipping steeply southeastward, a distinct low resistivity zones was detected but it increases in resistivity values toward the depth. This could be due to silicification. Interesting low resistivity zones for further exploration were detected below the Osohuayco mineralized zone.

### 4–1–3 Drilling

The size of the mineralized zone A where drilling was carried out is about 50m in width and 200m plus in extension on the surface. The drilling confirmed the expansion of mineralized zone A and the existence of an underlying concealed mineralized zone (Fig. II–1–35).

The mineralized zone A dips 60° southeast and continues toward the depth with swelling downward. The size at the outcrops in the northeastern part is about 30 to 50m in width, and about 100m wide at about 120m away southeastward, The ore grade of the mineralized zone, though ore minerals commonly occur in networked veins and host rocks, is generally low with the contents of 0.01 ~ 0.21% Cu.

Quantitative ratio of constituent minerals of the mineralized zone A in the brecciated zone of granodiorite is variable in places. Although pyrite is omnipresent in the entire brecciated zone of granodiorite, chalcopyrite is locally concentrated. Macroscopically, molybdenite is relatively abundant in the outer side or in the shallow portion of the mineralized zone. The rock alteration, mainly sericitization is predominant in the subsurface. In the deeper portion, chloritization and silicification are observed only along the contact between veins and host rocks.

The underlying concealed mineralized zone occurs as a networked vein mineralized zone about 150 to 200m below the mineralized zone A. Ore minerals are pyrite > chalcopyrite-molybdenite > scheelite-pyrrhotite- magnetite, and gangue minerals are mostly quartz, chlorite and secondary biotite. The size of this mineralized zone is 60m wide and a content of Cu is 0.04 ~ 0.36%.

### 4–1–4 Discussion

Mineralization in the Balzapamba area includes the three types of porphyry copper, vein and hot spring. In the El Torneado and Osohuayco mineralized zones of porphyry copper type, mineralized zones extend in NNE-SSW to NE-SW directions. These directions are consistent with the directions of NNE-SSW to NE-SW system tectonic lines that develop in the northern and southern part of the Bolivar area. This fact, combined with the NE-SW trend of distribution of granodiorite mass in the Balzapamba area, suggests that there may be genetical relationship between tectonic movement and intrusion of granodiorite, as well as further subsequent hydrothermal activities. The mineralized zones are distributed in the peripheral zones of granodiorite mass and mineralization extends up to adjacent the Macuchi Formation. This fact indicates that the peripheral areas of granodiorite mass are favorable for ascending of hydrothermal fluids.

Hydrothermal activities in the Bolivar area can broadly be divided into three stages (Fig. I–4–1). Mineralizations of both porphyry copper type and vein type are formed by the first stage hydrothermal activity accompanied by sulfide minerals. In the El Torneado mineralized zone, disseminated mineralized zones are intersected with networked vein mineralized zones. From this fact, the mineralization in the Balzapamba area can be further subdivided into two stages of dissemination and networked veins. In the networked veins, sulfide minerals-chlorite-quartz networked veins intersect sericitized and silicified zones of host rocks, and further late quartz veins accompanied by molybdenite cut chalcopyrite-pyrite-chlorite veins, and magnetite occurs together with sulfide minerals in networked veins. These facts suggest that network mineralization itself also consists of several stages of hydrothermal activities under the circumstances of change in chemical composition of hydrothermal fluids and change of environment from reduction to oxidation. Scheelite occurs in networked veins of the El Torneado mineralized zone. This is a noteworthy fact because it closely resembles mineral assemblage of porphyry-molybdenum mineralization of quartz monzonite type classified by White et al (1981). However, the relationship between copper and molybdenum mineralizations should be investigated more detail because molybdenum-bearing quartz veins intersect copper-bearing secondary biotite-chlorite-quartz veins, and chalcopyrite-pyrite-chlorite veins cut molybdenite disseminated zones in the alteration zone. The detection of the factors related to copper and molybdenum mineralizations by geochemical survey is considered to suggest the presence of plural stages of mineralization.

Furthermore, it is a subject for further study to determine whether mineralization in the El Cristal mineralized zone and that in San Miguel are formed in the same stage or in another stages.

The Las Palmas and Cochapamba alteration zones are characterized by acid hydrothermal alteration (silica-kaolinite-halloysite), silicification with leaching and occasional appearrance of hematite-(silica sinter)-clay networked vein zone. These alteration are quite similar to that observed in the Lourdes Volcanic Rocks of the San Miguel area which correspond to the alteration episode of the second stage hydrothermal activity in the Bolivar area. Furthermore, alteration zone of this type is observed as horizontal layers in unaltered host rocks in outer zone of the Las Palmas alteration zone. This indicates a remnant of lateral current of hydrothermal solution.

## 4–2 Other Areas

### 4–2–1 Characteristics of Geological Structure and Mineralization

The geology of the Bolivar area mainly consists of volcanic rocks of the Macuchi Formation of Late Cretaceous and Tertiary granitic rocks that have emplaced in the Macuchi Formation. In the central eastern part of this area, these rocks are overlain unconformably by the Lourdes Volcanic Rocks of Pliocene to Pleistocene and the Guaranda Volcanic Rocks of Quaternary (Fig. I–4–1). Within the area, porphyry copper type, vein type and hot spring type mineralized zones can be observed (Table I–4–1). Characteristics of geological structure and mineralization in each survey area are as follows:

(1) **Chaso Juan Area**

This area is underlain by mafic hornfels of the Macuchi Formation and late intrusive rocks of hornblende-biotite granodiorite batholith, melanocratic diorite and quartz diorite dikes (Fig. II–2–1). The determined isotopic age of hornblende-biotite granodiorite is 20.9 ± 0.7 Ma. In the area, there are porphyry copper type mineralized zones consisting of chalcopyrite-pyrite-molybdenite disseminated and networked vein zones. These mineralized zones occur in granodiorite batholith and surrounding volcanic rocks and are distributed in the north, east and south of this area. In the north, three mineral showings of 10 to 15m in width are found along a tributary of San Pablo valley. In the east, four mineralized zones of 150 to 300m wide are located in the midstream of Araloma valley and its tributaries. In the south, 20 to 200m wide mineralized zones occur in three places to the north of Mulidiahuan village. Assay results of ores are generally1.2 to 1.8g/t Ag and 0.24 to 0.44% Cu with maximum contents of 1.5g/t Au, 160.9g/t Ag and 9.03% Cu. From the previous IP survey result and present magnetic susceptibility measurements suggest that the mineralized zones in this area represent a general trend of N-S direction and have a higher chalcopyrite/pyrite ratio than those in other areas. The occurrence of scheelite has reported.

(2) **La Industria-Yatubi Area**

The geology of this area consists of batholith mainly of quartz diorite and hornfels xenoliths of the Macuchi Formation (Fig. II–2–4). Mineralization occurs as porphyry copper type and hot spring type. The former type mineralized zones are found in four places on a scale of 100 to 300m wide in quartz diorite in the northeastern part of this area. These mineralized zones are of chalcopyrite-pyrite dissemination and pyrite dissemination associated with argillized and silicified zones. Assay results of ores show 0.05% Cu. Hot spring type mineralized zones, similar to that in the San Miguel area, is suggested to occur from the presence of numerous boulders consisting of network of hematite-limonite-quartz veins spread over an extent of 600 x 700m in the southwest. Assay results of ores show 0.3g/t Au, 16.3g/t Ag and 0.03% Cu.

(3) **Tres Hermanas Area**

This area is entirely underlain by basaltic lava, basaltic andesite lava and fine tuffs of the Macuchi Formation. Basaltic andesite bears a localized chalcopyrite-pyrite disseminated zone and a few veinlets.

(4) **Telimbela Area**

The geology of the Telimbela area is dominated by hornfels metamorphosed from basaltic andesite of the Macuchi Formation and younger intrusive rocks of quartz diorite batholith, quartz porphyry stock, and melanocratic diorite and porphyritic quartz diorite dykes (Fig. II–2–7). The isotopic age of quartz diorite is 19.4 ± 0.6 Ma. Mineralization in this area is of porphyry copper type which occurs as dissemination/network of chalcopyrite, pyrite and molybdenite. Macroscopically, these mineralized zones are formed in peripheral zone of quartz diorite batholith and adjacent Macuchi Formation. There are central and southern mineralized zones. The central mineralized zone consists of two aggregates of showings, 500m x 350m and 200m x 400m in size, and the southern mineralized zone also consists of two aggregates with size of 200m x 450m and 150m wide. Both the central and southern mineralized zones extend in NE-SW direction. Assay result shows a maximum value of 1.60% Cu.

(5) **San Miguel Area**

The San Miguel area is largely underlain by volcanic rocks of the Macuchi Formation with unconformably overlying the Lourdes Volcanic Rocks of dacite and its pyroclastic rocks and Quaternary Guaranda Volcanic Rocks (Fig. II–2–9). Mineralization consists of chalcopyrite-pyrite-quartz vein network zones and hematite-silica sinter vein network zones. Grade of ore from the former shows 0.01% Cu. These mineralized zones are held in echelon in NNW-SSE faults. Major mineralized zones of the former can be traced for about 250m. Acid hydrothermal alteration zone resulted from the later hot spring involving no metallic elements also is observed in the fault.

(6) **Las Guardias Area**

The geology of this area consists of the Macuchi Formation mainly of mafic hornfels which are intruded by granodiorite batholith and melanocratic diorite stock (Fig. II–2–12). Mineralization occurs as chalcopyrite-pyrite-molybdenite disseminated zones and networked vein mineralized zones. These mineralized zones are included in and around granodiorite in the north, center and south of this area. In the north, the mineralized zones of 50m in width are found in two places. In the center, mineralized zones are 50m x 350m in size, and in the south, they are 100m x 400m. Assay result shows 0.6g/t Ag, 0.09% Cu and 0.01% W in maximum.

(7) **Sicota Area**

This area is occupied by granodiorite, and Quaternary conglomerate bed which is locally cropped out along valleys. Mineralization includes pyrite disseminated zones in granodiorite and pyrite-clay zones in conglomerate bed.

### (8) Tambillo Area

The geology of this area consists of the Macuchi Formation composed mainly of andesite lava and granite porphyry intruding therein. Within the area, small-scale mineralized zones are found in three places. That in Palmar valley is 200m wide and occurs as chalcopyrite-pyrite disseminated zones in granite porphyry and silicified andesite. The mineralized zone in Placer valley consists of chalcopyrite-pyrite disseminated zone with 100m wide, and pyrite disseminated zones with 300m wide in andesite.

### (9) Tablas Pamba Area

The area is underlain by the Macuchi Formation consisting mainly of basalt and andesite lavas and melanocratic diorite stock that intrudes into this formation. Chalcopyrite-pyrite disseminated zones and pyrite disseminated zones are found in basalt and andesite. The former occurs in the western part of this area on a scale of 300m x 250m while the latter occurs in the northern part on a scale of 200m x 500m.

### (10) Balaron Area

The geology of this area is dominated by basalt and andesite lavas of the Macuchi Formation and unconformably overlying porphyritic andesite of the Alausi Formation. Basalt boulders containing malachite dissemination are noted in the southern part of this area and quartz veins in the southwest.

### (11) Chilcales Alto Area

This area consists mainly of andesite lava of the Macuchi Formation. Pyrite disseminated and veinlet zones as well as quartz networked veins are observed in the southern part of the area.

## 4–2–2 Relations between Results of Magnetic Susceptibility Measurement and Geochemical Survey, and Mineralization

Magnetic susceptibility measurements detected low magnetic susceptibility anomaly related to demagnetization caused by mineralization. Particularly, in the Chaso Juan and

Telimbela areas where porphyry copper type mineralizations are observed, distinct anomalous zones of 1km x 1km and NE-SW trending 2km x 750m were detected, respectively (Fig. II–2–3, 8). The scale of anomalous zones in the Las Guardias area is not so wider than the above areas (Fig. II–2–13). Also, in the areas of hot spring type mineralization, anomalous zones of 500m x 200m in scale in the La Industria-Yatubi area (Fig. II–2–5) and 2.5km x 500m extending to the direction of NNW-SSE in the San Miguel area (Fig. II–2–11) were detected respectively.

Geochemical survey revealed zones with high to moderate factor scores indicating Cu and Mo mineralizations in the Chaso Juan, Telimbela and Las Guardias areas. Also, in the La Industria-Yatubi and San Miguel areas, factors suggestive of hot spring type mineralization in a different stage were detected (Fig. II–2–3, 5, 8, 11, 13).

### 4–2–3 Discussion

In this section, implication between tectonic evolution and hydrothermal activities in the Bolivar area will be considered.

During Late Cretaceous, vigorous submarine volcanism formed the Macuchi Formation and it was subjected to Andean Orogeny in Eocene to Oligocene. Orogeny in Ecuador is emphasized by faulting mainly of lateral slip in NNE-SSW to NE-SW systems, as well as folding in these systems and plutonism (MRNE/DGGM, 1982). However, plutonism in this project area is characterized by granitic rocks which emplaced in N-S direction in Oligocene to Miocene. It is unknown whether this N-S system structure is initiated by differential movement of pre-Cretaceous basement rocks or other internal processes (MRNE/DGGM, 1982).

These events were followed by hydrothermal activities in Miocene to Pleistocene. As structures after Pliocene, faults which show vertical dislocation with NNW-SSE and NNE-SSW to NE-SW trends and folds can be cited.

Following evidence is important in considering hydrothermal activities such as porphyry copper, vein and hot spring type mineralizations and alteration in this area:

(1) Isotopic age of granitic rocks which form the main host rock of porphyry copper type mineralization is 19 to 30 Ma, and mineralization has extended to trachyandesite which intrudes into these rocks.

(2) Among the Lourdes Volcanic Rocks of Pliocene to Pleistocene, following zones occur: (i) vein type mineralized zones, (ii) hot spring type mineralized zones accompanied by acid hydrothermal alteration and (iii) hot spring alteration zones accom-

panied by acid hydrothermal alteration containing no metallic elements. In the Guaranda Volcanic Rocks of Pleistocene, the uppermost stratigraphic unit, hydrothermal alteration of (iii) is observed while the alterations of (i) and (ii) have not extended. Also, the mineralized zone of (i) has been cut by the veins of (ii). These evidence indicate that the sequence of activities is (i) → (ii) → (iii).

From the above, hydrothermal activities in the Bolivar area could broadly be divided into the following three stages:

Stage I: hydrothermal activities accompanied by precipitation and crystallization of sulfide minerals: Through these activities, porphyry copper type and vein type mineralized zones were formed. These hydrothermal activities are considered to have occurred in Miocene to Pliocene based on the evidence of (1) and (2) above. However, it is possible that porphyry copper type mineralized zones have been formed as post-igneous activity of granitic rocks in Miocene and vein type mineralized zones in Pliocene as activity accompanying tectonic movement. This is because porphyry copper type mineralized zones occur in granitic rocks and because, irrespective of granitic rocks, vein type mineralized zones, in the San Miguel area for example, exist in NNW-SSE system fault zones which are considered conjugate faults formed by reactivation of NNE-SSE to NE-SW system faults.

Stage II: hydrothermal activities accompanied by acid hydrothermal alteration and hematite: These activities are responsible for hot spring type mineralization of hematite-quartz networked veins that occur in the San Miguel and La Industria-Yatubi areas. The activities are considered to have taken place in Pliocene to Pleistocene based on the evidence of (2) above.

Stage III: hydrothermal activities accompanied by acid hydrothermal alteration involving no metallic elements: These activities formed what kaolinite alteration zones scattered in vicinities of the San Miguel area. The activities are considered to be hot spring activities in Holocene because they have altered the Guaranda Volcanic Rocks of Pleistocene in San Miguel.

As will be noted from the above, it is believed that properties of hydrothermal fluids in the Bolivar area changed from hydrothermal fluid of high sulfur fugacity containing various metallic elements to acid hydrothermal fluid with iron contents only and without sulfur content, and then finally to acid hydrothermal fluid free of metallic elements.

For direction of mineralized zones in the survey area, the Chaso Juan area shows N-S system, the Telimbela area, NE-SW, the Balzapamba area, NNE-SSW, the Las Guardias area, NW-SE, and the San Miguel area, NNW-SSE. Thus, the directions of these mineralized zones nearly agree with the directions of major tectonic lines in Ecuador and those of their conjugate sets. This is an important fact in exploration and calls for further study on their relations with igneous activities, tectonic movement and hydrothermal activities.

# Chapter 5 Conclusions and Recommendations

## 5–1 Conclusions

### 5–1–1 Balzapamba Area

The geology of this area consists of the Macuchi Formation of Late Cretaceous and granitic rocks of Oligecene to Miocene that intrude into this Formation.

Mineralization in this area can broadly be divided into the three types of porphyry copper type that occur in granitic rocks and adjacent Macuchi Formation, vein type and hot spring type, the latter two found in the Macuchi Formation. The El Torneado, Osohuayco and Las Juntas mineralized zones belong to porphyry copper type. The El Cristal mineralized zone is vein type, and the Las Palmas and Cochapamba alteration zones are hot spring type. In the El Torneado mineralized zone of porphyry copper type, five NNE-SSW trending major zones (A ~ E), 20 to 70m in width are formed within a range of 400m x 400m as bymodal occurrences of dissemination and network of sulfide minerals or quartz veins. For ore minerals, pyrite, chalcopyrite, molybdenite, magnetite, scheelite and pyrrhotite are observed. The results of drilling revealed that the mineralized zone A continues toward downward with dipping 60° SE and swells in the depth, and also that a concealed underlying networked mineralized zone exists below the mineralized zone A. The assay of ore samples from the mineralized zone A and the underlying mineralized zone are 0.09% to 0.66% Cu and 0.01 ~ 0.36% Cu, respectively.

Magnetic susceptibility measurements detected low magnetic susceptibility anomalous zones related to demagnetization caused by mineralization over each mineralized zones. Of these anomalous zones, those discovered in the El Torneado and Osohuayco mineralized zones are wide in scale.

Factor analysis of geochemical data identified the factors indicating Cu and Mo mineralizations in the El Torneado, Osohuayco and Las Juntas mineralized zones.

As a result of the geophysical survey, low resistivity zones were obtained over mineralized zone and alteration zone. Particularly, interesting low resistivity zones were found at the lower parts of the El Torneado and Osohuayco mineralized zones.

## 5-1-2 Other Areas

The geology of other 11 areas consists of the Macuchi Formation of Late Cretaceous, with intrusion of granitic rocks in Oligocene to Miocene.

Macroscopically, mineralization in these areas can be classified into the three types of porphyry copper, vein and hot spring. Porphyry copper type mineralized zones occur mainly in peripheral zone of granitic rocks and enclosing Macuchi Formation. Vein type occurs in the Lourdes Volcanic Rocks and hot spring type is observed in granitic rocks and the Lourdes Volcanic Rocks.

Mineralization of porphyry copper type is observed in the Chaso Juan, Telimbela and Las Guardias areas, vein type in the San Miguel area, and hot spring type in the La Industria-Yatubi and San Miguel areas.

In the Chaso Juan area, mineral showings of 20 to 200m in width are located at 10 places and form the north, the east and the south mineralized zones. Grades of ores show 1.2 to 1.8g/t Ag and 0.24 to 0.44% Cu with maximum contents of 1.5g/t Au, 160.9g/t Ag and 9.03% Cu. In the Telimbela area, mineralized zones are confirmed at four places, 500m x 350m to 400m x 200m in scale, and 150m wide. Grades of ores gave maximum content of 1.60% Cu. In the Las Guardias area, mineralized zones are located at three places, 400m x 100m to 350m x 500m in scale, and 150m in width. Maximum contents of ores are 0.6g/t Ag, 0.09% Cu and 0.01% W.

The mineralized zones in the Chaso Juan, Telimbela and Las Guardias areas are relatively large in scale. The mineralized zones in the Chaso Juan area are high in chalcopyrite/pyrite ratio and the occurrence of scheelite was reported. General trends of mineralized zones are N-S direction in the Chaso Juan area, NE-SW in the Telimbela area, NW-SE in the Las Guardias area, and NNW-SSE in the San Miguel area.

*Measurements of magnetic susceptibility* showed *anomalous zones* of *low magnetic* susceptibility related to demagnetization caused by mineralization. The anomalous zones of 1km x 1km in scale in the Chaso Juan area and 2km x 750m of NE-SW system in the Telimbela area, were detected, respectively. The anomalous zones were also clarified in the La Industria-Yatubi and San Miguel areas where hot spring type mineralizations are observed. The scale of the former is 500m x 200m and the later 2.5km x 500m of NNW-SSE system.

As a result of geochemical survey, zones with high to moderate factor scores characterizing Cu and Mo mineralizations were obtained in the Chaso Juan, Telimbela and Las Guardias areas. In the La Industria-Yatubi and San Miguel areas, factors indicating hot spring type mineralization in another stage were also detected.

## 5–2 Recommendations for Phase II Survey

### 5–2–1 Balzapamba Area

(1) Borehole geophysical survey (IP) and drilling to clarify the detailed occurrence of the El Torneado mineralized zone

(2) Geophysical survey (IP or SIP) to clarify bonanza of mineralized zone related to low resistivity zones at the lower part of the Osohuayco mineralized zone

### 5–2–2 Other Areas

(1) Detailed geological survey and geophysical survey (IP or SIP) to define the detailed occurrence of mineralized zone in the Chaso Juan, Telimbela and Las Guardias areas where porphyry copper type deposits can be expected

(2) Soil geochemical survey in the southwestern part of the La Industria-Yatubi area where the occurrence of hot spring type gold deposits may be expected

(3) Geophysical survey (SIP) in the San Miguel area to clarify the detailed occurrence of mineralized zone of copper vein type and detailed geological survey in the San Miguel area to follow up the mineralized which may be expected hot spring type gold deposit.

# PART II DETAILS

## Chapter 1 Balzapamba Area

In this area, geological and geochemical surveys, geophysical survey and drilling were conducted.

### 1–1 Geological and Geochemical Surveys

#### 1–1–1 Purpose of Survey and Survey Method

The purpose of the survey was to clarify relations between mineralization, geological structure and igneous activity, give comprehensive consideration to both the investigation results and existing geochemical exploration data, and identify characteristics of distribution of mineralized zones, thereby locating further promising mineral showings.

For survey, the routes were established by studying existing data and the route map was prepared based on a topographical map on a scale of 1 to 5,000 which was enlarged from currently prepared 1/10,000 map. In compiling the route map, aerial photographs were used. The geochemical survey was carried out in parallel with the geological survey and rock samples were obtained in vicinities of zones where mineralization was observed. Along with the geological and geochemical surveys, magnetic susceptibility was measured for each outcrop along the main route, using portable magnetometer, to examine its relations with mineralization.

Samples used for various tests and analyses were obtained with careful consideration to sampling points. Location of these sampling points is shown in Fig. A–1, and results of tests and analyses on the samples are given both under appropriate sections and at the appendixes of this report.

#### 1–1–2 Geology

**(1) Stratigraphy**

Geology of the survey area consists of volcanic rocks of the Macuchi Formation in Late Cretaceous, with intrusion of granitic rocks and trachyandesite.

The Macuchi Formation is further divided into six members, or bottom A through top F. A geological map is shown in Plate II–1–1, Fig. II–1–1, a geologic profile in Plate II–1–2, a generalized stratigraphic columnar section in Fig. II–1–2, and stratigraphic correlation for each route in Fig. II–1–3.

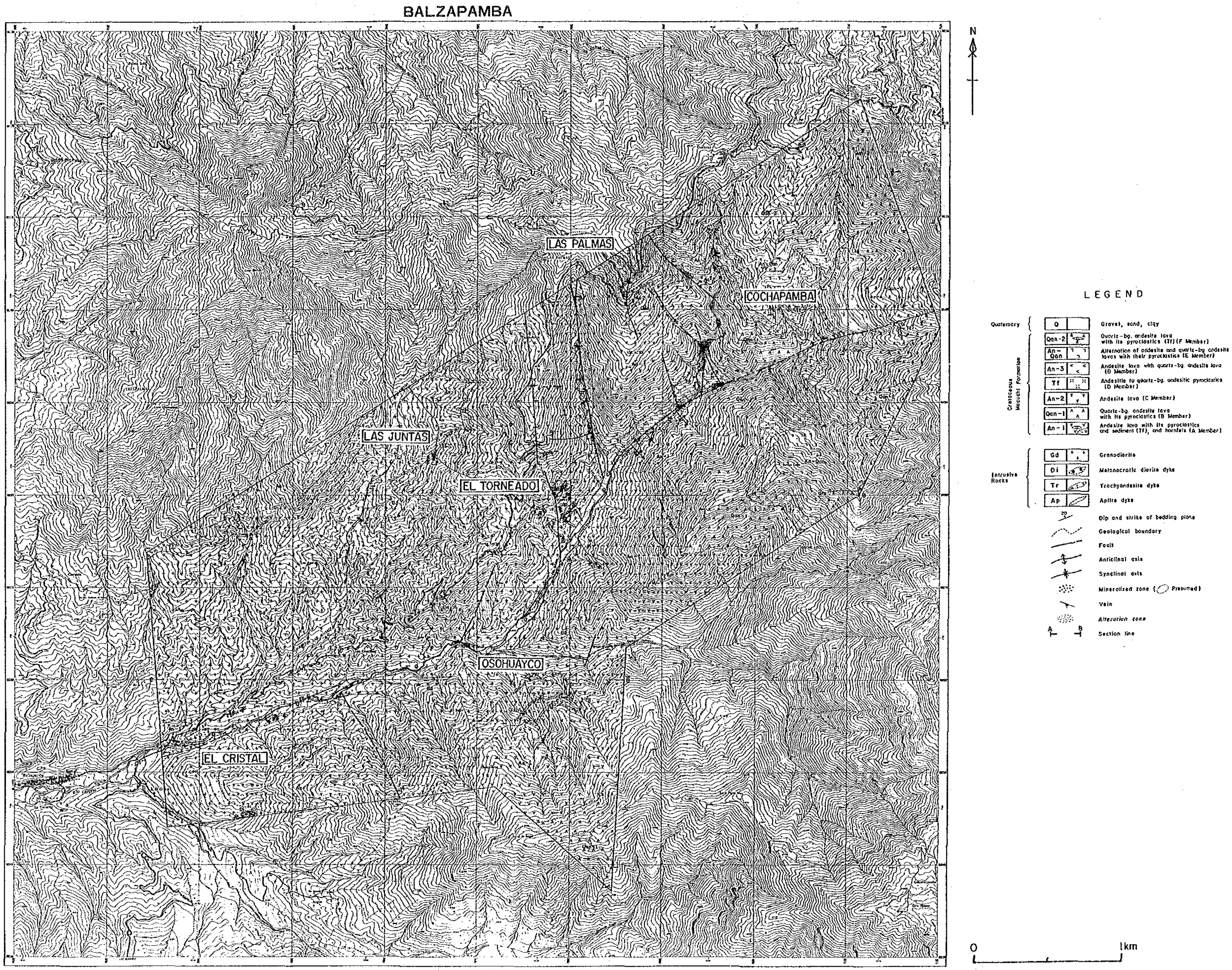
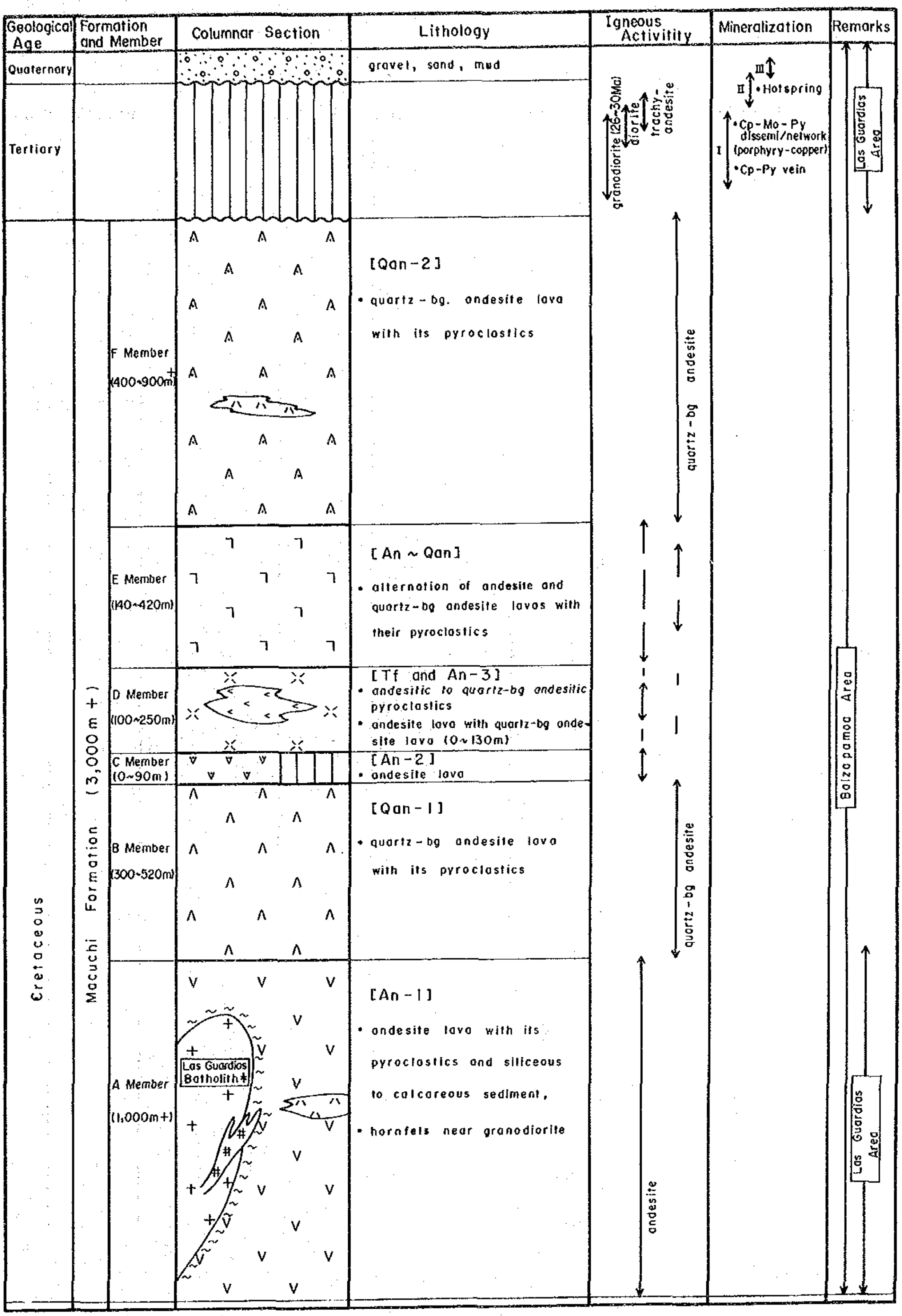



Fig. II－1－1　Geological Map and Distribution of Mineral Showings of the Balzapamba Area




* Las Guardias Batholith does not the geological time of its intrusion but its occurrence.

Fig. II – 1 – 2 Generalized Stratigraphic Columnar Section in the Balzapamba and Las Guardias Areas

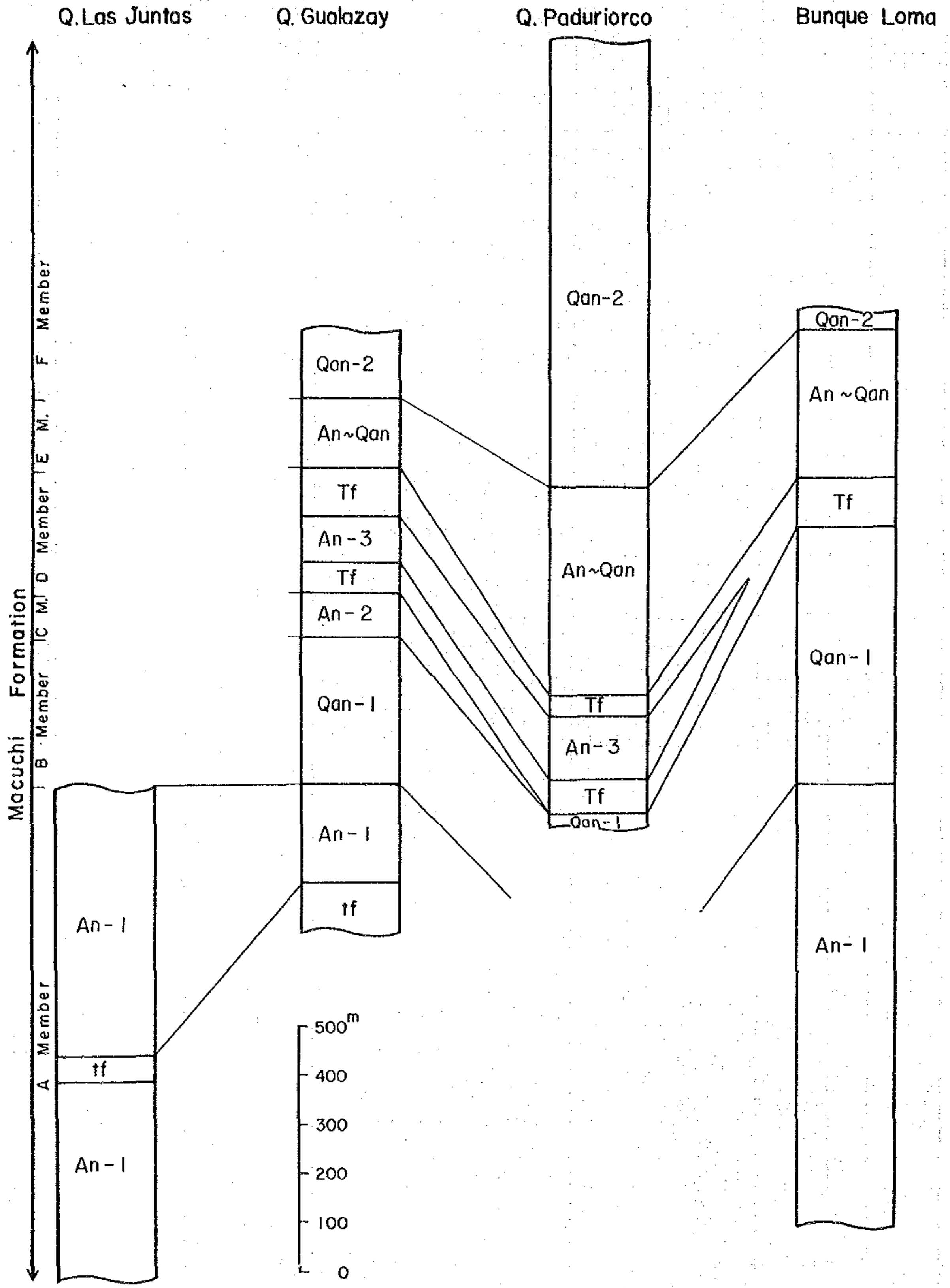



Fig. II－1－3　Geological Columnar Section and Stratigraphic Correlation of the Balzapamba Area

**Member A (An–1)**

This member is distributed in the northern, central eastern and southern parts, as it is encircling granitic rocks. Its thickness is estimated at more than 1,000m. It mainly consists of massive pyroxene andesite lava in dark green. It contains rhythmical thin alternation of greenish andesitic fine tuffs and dark gray siliceous ∿ calcareous sedimentary rocks along the Alcacer and Las Palmas valleys, in the south of the Osohuayco valley and the east of the Las Juntas valley.

In the area around granitic rocks, hornfels make it impossible to identify minerals and texture of original rocks and hard compact rocks comprising fine grained mafic minerals and/or quartz are distributed.

Results of microscopic observation of typical rocks are as follows:

Mafic hornfels (E1003)

Location : Northwestern part

Texture : Granoblastic

Principal and accessory minerals: Quartz, hornblende 〉 pyroxene 〉 opaque minerals

Alteration minerals : Epidote, chlorite

**Member B (Qan–1)**

This member is distributed in the eastern part of the Member A. Its thickness is estimated at 300 to 520m. It consists of dark green and gray, hard quartz-bearing andesite lava which contains a large amount of idiomorphic quartz crystal in the largest size of 2mm and secondary quartz plugging gas cavities of about 4mm. It locally contains its tuffs.

Results of microscopic observation of typical rocks are as follows:

quartz-bg. andesite (C1031)

Location : Upstream of Gualazay valley

Texture : Porphyritic

Principal and accessory minerals : Quartz, plagioclase, biotite 〉 K–feldspar 〉 pyrite

Alteration minerals : Quartz 〉 chlorite 〉 sericite, epidote 〉 calcite, leucoxene

Biotite has mostly been altered into chlorite and epidote, and K–feldspar partially into sericite.

**Member C (An–2)**

This member is distributed in narrow strips in the midstream of the Gualazay valley and its tributary only, and no development is observed in the south of the Alcacer valley. Its thickness is estimated at 0 to 90m. It consists of andesite as is the case with the Member A.

**Member D (Tf, An–3)**

This member is distributed along the east side of the Members A and B in the upstream of the Las Palmas valley to Pallatanga and Bunque Loma. Its thickness is estimated at 100 to 250m. It consists of andesitic ~ quartz-beraing andesitic pyroclastic rocks (Tf) and andesite lava contained therein (An–3).

Tf is andesitic in the Gualzay valley but turns to quartz-bearing andesitic in other distribution areas. It mostly consists of coarse to lapilli tuffs but tuff breccia has locally developed in the upstream of the Alcacer valley.

Results of microscopic observation of typical rocks are as follows:

Lapilli tuff (C1016)

Location : Upstream of Las Palmas valley

Texture : Clastic

Principal and accessory minerals: Quartz > hornblende > plagioclase, apatite, sphene, opaque minerals

Alteration minerals : Quartz, chlorite > sericite, epidote

An–3 comprises andesite lava as in the Member A but holds two layers of quartz-bearing andesite lava in the Gualazay valley.

**Member E (An ∿ Qan)**

This member is distributed in the Gualazay valley ∿ upstream of the Alcacer valley ∿ Bunque Loma. Its thickness is estimated at 140 to 420m. It consists of alternation of andesite lava and quartz-bearing andesite lava but the latter dominates in Bunque Loma. It is locally interbedded with their tuffs.

**Member F (Qan–2)**

This member is distributed in the northeast to the east of the survey area. Its thickness is estimated at 400 to more than 900m. As is the case with the Member B, it consists of quartz-bearing andesite lava and contains its tuffs in the Padriorco valley.

**(2) Intrusive Rocks**

Intrusive rocks in the survey area consist of granodiorite batholith, small intrusion of melanocratic diorite and trachyandesite and aplite dikes.

Granodiorite (Gd)

It widely occurs to the west from the central area. Lithology comprises granular hornblende-biotite granodiorite. Although virtually no variation in lithology is observed, quartz diorite irregularly occurs in granodiorite in the Las Juntas mineralized zone. In the El Torneado mineralized zone, networked veins are found in host rocks subjected to argilization and silicification due to mineralization, presenting apparent brecciated texture.

Granodiorite generally intrudes into the Macuchi Formation on steep dipping as seen, for example, in Las Juntas valley. Meanwhile, this rock takes in xenolith of the Macuchi Formation or branches in sheets depending on areas, as observed on the road north of Santa Lucia settlement and along path to El Torneado. In this manner, it presents various aspects.

Results of microscopic observation of typical rocks are as follows:

Biotite granodiorite (A1019)

Location : One Km east of Santa Lucia settlement

Texture : Holocrystalline and granular

Principal and accessory minerals : Plagioclase, quartz, biotite 〉 K-feldspar 〉 apatite, allanite, opaque minerals

Alteration minerals : Secondary biotite 〉 sericite, actinolite, chlorite, leucoxene

Biotite has slightly been altered to chlorite.

This time, isotopic age determination by K-Ar method was made on rock (A1131) in the vicinity of Santa Lucia settlement. As a result, 25.7 + 0.9Ma was obtained (Table II–1–1).

Results of chemical analysis of granitic rocks, $SiO_2$–FeO*/MgO variation diagram and normative quartz-orthoclase-plagioclase diagram are shown in Table II–1–2 and Fig. II–1–4. Consequently, granitic rocks in this project area were found to be rocks in calc-alkali series and were plotted in the area of granodiorite.

**Melanocratic diorite intrusive rock (Di)**

This rock is abundantly distributed in the vicinity of granodiorite batholith and is observed in both El Torneado and Las Juntas mineral showings as well as in the southwestern part. It is black and is a diorite mainly consisting of fine-grained biotite. Intrusive rocks are 20 to 50m wide and many of them are in the direction of NE–SW. In Esperansa valley, they locally present a porphyritic texture. Results of microscopic observation of typical rocks are as follows:

Biotite quartz diorite (A1011)

Location : El Torneado mineralized zone, Esperansa valley

Texture : Holocrystalline and granular

Principal and accessory minerals : Plagioclase 〉 biotite 〉 quartz 〉 K–feldspar 〉 apatite, allanite, opaque minerals

Table II − 1 − 1 Results of Isotopic Age Determination (K-Ar Method)

| No. | Sample No. | Location Coordinates | | Rock Name | Mineral | K (wt%) | Radiogenic 40Ar ($10^{-8}$cc/g) | K-Ar Age (Ma) |
|---|---|---|---|---|---|---|---|---|
| | | E | N | | | | | |
| 1 | A1131 | Balzapamba 707.56 | 9807.83 | bt-hb q. dio | Hornblende | 0.37 | 37.2 ±0.7 | 25.7 ±0.9 |
| 2 | B1109 | Chaso Juan 706.17 | 9845.14 | bt grd | Biotite | 6.68 | 543.8 ±6.3 | 20.9 ±0.7 |
| 3 | C1079 | La Industria 690.97 | 9825.26 | bt-hb q. dio | Hornblende | 0.90 | 89.2 ±1.6 | 25.5 ±0.9 |
| 4 | B1166 | Telimbela 703.68 | 9816.01 | bt-hb q. dio | Biotite | 5.75 | 434.2 ±5.2 | 19.4 ±0.6 |
| 5 | B1071 | Las Guaradias 708.14 | 9798.66 | hb q. dio | Hornblende | 0.25 | 29.4 ±0.7 | 30.1 ±1.1 |

Table II − 1 − 2 Results of Chemical Analysis of Granitic Rocks

| | No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| | Sample No. | A1131 | B1109 | C1079 | B1166 | B1071 |
| Coordinates | E | 707.56 | 706.77 | 690.97 | 703.68 | 708.14 |
| | N | 9807.83 | 9845.14 | 9825.26 | 9816.01 | 9798.66 |
| | Rock Name | bt-hb quartz diorite | bt granodiorite | bt-hb quartz diorite | bt-hb quartz diorite | hb quartz diorite |
| Chemical Composition | $SiO_2$ | 58.24 | 71.63 | 65.40 | 62.60 | 64.59 |
| | $TiO_2$ | 0.69 | 0.21 | 0.45 | 0.55 | 0.40 |
| | $Al_2O_3$ | 17.11 | 14.41 | 15.65 | 16.32 | 16.47 |
| | $Fe_2O_3$ | 3.87 | 0.87 | 2.64 | 2.69 | 2.47 |
| | FeO | 4.68 | 1.56 | 2.34 | 3.38 | 2.73 |
| | MnO | 0.16 | 0.02 | 0.12 | 0.11 | 0.10 |
| | MgO | 3.48 | 0.83 | 2.14 | 2.75 | 1.96 |
| | CaO | 7.79 | 2.89 | 5.21 | 6.19 | 6.20 |
| | $Na_2O$ | 2.97 | 3.29 | 3.38 | 3.19 | 3.03 |
| | $K_2O$ | 0.59 | 3.35 | 1.10 | 1.31 | 1.25 |
| | $P_2O_5$ | 0.09 | 0.04 | 0.09 | 0.09 | 0.05 |
| | Ig–loss | 0.57 | 0.60 | 1.23 | 0.82 | 1.07 |
| | Total (%) | 100.24 | 99.70 | 99.75 | 100.00 | 100.32 |
| CIPW Normative Mineral | q | 16.40 | 31.52 | 26.92 | 21.24 | 25.58 |
| | c | 0.00 | 0.21 | 0.00 | 0.00 | 0.00 |
| | or | 3.49 | 19.80 | 6.50 | 7.74 | 7.39 |
| | ab | 25.13 | 27.84 | 28.60 | 26.99 | 25.64 |
| | an | 31.61 | 14.08 | 24.28 | 26.34 | 27.65 |
| | ne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | ac | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | ns | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | ks | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | wo | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | diwo | 2.69 | 0.00 | 0.41 | 1.58 | 1.16 |
| | dien | 1.66 | 0.00 | 0.29 | 1.00 | 0.72 |
| | difs | 0.87 | 0.00 | 0.09 | 0.48 | 0.37 |
| | hyen | 7.01 | 2.07 | 5.04 | 5.85 | 4.16 |
| | hyfs | 3.75 | 1.86 | 1.53 | 2.85 | 2.16 |
| | olfo | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | olfa | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | mt | 5.61 | 1.26 | 3.83 | 3.90 | 3.58 |
| | hm | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | il | 1.31 | 0.40 | 0.85 | 1.04 | 0.76 |
| | tn | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | pf | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | ru | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | ap | 0.21 | 0.09 | 0.21 | 0.21 | 0.12 |
| | cc | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | pr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Total | 99.74 | 99.13 | 98.54 | 99.23 | 99.29 |

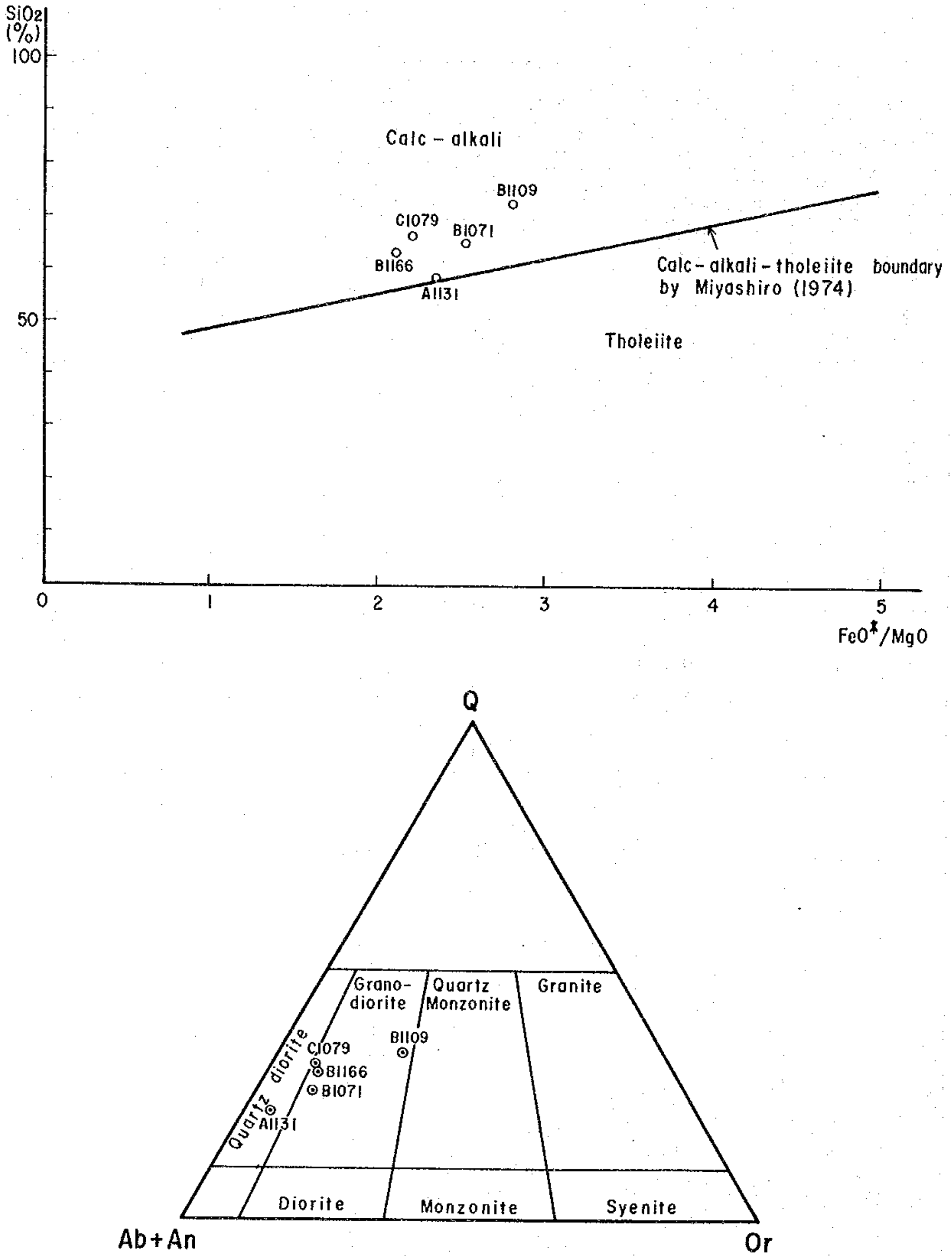



Fig. II − 1 − 4 Chemical Variation Diagrams for Granitic Rocks :(1) $SiO_2$-($FeO^*$/MgO) Variation Diagram (2) Normative Quartz (Q) -Orthoclase (Or) -Plagioclase (Ab+An) Diagram

Alteration minerals : Secondary biotite > chlorite > sericite, actinolite, epidote, leucoxene

Biotite is locally affected by chloritization.

**Trachyandesite (Tr)·Aplite dikes (Ap)**

These dikes, several meters in width, are observed in the El Torneado mineral showings. Trachyandesite dikes are greenish gray in color and contains feldspar with a small quantity of pyroxene phenocryst. Most dikes run is NE–SW ~ E–W directions. Aplite dikes mainly comprise colorless minerals with some biotite and NE–SW and NW–SE systems were observed as their direction.

### (3) Geological structure

The Macuchi Formation is generally in N–S strike and gently dips toward east as a whole. Gentle folding structures are observed in the east and west of Las Palmas valley and along Alcacer valley. In the south, the strike changes to E–W and dipping steeply increases in the direction of south due to the effect of granodiorite.

Major faults are NE–SW systems along El Salto river from upstream of Alcacer valley and NNW–SSE systems are found in the El Torneado mineralized zone, Las Palmas valley and down stream of Gualazay valley. In addition, E–W system develops along Osohuayco valley.

## 1–1–3 Mineralization and Alteration

Mineralization in this area can be classified into the three groups of porphyry copper type, vein type and hot spring type. Porphyry copper type includes the El Torneado, Osohuayco and Las Juntas mineralized zones. Vein type includes the El Cristal mineralized zone, and hot spring type, the Las Palmas and Cochapamba alteration zones, respectively.

### (1) El Torneado Mineralized Zone

This meneralized zone is situated about 1km east of Santa Lucia settlement and is distributed over a range of about 400m x 400m. As the geology in the vicinities of El Torneado, granodiorite, melanocratic diorite, and mafic hornfels of the Macuchi Formation are distributed. Locally, trachyandesite dikes which cut granic rocks in irregular shapes exist. Mineralized zones are porphyry copper type deposits and occur in granitic rocks. In the Macuchi Formation, mineralized veins exist only locally in the bordering area with granitic rocks. Granitic rocks in this area has the dissemination of pyrite, but principal mineralized zones are five mineralized zones of dissemination/networked vein containing chalcopyrite-pyrite-molybdenite, etc., 20 ~

70m wide, 70 ~ 350m in extension, and running in NNE–SSW direction.

These mineralized zones can be divided into the two types of the disseminated mineralized zone and the networked vein mineralized zone. The disseminated mineralized zones are cut by the networked vein minralized zones. From this fact, it is considered that the latter was formed after the former.

(i) Disseminated mineralized zones: Ore minerals exist wholly as dissemination or film in granitic rocks which do not show brecciated structure. The mineralized zone B fails under this category and a large quantity of pyrite and a small quantity or chalcopyrite are disseminated in granodiorite. Alteration consists of secondary biotization and weak chloritization.

Macroscopically, pyrite with a very small quantity of chalcopyrite is disseminated throughout granodiorite in the El Toreado mineralized zones, and the mineralized zone B is abundant with chalcopyrite.

(ii) Networked vein mineralized zones: These zones are formed in the brecciated granitic rocks. The interstices of breccias are filled with ore minerals and gangue minerals in irregular network pattern. As ore minerals, a large quantity of pyrite, a small quantity of chalcopyrite and molybdenite and a very small quantity of magnetite and scheelite are observed, along with local occurrence of pyrrhotite. The gangue minerals include quartz, chlorite, and secondary biotite. Epidote locally occurs. Relatively large ore minerals are observed in these mineralized zones. Chalcopyrite lenses more than 1cm, pyrite lenses more than 5cm and molybdenite lenses more than 1cm are locally observed.

A brecciation is most intense in the mineralized zone, consisting of aggregates of breccias few cm to 30cm across, and it gradually become weaker toward marginal mineralized zone which only shows twiggy interstice in granitic rocks. A rugged surface of individual breccias generally fit well with surface of adjacent breccias. Each breccia can be easily reconstruct to the primary aspect before the development of brecciation and interstices between breccias are filled with ore and gangue minerals. Further, the texture representing the early stage of brecciation is observed in the marginal part of the mieralized zone and its peripheral area (Photo A–3). These aspects suggest that the brecciation in this area was caused by hydrofracturing during hydrothermal event.

Outcrops of the mineralized zones A, C, D and E are these areas. In the mineralized zones A, C and D, networked veins formed with above ores exist in breccia zones which were subjected to sericite alteration as a whole. Assay results show 0.2g/t Au, 2.0g/t Ag and 0.66% Cu for the mineralized zone A, and 0.03% Cu for the mineralized zone D. Results of X-ray diffractive analysis show that alteration minerals in these zones comprise potash feldspar, sericite, chlorite and secondary biotite. Kaolin which is considered associated with hot spring activities in the later period also exists in places.

Mineralized zone E is a pyrite-chlorite-quartz networked vein that exists in the bordering area between granodiorite and the Macuchi Formation. Alteration consists of chloritization and silicification at the surroundings of vein only.

**(2) Osohuayco Mineralized Zone**

This mineralized zone is situated about 2km south of Santa Lucia settlement. Macroscopically, it lies in the vicinity of the contact between granodiorite and the Macuchi Formation. As mineralized outcrops, three mineralized zones are observed in two valleys that run in the northwest direction toward the Osohuayco river. Mineralized zone in the north comprise chalcopyrite-pyrite-chlorite-quartz networked veins and their sulfide minerals disseminated zones which occur in coarse granodiorite. This mineralized zone is considered continuing to chalcopyrite-pyrite-grosslularite-quartz networked vein zones in hornfels metamorphased from andesite which belongs to the Macuchi Formation exposed in valleys in the north. For alteration, silicification and chloritization are conspicuous. This mineralized zone is about 100m in width and about 200m in extension. Analyses of chip samples obtained from this mineralized zone show 0.08% Cu for dissemination ore in granodiorite, 0.4g/t Au, 27.8g/t Ag and 2.60% Cu for veins in the Macuchi Formation.

Mineralized zone in the south comprises chalcopyrite-pyrite-grossularite-quartz veinlets that occur in the area of the Macuchi Formation which was subjected to silicification and skarnization. Skarnized zone is about 10m in width and can be traced for about 400m in NNE–SSW direction. The mineralized zone in the central part is a skarnized zone exposed at a summit between two valleys. The size of the outcrop is 2 to 3m wide and 10m in extension.

***(3) Las Juntas Mineralized Zone***

The Las Juntas mineralized zone is situated in a tributary of Las Juntas valley and consists of chalcopyrite-pyrite disseminated zone in granodiorite and quartz diorite and pyrite-quartz networked vein zone in hornfels of the Macuchi Formation.

For the former, there is lack of continuity with a lenticular disseminated zone of less than 2 to 3m in width observed in two palces only. The latter is similar to the El Cristal mineralized zone to be described next. However, only a few veins less than 1m wide are observed in outcrops of 10m x 2m. Results of ore analysis show 1.1g/t Ag and 0.11% Cu. According to existing data, chalcopyrite-sphalerite-galena were observed along with pyrite. However, the situation cannot be confirmed at present becuase most outcrops are buried due to landslide.

#### (4) El Cristal Mineralized Zone

The El Cristal mineralized zone is situated in the western end of this area and is a vein type mineralized zone which was formed in hornfles of the Macuchi Formation (Fig. II–1–5). Its strike is N80°W, dip 75–80°S, extension more than 30m and vein width 17m. Principal minerals are pyrite and quartz with chalcopyrite in an extremely small quantity. Pyrite is disseminated and occurs in the entire mineralized zone. Furthermore, from the center to the hanging wall, pyrite forms three strips of concentration, ranging 0.7 to 1.8m in width. Quartz is observed in veins in the center, coexisting with a large amount of limonite. Results of ore analysis show 2.1g/t Ag and 0.16% Cu.

#### (5) Las Palmas Alteration Zone

The Las Palmas alteration zone is distributed over an area of more than 2km from upstream of Las Plams valley in the northeastern direction. It mainly consist of argillized and slicified rocks with localized hematite. This alteration zone can be classified into (1) products of hydrothermal activities which involve the same type of sulfide minerals in the same period as the activities in El Torneado, and (2) products from later hot spring activities. For the former, chalcopyrite-pyrite dissemination is locally observed while hematite-quartz veinlet is noted in the latter. Results of X–ray diffractive analysis identified assemblage of quartz-chlorite which is considered associated with the former and of quartz-kaolinite-halloysite which is considered related to the latter.

In the south of this alteration zone, mineral showings are spotted in three places along the fault of N–S system. One of them is a chalcopyrite-chalcocite-pyrite-quartz networked vein in fault breccia zone. The other two are chalcopyrite-pyrite dissemination zones which exist in both granitic rock dikes and highly silicified andesite in the Macuchi Formation in vicinities of faults. Either of these mineral showings is small in scale, being only about 2 to 3m in width. Results of ore analysis show 7.6g/t Ag and 0.60% Cu for the networked zone and 0.02% Cu for the disseminated zone. Results of X–ray diffractive analysis indicated assemblage of quartz-sericite-chlorite in both of them.

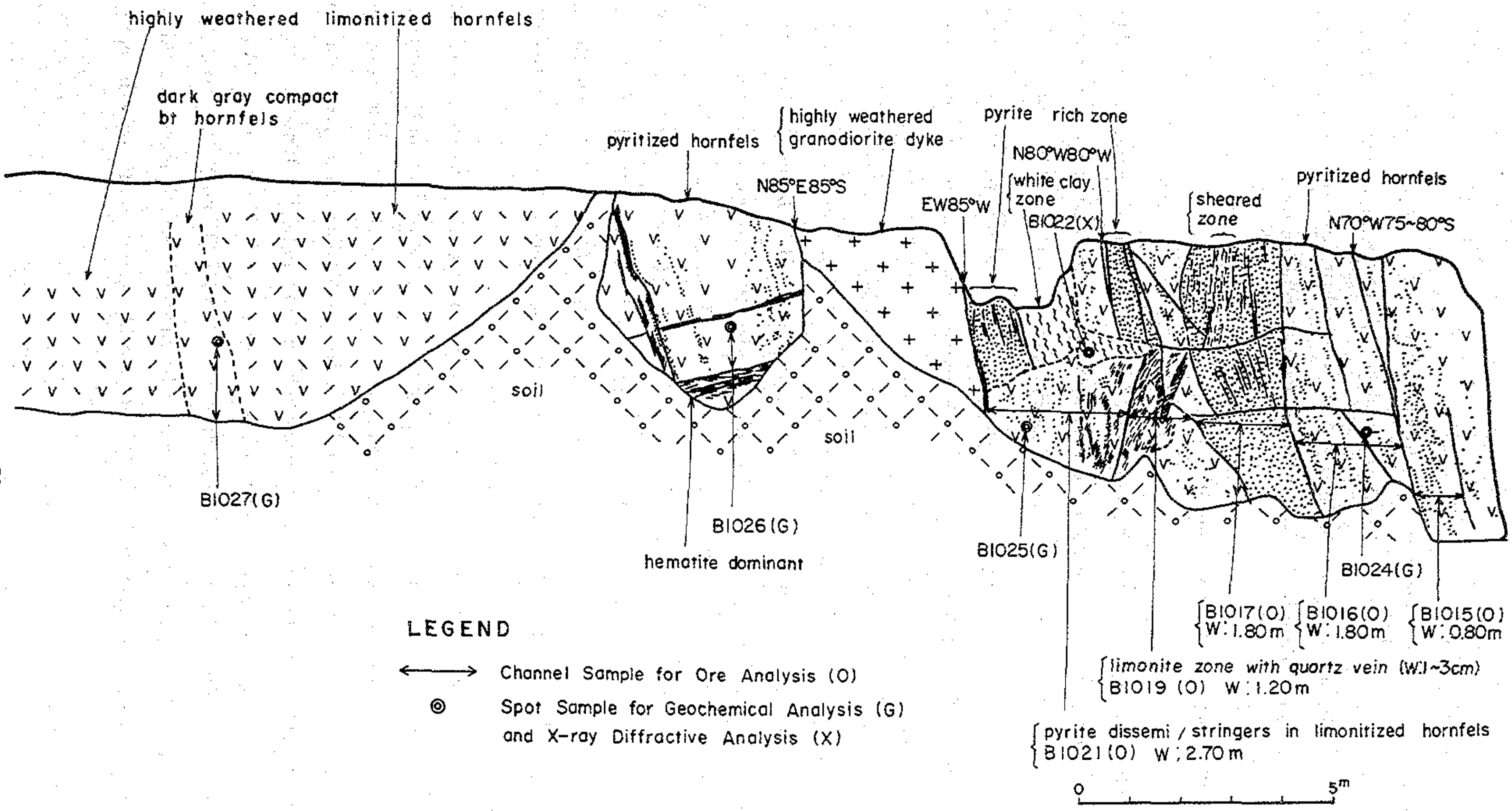



Fig. II − 1 − 5 Geological Sketch of the El Cristal Mineralized Zone

### (6) Cochapamba Alteration Zone

Highly silicified alteration zone is widely distributed in volcanic rocks of the Macuchi Formation along Alcacer, Gualazay and Paduriorco valleys. In this alteration zone, pyrite dissemination and argillized alteration are locally observed. X–ray diffractive analysis on the clay identified chlorite and halloysite as in the case of the Las Palmas alteration zone.

## 1–1–4 Magnetic Susceptibility Measurement

To quantitatively determine demagnetization due to mineralization, magnetic susceptibility was measured, using a portable magnetometer. This magnetometer was Kappameter Model KT–5 of Czechoslovakia and can measure magnetic susceptibility in units of $1 \times 10^{-3}$ SI.

Before measurement, efforts were made to completely strip weathered portions from outcrops and eliminate surface unevenness to prevent measuring errors due to weathering and surface unevenness. Measurements are made five times and the average of three values was made the measured value by disregarding the highest and lowest values. (Talbe A–5).

Measurement values sharply fluctuated from 0.1 to $156 \times 10^{-3}$ SI units. Fresh granodiorite showed 20 to $40 \times 10^{-3}$ SI units, melanocratic diorite, 40 to $156 \times 10^{-3}$ SI units, andesite lava in the Macuchi Formation, 50 to $70 \times 10^{-3}$ SI units, quartz-bearing andesite lava, tuffs, and sedimentary rocks in this formation, all less than $10 \times 10^{-3}$ SI units. Main mineralization in this area was porphyry copper type. With values below $20 \times 10^{-3}$ SI units as anomalously low, anomalous values for low magnetic susceptibility were set as follows: $0.1–5.0 \times 10^{-3}$ SI units (extremely low), $5.1–10.0 \times 10^{-3}$ SI units (considerably low), $10.1–20.0 \times 10^{-3}$ SI units (low), more than $20.1 \times 10^{-3}$ SI units (background). Based on these four anomalous values, an analytical chart for anomalous zones was prepared (Fig. II–1–6).

Distribution of anomalous zones well coincide with that of above mineralized zones. In other words, three anomalous zones in NE–SW direction ($0.2 \sim 20 \times 10^{-3}$ SI units) observed in the El Torneado mineralized zones agree with mineralized zones A, C, D and E in location. In the Osohuayco mineralized zone ($0.58 \sim 12 \times 10^{-3}$ SI units), anomalous zones agree with disseminated zones in granodiorite and veins in the Macuchi Formation. In the Las Juntas mineralized zone, anomalous zones were found in two places for quartz diorite ($0.83 \sim 1.1 \times 10^{-3}$ SI units), and in one place for the Macuchi Formation ($0.4 \sim 8 \times 10^{-3}$ SI units). The anomalous zone in the Macuchi Formation amounts to 750 m in width and shows values inherently held by rocks, aside from results of alteration. In the El Cristal mineralized zone, pyrite-clay veins are as

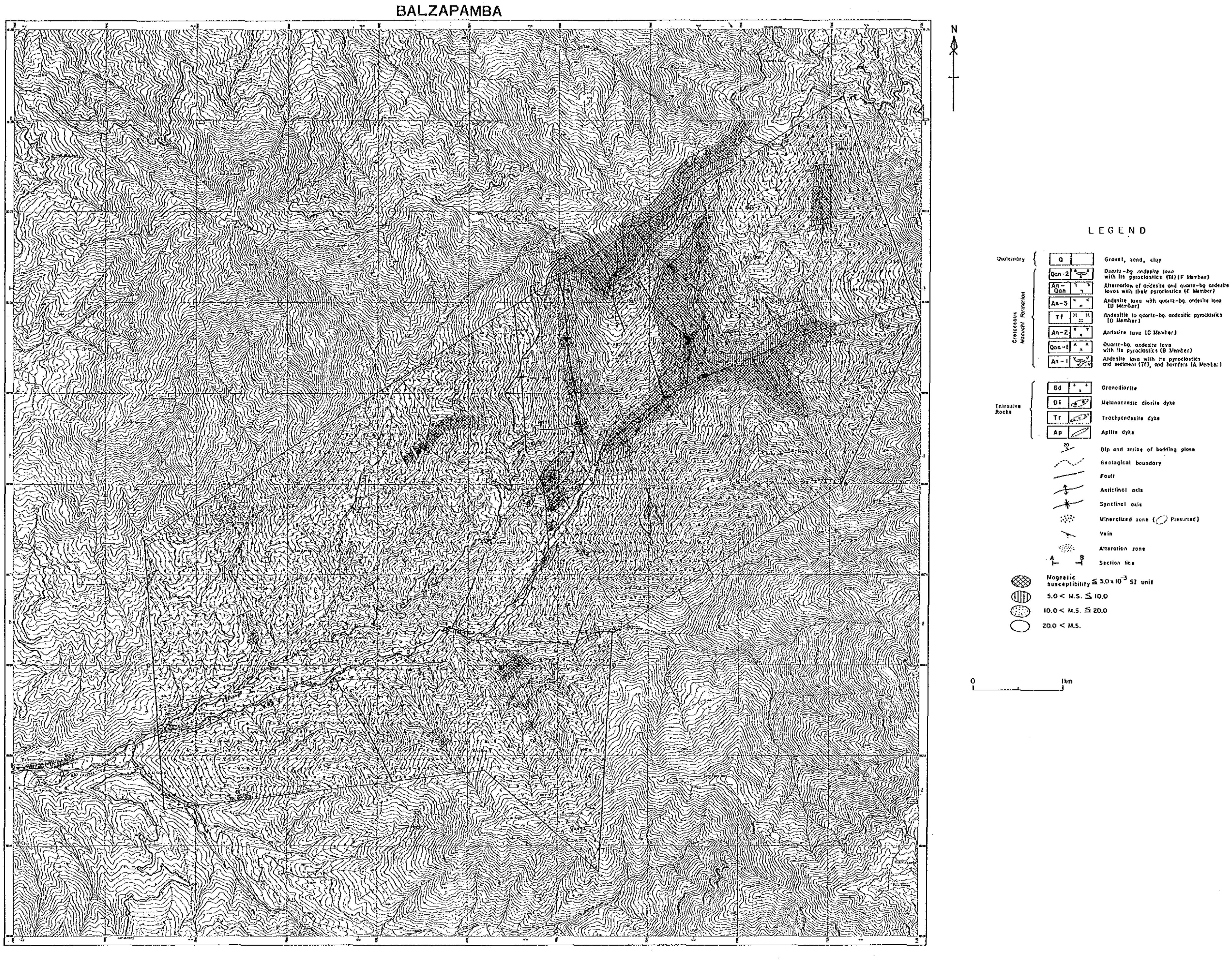



Fig. II − 1 − 6 Interpretation Map of the Mineralization and Magnetic Susceptibility of the Balzapamba Area