REPORT ON GEOLOGICAL SURVEY

OF

THE MICHIQUILLAY AREA, REPUBLIC OF PERU

(Consolidated Report)

November 1975

METAL MINING AGENCY

JAPAN INTERNATIONAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

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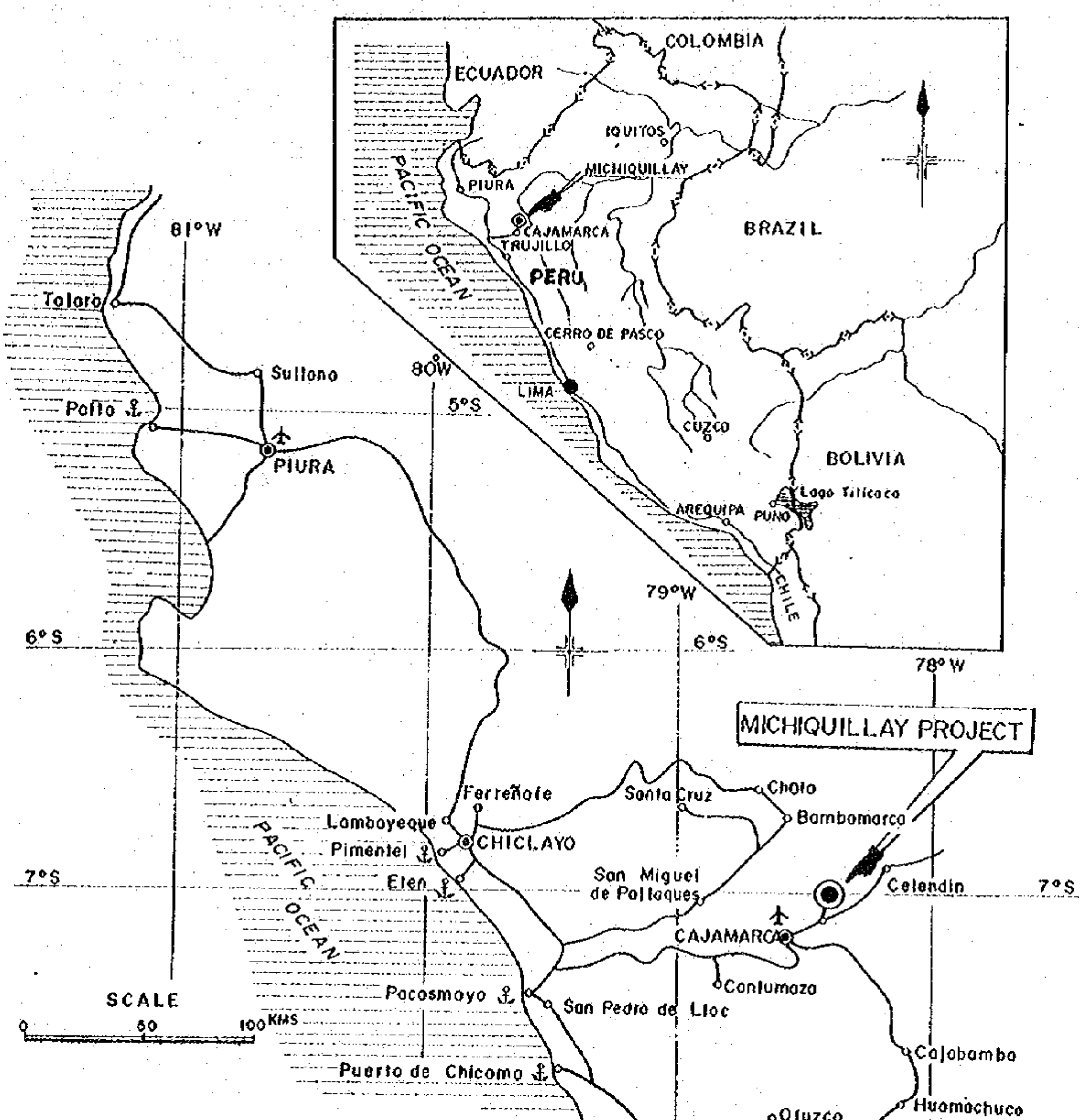
Fig. 1 LOCATION MAP



TRAFFICWAY DISTANCE

MICHIQUILLAY
↓ 50KM
CAJAMARCA
↓ 194KM
PORT PACASMAYO
300KM → TRUJILLO
848KM → LIMA

CONTENTS

A B S T R A C T

(1) The tunnelling with total advance of 1,240 meters and diamond boring, both underground and surface, with total drilled length of 2,600 meters constituted the main part of the operations of the present survey.
The greater part of the works were performed for the precise investigation of the main part of the Michiquillay Ore Deposit, but three surface borings were drilled vertically for the unexplored areas of mineralization.

(2) Following the advance of these works, the precise geological sketches and collection and preparation of assay samples were done, in which the total samples amounted to 1,328.

Through the comprehensive analyses of all the data thus obtained and accumulated, such fundamental geological features of the deposit have been clarified as follows;

1) two stages of copper mineralization as dissemination and in veinlets were exactly recognized,

2) the features of the associated alteration and the zonal arrangement of the altered zones were accurately observed,

3) the fracture control of the ore distribution was well recognized,

4) the formation of the secondary copper minerals by the supergene alteration and their inter-relation were well studied, as well as,

5) the relation of such geological features to the assay distribution was clarified.

Consequently, the geology of the Michiquillay Ore Deposit, so far as 3,500 m Level is concerned, was investigated almost thoroughly, which

enabled fully to understand the fundamental geological natures of the deposit, and thus, the initial scheme of the present survey has been well attained.

(3) Further, the results of the outdoor geological observation enabled to make an interpretation of the structural history of the Michiquillay Ore Deposit, which will be briefly summarized as follows;

1) During the course of formation of the Andes Mountains which is estimated in Late Cretaceous or Early Tertiary, the Michiquillay area was involved in a zone of deformation intersecting diagonally to the Andes and including Cajamarca District. The area was put under the influence of the lateral compressive stress of mountain forming as well as the influence to twist the initial general trend of the structure duplicatedly.

2) Naturally, in response to such the fields of stresses, a series of fault and fracture systems were formed by which the intrusion of magma, presently represented by hornblende monzonite porphyry, was induced. A part of the magma intruded discordantly to the geological structure at the very location of the present Michiquillay Ore Deposit, and captured a great amount of wall rocks and assimilated them. Consequently the magma of this limited portion was converted into a facies represented by biotite quartz monzonite porphyry through the contamination. Moreover, the concentration of copper element is understood to have taken place only in this limited portion, which caused to yield a porphyry copper deposit.

3) Microscopic observation of the ore has revealed that the crystallization of copper mineral, chalcopyrite, had started already in the latest

stage of the crystallization of biotite phenocryst, and it may be safely infered that even in the groundmass, still fluidal in the said stage, there might have existed the sprouts of the copper mineral to crystallize out, which, along with the solidification of the groundmass, were confined in the groundmass resulting in to form the porphyry copper deposit. After the solidification of the groundmass, opening of the fractures in the host rock offered the spaces for the ore forming materials to migrate or to deposit, yielding numerous copper-bearing stringers and veinlets.

4) Such the characteristic coincidence of the discordant intrusion of magma and the resultant contamination of the magma to the concentration of copper element is observable only in the location of the present Michiquillay deposti as far as the area is limited in the Michiquillay area. Except this portion, in the Michiquillay area, the intrusion of magma represented by hornblende monzonite porphyry is more or less concordant to the geological structure of the wall rock formations, and the mineralization effects caused by it is pyrometasomatic type in the adjacent limestone or calcareous sediments, and as far as the observation is concerned, they are quite local and small in scale.

5) It may safely be said that the Michiquillay Ore Deposit has nearly passed through the stage of exploration along with the completion of the present survey. As the various natures of ore observed on 3,500 m Level in the present survey may involve all the possible features of ore to be mined in the early stage of operation, it may well contribute to plan out the reasonable production schedule.

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Geological Data

GENERALS

G E N E R A L S

Chapter 1 Introduction

1-1 Purpose of Survey

The present survey was carried out in response to the request by the Government of the Republic of Peru for the purpose to contribute for programming the future development of the Michiquillay Mine existing in the country, by collecting as much fundamental geological informations of the Michiquillay Ore Deposit, for which tunnelling as well as underground and surface boring operations were executed this time.

1-2 Summary of Survey

The works performed in this survey consisted of tunnelling, underground horizontal boring, and surface vertical boring, and the greater part of the works were done for the investigation of the Michiquillay Ore Deposit and the rest was to explore the unconfirmed areas of mineralization. The underground works were entirely done from the pre-existing tunnel of 3,500 m Level driven by American Smelting and Refining Co.

1-2-1 Tunnelling

Five cross cuts were driven, being branched out from the main drift of 3,500 m Level, and four raises were driven too, to investigate the vertical change of the deposit, with the overall advance of 1,240 meters. Geological sketch in 1/200 scale was followed after the newly driven tunnels, in which the back and one side wall of the tunnel were sketched as well as assay samples were collected regularly, and the data were compiled as "Underground Geological Sketches and Assay Maps of Crossouts" in a scale of 1/200. In the raises, the sketch and sampling were done on one of the side walls, and the data were compiled into "Underground Geological Sketches and Assay Maps of Raises".

1-2-2 Underground Boring

Sixteen horizontal holes were drilled in various directions from the main drift and newly driven cross cuts, which were layed out to promote the precisity of investigation as much in the ore body. The drilled cores were sketched in a scale of 1/100 as well as systematic assay samples were collected, and the data were compiled into "Geological and Assay Logs of Underground Drill Holes" of scale 1/200.

1-2-3 Surface Boring

Four holes were drilled all vertically at four sites. One of the four was drilled in the ore body, while the rest three were drilled to explore the unconfirmed areas of mineralization, of which drilled length was 706.28 meters. The overall drilled length both underground and surface amounted to 2,600 meters. Data were collected and recorded just as similarly to the underground holes and were compiled into "Geological and Assay Logs of Surface Drill Holes".

1-2-4 Data Analysis

Based upon the data obtained from the field survey, the comprehensive analyses have been done regarding to the geological structures, mineralization alterations, assay distributions, etc.. In addition, the assay samples collected and prepared amounted to 496 (including 85 composits) from the tunnels, 832 (including 143 composits) from boring cores, and their total amounted to 1,328 including 228 composits.

1-3 Members of Survey Team

The followings are the members of survey teams for each year Phase;

	First Year Phase		Second Year Phase	
Leader of Team	Choki Ohkura	MESCO*	Choki Ohkura	MESCO
General Super-vision and Liaison	Yukio Shimatani	"	Yukio Shimatani	"
	Yasuo Mukai	"	Saburo Abe	"
	Sakura Matsumura	"	Takafumi Kado	"
	Takashi Hasegawa	"	Takashi Hasegawa	"
Tunnelling	Kunihiko Tsukanaka	"	Kunihiko Tsukanaka	"
Boring	Harukichi Shimode	"	Harukichi Shimode	"
Geological Survey	Hiroshi Sato	"	Tatsuzo Iwafune	"
	Hiroshi Hama	"	Hiroshi Sato	"
	Minoru Kamezawa	"	Hiroshi Hama	"
			Minoru Kamezawa	"
Counterpart	Samuel Guia Canales	M.P.**		
"	Fernando Castilla Barrios	"	Fernando Castilla Barrios	M.P.
"	Hector Zarate Olazabal	"	Hector Zarate Olazabal	M.P.
"	Felix Valencia Ponce	"	Felix Valencia Ponce	M.P.

* Abbreviation of Mitsui Kinzoku Engineering Service Company, Ltd.

** Empresa Minera del Peru

Chapter 2 Geographical Environment of Surveyed Area

2-1 Location

Departamento Cajamarca in which the Michiquillay Mine is located, is an inland region being bordered by Ecuador in the north, by Departamentos Piura and Lambayeque in the west, by Departamento La Libertad in the south, and by Departamento Amazonas in the east.

The Michiquillay Mine belongs to the municipality of Distrito Encañada, Provincia Cajamarca, which is the southeastern part of Departamento Cajamarca, approximately in lat. 7° S, and long. 78° 20' W. The city of Cajamarca, the capital of the said Departamento, is about 25 km WSW of the Mine.

2-2 Transportation and Accessibility

The construction project of highway improvement is now in progress in the northern Andean territory where the Michiquillay Mine is, and the highway from Lima, the Capital of Peru, to Cajamarca, the municipal city, has been asphalted almost all the way.

The access to the Michiquillay Mine from Lima is diagrammatically shown as follows;

via Pan-American Highway, double laned and asphalted,

```
Lima ---------- Trujillo ---------- Pacasmayo ---------- Junction to Cajamarca
      548 km                106 km              16 km

           8m wide,              8m wide,              4m wide,
           asphalted             asphalted             unpaved

Junction ---------- Chilete ---------- Cajamarca ---------- Michiquillay
            89 km               89 km                50 km
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It requires about 7 hours by car from Lima to Trujillo, about 5 hours from Trujillo to Cajamarca, and about one hour from Cajamarca to the Mine; thus the mine is accessed by about 13 hours drive from Lima.

There is another way of access by air. The one is on route Lima ----- Trujillo ------ Cajamarca (3 flights a week, flight time, about 2 hours), the other is on route Lima ----- Chiclayo ------ Cajamarca (2 flights a week, flight time about 2.5 hours), total of 5 flights a week are on regular service. The shortness of distance between Cajamarca city and the mine as well, makes the accessibility much easier, in spite of its location in the midst of the Andean highland.

2-3 Regional Features

The city of Cajamarca is noted for its historical site where Atahualpa, the last emperor of the Inca Empire, was captured by the Spanish invaders in 1532, and was executed by Francisco Pisarro in the next year 1553. It is also famous for its sulphur hot spring of Los Baños del Inca, known since the Inca Era, which is about 6 km east of the city and is on the way to Michiquillay.

Departamento Cajamarca has an area of 35,418 square kilometers which may be divided into three climatic provinces; the arid deserts of the Pacific side, the Altiplano of northern Andes, and 'Zonas Amazonas', the jungle region covered by the thick tropical rain forests. The highlands of this district, being different from those of the central and southern Andes, has rather lower altitude, in which gently rolling hills of about 3,000 meters S.L. are spread vastly, and depressed basins are more enriched in grass fields than in the central and southern Peru which causes the pasturage more active in such fields.

The Michiquillay Mine is in the east of this highland as well as on the uppermost stream of the Amazon.

The climate of this district is Andean highland type, having two seasons of dry and wet, but the climate is more or less moderate because of its lower altitude and nearness to the equator. It is very seldom to freeze all through the year, and the temperature is higher in the wet season (October---April) and lower in the dry season (May---September). The rain fall is 1,500 mm throughout the year which is more than the southern Altiplano.

Chapter 3 General Geology

3-1 Regional Environment of Geology and Ore Deposits

The comprehensive geological succession has been established by Benavides (1956), and Bellido has compiled the current geological status (1969). Further, Bellido and others have established the metallogenic provinces through the compilation of the results of investigation of ore deposits throughout the country (1969, 1972).

According to their calssification, the Michiquillay deposit belongs to the sub-province of polymetallic mineralization of the western Altiplano (Sub-Provincia Polimetalica del Altiplano). The mineralization of this category is vastly distributed, starting from the border of Ecuador in the north and extending towards the border of Bolivia in the south, which consists of two types of mineralization, the one is in the volcanic formations of the west side of the western Altiplano, and the other is in the sedimentary formations in its eastern side. The ore deposits in these two zones of mineralization show some differences in their mineral compositions, temperatures of ore deposition, and morphology of the deposits. The mineralization observable in the volcanic formations are mostly of epithermal type which is represented by these mineralized zones of Cordillera Negra and Paquio-Cailloma. The ore deposits in the sedimentary formations are varying widely from the small scale deposits of veins to replacement deposits and the disseminated and stock-work deposits, which are enumerated as Sinchas-Michiquillay, Sayapullo-Antamina, Huallanca-Oyon Pasco, Huaron-Morococha, and Andahuaylas-Yauli.

The mineralization to have formed the Michiquillay ore deposit is so-called porphyry copper type in the igneous body which intruded into the sedimentary formations. In its northern neighbourings, there is Hualgayoc mineralized zone, which consists of mostly veins in the sedimentary formations and replacement deposits in limestone, and in its northeastern neightbourings there is Punre Mine of vein type deposits. All of them are deposits of copper, lead, and zinc, but they were noted of silver mines formerly because of their high contents of silver.

Most of the mineralizations in the metallogenic province of the western Andes are considered to have occurred in late-Cretaceous, middle Tertiary, and the beginning of late-Tertiary, which are involved in the orogenic epochs of the Andes.

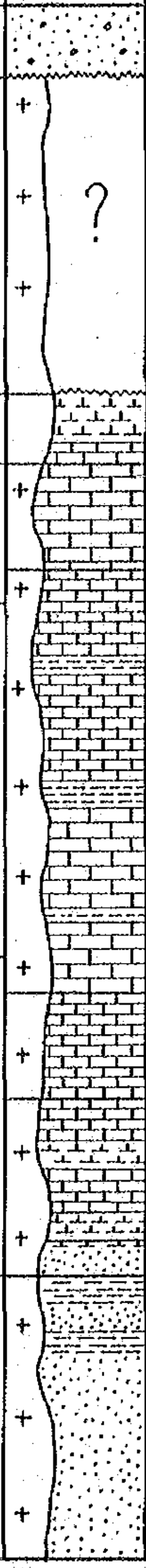
It is remarkable that the geological structures of Peru are arranged parallely to the elongation of the Andes Mountains. To consider about the lineament of the geological structure, there are two characteristics; the one is near 7° S in lat., and the other is between long. 70°---60° W. In the latter, the formation having the trend of. N 30° W from north towards south, is twisted in this point to have the trend of N 80° W, and is again switched into N 0° W in farther south and extended into the northern Chile.

3-2 Geology of the Mine Area

3-2-1 Outline of Geological Set-up

As is shown by the geological column on Table 3-1, the area is composed of a thick series of Cretaceous sediments, by which the remarkable change of the sedimentary environments from terrestrial to littoral or marine is clearly shown. The Cretaceous system consists mostly of quartzite in the

Table 3-1 GEOLOGICAL COLUMN OF THE MICHIQUILLAY AREA, CAJAMARCA, PERU.



Era	Period	Epoch	Columnar Section	Formation	Remarks
Cenozoic	Quarternary				Glacial deposits and alluvium
	Tertiary		?	Intrusion of Quartz monzonite porphyry	K-Ar dates by A.W.Laughlin et al. (1968) 20.6±0.6m.y Biotite of the qtz monzonite porphyry from Michiquillay ore deposit 46.4±1.8m.y. Hornblende of the qtz monzonite porphyry from Michiquillay area
Mesozoic	Upper Cretaceous	Coniacian, Santonian		200m Celendin	Marl with Limestone
		Turonian		300m Cajamarca	Bluish grey massive limestone
		Cenomanian		1200m Jumasha	Alternation of limestone, marl and shale with fossils
	Lower Cretaceous	Albian		300m Pariatambo	Grey limestone with bituminous shale
				400m Chulec	Yellowish grey marl with limestone
				100m Inca	Brown shale with grey quartzite and muddy limestone
		Hauterivian, Barremian, Aptian		900m Goyllarisquizga	Massive quartzite with black shale and andesite sill

lower part, which shows transitional change upwards through the alternation of sandstone and shale into limestone intercalating the layers of shale in the upper part. This sedimentary system shows repeated foldings having regional axial trend in the direction of WNW-ESE as shown on Plate 3-1, but in the vicinity of the ore deposit, the system has a monoclinal structure striking approximately parallel to the folding axes and dipping in SSW.

Penetrating this system, there are distributed the patches of quartz monzonite porphyry, a part of which was the host to mineralization. Although the exact continuity of such intrusive bodies is still unconfirmed due to the coverings of glacial deposits, the general trend of the intrusion might have been controlled to follow along the folding axes. The intrusive bodies are involved in an area of about 5 km in the direction of NW-SE and more than 1.5 km in NE-SW.

3-2-2 Sedimentary Formations

Most of the sedimentary formations in this district belong to the Cretaceous system, which will be described here briefly following after the succession established by Bellido (1969) and Nakamura (1975).

(1) Goyllarisquizga Formation (approx. thickness, 900 m)

This formation consists of white or gray quartzite and quartzitic sandstone, which are medium to coarse grained, sometimes fine-grained conglomeratic, and mostly terrestrial.

In the mine area, this formation consists of white or gray quartzite and sandstone, showing generally distinct crossbedding. It shows very peculiar view sight in case it forms the mountain summit resisting against erosion.

(2) Inca Formation (approx. thickness, 100 m)

This formation consists of dark gray sandstone, locally intercalating dark colored or yellow layers of shale.

In the mine area, it consists of yellowish-brown shale and calcareous sandstone intercalating basic lava, which tells transitional change to the sedimentary environments from terrestrial to marine. Its yellowish-brown apparence serves as a key bed in this area.

Inca Formation in the mine area seems to contain limestone or calcareous shale in its lowermost horizon, as gossans containing magnetite have been recognized in such localities as on the slope between the surface drill holes No. 1 and No. 2, on Magnetite Hill, and on the northern upstream of the West River. Magnetite has also been recognized in the surface drill hole No.1.

A zone of sandstone of the upper part of this formation is observed on the East River, where shell fossils have been found as shown by the specimens No. 1301 and No. 1305 (cf. Appendices, Geology A-6).

(3) Chulec Formation (approx. thickness, 400 m)

The general characteristics of this formation in Cajamarca district is that this formation consists of dark yellowish marl intercalating gray or dark gray limestone. Similarly in Michiquillay area, it consists of marl intercalating the layers of limestone, which indicates the sedimentary environments from shallow sea to deep sea.

More or less well preserved fossils of bivalve, Neithea facalhoi, Choffat, was determined from specimen No. 1306, collected on the East River, by which the sedimentary environments of shallow sea is indicated in Michiquillay area.

(4) Pariatambo Formation (approx. thickness, 300 m)

This formation generally consists of dark colored or black limestone, marl, and shale, and they are said very bituminous (Bellido, 1969). The sedimentary environment is assumed comparatively shallow sea but under unstable condition.

In Michiquillay area, it consists of the alternation of limestone, shale, and marl, which are repeated at about every 10 meters thickness.

(5) Jumasha Formation (approx. thickness, 1,200 m)

This formation has been classified into three subdivisions in Cajamarca district, namely, Quillquian, Pulluicana, and Cajamarca formations. But as the rock facies of Cajamarca formation indicates the sedimentary environment distinctly different from the other two, Nakamura has made Cajamarca formation independent from Jumasha formation.

Jumasha formation is characterized by containing abundant fossils of bivalves, either big or small, being consisted of the alternation of limestone, marl, and shale, of the thickness of 1 or 2 meters each, and having the layer of shale at its basement.

In Michiquillay area too, it is found to contain abundant fossils which is shown by the specimens Nos. 2904, 2905, 2906, 3001, 3002, and 3003.

(6) Cajamarca Formation (approx. thickness, 300 m)

It consists of dark gray or bluish gray massive limestone containing abundant nodules of marl. It is characteristic for this formation to display such a topographic feature of projecting lineament of the formation on the weathered surface.

(7) Celendin Formation (approx. thickness, 200 m)

It generally consists of yellow or light gray, and soft calcareous shale containing partings of dark gray thin layers of limestone.

In Michiquillay area, it consists of marl containing the partings of thin layers of limestone. It has never been recognized in the vicinity of the ore deposit.

The fossils collected in this area will be shown on Appendices A-6.

3-2-3 Quartz Monzonite Porphyry

Laughlin and others (1968) have reported that the age of intrusion of quartz monzonite porphyry is middle Tertiary as a result of age determination by K-Ar method. The rock can be classified into two facies, namely, hornblende quartz monzonite porphyry and biotite quartz monzonite porphyry, as the phenocrysts show considerable variations.

(1) Quartz Monzonite Porphyry Characterized by Hornblende

This rock is found more or less in fresh state in the area surrounding the Michiquillay deposit. Under the microscope, many of quartz phenocrysts present the corroded forms and those of plagioclase show distinct zonal structure. Orthoclase sometimes occurs as phenocryst with perthitic texture, but it mostly composes the groundmass. Some of the phenocrysts of hornblende, though seldomly, show distinct zonal structure. Amount of biotite phenocrysts is much less than hornblende. Epidote is also found though minor in amount.

The groundmass is fine-grained and composed of quartz, plagioclase, and orthoclase, presenting distinct porphyritic texture. The rock is generally fresh, although some of the phenocrysts and parts of groundmass have been obliterated by calcite, sericite, and chlorite as alteration products.

(2) Quartz Monzonite Porphyry Characterized by biotite

1) General Features

The distribution of this rock is limited in the ore body itself and its immediate surroundings, in which alteration is intensely advanced all through. Phenocrysts are characterized by advancedly corroded quartz, plagioclase with distinct zonal structure, and euhedral biotite. In very limited cases, plagiclase with perthitic texture, relicts after hornblende due to alteration, and epidote are observed. The groundmass is composed of quartz, plagioclase, orthoclase, and biotite. Either groundmass or phenocrysts are found altered into sericite, chlorite, and kaoline.

Often quartz can hardly be distinguished as phenocryst within the ore body. For the sake of convenience during underground geological observation, the name quartz monzonite porphyry has been given to the rock in which the phenocrysts of quartz are well distinguished, while the name monzonite porphyry to the rock in which the phenocrysts of quartz can hardly be distinguished from other quartz. Under the microscope, quartz in groundmass are almost completely recrystallized into grains of considerable size, which makes it difficult to discriminate the quartz of phenocryst from the quartz of groundmass.

2) Contamination and Origin of Biotite

Quartz monzonite porphyry within the ore body is characterized to contain widely almost perfectly euhedral phenocrysts of biotite, while the phenocrysts of hornblende, though scarce, can only be recognized as relicts by alteration. Under the microscope, biotite displays clear pleochroism, but once altered, it is turned into chlorite and sericite, and very rarely into epidote. The relicts after biotite are only recognizable where sericitization and silicification is fairly advanced, but even the relicts are obliterated where the alteration is much more intense. However, the euhedral biotite can be recognized almost all over the ore body, and this may suggest that the quartz monzonite porphyry characterized by biotite is the very host to the ore deposition. The refractive index (γ) of the euhedral biotite from the Michiquillay deposit has been determined 1.6325 ± 0.0003 by Inst. Tech., Univ. Tokyo. By applying the value to Wones' formula, Mg/Fe is obtained as 1.2---1.7. According to Beane (1974), Mg/Fe is smaller than 1 in biotite of igneous origin and Mg/Fe is bigger than 1.5 in metamorphic biotite. The Mg/Fe of the Michiquillay deposit will just stand in between. On the other hand, biotite can be classified into two, the one is euhedral biotite and the other is fine flakes of subhedral or anhedral, in which the latter is considered to have crystallized along with the consolidation of the groundmass.

Quartz monzonite porphyry contains comparatively abundant xenoliths. In hornblende quartz monzonite porphyry, xenolith of hornblende micro-dioritic rock is observed, and xenoliths of quartzite and shale are found in biotite quartz monzonite porphyry. Microscopic examination of biotite quartz monzonite porphyry constituting the ore body has revealed that andalusite is recognized in Cross-cuts No. 4 and No. 4-A, and garnet in Cross-cut No. 3. They are considered the products by capturing into magma the argillaceous and calcareous wall rocks during the time of intrusion.

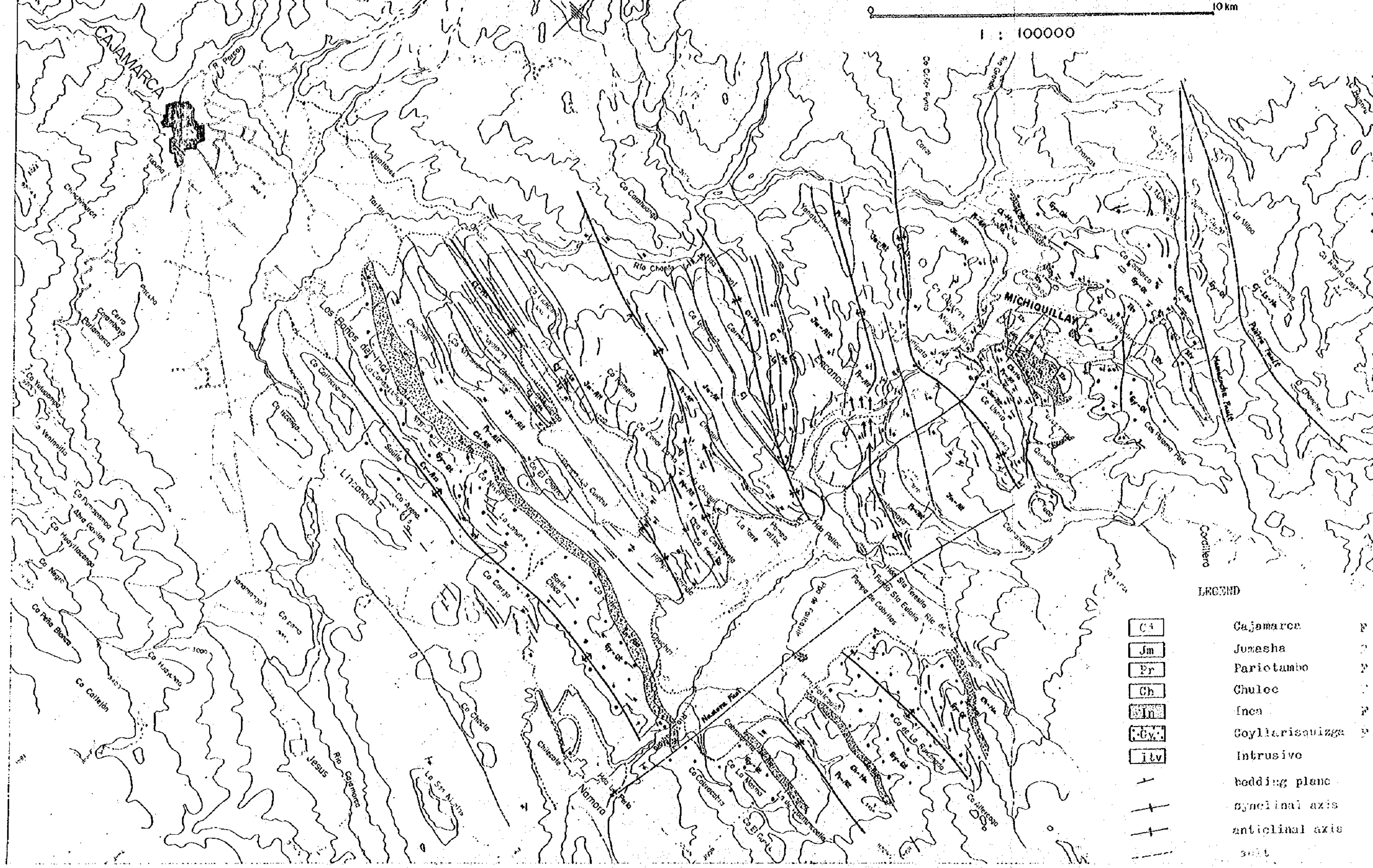
Such characteristic features as generation of fairly abundant biotite, existence of xenoliths, occurrence of 2 or 3 metamorphic minerals probably derived from the xenoliths, would suggest the feature of magmatic contamination, from which biotite quartz monzonite porphyry is derived. In other words, this can be understood to have produced biotite quartz monzonite porphyry by assimilation of foreign rocks caused by magnatic stoping of the wall rocks by the initial magma represented by hornblende quartz monzonite porphyry.

3-2-4 Glacial Deposits

In Michiquillay area, moraines, either in small or medium scaled patches, and fluvio glacial deposits are covering the underlying geological formations in the northwestern area from the ore deposit, as well as the area surrounding the ore deposit. They were deposited by the Pleistocene glaciation, that is to say the deposits of mountain glaciers. The materials of these glacial deposits honestly reflect the geology of their hinterlands, of which differences are distinctly recognized in the components of boulders and matrices. For instance, the glacial deposits covering the ore body contain mostly quartz monzonite porphyry, quartzite, sandstone, and shale, which are exposed on the backward highlands, while in the West River area, quartzite, sandstone, quartz monzonite porphyry, and magnetite-bearing gossans from direct uphill are recognized.

Fig 4-1

REGIONAL GEOLOGICAL MAP OF CAJAMARCA AREA



Chapter 4 Geological Structure

4-1 Structural Anomaly in Northern Peru----Cajamarca Trend

According to 'Mapa Metalogenico del Peru', scale 1:2.5 mil., 1972, the general structural trend, represented by the axes of anticline and syncline, in the Northern Peru, having the bearing of about N 30° W and extending from south towards north, changes its direction to N 70°---60° W and in farther north its direction regains the initial trend of N 30° W and extending towards Ecuador, where it is again twisted sharply into northeastwards near the border of Ecuador and extending into the country.

According to the said map, the zone to transform the Andean trend has a width of about 85 km and seems to interesect the Andean trend diagonally and extend in the direction of N 30° E. The terrain from Cajamarca City to the Michiquillay Mine is perfectly included in this trend anomaly zone, which can be taken as a remarkable structural feature of the district.

It is also noteworthy that many of the ore deposits included in the so-called 'Sub-Provincia Polimatalica del Altiplano', which extends more or less along the Andes Mountains, are located in such anomalous areas of geological structure or near by them.

In view of the geological importance, the structural trend in such the distorted zone as above mentioned will be called the Cajamarca trend (N 60°--70° W) hereafter in this paper, while the general trend of the Northern Andes Mountains, N 30° W, will be called the Andean trend.

4-2 Geological Structure of Mine Area

4-2-1 Folding Structure

The Cretaceous system within the area is repeating the foldings of anticline and syncline of which axes are in the direction of WNW--ESE. Goyllarisquizga formation, the lowermost formation of the Cretaceous system in this district, is exposed around Cajamarca City, then the younger formations cover the area between the city and the mine repeating gentle foldings, and the lowermost formation is exposed again in the mine area, which may suggest that the Cretaceous system forms a synclinorium as a whole.

The general strike of the formation in the mine area is more or less N 50°--70° W, but precisely speaking, this is composed of finely changing strikes of NW system (N 30°--50° W) and WNW system (N 60°--75° W) alternatively. The dips of the formations vary from 20° NW to 60° SE. The local geological survey in the eastern and western sections of this area indicates that, while the general trend of the formation is turned into NE--SW, the minor foldings are repeated with their axes in NW--SE or E--W, but in farther outside areas through these deformation zones both in the east and west, the trend of the formation seems to regain its general trend of WNW--ESE.

4-2-2 Structure of Faults and Fissures

The prominent systems of faults and fissures in the Michiquillay deposit are WNW, EW, and NNW systems.

(1) WNW System

This system is best represented by the Michiquillay Fault which is located in the south of the ore body. Its general strike is N 70° W and average dip is 65° NE, accompanying farctured zone of about 20 meters wide. The fractured zone contains the breccias and sub-breccias of quartzite and shale of which size reaches 20 x 30 cm in maximum, but averagely 3 to 10 cm. The matrix is composed of limonite which might have derived from pyrite.

This fault is located at the contact of quartz monzonite porphyry and Mesozoic sediments which can be observed very evidently. But the extension of this fault seems to fade away suddenly as it goes apart from the ore body either in the east or in the west. Thus, this fault has controlled the intrusion of igneous rock as well as it has been formed before the mineralization. This will be evidenced by the occurrence of skarn minerals such as garnet and vesuvianite in the limestone existing in the hanging wall block of this fault. This will tell the existence of this fault prior to the mineralization stage, too.

(2) Faults of EW System

This system is distinctly observed in the hanging wall block of the Michiquillay Fault in the south of the ore body. Having the strike of almost EW with the average dip of 55°, this is a sort of reverse fault with clay zone of 2 meters. In this clay zone, limonite, hematite, and magnetite are observed, being arranged parallel to the strike and dip of the fault. They are also considered pre-mineralization.

(3) NNW System

The faults which are arranged regularly at about 300 meters intervals right on top of the ore body have strike of N 20° W with the dip of 65° SW, accompanying clay zone of averagely 1 meter, and are considered of thrusting nature. They are considerably persistent and well observed in the tunnels of Level 3,500 m of the Michiquillay ore deposit. They are considered pre-mineralization, too.

(4) Underground Fissure System

Fig. 5-2A and B show the stereographic projections of fissures in the form of poles which have been described during geological sketching of the tunnels. A system of fissures with the averaged strike of N 31° E and dipping 65° SW appear most frequently among all the fissures throughout the tunnels either existed or newly driven. They are estimated as tensional cracks generated under the compressive stress.

4-2-3 Development of Cajamarca Trend

As is stated in 4-1, the terrain showing the Cajamarca trend in the Andes Mountains is involved in a zone of about 85 km wide extending in the direction of N 30° E, and in spite of such variation of the trend, the structure of the Andes itself is kept continuous without any sudden break of structure caused by this zone of the Cajamarca trend.

This may suggest that the deformation, or the twisting of the trend, should be understood as a local structural anomaly generated during the orogenic epochs of the Andes Mountains. It may be interpretted that a sheared zone was generated intersecting the Andean trend in the direction of N 30° E by certain factor which might have prevented the uniform development of its general trend of N 30° W during the said orogeny, although it is difficult to point out the exact factor here, and that the sheared zone took a sort of coupling movement, with northward movement by the eastern side of the zone, and southward movement by the western side, and consequently the terrain between the two sides was forced to be distorted, resulting in changing its trend into the system of WNW, the Cajamarca trend.

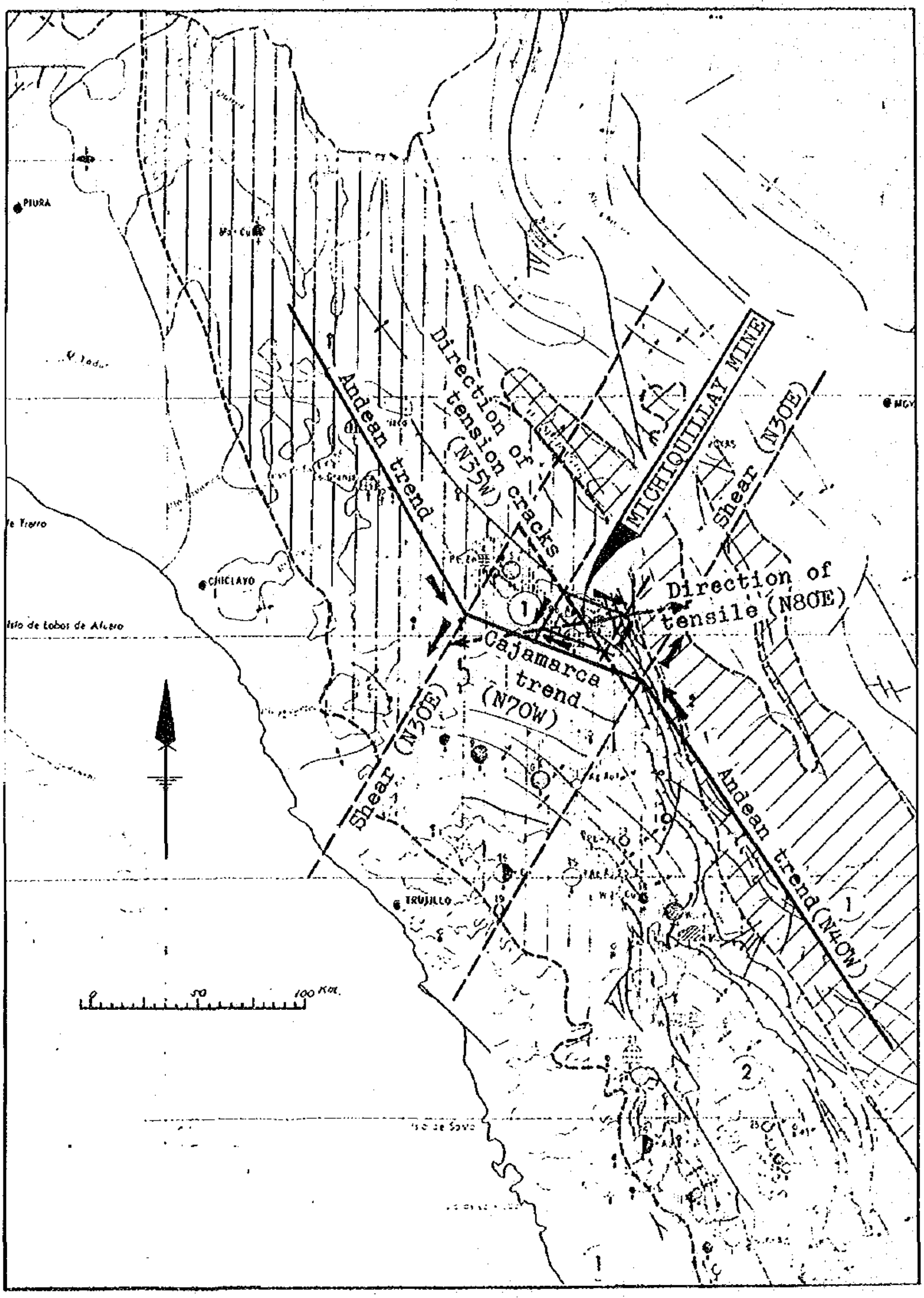


Fig. 4-2 DIAGRAMMATIC EXPLANATION HOW TO DEFORM THE ANDEAN TREND INTO CAJAMARCA TREND

BASE MAP: MAPA METALOGENICO DEL PERU (1972)

Scale 1:2500000

4-2-4 Development of Faults and Fissures

(1) Ruptures Caused by Folding

As stated in 4-2-1, the Mesozoic sediments forms the repeated folding quite orderly in the terrain between Cajamarca City to the mine, though the terrain involved in the zone of distortion of N 30° E, and the Michiquillay Mine area is a part of this folding structure.

The lateral compressive force which caused the folding worked perpendicularly to the axis of folding and yielded a tensile in the direction of the axis. Under the influence of this tensile, a group of tension cracks were generated in the direction perpendicular to the tensile, in other words, approximately in the direction of the compressive force. And the rupture in the direction of tensile produced the fissure of thrusting movement.

In summary, the direction of the lateral compressive force (N 20°--30° E) will be the direction of tensional cracks and the direction of the tensile (N 60°--70° W) will represent the direction of reverse fault. The former will be represented by the group of ore-bearing veinlets which show the most frequent occurrence in underground as stated in 4-2-2 (4). (calculated average in strike and dip; N 31° E, 67° SE) The latter will be represented by the Michiquillay Fault.

(2) Ruptures Caused by the Development of the Cajamarca Trend

In the course of development of Cajamarca trend from the original Andean trend of N 30° W by the coupling movement of N 30° E as stated in 4-2-3 (1), another pair of coupling movement will be generated along the newly developed trend in the blocks sandwiched between the major coupling of N 30° E (Fig. 4-2).

Consequently, any structural unit within the terrain will be put under the influence of two sets of couples arranged in a way of parallelogram. In such a parallelogram, the longer diagonal will represent the direction of tensile and will rupture into a fissure of thrusting nature at the stage of extreme deformation, while in the direction of the shorter diagonal a few cracks will be developed as the results of the tensile, tension cracks. Two sets of fissures parallel to the two sets of couple will also be developed as shear fissures along with the deformation.

In Michiquillay area, assigning a terrain of about 5 km east-westwards and about 4 km north-southwards as a unit structural parallelogram surrounded by the average trends of N 30° E and N 70° W, the direction of tensile above stated comes to N 80° E, or EW system, and the tension fractures of N 35° W, or NW, NNW system, in which 4 sides are defined by taking the patch along the West River as the western side where the trend of the Cretaceous formation is twisted in N 30°E, and the other patch along the East River as the eastern side where the trend is also turned into north-south, and the Michiquillay ore body being about in the middle; and by taking the Michiquillay Fault as the southern side, and Coshorco Hill, on the road northward to Punre, as the northern side.

As stated in 4-3-2, the resultant ruptures in such a field of deformation will be co-related to the fissures observed in the field as follows;

(1) As the fissure represents the direction of tensile, an east-westward fault, dipping 55° south, may be considered the representative of this category, which is observed in the south of the ore body, cutting across the hanging-wall block of the Michiquillay Fault.

(2) To say about the two sets of shearing fissures of NNE and WNW systems, twisting of the strikes of the formations observed on the East and West Rivers are considered to be the direct evidence of the shearing of NNE system, and of WNW system amy be represented by the Michiquillay Fault.

The Michiquillay Fault is evidently a reverse fault observable in the field, which may be considered to have been formed as a reverse fault during the folding stage, and moved again as shearing fissure during the stage of deformation. On the other hand, as this fault controlled the intrusion of quartz monzonite porphyry as the host of the ore body, the reversal movement of the fault might have been emphasized by the upward drugging force of the magmatic intrusion. The lateral extension of this fault seems not persistent. This might tell that the fault was generated as a minor local fissure but its displacement was emphasized only localy near by the ore deposit by the intrusion of the igneous rock.

Some of the ore bearing veinlets of NNE system in underground accompny clay along themselves, which may suggest that once they were formed as tension cracks suitable to accept ore forming fluid during the rupture of folding stage but moved again as shear planes of NNE system during the stage of deformation.

(3) Ruptures of NNW system as tension cracks are deservedly controlling the intrusion of igneous rock. But the system must have the nature of shearing as the rupture during the folding, which are obsevable in the field as the faults showing reversal movement as stated in 4-2-2.

Fig 4-3 Geological Sketch of Upper Stream of the West River

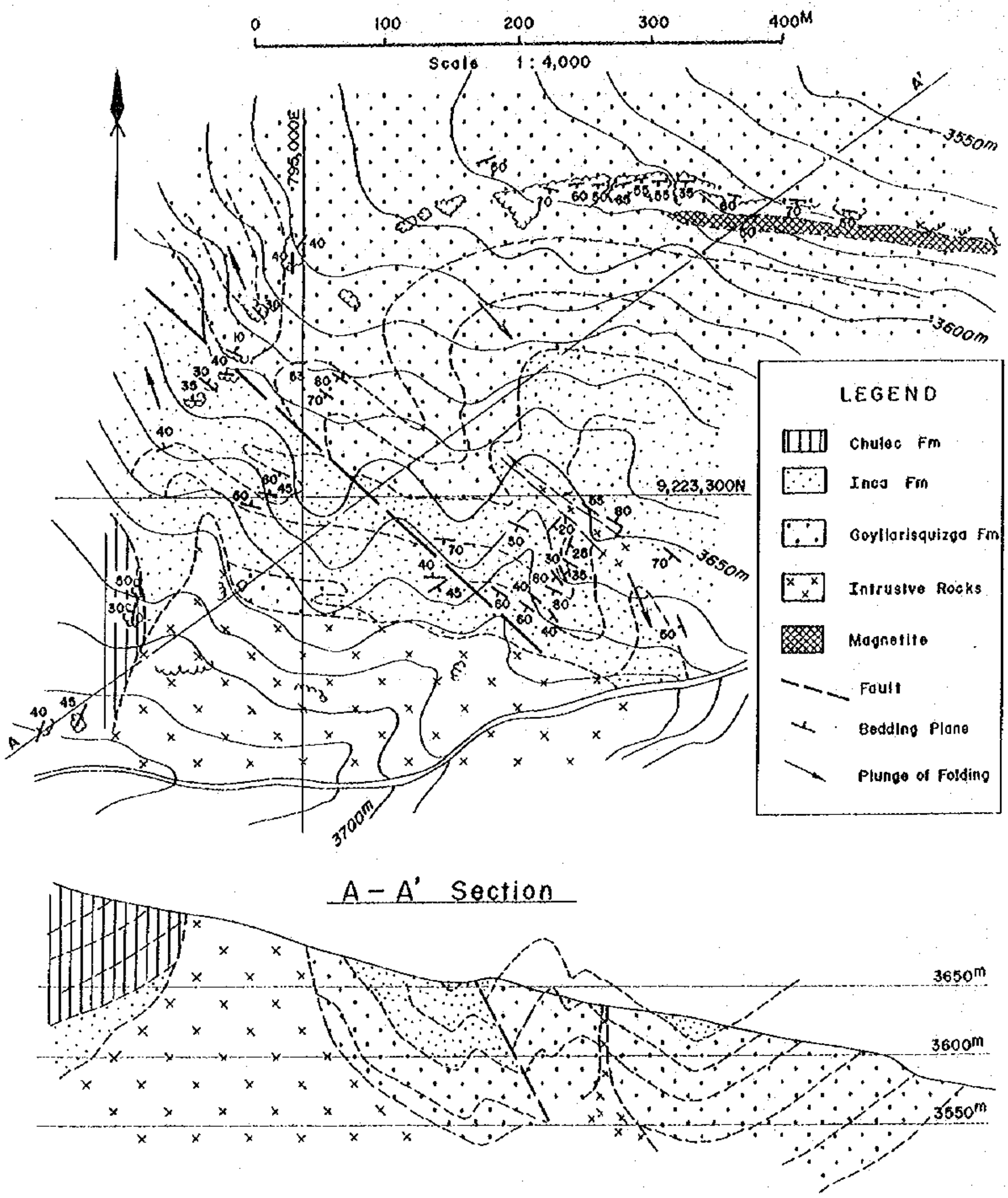
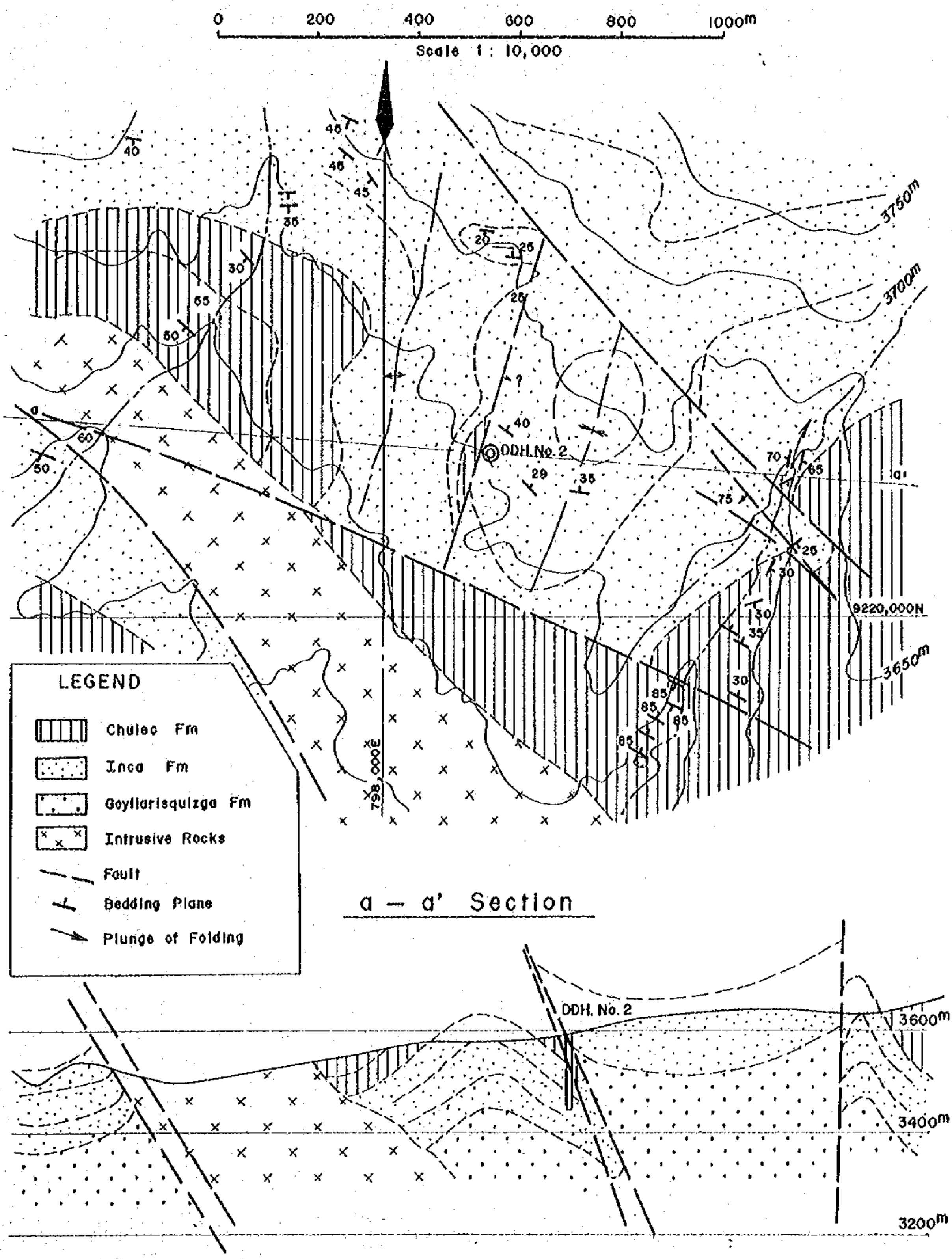


Fig 4-4 Geological Sketch of the East River



The rupture in two kinds of the stress field as stated above might have produced the similar pattern from its, but it will be noteworthy that any fault or fissure estimated affin to unit pattern took the movement of different nature in each of the stress field. And it would be understood that such might have produced more chances favorable to accept the fluids of magma and ore solution.

4-2-5 Geological Structure As Related to Igneous Intrusion

The structural features of the intrusion of quartz monzonite porphyry are summarized as follows;

(1) the southern border of the ore body, foot wall side, is streched along the Michiquillay fault,

(2) while being controlled by the fissures of NNW system in the northern area of the ore body, quartz monzonite porphyry has intruded more or less concordantly to the Mesozoic sediments,

(3) The distributed area of the igneous rock is nearly of a rhombic shape which is pinched either in NW ans SE corners, while it is wider in the middle of them including the ore body.

The period of intrusion is considered during the time of deformation of geological structure, and the intrusion must have been accelerated by the rupture of the tensional craks under the influence of tensile of EW system generated during the time of deformation.

The axes of minor foldings are gently plunging toward west in the eastern outside of the ore body and toward east in the western outside of it, which may suggest that the very location presently occupied by the ore body would correspond to a structural anomaly of the wall rock formations of E-W or WNW system gently warped downward. While, the Michiquillay

Fault is dipping about 65° north and limiting the southern end of the ore body, and the sediments are dipping southward as a whole in the northern outside of the ore body. Thus, a structural depression like a caldron bottom may be inferred to have existed in the very location of the present ore body prior to the intrusion. On the other hand, in the outside areas of the distortion zones by NS system, well represented by the West and East Rivers, their axes are plunging outwards. Although it can not be clarified satisfactorily by what was such a depressional warping derived, it may be said at least such a structure had been formed before the mineralization, as some parts of such structure are cut by the intrusion of the magma composing the ore body, which is recognized clearly in the field geological observation.

Whatever the cause might have been, once such a warping should be formed, the concaved portion might have become full of tensional cracks radially arranged downwards, by which the wall rock would have been cut into pieces either big or small. Once magma would have ascended to this portion, abundant fragments of the wall rock would be captured in the magma by so-called 'magmatic stoping', which made the magma more enriched of xenoliths than average.

In this case, the captured rocks must have been

(1) arenaceous rocks such as quartzite, sandstone, etc.,

(2) argillaceous rocks such as shale,

(3) calcareous or argillo-calcareous rocks such as limestone, marl, etc.

These fragments of foreign rocks might have produced some specific minerals in respond to their chemical compsition by reaction with magma. Especially characteristic is the formation of abundant biotite, by which the quartz monzonite porphyry composing the ore body is enriched remarkably either as phenocryst or in groundmass, while in the outerside of the ore body, the porphyry is rather fresh and is characterized by hornblende phenocryst, hornblende quartz monzonite porphyry. As already stated, occurrence of such metamorphic minerals as andalusite, garnet, corundum, zoisites, and siderite, have been recognized microscopically from the host rock of ore body. Especially, the occurrence of andalusite has been reported on the surface in the argillaceous hornfels derived from shale. The xenoliths of quartzite are found frequently either underground or surface. And even in the drill cores they are easily recognized as they maintain the initial features. Many of the quartzite xenoliths might have been left free from reaction with magma, as the magma itself might have been fairly saturated by silica originally.

Such features will tell that biotite quartz monzonite as the host of ore body is a sort of contaminated facies of the initial magma, derived from capturing abundant foreign rocks and inter-reaction between them. Once such would happen, the various physico-chemical changes were brought out in the magma to reach to a new equilibrium. Putting aside whatever were the details of the changes, there would be enough possibility that such an unnusual changes only particular in this portion of the magma, might be connected either directly or indirectly to the accumulation of heavy metals and their migration---mineralization.

The hornblende quartz monzonite porphyry, the standard facies of monzonite porphyry of this district, has been recognized only to have formed small ore bodies of magnetite at its contact with argillaceous rocks (cf. West River & Magnetite Hill), or given a small scaled mineralization of pyrometasomatic type consisting of chalcopyrite, spharelite, and galena, against the adjacent limestone (cf. Surface Boring No. 3).

Fig 4-5 Geological Profile of Michiquillay Deposite

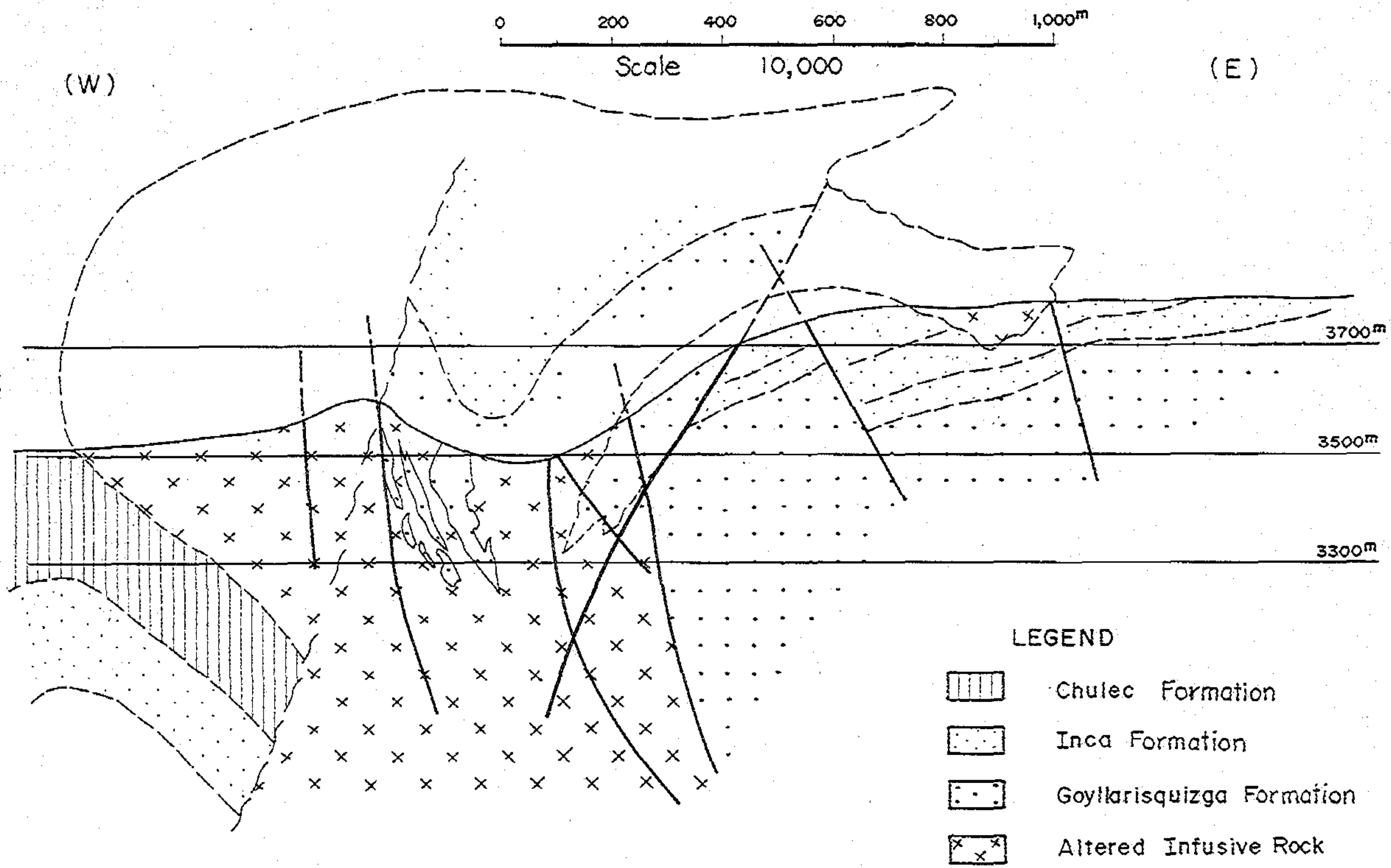
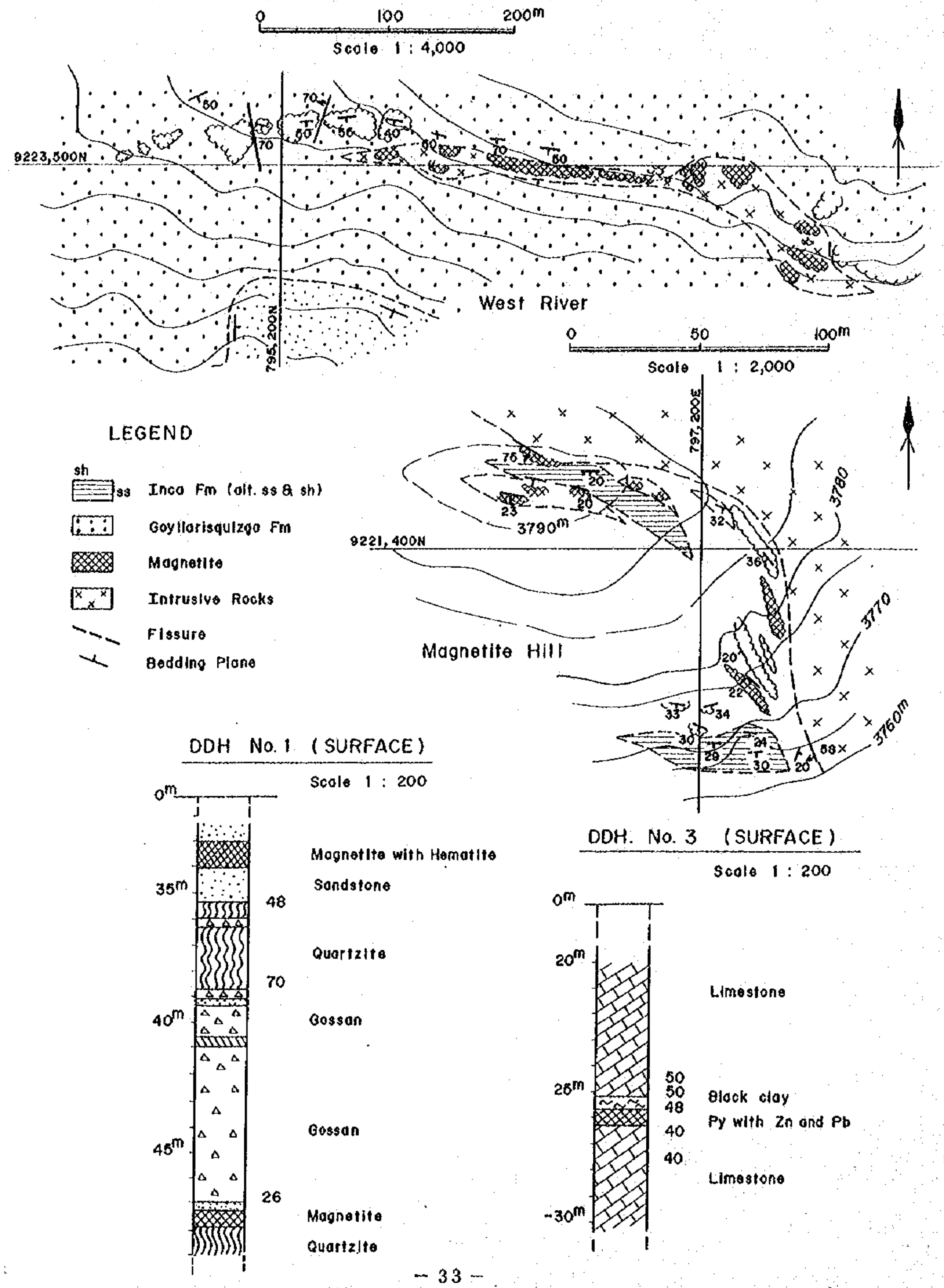


Fig 4-6
Geological Sketches of Magnetite Mineralization on the Up-Stream of West River, Magnetite Hill, and Drill Holes.



Chapter 5 Geology of Ore Deposit

It has been said that the Michiquillay Ore Deposit was built up in such the way that two mineralization sphares, north and south, were united into one. Based upon this interpretation, the present survey was so conducted about the northern ore body on the level of the pre-existing tunnel called 3,500 Level at the elevation of 3,490 meters SL., that the other one, the southern, will be properly infered.

Followings are the results of the studies about the Michiquillay Ore Deposit. The Michiquillay Ore Deposit will mean the northern ore body of it whenever mentioned in the paragraphs after 5-2.

Petrological descriptions of quartz monzonite porphyry, the host rock of the deposit, are omitted hereafter in this chapter either magascopic or microscopic, as they have been described in Chapter 3. The paragenetic relations between ore minerals and alteration products are shown on Fig. 5-1., mainly based upon the microscopic observations. The results of microscopic observations about the tunnels newly driven and the drill cores of diamond borings are summarized as Table 5-1.

5-1 Introduction

The results of the previous study on the Michiquillay ore deposit has been compiled jointly by the Minero Peru and M.C.C. (Michiquillay Copper Corporation), which are summarized as follows;

(1) mineralization and related alteration took place at two stages,

1) the first stage of copper mineralization associated with the formation of pink feldspar-biotite in the center and chloritization

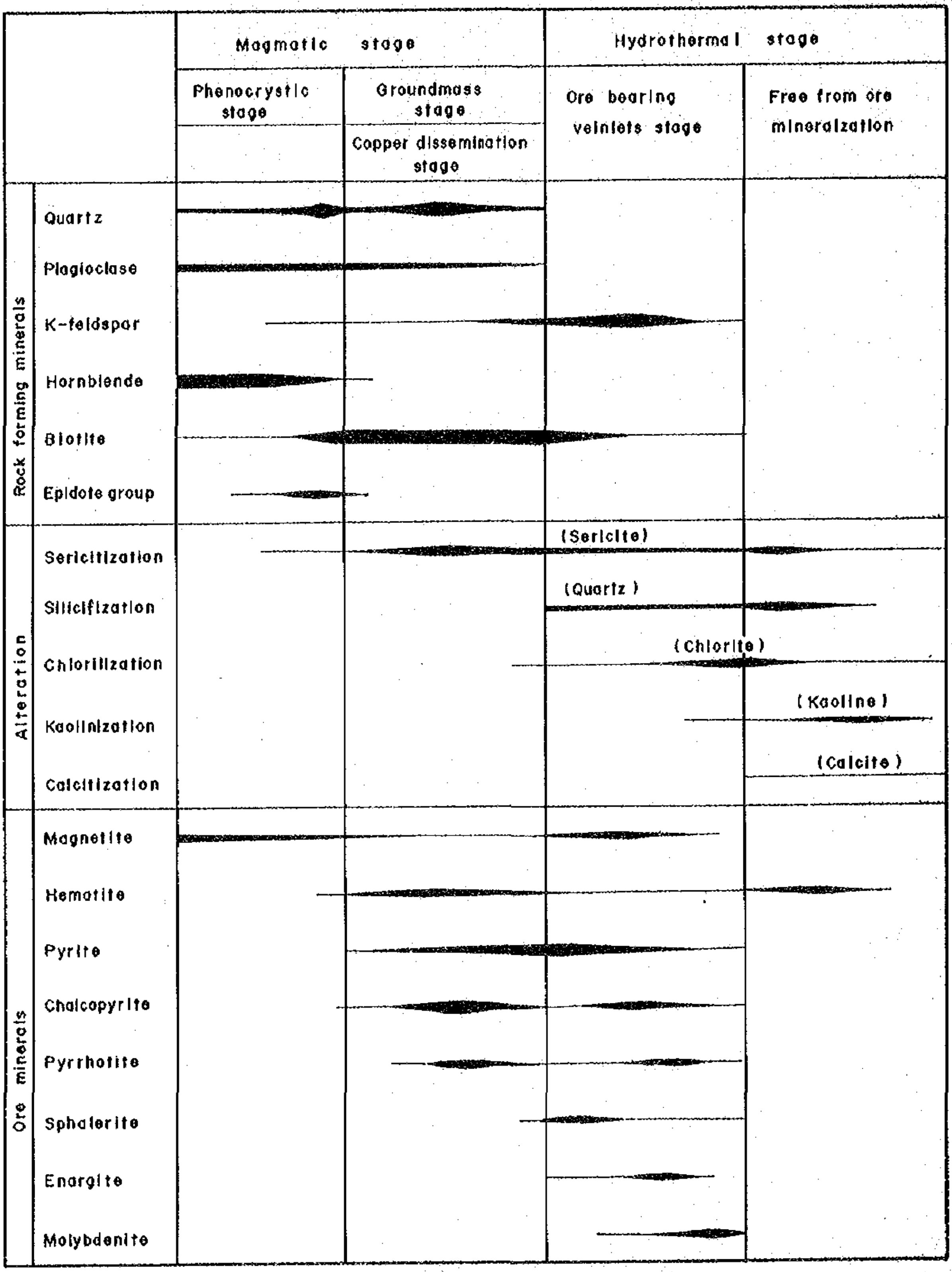


Fig. 5-1 PARAGENESIS ON MINERALIZATION AND ALTERATION

Table 5-1

MICROSCOPIC OBSERVATIONS

LOCATION	SAMPLE No.	ROCK	THIN SECTION: PHENOCRYST: QUARTZ	PLAGIOCLASE	K-FEL	HORNBLENDE	BIOTITE	EPI GROUP	OTHERS	GRANDMASS	POLISHED SECTION: Cp	Bn	Cv	Cc	En	Py	Mt	Hm	Moly
CROSS CUT No.1	3101	qtz monzonite porphyry	+ resor	+ zoning (Ser Bio)	perth(Ser)		++ {X p brownish, Y=Z dark br} (Chl)		apatite zircon siderite	qtz pl bio (Chl)	+ <39 7>					+ <31 8>	++ <134 19>	+ <3>	- <4>
	3102	〃	recryst						zircon barite	quartz (Ser)	-					-	+ <53 13>	+	
	3103	〃	+ resor	+ zoning (Ser Chl)			(Chl Ser Epi)	epidote	apatite siderite	quartz (Ser Chl)	+ <13 5>					((sp pyrr)) + <13 8>	+ <7>	+	
	3104	〃	recryst	(Ser)			(Chl Ser)		zircon	quartz (Ser Chl)	++ <65 13>					+ <60 10>		++	-
	1432	〃	recryst	(Ser)	perth(Ser)		++ {X p brownish, Y=Z dark br} (Chl)		apatite	quartz k-fel bio (Ser)	++ <50 10>					((cp)) + <25 3>	((cp)) ++ <15>	+ <6>	
	1818	〃	+ resor	An 39 ? ++ zoning (Chl Ser)			++ {X p brownish, Z dark br} (Chl)	epidote	apatite zircon	quartz pl bio k-fel	+ <31 4>						((cp)) ++ <36>	+	
CROSS CUT No.2	3201	qtz monzonite porphyry	recryst	(Ser Chl)					apatite zircon	quartz (Ser)	+ <33 5>					((sp pyrr sp)) ++ <80 20>		+ <4>	
	3202	〃	recryst	(Kao Ser)			(Chl Ser)		zircon	quartz (Ser Chl)									
	3203	〃	recryst	(Ser Kao)						quartz (Ser Kao)	((mt)) ++ <16 1>					((mt)) ++ <100 25>	-	+	
	3204	〃	recryst	(Ser)					hematite zircon apatite	quartz (Ser)			-		++ tetra	++			
	3205	〃	- resor	(Ser Chl)					hematite apatite zircon	quartz (Ser Kao)	+ <20 10>	+	++	-	-	((mt sp pyrr)) ++ <75 10>	-	+	
	3206	〃	+ resor	(Kao Ser)	perth		+ {X p brownish, Y=Z dark br}		hematite	qtz k-fel bio (Ser Chl Kao)	- <16 6>			film - <0.3>		((cp sp)) - <20>		+ <5>	
	2508	〃	recryst	(Ser Kao)					apatite	quartz (Ser)	+ <35 4>					((cp pyrr sp)) ++ <70 15>		++ <3>	
CROSS CUT No.3	3301	qtz monzonite porphyry	recryst						hematite	quartz (Ser Kao)	- <75 13>					+ <70 10>	- <3>	((sp)) ++ <36>	
	3302	〃	+ resor	(Ser Kao Chl)			(Ser Chl)		hematite zircon	quartz (Ser Kao)	++ <56 16>	+ <18>	-	-		((cp en mt)) ++ <105 25>		++ <5>	
	3303	〃	++ resor	(Ser Kao)					zircon	quartz (Ser)	++ <38 10>	+				+ <55 11>		- <1>	
	3304	〃	++ resor	(Ser Kao)					hematite zircon	quartz (Ser Kao)	++ <25 10>					((hm)) ++ <95 10>		- <3>	- <5>
	3305	〃	recryst	(Kao Ser)			(Chl Ser)	zoicite	hematite zircon	quartz (Ser)	+ <28 8>					((sp pyrr)) - <31 5>	-	++ <6>	
	3306	〃	+ resor	(Kao Ser)					hematite zircon apatite	quartz (Ser Kao)	- <38 8>					((hm)) ++ <60 8>		- <8>	-
	3515	〃	recryst	(Ser Kao)					zircon garnet corundum	quartz (Ser)	+ <34 6>					((cp hm)) ++ <105 11>		++ <8>	
CROSS CUT No.4	3401	qtz monzonite porphyry	++ resor	(Ser Kao)					apatite zircon	quartz (Ser)	- <16 3>	++ <21 5>		+		((sp pyrr)) ++ <66 5>		++ <8>	++ <15>
	3402	〃	recryst	(Ser Kao)	perth(Ser)		(Chl)		hematite zircon	quartz k-fel (Ser)	- <25 8>			+		+ <69 20>		++ <11>	+ <15>
	3403	〃	+ resor	(Ser Kao)	perth(Ser)				zircon andal	quartz k-fel (Ser Kao)	++ <35 8>	++	+	-		((cp)) + <75 15>		((op)) ++ <5 1>	+ <9>
	3404	〃	recryst	(Kao Ser)					hematite zircon corundum	quartz (Ser)	++ <31 8>	-	+	-		++ <75 10>		++ <8>	+ < 6>
	3405	〃	+ resor	(Ser Kao)					hematite zircon	quartz (Ser)	++ <31 6>	+	+	++		((cp pyrr)) + <90 20>		++ <8>	+ <55>
CROSS CUT No.4	5221	qtz monzonite porphyry	++ resor	(Ser Kao)					andal hematite	quartz (Ser)	- <50 4>				- <18>	((sp pyrr)) + <70 10>			+ <15>
UNDERGROUND BORING No.5	4501	qtz monzonite porphyry	recryst	- zoning (Ser)	perth		++ {X p brownish, Y=Z dark br} (Chl)		apatite zircon	quartz (Ser Kao)	((mt en)) - <113 6>	-		+	-	((cp mt)) + <69 15>	((mt)) + <20>	+ <5>	
No. 6	4601	〃	recryst						hematite zircon	quartz (Ser Kao)	- <15 1>					((cp)) ++ <3? 4>		++ <11>	
No.7	4701	〃	recryst				(Chl Ser)		hematite zircon	quartz (Sil Ser)	((mt)) ++ <44 10>			-	- <8>	((cp hm)) ++ <65 25>	- <15>	++ <8>	
SURFACE BORING No.8	2821	qtz monzonite porphyry	- resor	++ zoning (Ser Kao Chl)			(Chl epi sid)	epidote zoicite	apatite siderite	quartz (Ser)	- <25 1>					+ <29 8>	++ <5>	+	
	2822	〃	+ resor	++ zoning (Ser Chl Kao)			(Chl epi Ser sid)	epidote zoicite	apatite zircon	pl (Ser Chl)	- <119 8>					+ <43 20>	+ <5>	+	
SURFACE BORING No. 1	2102	fine grained sandstone								hematite opaque							+	-	
	2103	sandy shale								hematite							-	+	
	2104	porphyrite		(Ser)						pl (Ser Chl)									
SURFACE BORING No. 2	2201	sandy tuff								pl qtz									
	2202	shale with sandstone							zircon	qtz pl bio									
	2203	sandstone(tuffaceous)							zircon	qtz pl bio									
SURFACE BORING No.3	2301	porphyrite		(Ser Cal Chl)		altered mafic (Chl Ser mt hm)				pl (Chl Cal Ser)									
	2302	qtz monzonite porphyry	++	++ zoning (Cal Chl)		(Cal epi Chl)	(Chl Cal)		apatite	pl (Cal)									
	2303	〃	+ resor	- zoning (Cal Ser)		altered mafic (Cal epi Chl)		epidote	apatite zircon	pl (Chl Cal)									
	2304	〃	++ resor	+ zoning (Cal Ser)		(Cal Chl epi)		epidote	apatite	pl qtz (Chl)									
	2305	〃	++ resor	+ zoning (Cal epi)		(Cal Chl epi hm mt)		epidote	apatite	pl qtz (Chl)									
	2306	〃	++ resor	++ zoning (Cal Chl)		(X p br. Z green) ++ zoning (Chl epi Cal)	(Chl epi)	epidote	apatite	pl quartz k-fel									
	2307	〃	++ resor	+ zoning (Cal Ser)		+ {X light brownish, Z green}	(Chl Ser epi)	epidote	apatite zircon	pl qtz hb									
EASTERN WALL OF MICHIQUILLAY DEPOSIT	Q401A	qtz monzonite porphyry	recryst	(Ser)					zircon										
	0401B	silicified rock							zircon	quartz (Ser)									
	0601	limestone with skarn							woll.	calcite									
	1001	sandstone							zircon	quartz (Ser)									
		qtz monzonite porphyry	+ resor	(Ser Chl)			(Ser Chl hm)												
	1002	〃	+ resor	++ zoning (Ser)			+ {X p yellowish, Z dark br} (Chl)	zoicite	apatite zircon	pl quartz k-fel									
MAGNETITE HILL	0201	shale																	
	0202	qtz monzonite porphyry	++ resor	(Ser Kao)		altered mafic (hm)													
	0203	sandstone							zircon	quartz (Ser)									
	3000	qtz monzonite porphyry	+ resor	++ zoning (Ser Cal)		++ {X p brownish, Z olive green}			apatite zircon										
	0205	Xenolith in qtz monzonite porphyry				++ {X p brownish, Z olive green} (Chl)	(Chl Ser)		zircon	pl k-fel									
WESTERN VALLEY	2805	qtz monzonite porphyry	++ resor	+++ zoning (Cal)		++ {X p brownish, Z olive green}	+ {X p yellowish, Z p yel green}		apatite zircon	pl (Cal Chl)									
	2806	〃	++ resor	+ zoning (Cal)	perth(Cal)	+ (Chl Ser Cal hm)	(Ser Cal)		hematite apatite zircon	pl k-fel									
	2812	〃	+ resor	+ zoning (Ser)		++ {X p brownish, Z brownish green} (Chl epi)		epidote	hematite apatite	pl k-fel									
	2901	〃	++ resor	+ zoning (Ser)		++ {X p green, Z green} (Chl Cal)		epidote	apatite	pl k-fel (Ser)									
	2904	quartzite							hematite zircon	quartz									
EASTERN VALLEY	2907	andesite tuff		zoning (Ser Chl Cal)						pl									
	1304	porphyrite		(Ser Chl Cal)						pl									

ABBREVIATION

qtz	quartz	cp	chalcopyrite	resor	resorbed	Cal	calcitization
pl	plagioclase	bn	bornite	recryst	recrystallized	Ser	sericitization
k-fel	potash feldspar	cv	covellite	perth	perthite	Chl	chloritization
hb	hornblende	cc	chalcocite			Kao	kaolinization
bio	biotite	en	enargite			Sil	silicitization
epi	epidote	mt	magnetite				
andal	andalucite	hm	hematite			p	pale
woll	wollastonite	pyrr	pyrrhotite			br	brown
sid	siderite	sp	sphalerite			yel	yellow
		tetra	tetrahedrite				
		moly	molybdenite				

- less abundant
+ moderately abundant
++ more abundant
+++ very abundant

SYMBOL

( ) alteration and its mineral
{ } color of pleochroism
< > maximum and average size of grain "m/m"
(( )) inclusion

outside, and

2) the second stage, mineralization of chalcopyrite and pyrite accompanying intense sericitization and silicification, with the formation of low grade argillized zone in the center,

(2) the alteration zones are classified into the zones of biotite, quartz-sericite, chlorite, that of argillization, and the outer zone,

(3) the Michiquillay deposit was formed by the unity of two mineralization spheres represented by the two biotite zones.

(4) as regards to the relation of ore body with geological structures, the elongation of the porphyry is WNW--ESE, while the elongation of the ore body is NNE--SSW which is the direction of tension cracks generated in respond to the compressive stress during the time of folding, and these cracks had much to do with the emplacement of ore body.

5-2 Types of Mineralization

5-2-1 Dissemination

It has been stated in 3-3-4 that the host rock of the Michiquillay ore deposit is the one to be properly called quartz monzonite porphyry, a characteristic facies containing large sized and euhedral biotite as phenocrysts and small flakes of it in the groundmass, being considered a contaminated facies derived from capturing a great amount of wall rocks and assimilating them during the time of intrusion of the magma represented by hornblende monzonite porphyry which is taken as the standard facies of the porphyry in this district.

Moreover, characreistic is that some of the euhedral biotite phenocrysts contain minute grains of pyrite and chalcopyrite in their outer zone, so conformable arranged along their crystalline outlines. This fact may suggest that the crystallization of such sulphide minerals had already begun in the latest stage of the crystallization of biotite phenocrysts, while the groundmass might still have been in fluidal state, containing embrios of such sulphide and perhaps iron-oxide minerals. But, at the moment of consolidation of the groundmass, such minerals were confined in the groundmass together with other rock forming minerals, yielding so-called disseminated occurrence.

The mineral assemblage of this stage is rather simpler, consisting of chalcopyrite, pyrite, and very minor amount of magnetite. Some pyrite, though rarely, contain pyrrhotite.

5-2-2 Formation of Veinlets

The formation of numerous ore-bearing veinlets, containing chalcopyrite and others, was, of course, an event after the consolidation of the groundmass, during the stage succeeding to that of dissemination. The mineral assemblages of this stage are considerably complicated as follows;

(1) consisting of pyrite, chalcopyrite, and hematite, in which pyrite includes minute grains of pyrrhotite, chalcopyrite, enargite, and spharelite,

(2) pyrite, enargite, and spharelite,

(3) molybdenite-bearing quartz veinlets.

The molybdenite-bearing quartz veinlets among them represent the latest stage.

The succession of crystallization of these minerals is shown on Fig. 5-1 diagrammatically.

5-2-3 Fracture Control of Ore Distribution

All the systems of the fractures prevailing in this district are existing as ore-bearing veinlets in the ore deposit. Among them, the system of NNE has the most frequent occurrence in the ore deposit as already stated in 3-3-2, which is followed by the system of NNW. These two systems played the roles of shearing fractures as well as tension cracks in the stress fields of folding and destruction, in other words, they were the ones capable to offer the openings for the ore fluid to pass or to deposit. Thus, their high frequency of existence may well be understood. The elongation of the ore body in the direction of NW may be much due to the combination of these two fracture systems.

Local features of the fracture control are explained as follows; (cf. Fig. 5-2A, 5-2B)

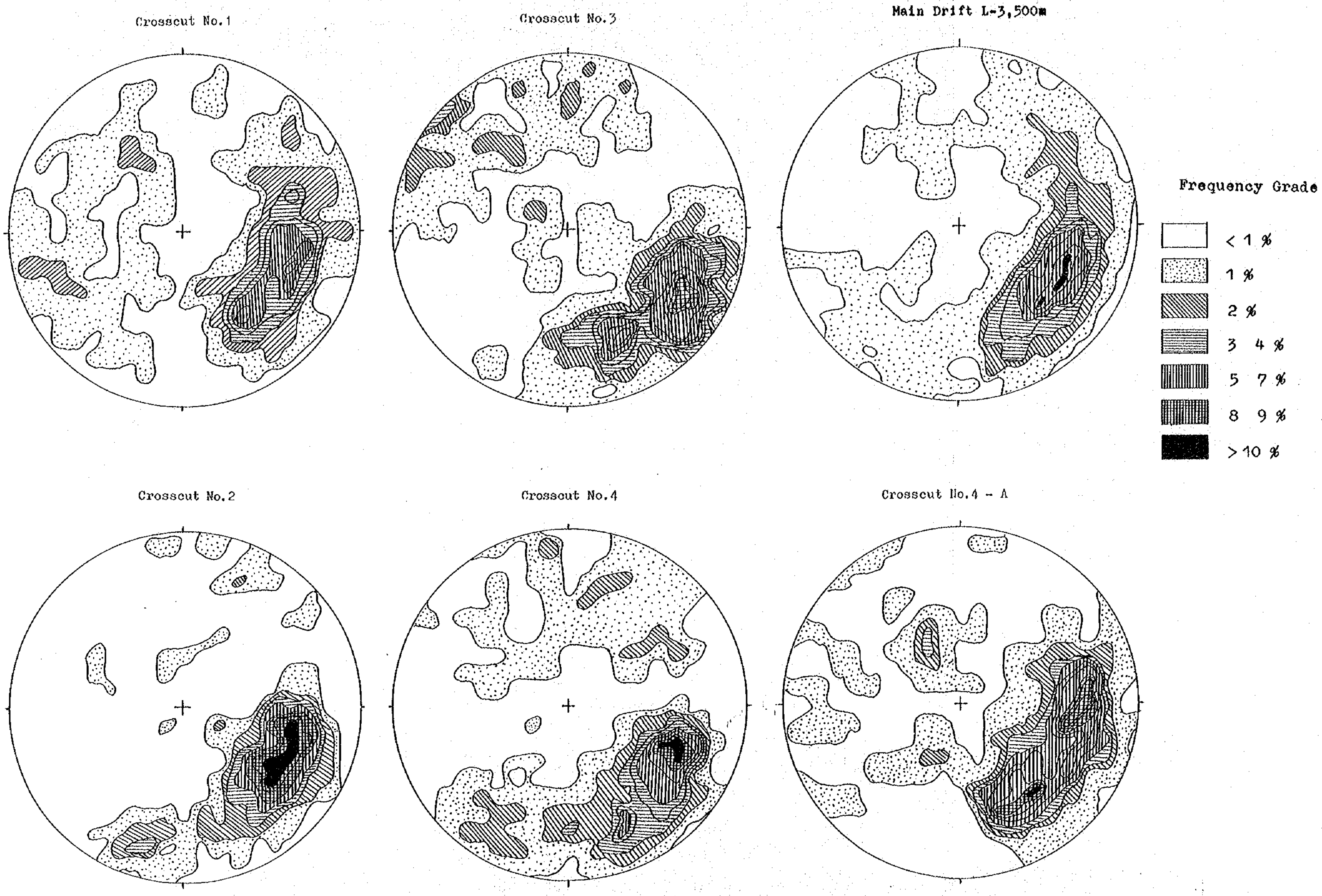
(1) at Cross-cut No. 1, the peaks of high frequency among those of NNE--SSW system are recognized in the fractures of N 18° E, 65° SE and N 55° E, 61° SE. The former peak will roughly coincides to the tendency of the iso-grade contours extending southwards, while the latter to the isograde contours extending northwards,

(2) at Cross-cut No. 2, the fractures of approximately N 26° E, 65° E are predominant,

(3) at Cross-cut No. 3, peaks are observed in the fractures of N 30° E, 72° NE and N 64° E, 68° SE. They also show the conformity to the tendencies of the iso-grades, the former to the trend from the north and the latter to the south.

(4) at Cross-cut No. 4, peaks are observed in the fractures of N 20° E, 65° SE and N 60° E, 72° SE. The former coincides to the trend of iso-grades from the north, while the latter to the south.

Fig 5-2A CONTOUR DIAGRAMS SHOWING FREQUENCY DISTRIBUTION OF FRACTURES IN EACH CROSSCUT ON LEVEL 3,500m



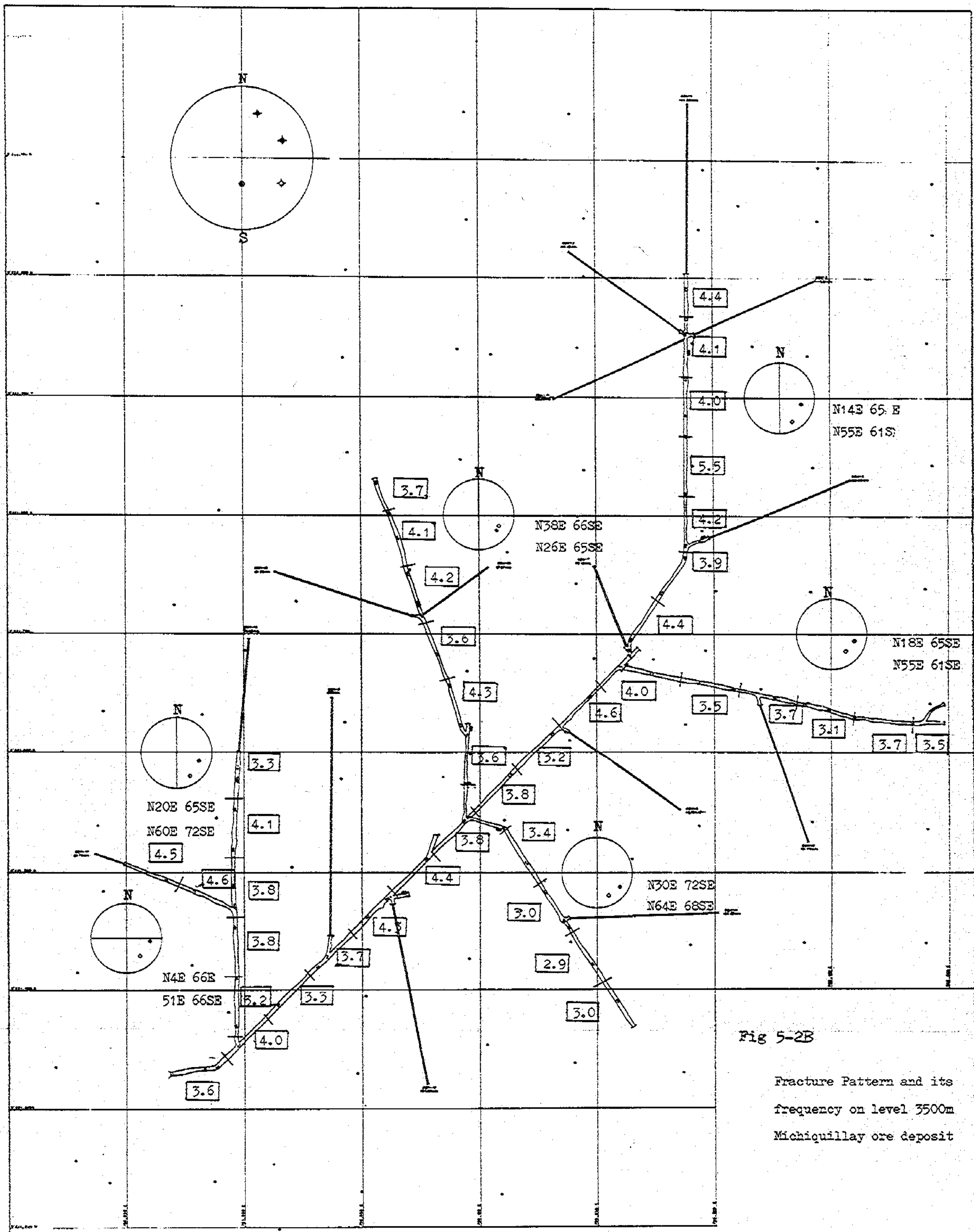


Fig 5-2B

Fracture Pattern and its frequency on level 3500m Michiquillay ore deposit

- average of all fracture
- the f rst peak of frequency
- the second peak of frequency
- michiquillay fault
- EW fissure system
- NNW - SSE fissure system
- average number in 10cm length

(5) at Cross-cut No. 4-A, peaks are observed in the fractures of N 04° E, 66° E and N 51° E, 66° SE and they also show fair conformity to the trends of iso-grades,

(6) among the fractures observed for 250 meters from the face outwards in the pre-existing tunnel, the frequency peaks are recognized in the fractures of N 74° E, 65° E and N 62° E, 71° SE. The direction of the former is not well reflected in the trend of the iso-grades, which is more distinctly controlled by the faults of NNW--SSE system intersecting here, but the latter well coincides to the trend towards southwest.

The intersection of the reverse fault of NNW--SSE and fissures of NNE--SSW system show the plunge of 68° SE (approx. 70° in SE) in the direction of N 78°E. It is recognized on the cross-section of the ore deposit that the isogrades follow more or less the trend above mentioned.

The characteristic pattern of the extent of copper mineralization show almost an oval shape, showing the zonings of mineralization effects, which may be classified from the inner towards outer zones as argillized zone in the innermost, low grade zone, high grade zone, outer low grade zone, and the outermost barren zone. As regards to molybdenite, similar tendency of transition is observed from the inner low grade zone to the outer high grade zone, showing the similar way of distribution as copper with a slight difference that the molybdenite high grade zone is located in the outer side of the copper high grade zone. A very high grade area is recognized in the south, which may be considered the overlapping of two mineralization spheres constituting the Michiquillay ore deposit.

5-3 Wall Rock Alteration

5-3-1 Zonal Arrangement of Alteration Zones and Biotite Zone

Through the geological observations of the drill cores on 3,500 Level, the zonal arrangement of the zones of alteration products have been revealed, each of which is characterized by particular mineral as follows;

1) the innermost zone, characterized by pink feldspars,

(2) magnetite concentrate zone involving the zone (1),

(3) biotite zone involving the said two and extending outer than them.

The distribution pattern of these zones, located northeastern annex to the argillized zone which will be mentioned later, forms a crescent domain as if to hug the argillized zone.

The corresponding opposite, to be expected to the southwestern annex to the argillized zone, and to be consisted of the zones of biotite, magnetite, and pink feldspars as well, can not be observed as it should be outside of the exploration area on 3,500 Level, but only chlorite zone observable near the portal.

Overlapping all of them, silicification and sericitization are observed, of which distribution roughly coincides to the extent of the ore deposit.

As has been stated already, biotite constituting the biotite zone might have been derived from the contamination between the magma and its captured rocks. But the stage of biotite, especially the stage of biotite in the groundmass is the beginning of the copper mineralization of dissemination type, therefore the genesis of boitite cannot be discussed independently from the mineralization. At the same time, as this zone of biotite shows the zonal arrangement together with other zones of alteration commonly accepted, this zone will be treated hereafter in this paper as a sort of alteration zone as well as for the sake of convenience in the discussion of inter-relationship. In any case, as it is commonly observed ~~that such biotite as the product, as it is commonly observed that such~~ that such biotite as the product of the earlier crystallization have been altered partly or entirely into chlorite and sericite, at least some parts of its initial domain must have been modified by being overlapped by the later alteration processes related to the mineralization.

5-3-2 Inter-relation of the Alteration Zones

Silicification and sericitization appear closely associated and observable almost all over. Quartz as the alteration product by sericitization and silicification are observable almost all over, too. In other words, these alterations are considered to have begun since considerably earlier stage of mineralization.

As regards to what has been called 'argillized zone', it has been found that this part is essentially consisted of minute sericite, while kaolinite and montmorillonite are contained only a little amount. Since what has been distinctly recognized and called 'argillized zone' has been revealed to be due to the formation of minute sericite, or sericitization, it is made difficult to deliniate the 'argillized zone' in its strict sense. However, the word 'argillization' will be used in this paper as it has customarily been, but the meaning it involves will be as stated above.

Taking the center of the argillization as the center of the alteration, the following arrangement may be deliniated;

(1) the innermost zone of argillization,

(2) zone of sericitization and silicification, overlapping the above and spread outer than it,

(3) chloritization zone, surrounding them and involving biotite zone.

In the course of development of such alteration zones as silicification and sericitization zones from this center, the alteration domain of the earlier formation like biotite zone must have been etched up partly by the later processes, and consequently dissected into two domains of zonal arrangement confronting each other on the line of elongation of ore body with the central argillized zone in between. (Plate 4-3)

Taking for the examples the underground drill holes Nos. 11 and 13, pink feldspars are recognized there, and in Cross-cut No. 4, the euhedral biotite is locally observed and hemetite almost all over. The former two will represent the remains of the initial zoning of alteration even in the 'etched' zone by the later alteration, while hematite is considered due to the later alteration of magnetite.

Taking several features of alteration into account, the succession of the alteration may be classified by stages as follows;

the first stage when silicification had begun a little later than the crystallization of biotite phenocryst in the crystallization stage of phenocrysts, the second stage, when magnetite, pink feldspar, and fine flakes of biotite along with the consolidation of the groudmass, and

the third stage, when argillization took place accompanying silicification, producing mostly minute sericite, partly kaolinite, and very limitedly montmorillonite.

The zonal arrangement performed already in the stages of the first and second, were overlapped by silicification and sericitization in the third stage, in which the pre-existed minerals such as biotite flakes, pink feldspars, and magnetite, were altered into sericite, kaolinite, and hematite respectively, and thus the initial domain of alteration was dissected in such the way as a crescent domain of the biotite zone to be left.

As for the silicification, silica is considered to have been existing abundantly since the stage of the crystallization of phenocrysts till the stage of consolidation of the groudmass minerals, and continuously giving various reactions to other minerals. But here in this chapter, only the third stage has been mentioned, when it appeared in the form of the distinct groups of quartz veinlets and replaced the minerals of their surroundings.

5-3-3 Mineralization and Alteration (Summary)

Mineralization and alteration are considered to have worked almost simultaneously, and the succession of the events may be summarized as follows through geological analysis of their relational features;

(1) the stage of copper mineralization from the innermost zone, represented mainly by chalcopyrite, and accompnying sericitization and silicification (the stage of copper dissemination as well as partial destruction of the biotote zone),

(2) the stage of mineralization represented mainly by pyrite, accompanying magnetite, minute flakes of biotite, and pink feldspars (stage of the formation of ore-bearing veinlots),

(3) the stage of silicification in association with molybdenite,

(4) the stage of argillization which altered the gangue minerals formed in the stage (2).

It may be said that at the stage of copper dissemination, the outline of the ore deposit had been almost built up, or the extent of this process had decided the domain of copper distribution almost as similarly as is seen at present.

The later mineralization of copper in the form of veinlets might have given additional concentration of copper within that domain.

The argillization stated in (4) destroyed or dissected the zonally arranged alteration zones initially formed during the stages of (1) and (2), resulting in producing the present pattern in which two crescent domains of alteration zones are left, confronting each other in north and south, and hugging the argillized zone in between.

5-4 Supergene Enrichment

The enrichment processes due to the supergene alteration are recognized distinctly in the southwestern part of the ore deposit. The following three zones may be classified from the inner to the outer zones of the tunnel, by the proportions of chalcocite, bornite, and covellite to chalcopyrite;

(1) the zone where no chalcocite, bornite, and covellite are recognized,

(2) the zone where the proportion of chalcocite, bornite, and covellite is less than chalcopyrite,

(3) the zone where the proportion of chalcocite, bornite, and covellite is more than chalcopyrite.

In this paper, the names of the primary zone, transitional zone, and enriched zone are given to each of the zones above mentioned respectively, as well as the leached zone near the portal where no copper mineral was

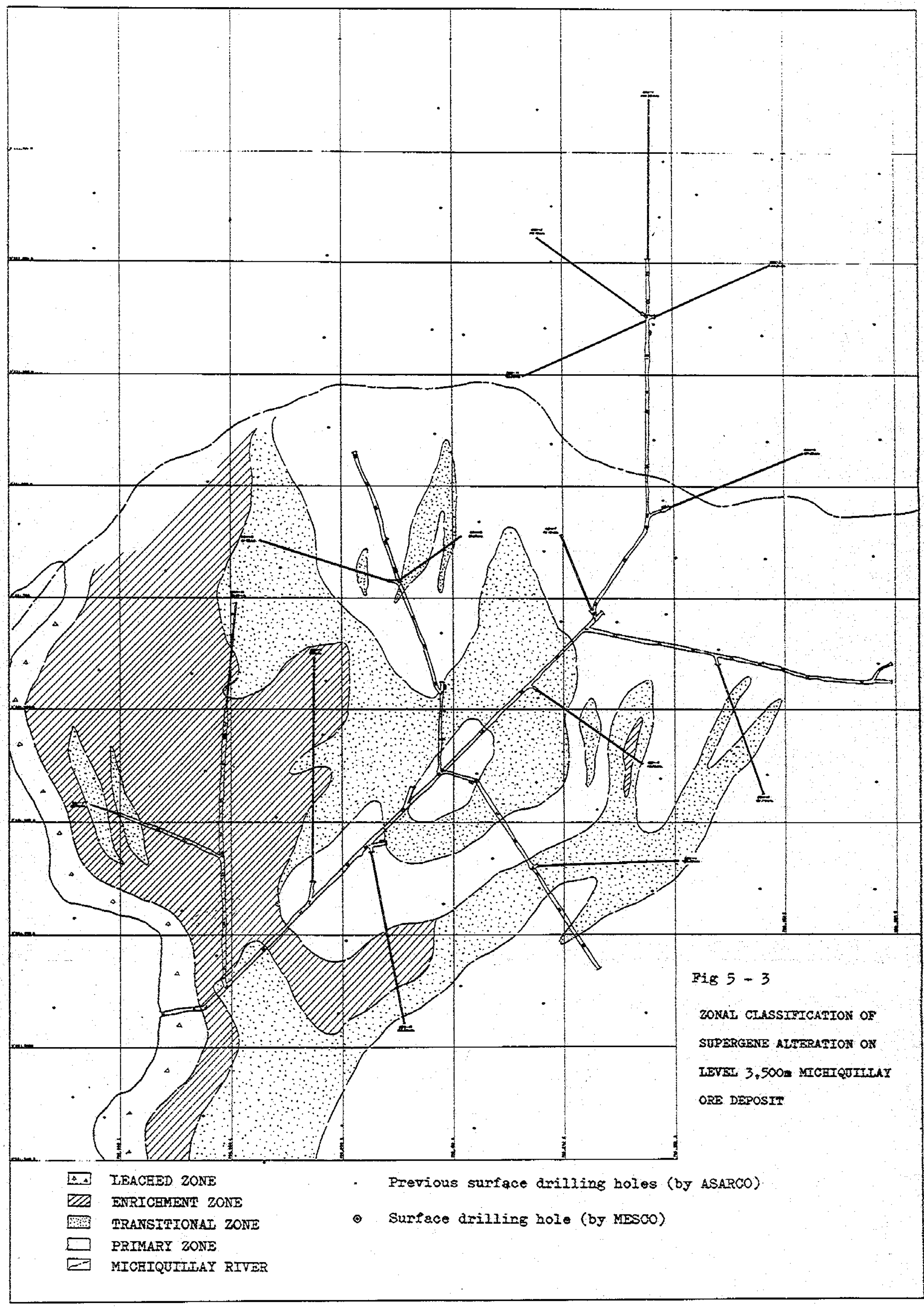


Fig 5 - 3

ZONAL CLASSIFICATION OF SUPERGENE ALTERATION ON LEVEL 3,500m MICHIQUILLAY ORE DEPOSIT recognized. They are shown diagrammatically on Fig. 5-3.

In the arrangement of these zones, such characteristic features are recognized as;

(1) the primary zone occupies the deeper zone of ore deposit,

(2) the enriched zone appears almost parallely to the ground surface with more or less definite depth (about 55 meters averagely), and partly controlled by fissures,

(3) the transitional zone occupies the inner side of the enriched zone, and strongly controlled by faults and fissures.

The copper minerals in the enriched and transitional zones are chalcopyrite, chalcocite, bornite, and covellite. Chalcopyrite is the product of the primary mineralization, while the rest three are the secondary minerals caused by the supergene enrichment process.

The general rule of arrangement of these secondary minerals in relation to chalcopyrite is that chalcopyrite is usually in the innermost, then others are arranged in the order of bornite, covellite, and chalcocite from the inner outwards. Chalcocite is found generally more concentrated towards outside of the enriched zone, but in the inner part of enriched zone and in the transitional zone, it occurs only as very thin coating film, and the secondary copper minerals are rather represented mainly by covellite with a little amount of bornite.

In any case, characteristic is that these four copper minerals are recognized co-existing in the individual grains with various proportions of assembly.

5-5 Some Mineralogical Features of Ore

The host rock of the Michiquillay Ore Deposit is entirely quartz monzonite porphyry. The porphyry has been subjected to such alterations related to the mineralization as silicification, sericitization, and argillization, while some parts of the porphyry contain the euhedral biotite and minute flakes of it.

The copper mineral in these alteration zones is almost essentially chalcopyrite. It has the disseminated occurrence as well as in veinlets, in which the former is predominant. The disseminated chalcopyrite generally shows an average grain size of 0.2 ~ 0.3 m/m in diameter, while in the veinlets, it is a little smaller as 0.1 ~ 0.2 m/m. Many of the disseminated chalcopyrite generally occur as isolated crystals, while these in the veinlets generally occur to surround pyrite or to be contained in it. An average diameter of chalcopyrite graines contained in pyrite is 0.05 m/m, but they are minor in amount.

The disseminated chalcopyrite and that in the veinlets are altered into chalcocite, bornite, and covellite due to the supergene alteration. Chalcopyrite in the supergene enrichment zone has the zonally arranged coatings of bornite, covellite, and chalcocite almost unexceptionally from the inner towards the outer zones within each crystal grain. The amount decreases in order of covellite, chalcocite, and bornite. In the transitional zone, bornite is observed dominant as the secondary copper mineral. Sometimes, chalcocite is observed as coatings of about 0.003 ~ 0.004 m/m thick, surrounding the grains of chalcopyrite or pyrite. Either in the enriched zone or in the transitional zone, it can be observed in general that the three kinds of the secondary minerals are co-existing within a single crystal of chalcopyrite of averagely 0.2 ~ 0.3 m/m in diameter.

Pyrite is widely distributed in this ore deposit. Especially in the environs of the argillized zone where the pyrite bearing veinlets are well distributed, pyrite sometimes occupies 15% in areal proportion, but about 5% generally. The normative pyrite calculated from the chemical analysis shows 0.2 ~ 0.3% in the biotite zone in molecular percentage, 18.5% in the silicified zone, and 6.1 ~ 7.2% in the sericitized zone.

It has to be mentioned specially that the precipitation of the green copper oxide minerals is observed in the Michiquillay Ore Deposit as the results of oxidation with time. As an example of the quickest change, the green copper began to appear after two weeks on the exposed surface, and within about two months it covered all over the spot as shown on the photographs in the Appendices. In the observation of the outdoor stock pile of ore, the green copper began to precipitate about in a month under the rainy condition.

5-6 Variation of the Chemical Compositions of the Mineralized Monzonite Porphyry

The following samples were taken in and around the ore body and were subjected to chemical analysis in order to pursue the variation of their chemical compositions;

one, taken as a representative of the original rock type, hornblende quartz monzonite porphyry, from the Magnetite Hill, northeast of the deposit, and related to form the magnetite deposit (0205),

two from the biotite zone including pinkfeldspar-magnetite zone of Cross cut No. 1 (1818 and 1432), one from the sericitized zone of Cross cut No. 4-A (5221),

one from the silicified zone of Cross cut No. 2 (2508), and

one from Cross cut No. 3 where the silicified and sericitized zones co-exist (3615).

The results of chemical analysis are shown on the upper half of Table 5-2. In the samples taken within the ore body (1818, 1432, 5221, 3515, and 2508), total Fe is represented in Fe_2O_3, as FeO can not be determined quantitatively due to the co-existence of sulphides. After allocating Cu and S for pyrite and chalcopyrite, or pyrite and covelline, the balance of iron component was distributed according to the ratio of FeO and Fe_2O_3 in the fresh monzonite porphyry outside of the ore deposit (0205). The results of such calculated adjustment are shown on the lower half of Table 5-2, in which the total of each sample comes close to 100% or so. After subtracting the corresponding components to sulphides from the calculated compositions cited on the lower half of Table 5-2, and by readjusting the components of each sample into 100%, the values are obtained as shown on the upper half of Table 5-3 and their corresponding normative compositions are given on the lower half of the said table.

1) Variation of Each Component Relative to SiO_2

Fig. 5-4 and Fig. 5-5 show the variation of chemical components relative to SiO_2, in which the unmodified analytical values are applied in the former, and the readjusted values to have excluded sulphides are plotted in the latter.

The relation between SiO_2 and other components in terms of their analytical values in each corresponding zonal arrangement will be explained as follows (cf. Fig. 5-4);

Sample No.	0205	1818	1432	2508	5221	3515
SiO_2	59.72	62.13	62.35	63.45	66.57	68.21
TiO_2	0.55	0.52	0.61	0.37	0.50	0.55
Al_2O_3	17.49	16.18	16.72	9.26	14.33	15.05
FeO	2.59					
Fe_2O_3	3.10	6.12*	4.54*	15.40*	5.48*	5.28*
MnO	0.14	0.03	0.04	0.01	0.01	0.01
MgO	2.06	2.24	2.57	0.36	0.92	0.58
CaO	5.12	3.27	0.80	0.06	0.03	0.04
Na_2O	3.83	3.28	1.87	0.16	0.23	0.18
K_2O	2.55	3.23	6.14	3.14	5.37	4.88
P_2O_5	0.23	0.25	0.21	0.07	0.22	0.07
Cu		0.33	0.55	0.49	1.99	0.47
S	0.01	0.38	0.68	7.52	3.33	3.15
H_2O +	2.75	1.73	2.26	2.40	2.05	2.18
H_2O -	0.41	0.58	0.48	0.45	0.25	0.40
Total	100.13	100.27	100.18	103.14	101.28	101.05
SiO_2		62.13	62.35	63.45	66.57	68.21
TiO_2		0.52	0.61	0.37	0.50	0.55
Al_2O_3		16.18	16.72	9.26	14.33	15.05
FeO		2.38	1.66	2.52	1.15	0.65
Fe_2O_3		2.96	1.92	3.12	1.36	0.72
MnO		0.03	0.04	0.01	0.01	0.01
MgO		2.24	2.57	0.36	0.92	0.58
CaO		3.27	0.80	0.06	0.03	0.04
Na_2O		3.28	1.87	0.16	0.23	0.18
K_2O		3.23	6.14	3.14	5.37	4.88
P_2O_5		0.25	0.21	0.07	0.22	0.07
H_2O +		1.73	2.62	2.40	2.05	2.18
H_2O -		0.58	0.48	0.45	0.25	0.40
Sub Total		98.78	97.99	85.37	92.99	93.52
Fe**		0.39	0.56	6.61	1.79	2.74
Cu**		0.33	0.55	0.49	1.99	0.47
S**		0.38	0.68	7.52	3.33	3.15
Grand Total		99.88	99.78	99.99	100.27	99.88

* Total iron as Fe_2O_3
** to be allocated for pyrite, chalcopyrite, covellite.

Table 5-2 Chemical composition and its calculated composition of quartz monzonite porphyry from Michiquillay Deposit, Peru.

Sample No.	0205	1818	1432	5221	3515	2508
SiO_2	59.72	62.90	63.63	71.59	72.94	74.32
TiO_2	0.55	0.52	0.62	0.54	0.59	0.43
Al_2O_3	17.49	16.38	17.06	15.41	16.09	10.85
FeO	2.59	2.41	1.69	1.24	0.70	2.95
Fe_2O_3	3.10	3.00	1.96	1.46	0.77	3.66
MnO	0.14	0.03	0.04	0.01	0.01	0.01
MgO	2.06	2.27	2.62	0.99	0.62	0.42
CaO	5.12	3.31	0.82	0.03	0.04	0.07
Na_2O	3.83	3.32	1.91	0.25	0.19	0.19
K_2O	2.55	3.27	6.27	5.77	5.22	3.68
P_2O_5	0.23	0.25	0.21	0.24	0.07	0.08
H_2O +	2.75	1.75	2.67	2.20	2.33	2.81
H_2O −	0.41	0.59	0.49	0.27	0.43	0.53
Total	100.13	100.00	100.00	100.00	100.00	100.00
Q	13.1	19.7	22.7	45.9	49.9	58.5
Or	15.5	20.0	38.5	36.0	33.0	24.0
Ab	35.5	30.5	17.5	2.0	2.0	2.0
An	23.5	15.5	2.5			
Wo	0.4					
En	6.0	6.6	7.6	3.0	1.8	1.2
Fs	1.4	1.0	0.4	0.2		1.6
C		2.1	7.2	10.2	11.6	7.8
Ap	0.5	0.5	0.5	0.3	0.1	0.1
Il	0.8	0.8	1.0	0.8	0.8	0.6
Mt	3.3	3.2	2.1	1.6	0.4	4.2
Hm					0.4	

Table 5-3 Calculated chemical composition of rocks and its Norm from Michiquillay Deposit
(above halves are converted into 100% from the sub-totals of previous page)

in the biotite zone, including pink foldspar-magnetite zone, SiO_2, MgO, and K_2O increase in comparison to the original rock, hornblende-quartz monzonite porphyry, while Al_2O_3, CaO, Na_2O and total Fe decrease,

in the sericitized zone, SiO_2 and K_2O increase compared to the original rock, while Al_2O_3, CaO, Na_2O, MgO and total Fe decrease, and

in the silicified zone, SiO_2 and K_2O increase, while Al_2O_3, CaO, Na_2O, MgO and total Fe decrease.

Relation between SiO_2 and calculated (readjusted) chemical compositions is shown on Fig. 5-5. In the variation of the chemical components in terms of analytical values, the variation of the oxide components are influenced by the existence of sulphides, resulting in the zones to be put in disorder. In other words, the zones are so arranged on Fig. 5-4 in the increasing order of SiO_2 %, as silicified zone, sericitized zone, and sericitized-silicified zone. But according to Fig. 5-5, where the sulphide components have been eliminated and recalculated in terms of oxides only, the zones are arranged in order of sericitized zone, sericitized-silicified zone, and silicified zone in the increasing order of SiO_2 %, which is more normally coincident to the megascopical appearences.

The comparison of the variation of modified components eliminating sulphides to the original rock will be explained as follows;

in the biotite zone, SiO_2, K_2O and MgO show increase, while Al_2O_3, CaO, Na_2O and total Fe decrease,

in the sericitiezed zone, SiO_2 and K_2O increase, while Al_2O_3, CaO, Na_2O, MgO and total Fe decrease, and

in the silicified zone, SiO_2, K_2O and total Fe increase, while CaO, Al_2O_3, Na_2O and K_2O decrease.

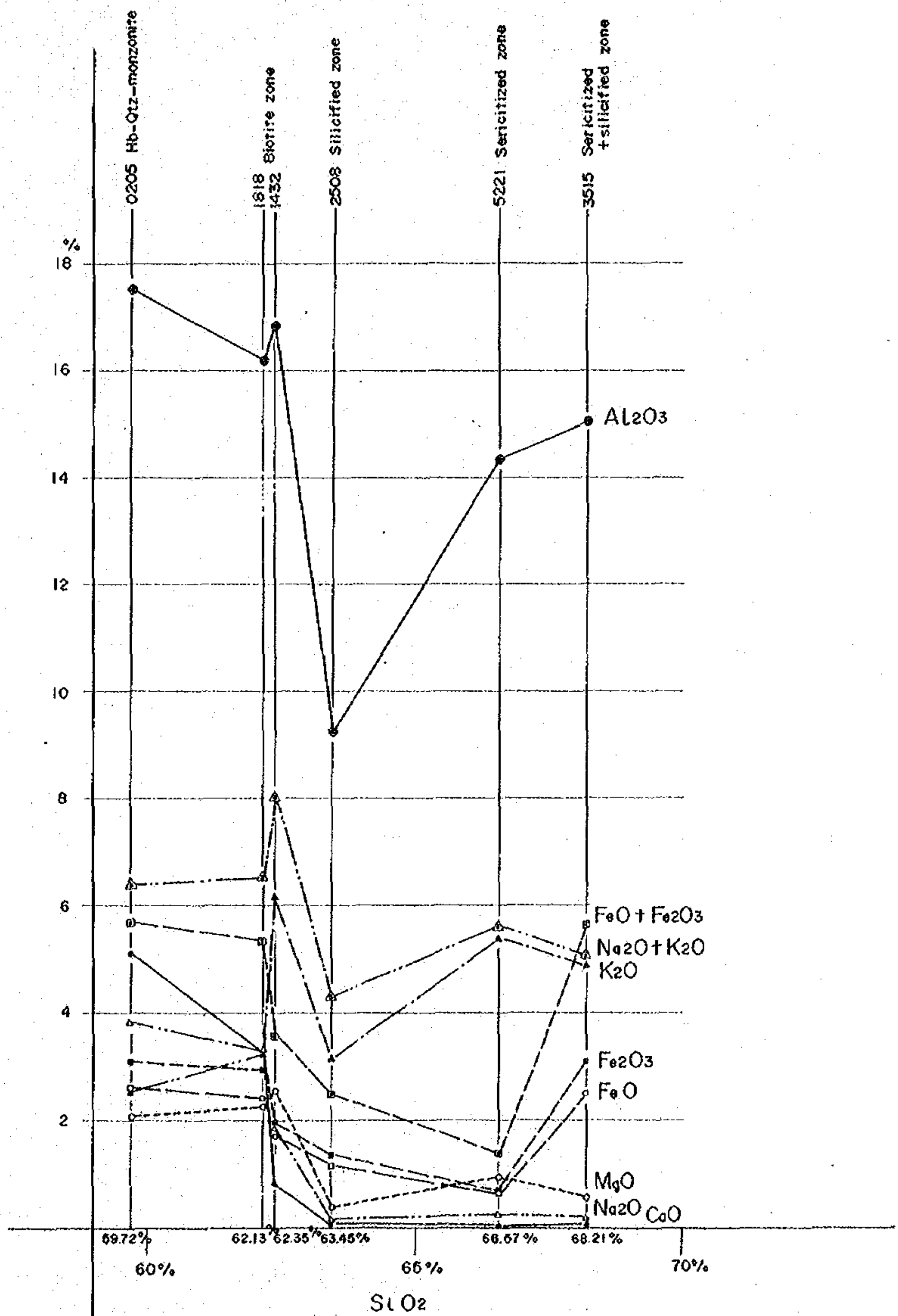


Fig. 5-4 THE RELATION BETWEEN SiO_2 AND THE OTHER COMPONENTS.

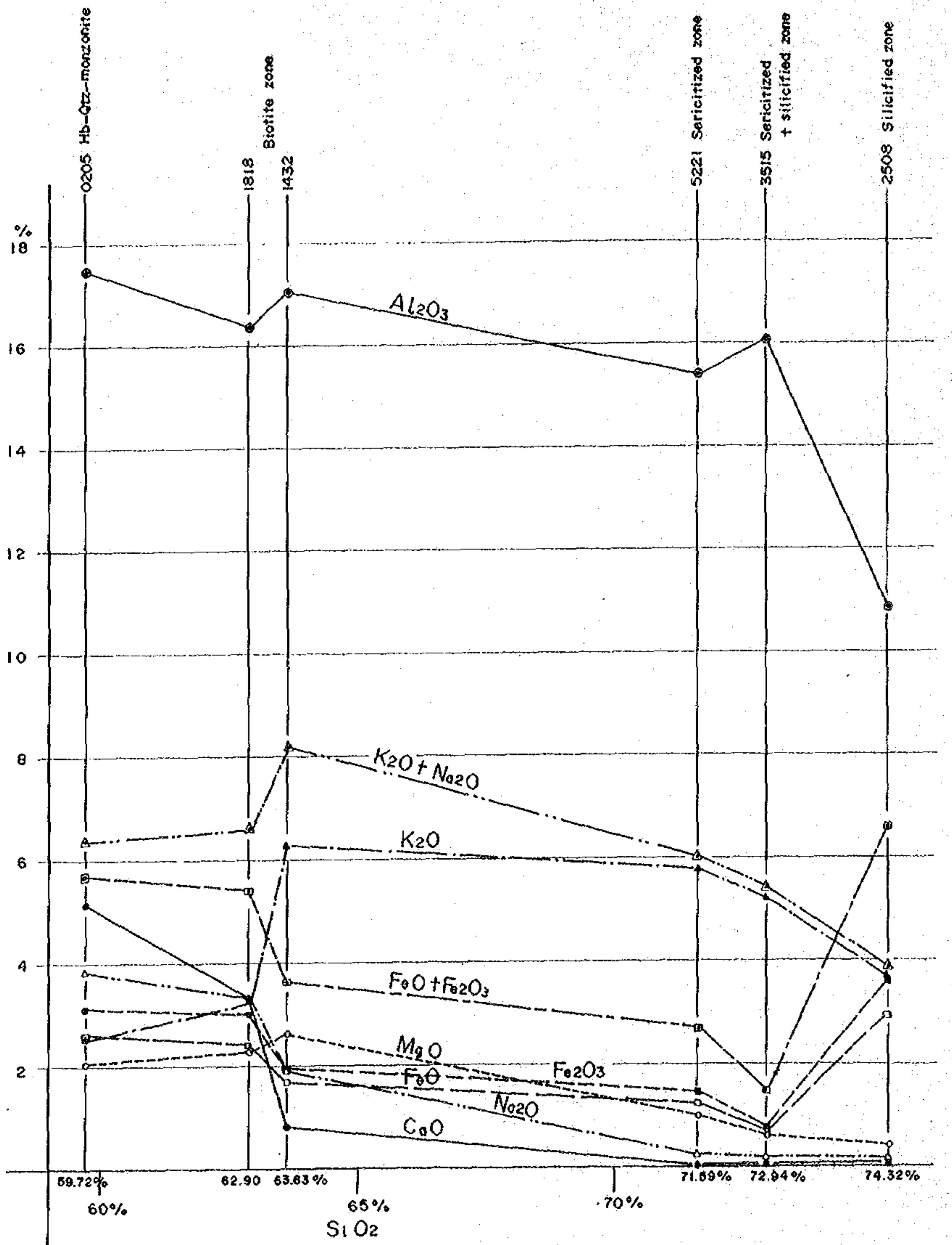


Fig.5-5 RELATION BETWEEN SiO_2 AND THE OTHER COMPONENTS, BASED ON THE MODIFIED CHEMICAL COMPOSITIONS

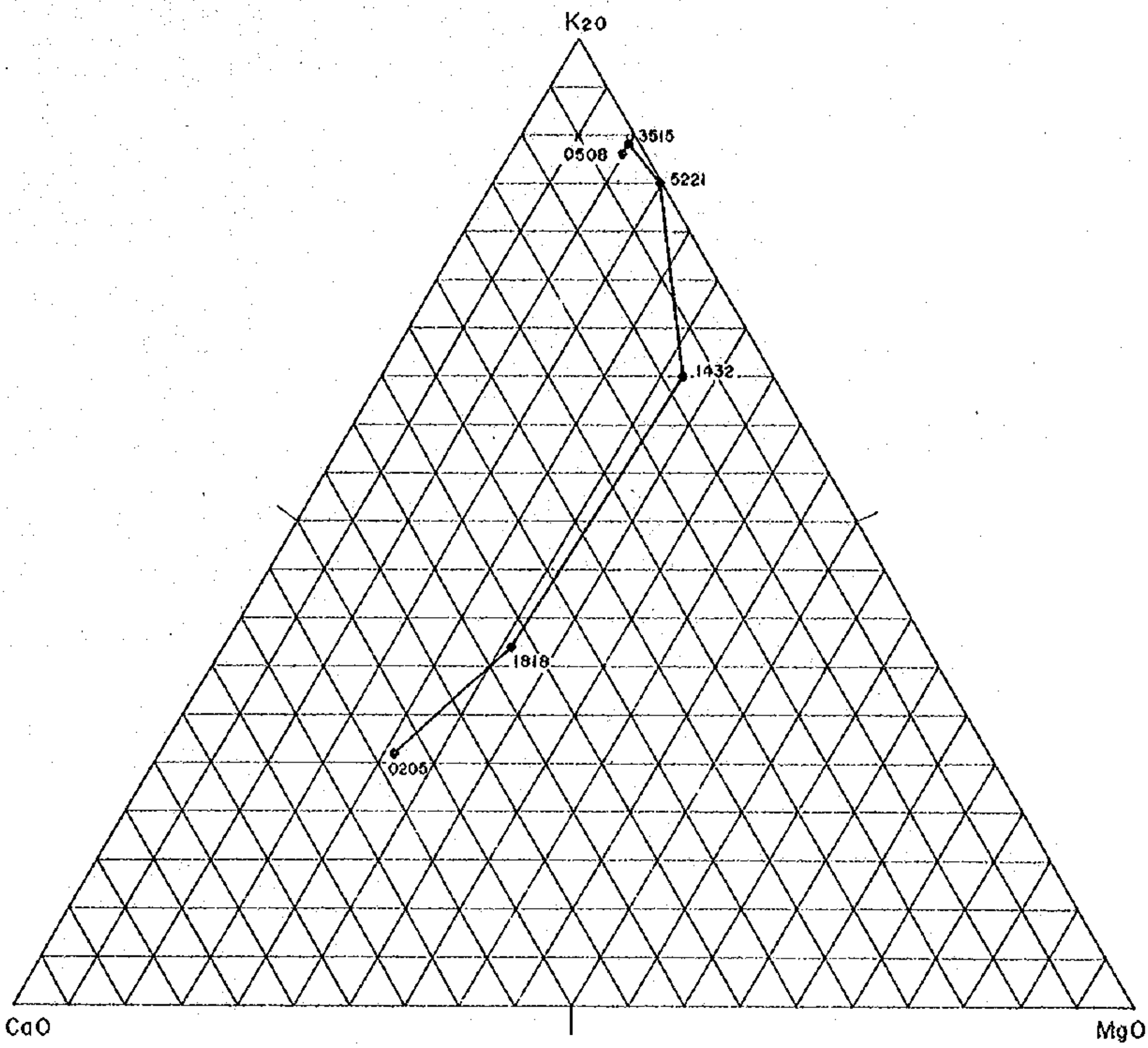


Fig. 5-6 K_2O - CaO - MgO SYSTEM BY MODIFIED COMPONENTS

Considering the formation of minerals in each of the altered zones from the point of such variation of chemical compositions, the increase of MgO and K_2O in the biotite zone would correspond to the formation of biotite and pink feldspar. Increase of K_2O in the sericitized zone and silicified zone would correspond to the formation of sericite. The steady increase of SiO_2 in each of the alteration zones would have been caused by the concentration of SiO_2 at the latest stage of magmatic consolidation.

2) Variation in Cao-MgO-K_2O (Fig. 5-6)

In this ternary system, the variation of chemical composition may perfectly reflect the variation of mineral composition. The generation of biotite along with the decrease of hornblende in the original rock would be indicated by the increase of K_2O and MgO along with the decrease of CaO (1818 and 1432 against 0205), and the formation of sericite against the decrease of biotite would be indicated by the increase of K_2O against the decrease of MgO (5221, 3515 and 0508 against 1818 and 1432).

5-7 Structural History of the Michiquillay Ore Deposition

In finalizing this chapter, a historical review of a series of geological events which the Michiquillay Area experienced, will be given herewith as a historical summary of the Michiqullay ore deposition.

1) Epoch of sedimentation; starting with the terrestrial sedimentation represented mainly by quartzite in the Lower Cretaceous Period and succeeded by the later submarine sedimentation which formed a thick series of limestone.

2) Epoch of tectonic movements; land upheaval with the formation of folding structures of NW-SE axial trend, and later deformation to have

changed the general Andean trend of NW-SE system into the Cajamarca trend of WNW-ESE system. Faulting movement occurred consequently.

3) Epoch of igneous activity; monzonite porphyry intruded following the ruptures thus formed, a part of which was modified to quartz monzonite porphyry characterized by biotite, a variety produced by magmatic contamination.

4) Epoch of mineralization; along with the coolong and solidification of the igneous rock, the mineralization took place limitedly in the contaminated facies. (in Paleogene)

The ore deposit was exposed under the later erosion and the supergene alteration has given the secondary enrichment effects.

Chapter 6 Exploration Problems and Future Aspects

The tunnelling and diamond boring operations have accomplished the scheduled amount of works without any serious trouble for the two year phases and the data of geological investigations which followed the said operations have been amply accumulated. In view of this, the geological aspect of the Michiquillay Ore Deposit on 3500 m Level has been investigated almost thoroughly.

6-1 Problems of Prospecting New Ore Deposits

The hornblende monzonite prophyry as the host to the Michiquillay Ore Deposit has intruded discordantly to the surrounding geological structures and has converted itself into a variety of biotite quartz monzonite porphyry due to the magmatic contamination with the wall rocks, and the mineralization of porphyry copper type is limited only in this contaminated facies.

In other part of the intrusives excluding the area of the biotite quartz monzonite, the magma is intruded as hornblende monzonite porphyry more or less concordant to the invaded formations, and has deposited magnetite and hematite of pyrometasomatic type in the calcareous beds of wall rock formations. Such deposits are observed on the up-stream of the West River and Magnetite Hill, and the probable extension of the deposit of Magnetite Hill has been captured by the surface boring No. 1. They are generally in small scaled and cannot be taken into consideration of further development as the resources of iron ore.

A mineralization of limestone replacement type has been recognized in the surface boring No. 3, of which ore is essentially pyrite accompanying chalcopyrite, galena, and spharelite in small amount in close association of a small intrusive body of hornblende monzonite porphyry. Although the mineralization is so small in scale that it is difficult to tell its future possibility, some necessity might arise to consider further exploration, in case some surface construction may happen to be attempted in the future.

As stated above, there seems no urgent problem to exist in regards to the exploration of other new ore deposit, and the Michiquillay Ore Deposit may safely be said that it has nearly passed through the exploration stage.

6-2 Some Mineralogical Features of Ore in Relation to Development

The present survey of the Michiquillay Ore Deposit has been confined on 3500 m Level, but as far as this level is concerned, it has enabled to investigate the deposit much more in details and widely than before, by driving 5 Cross cuts, 4 raises, and by drilling 16 horizontal diamond borings. In addition to the data of geological observation, the data of microscopical observations and chemical analysis of rocks and ores have been accumulated, through which various interpretations have been attempted to perform regarding to the mineralization, and as the results of such studies, these fundamental geological features of the Michiquillay Ore Deposit relating to the problems of development and operation have been well understood, which are enumerated as the fracture control of ore distribution, the zonal arrangement of alteration zones and variation aspects of ore natures, and the secondary alteration of copper minerals by the supergene alteration and its effects to the assays, etc. In view of this, the initial attempts of the present survey has been well attained.

Once the Michiquillay Ore Deposit could be put under development, the open pit mining will be most probably applied, and the variation of ore natures recognized on 3500 m Level may suggest all kinds of variety of ore to be mined in the early stage of operation. In other words, the ore to be mined in this stage may contain not only the primary ore but also the ore from the enriched and transitional zones affected by the supergene alteration. Naturally, the ore to be milled may contain as the copper minerals not only chalcopyrite and pyrite but also contain chalcocite, covellite, and bornite, and the modes of their occurrence may not be uniform but intergrown each other in various manners. In view of this, it is advisable to refer to the results of microscopic observations in regards to the inter-relation of these copper minerals and relation of them to pyrite, etc., in the determination of milling sizes and flotation conditions.

As the supergene alteration is under progress still at present, the ore is considered to contain more or less acid soluble copper.
According to the experiment of oxidation with time done on the side wall of the main drift about 30 meters from the adit of 3500 1 Level, it has been revealed that the first precipitation and deposition of the green oxide copper minerals had required about two weeks. But under the normal operation, the mined ore will be delivered to the mill much more quickly and the changes of assays in the mined ore caused by the oxidation with time may be negrigible. But in the treatment of ore from the outdoor stock piles exposed more than two months, it is advisable to make precautional checking not only of the determination of acid soluble copper content but also of the determination of the kinds of copper minerals, their sizes,

and their modes of occurrence.

There exist onargite containing As and spharelite containing Cd, but they occur very localized and the amounts seem negrigibly minor, not causing any problem in the actual operation. But from the view point of the environmental problem, their existence, even minor, has to be kept in mind.

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Chapter 1 Procedure of Geological Survey

1-1 Underground Geological Survey

Underground geological survey was carried out by sketching the backs and northern side walls of drifts and the southern side walls of raises in a scale of 1:200.

The items of survey were lithology, mineralization, alteration, fracturing, and granularity of phenocrysts. In its practice, marks were made on the side walls of tunnels at every one meter interval starting from any of the spads installed by the underground survey of MINERO PERU to make them serve for the distance markers. Piece samples of rocks were collected at every two meters interval from the sketched side wall (average size, 5cm x 5cm x 3cm), with which the lithology, mineralization, and granularity of phenocrysts were observed. In indicating the fracturing, the fissures and veinlets of more than 10 cm wide were drawn on the sketch as they were, while those less than 1 cm wide were substituted by indicating the numbers of them observed within a wooden frame of 10 cm square, held at about 1.2 meters above the floor at every one meter interval on the sketched side wall, and at every two meters interval on the opposite unsketched side wall.

The strikes and dips of the fissures and veinlets of more frequent occurrence were described on the sketch as well. The system of observation and description of the piece samples collected in the underground geological survey was quite similar to what was mentioned in the paragraphs of geological survey of the boring cores.

1-2 Underground Sampling

The practice of underground assay investigation consisted of the procedures of sample collection, preparation of assay samples, and chemical analysis, which were quite similar to that of the drilled cores.

Any assay sample was collected for three meters continuously by channelling a side wall and the sampled locations were arranged in a zigzag way on both side walls, that is to say, any next sample was collected from the opposite side wall for another three meters, instead of being collected from the next three meters annex to the first one on the same wall. A sampling party was composed of three crews, the one was assigned for making a channel of 10 cm wide with 2 cm depth by a hammer and a chisel with a tip of tungsten-carbide inserted, and the other two were assigned for receiving the channeled samples by holding a sheet of canvass of 1 m x 2 m. The amount of each sample collected was about 10 kg for three meters.

Each assay sample was prepared by using the facilities installed by ASARCO, of which flow sheets are attached as Fig. A-7, and it was quartered so as the one to be sent for assay to the local laboratory, the second for analysis in the mine site, the third for check analysis in Japan, and the last to be reserved.

Chemical analysis was done by Plenge Laboratory in Lima for the components of total Cu, acid soluble Cu, MoS_2, Au, Ag, Fe, S, and SiO_2. The flow sheets of analysis are attached as Fig. A-8.

1-3 Drill Core Logging

The geological features of the drilled cores were sketched in a scale 1:100, and the results were compiled into the geological and assay loggs of 1:200. The items of survey were lithology, core recovery, mineralization, alteration, fracturing, and granularity of phenocrysts.

Among the ore minerals, chalcopyrite and pyrite were classified into two, occurrences, disseminated and in veinlets. The latter involves all what occur vein-like, and the former involves all what are out of category of the latter.

Alteration was observed about biotite, quartz, sericite, clay minerals, chlorite, and others (mostly about pink feldspars and epidote), and classified as biotite alteration, silicification, sericitization, argillization (specified kaolinization so far as kaoline was assertained to exist), and chloritization, of which intensity was graded into the following 5 classes according to the amount and grain sizes of the minerals; 5--very strong, 4--strong, 3--moderate, 2--weak, and 1--very weak.

Fracturing intensity was determined by measuring the numbers of fissures or veinlets to appear in the 10 cm length of cores and was classified into the following four grades; '-' (weak, 1-2 frac.), '+'(moderate, 3-4), '++' (strong, 5-6), and '+++' (very strong, more than 7).

The granularity of phenocrysts was indicated by the maximum of all the measured values of the phenocrysts so far recognized in each division of core recovered.

1-4 Sampling of Drill Cores

The practice of assay investigation of drill cores consisted of sample collecting, preparation of assay samples, and chemical analysis.

The samples were collected from the cores corresponding to every 3 meters advance starting from the collar, which were split into two halves by core splitter and the one half was allocated for assay and the other half for reservation in the Michiquillay Mine.

The preparation of assay samples and chemical analysis were quite similar to that in the underground sampling.

Chapter 2 Underground Geology

2-1 Cross-cut No. 1

Position Started from; 9,221,672.70 N, 796,269.12 E

Bearing; 110°

Advanced Length; 300 meters

Monzonite porphyry appears almost throughout the length, which contains the phenocrysts of plagioclase (max. 4 x 7 mm, ave. 2 x 4 mm) and biotite (max. 5 x 7 mm, ave. 1 x 1 mm). But the phenocrysts of quartz are only observed seldomly, and even under the microscope, they are as small as about 0.2 mm only recognized seldomly. Biotitization is dominantly distinct, with associated silicification and chloritization commonly seen throughout. Sericitization and argillization are found rather locallized. According to the results of X-ray diffraction, the clay minerals are mainly kaolinite associating a little montmorillonite. Under the microscope, all the quartz phenocrysts are corroded, and the phenocrysts of plagioclase are altered almost entirely into sericite and kaoline with partial remnants of distinct zonal structure. According to the determination of composition of plagioclase by means of the maximum symmetrical extinction angles on Albite twinnings,it corresponds nearly to An_{39}. Orthoclase is rarer in phenocrysts, but more in groundmass with unexceptional perthitic texture. Biotite, either in phenocryst or in groundmass, shows the pleochroism as X : pale brownish, Y : light brown, and Z : dark brown, and partly altered into chlorite, sericite, and epidote. As accessory minerals zircon and apatite occur widely, but siderite rarely. The fissures more than 10 cm wide are the clay veins observable at the points of 41 m (N 25° W, 50° E), 55 m (N 60° E, 60° S), 128 m (N 10° W, 60° E), 133.5mm (N 75° E, 90°), 142 M (NS, 60 E°, a reverse fault with gray clay of 30 cm wide), 146 m (N 15° W, 75° W), 156 m (N 10° E, 60° E), 171 m (N 5° E, 60° E), 196 m (N 20° E, 80° E), and 228 m (N 30° E, 70° E).

Copper minerals are chalocopyrite and bornite, and other ore minerals are pyrite, magnetite, hematite, and molybdenite. The disseminated occurrence of chalcopyrite and pyrite is generally dominant, but the occurrence of pyrite in veinlets exceeds upto the advance of 120 meters. Many of magnetite are associated with biotite, but beyond the point of 131 m, some of them form the veins in association with pink feldspars. Many of hematite are altered from magnetite, which are very minute in sizes (less than 0.002 mm in diam.) and less in amount. Molybdenite, mostly associated in quartz veinlets, are observed almost throughout and especially remarkable beyond the point of 225 m. Bornite occurs only as coating films over chalcopyrite. Under the microscope, many of chalcopyrite are in irregular shapes, and pyrite has inclusions of pyrrhotite and chalcopyrite. Some of magnetite associated in veinlets contain the inclusions of chalcopyrite.

2-2 Cross-cut No. 2

Position Started from; 9,221,622.79 N, 796,133.67E

Bearing; 340°

Advanced Length; 231.5 meters

The rock appears in this tunnel is almost entirely monzonite porphyry, containing the phenocrysts of plagioclase (max. 4 x 6 mm, ave. 2 x 3 mm) and biotite (Max. 4 x 5 mm, ave. 2 x 2 mm). Silicification and sericitization are generally intense, and argillization gradually increases from the starting point inwards. Biotitization is observable only in the section between 196 and 210.5 m, and chloritization is very rare and faint.

Under the microscope, quartz is considered of recrystallized, being impossible to be distinguished as phenocryst or groundmass. Plagioclse is almost completely altered into sericite and kaolinite only with relic outlines remained. By the X-ray diffraction, a little amount of montmorillonite is contained. Orthoclase is found only in the biotite zone, having perthitic texture. Biotite is partly altered into chlorite, or some are completely altered into chlorite, sericite, and phlogopite with remaining outlines. The common accessory minerals are apatite, zircon, and hematite. The faults and fissures of more than 10 cm wide are those white or grayish white clay zones impregnated by pyrite, observable at the advances of 125 m (N 10° E, 55° E), 178 m (N 15° E, 55° E), 185 m (N 10° E, 75° E), 192 m (N 45° E, 53° SE), and 215 m (N 40° E, 20° E). Copper minerals are chalcopyrite, covellite, chalcocite, bornite, enargite, and green copper oxides, and other ore minerals are pyrite, magnetite, hematite, and molybdenite. The copper sulphide minerals and iron oxide minerals mostly occur as disseminated, while pyrite is predominant in veinlets. Under the microscope, pyrite is found to include the grains of magnetite, spharelite, and enargite. Chalcopyrite is surrounded zonally from the inner to the outer by bornite, covellite, and chalcocite. In case chalcocite directly surrounds chalcopyrite, its thickness is about 0.004 mm. Some of chalcopyrite includes magnetite, though rarely. Enargite occurs very seldomly in association with tetrahedrite.

2-3 Cross-cut No. 3

Position Started from;	9,221,538.84 N, 796,169.09 E
Bearing;	145°
Advanced Length;	200 meters

The rock appearing in this tunnel is entirely monzonite porphyry, in association with such alterations of sericitization as the main, and silicification, argillization, and very rarely chloritization. Many of the quartz phenocrysts under the microscope are so corroded that distinction from the groundmass is made difficult. Many of plagioclase are completely altered into sericite and kaolinite, and even the relic outlines are made obliterated. According to the X-ray diffraction, weak peaks of montmorillonite can be recognized. Orthoclase, though very little in amount, is almost completely chloritized, and partly sericitized. Biotite is altered perfectly into chlorite and sericite, which can only be guessed by the relic outlines. Accessory minerals are zircon, hematite, and rarely apatite, garnet, and corundum. The fissures more than 10 cm wide are gray or white clays observed at the points of 73 m (N 30° E, 85° NE), 95 m (N 80° E, 58° N and N 30°E, 70° SE), 106.5 m (N 40° E, 65° SE), 116 m (N 75° E, 70° S), 139.5m (N 70° W, 80° N), 144 m (N 80° W, 50° N), 147 m (N 5° E, 56° E), and 173 m (N 70° W, 60° N). Copper minerals are chalcopyrite, covellite, bornite, chalcocite, and enargite, and other ore minerals are pyrite, molybdenite, and hematite. Pyrite is predominant in veinlets, while chalcopyrite is dominantly disseminated. Most of molybdenite and enargite occur in veinlets. Under the microscope, pyrrhotite in association with chalcopyrite can be recognized as included in pyrite. The sulphide copper minerals form a zonal arrangement, with chalcopyrite being the center, surrounding it in order of, from the inner to the outer, bornite, covellite, and chalcocite, accompanying minute grains of hematite and, limitedly, magnetite.

2-4 Cross-cut No. 4

Position Started from; 9,221,370.70 N, 795,943.11 E

Bearing; 0^{o}

Advances Length; 238.5 meters

This tunnel is entirely composed of monzonite porphyry containing the phenocrysts of plagioclase (max. 4 x 7 mm, ave. 2 x 4 mm) and very limitedly biotite, with very rare exception of containing quartz phenocrysts (max. 3.5 x 2.5 mm, ave. 1 x 1 mm). Main alterations are sericitization and argillization, while silicification and chloritization are weak. Biotitization is only limitedly recognized. Under the microscope, some of the phenocrysts of quartz are so corroded as to be undistinguishable. Plagioclase is completely altered into sericite and kaolinite, with most of their relics obliterated, causing blurred porphyritic texture. According to the X-ray diffraction, it associates montmorillonite. Orthoclase, though little in amount, has the perthitic texture and is altered into minute crystals of sericite. Biotite is only recognized through its relics, as it is completely altered into sericite and chlorite. Accessory minerals are zircon, hematite, and rarely apatite, andalusite and corundum. The fissures of more than 10 cm wide are observed at the points of 7.5 m (N 80^{o} W, 51^{o} N), 62 m (N 75^{o} E, 63^{o} N), 78 m (N 75^{o} W, 45^{o} N on F.W. and N 70^{o} W, 45^{o} N on H.W.), 137 m (N25^{o} W, 70^{o} E), and 159 m (N 58^{o} E, 80^{o} NW), as clay veins of dark gray or light gray. Copper minerals are chalcopyrite, chalcocite, bornite, covellite, and green copper oxides, and other ore minerals are pyrite, hematite, molybdenite, spharelite, and galena. Most of the copper sulphides, pyrite, and hematite occur as disseminated, while molybdenite, spharelite, and galena occur in veinlets. Under the microscope, chalcopyrite is surrounded by bornite at the inner most, then by covellite, and by chalcocite in the outermost. The forms are very irregular and some are in net-works.

Throughout the length, it is affected by supergene enrichment, producing the transitional and enriched zones.

2-5 Cross-cut No. 4-A

Position Started from; 9,221,468.23 N, 795,940.14E

Bearing; 290°

Advanced Length; 100 meters

The tunnel is mostly composed of monzonite porphyry and partly of quartz monzonite porphyry. The monzonite porphyry contains the phenocrysts of quartz (max. 5 x 6 mm, ave. 1 x 1 mm) and plagioclase (ave. 1 x 2 mm). Main alterations are sericitization, silicification, and argillization, and very limitedly associating biotitization and chloritization. Under the microscope, many of the quartz phenocrysts are so corroded as to be undistinguishable from the groundmass. Plagioclase is so perfectly altered into sericite that even the relics are obliterated. The fissures of more than 10 cm wide are observed at the points of 42 m (N 15° W, 55° E), 48 m (N 15° W, 70° E), and 75 m (N 5° E, 70° E on H.W. and N 10° E, 60° E on F.W., a reverse fault) as gray clay veins. Copper minerals are chalcocite, chalcopyrite, bornite, and green copper oxides, and other ore minerals are pyrite, hematite, and molybdenite. Most of pyrite, chalcopyrite, and chalcocite occur as disseminated, while hematite and green copper oxides occur in the surroundings of the veinlets. Bornite is coating over chalcopyrite in veinlets, and molybdenite occurs in quartz veinlets. Under the microscope, pyrite has inclusions of associated chalcopyrite and pyrrhotite. Throughout the length, the enriched and transitional zones are formed by supergene enrichment.

2-6 Raise No. 2

Position Started from; 9,221,620.6 N, 796, 141.5E

Inclination; vertical

Advanced Length; 60 meters

The entire advance is composed of quartz monzonite porphyry, containing the phenocrysts of plagioclase (max. 3 x 5 mm), but the porphyritic texture is obliterated as a whole. The quartz phenocrysts (max. 1 x 1 mm) are very few. The main alterations are silicification and sericitization accompanying weak argillization. The fissures of more than 10 cm wide are observed as a fractured zone and a white clay vein respectively at the heights of 26 m (N40° W, 75° EN) and 35 m (N 50° E, 70° S). Copper minerals are chalcopyrite, chalcocite, bornite, and green copper oxides, and other ore mineral is pyrite. Occuurence of pyrite in veinlets exceeds a little to that of dissemination. Disseminated chalcopyrite is overwhelmingly dominant. Chalcocite is covering chalcopyrite as films, and pyrite in veinlets is also stained by chalcocite. Bornite mainly occurs as coating films over the disseminated chalcopyrite, and the green copper oxides associate with pyrite either in veinlets or disseminated. The supergene enrichment affects to form the transitional zone.

2-7 Raise No. 3

Position Started from; 9,221,725.2 N, 796,138.4 E

Inclination; vertical

Advanced Length; 60 meters

Monzonite porphry occupies the entire length, in which plagioclase phenocrysts (max. 3 x 5 mm) have often lost the crystalline outlines, and the porphyritic texture is often obliterated. Biotite occurs very limitedly, of which relict alone is remained, being altered into sericite and phlogopite. Sericitization, silicification, and argillization are predominant generally. The xenoliths of quartzite are locally recognized. The fissures of more than 10 cm wide are observed as white or gray clay veins at the heights of 46.5 m (N 15° W, 27° E) and 53 m (N 50° W, 85° N). Copper minerals are chalcopyrite and chalcocite, and other ore mineral is pyrite. Chalcopyrite occurs mostly as disseminated, while pyrite as disseminated in the lower portion and in veinlets in the upper portion. Chalcocite dominantly occurs as coating films over pyrite in veinlets in the lower portion, while in the upper portion, dominates as coating films over chalcopyrite. Molybdenite generally occurs in veinlets. As the effects of supergene enrichment, the upper portion represents the enriched zone, and the lower the transitional zone.

2-8 Raise No. 5

Position Started from; 9,221,472.2 N, 795,841.8 N

Inclination; vertical

Advanced Length; 20 meters

The entire advance is composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 3 x 4.5 mm) and plagioclase (max. 4.5 x 7 mm). Quartz is very little in amount and many of plagioclase have lost the outlines, resulting in the porphyritic texture obliterated. Silicification, sericitization, and argillization are predominant, but argillization can mostly be seen in plagioclase. Copper minerals are chalcopyrite, chalcocite, and covellite, and other ore minerals are pyrite and molybdenite. Disseminated chalcopyrite is dominant and pyrite also dominantly disseminated. Molybdenite generally occurs in quartz veinlets but is disseminated locally. Covellite and chalcocite are coating films over chalcopyrite. The supergene alteration has caused to form the enriched zone.

2-9 Raise No. 6

Position Started from; 9,221,576.4 N, 796,494.1 E

Inclination; vertical

Advanced Length; 30 meters

The entire raise is composed of quartz monzonite porphyry, containing the phenocrysts of quartz (max. 2.5 x 4 mm), plagioclase (max. 5 x 7 mm), and biotite (max. 2 x 3 mm). Quartz is very little in amount, and plagioclase has lost its outline due to the alteration which has resulted the porphyritic texture to have been obliterated. Biotite is so altered into sericite and phlogopite that only its relicts are remaining. Sericitization and silicification are very distinct but argillization also becomes distinct in the upper portion. The fissure of more than 10 cm wide is observed as a clay vein at 12.8 m (EW, 70° S) from the starting position. Copper minerals are chalcopyrite and chalcocite, and other ore minerals are pyrite and molybdenite. Either pyrite or chalcopyrite dominantly occurs as disseminated. The secondary enriched zone is formed by the supergene alteration.

Chapter 3 Geology of Drill Cores

3-1 Underground Drill Hole No. 1 (cf. Table 7-1)

Position of Collar; 9,222,005.27 N, 796,327.57 E

Direction; 0° 30', horizontal

Drilled Length; 144.38 meters

Quartz monzonite porphyry appears almost throughout the hole, but from the depth of 75 m to the bottom, xenoliths of quartzite (2 x 4--1 x 2 cm) appear frequently. Silicification and sericitization are commonly observable. Argillization is predominant near the collar and chloritization also appears stronger towards the collar. Not any distinct fissure is recognized. Copper minerals are chalcopyrite, chalcocite, and covellite, and other ore minerals are pyrite, molybdenite, and magnetite. Occurrence of chalcopyrite as disseminated is dominant, while pyrite as disseminated is dominant from the collar to the depth of 65 m, which is taken place by the one in veinlets from there to the bottom. Most of molybdenite occur in quartz veinlets, and chalcocite and covellite occur as coating films over chalcopyrite, and very rarely over pyrite in veinlets. Almost entire length of the hole is in the zone of primary mineralization except the supergene enrichment observable only in the cracks.

3-2 Underground Drill Hole No. 2 (cf. Table 7-2)

Position of Collar; 9,221,955.93 N, 796,321.37 E

Direction; 305° 15' , horizontal

Drilled Length; 116.19 meters

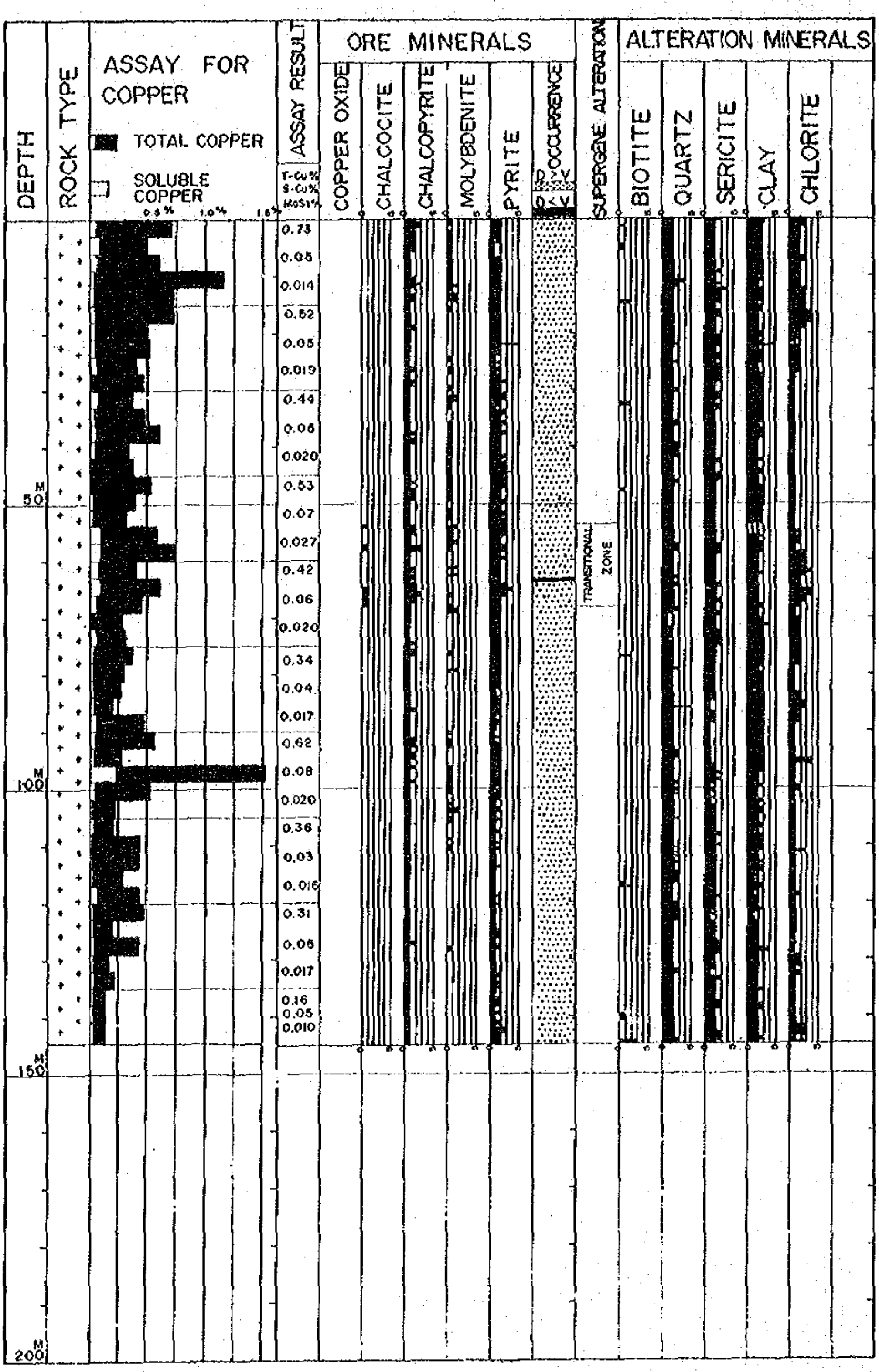
The hole is entirely composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 6.5 x 7 mm, ave. 1.5 x 2 mm), plagioclase

TABLE 7-1

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 1

AVERAGE	T-Cu	0.45%
	S-Cu	0.05%
	MoS₂	0.016%



(max. 4 x 9 mm, ave. 2 x 4 mm), and euhedral biotite (max. 6 x 7 mm, ave. 2 x 2 mm). Silicification and sericitization are observable throughout, argillization gradually increases from the collar towards the bottom, and the amount of biotite decreases gradually towards the bottom. Chloritization is stronger all over and pink feldspars are also observed almost throughout.

As a distinct fissure, a clay zone of gray colored, containing breccias of quartz monzonite porphyry (1--2 cm diam.), is recognized between 103.75 m and 104.05 m in depth. Copper minerals are chalcopyrite, chalcocite, and covellite, and other ore minerals are pyrite, magnetite, and molybdenite. Chalcopyrite and pyrite occur dominantly as disseminated, magnetite in association with biotite is extremely abundant, and molybdenite occur mostly in quartz veinlets with a few exceptions in disseminated state. Chalcocite and covellite are as coating films over chalcopyrite in veinlets. The entire length is in the primary zone, as supergene enrichment is so limited as to be seen only in veinlets.

3-3 Underground Drill Hole No. 3 (cf. Table 7-3)

Position of Collar; 9,221,952.86 N, 796,333.97 E

Direction; 65° 45', horizontal

Drilled Length; 114.21 meters

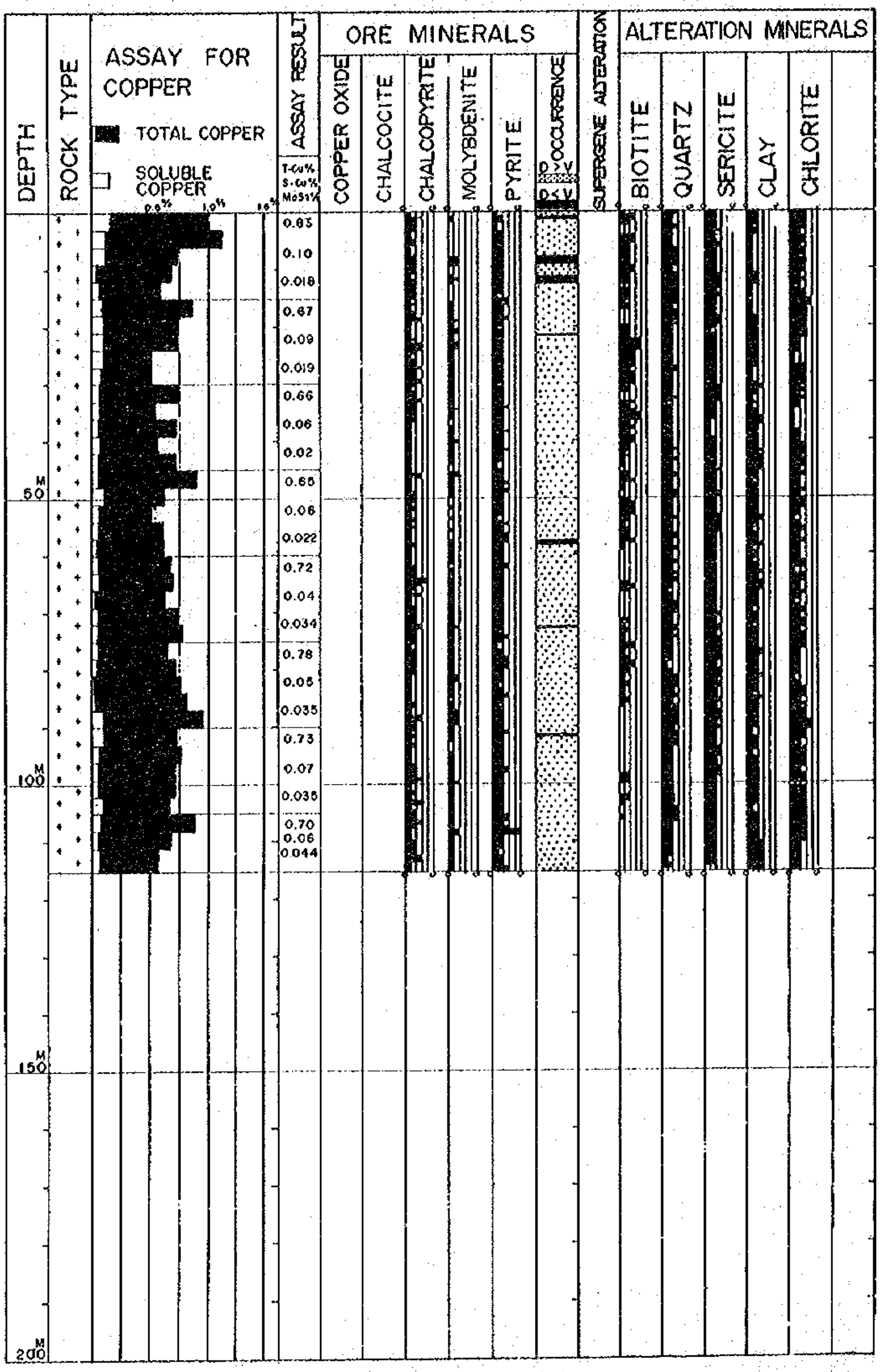
The entire hole is composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 5.5 x 6 mm, ave. 2 x 3 mm), plagioclase (max. 5 x 9 mm, ave. 3 x 5 mm), and euhedral biotite (max. 4 x 6 mm, ave. 2.5 x 3 mm). It contains the xenoliths of quartzite, shale, and metadiabasic rock. Under the microscope, the xenolith of metadiabasic rock is characterized by the lath shaped biotite, either euhedral or subhedral (0.1 mm in axis and 0.03 mm in c axis), and is disseminated by chalcopyrite and pyrite. Distinct fissures are represented by gray or pale brownish clay

TABLE 7-2

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 2

AVERAGE T-Cu 0.72% S-Cu 0.07% MoS2 0.026%



zones containing the breccias of quartz monzonite porphyry (0.5--2.0 cm in diam.) which appear between 23.25 and 24.6 m, 60.8 and61.35 m, and 75.0 and 75.6 m. Copper minerals are chalcopyrite, chalcocite, covellite, and bornite, and other ore minerals are pyrite, molybdenite, magnetite, and spharelite. Chalcopyrite mostly occurs as disseminated, but from the depth of 60 m towards the bottom, occurrence as veinlets becomes conspicuous. Similar tendency is also recognized with pyrite. Molybdenite mainly occurs in quartz veinlets, being observable throughout the hole with very rare exception of occurrence by dissemination. Chalcocite, bornite, covellite, and spharelite are entirely associated in the pyrite veinlets, and magnetite is mostly included near the periphery of biotite phenocrysts. Supergene enrichment is only observable as the features of transitional zone limitedly in veinlets and fissures or in their surroundings.

3-4 Underground Drill Hole No. 4 (cf. Table 7-4)

Position of Collar; 9,221,670.57 N, 796,278.89 E

Direction; 101° 15', horizontal

Drilled Length; 163.45 meters

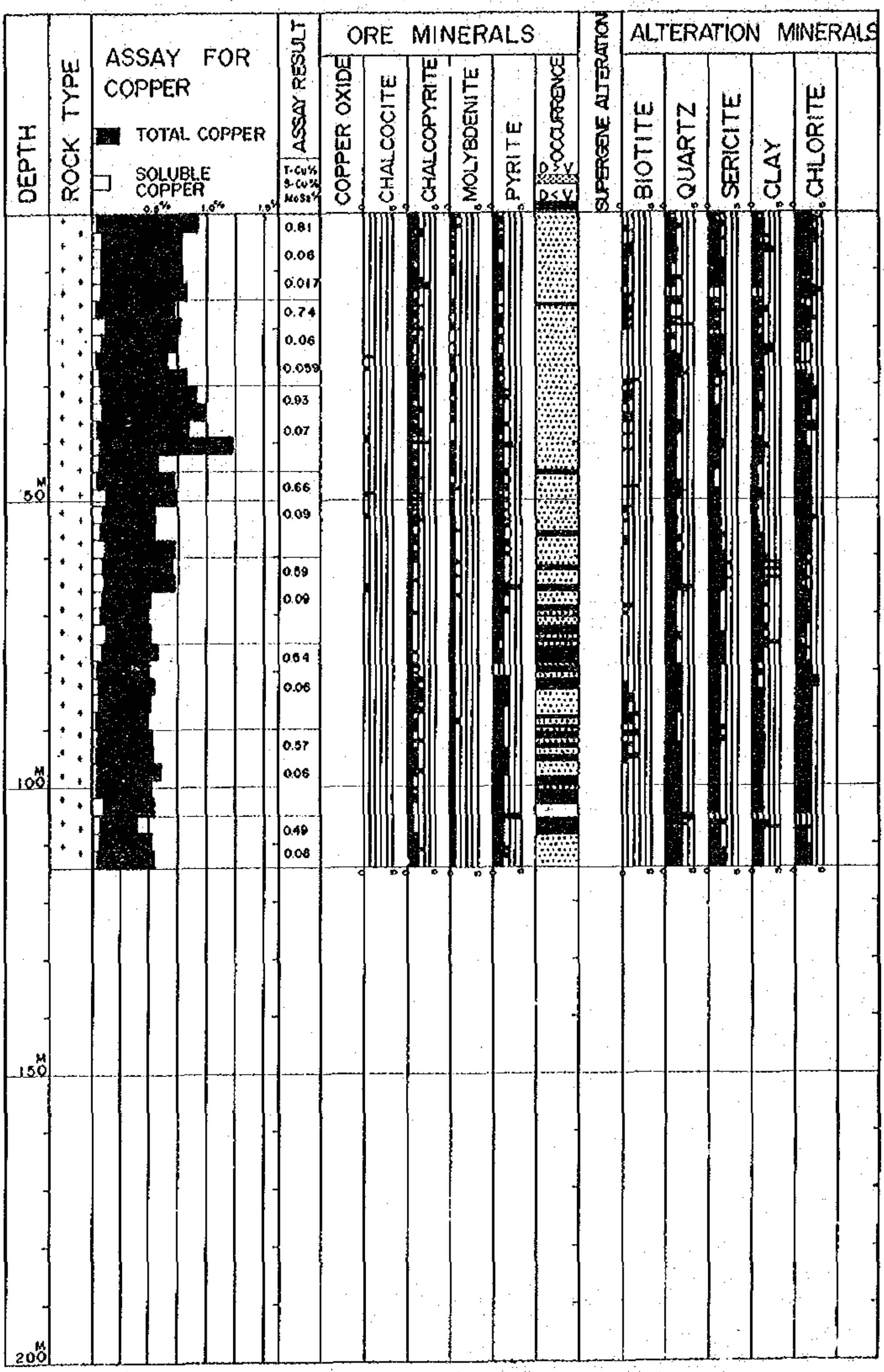
The entire length is occupied by quartz monzonite porphyry containing the phenocrysts of quartz (max. 3 x 3 mm, ave. 1 x 1 mm), plagioclase (max. 5 x 9 mm, ave. 2 x 4 mm), and euhedral biotite (max. 9 x 11.5 mm, ave. 1 x 2 mm). A tendency is observed in the intensity of silicification and sericitization to increase gradually from the collar towards the bottom of the hole. Argillization is stronger near the collar and bottom, while weaker in between. Biotite shows similar distribution, too, and chloritization can be seen throughout. Distinct fissures are recognized as dark gray or light yellowish-gray clay zones appearing between 15.0 and 15.1 m, 21.7 and 22.5 m,

TABLE 7-3

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 3

AVERAGE T-Cu 0.68% S-Cu 0.07% MoS_2 0.036%



36.3 and 36.9 m, and 150.55 and150.7 m in depth. Copper minerals are chalcopyrite and very minor amount of chalcocite, and other ore minerals are pyrite, magnetite, hematite, and molybdenite. The disseminated chalcopyrite is widely dominant, while pyrite in veinlets is dominant near the collar and so with disseminated pyrite near the bottom. Magnetite and hematite are in association with biotite in most cases but some occur in veinlets conspicuously. Molybdenite is limited in quartz veinlets but very minor in amount. Chalcocite is also limited as coating film over chalcopyrite in veinlets.

3-5 Underground Drill Hole No. 5 (cf. Table 7-5)

Position of Collar; 9,221,781.17 N, 796,345.72 E

Direction; 67° 30', horizontal

Drilled Length; 129.90 meters

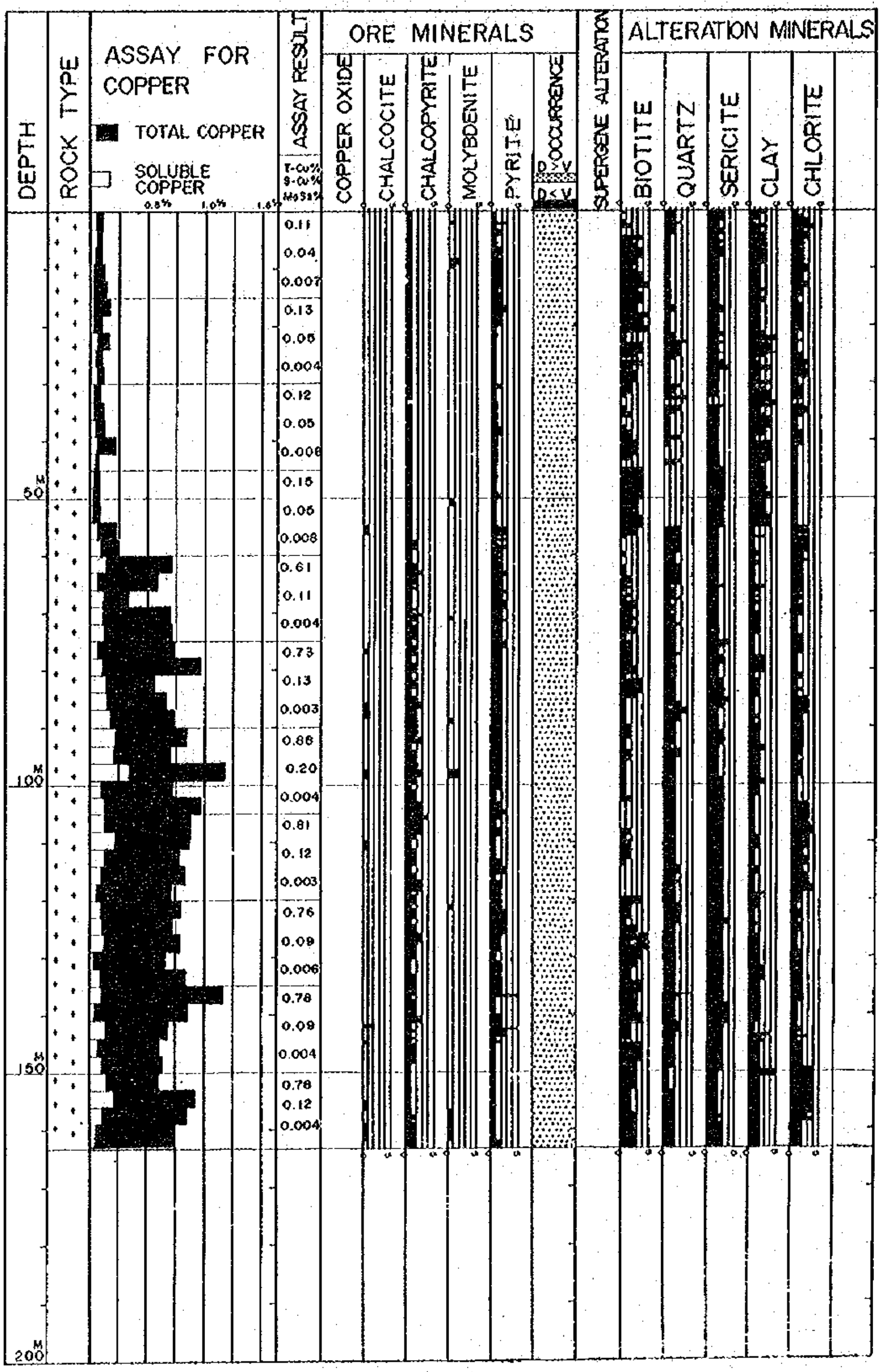
The hole penetrates entirely quartz monzonite porphyry containing the phenocrysts of quartz (1 x 1.5 mm), plagioclase (max. 6 x 9 mm, ave. 3 x 6 mm), and euhedral biotite (max. 7.5 x 9.5 mm, ave. 2 x 2 mm). Intensity of silicification increases from the collar towards the bottom, while argillization, chloritization, and biotite are observable almost all over the hole. Pink feldspars are also observable throughout. Distinct fissures are represented by the zones of gray clay observable betwen 25.6 and 25.85 m, 35.15 and 35.3 m, 94.0 and 94.1 m, 104.45 and 104.6 m, and128.4 and 129.9 m (the bottom). Copper minerals are chalcopyrite, chalcocite, covellite, and green copper oxides, and other ore minerals are pyrite, magnetite, hematite, and molybdenite. The disseminated chalcopyrite and pyrite are predominant, and magnetite and hematite are either included in the periphery of biotite phenocrysts or occur in veinlets. Molybedenite is limited in quartz veinlets

TABLE 7-4

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 4

AVERAGE T-Cu 0.63% S-Cu 0.10% MoS₂ 0.005%



but very minor in amount. Chalcocite and covellite occur as coating films over chalcopyrite, while the green copper oxides are very minor in amount, surrounding pyrite or occurring in pyrite veinlets.

3-6 Underground Drill Hole No. 6 (cf. Table 7-6)

Position of Collar; 9,221,617.17 N, 796,225.23 E

Direction; 124° 45', horizontal

Drilled Length; 115.75 meters

The hole is entirely composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 3 x 6 mm, ave. 1 x 1 mm), plagioclase (max. 5 x 8 mm, ave. 3 x 5 mm), and biotite (max. 9 x 11 mm, ave. 2 x 2 mm). The intensity of silicification and chloritization decreases gradually from the collar towards the bottom, while argillization increases downwards. Sericitization is widely recognized but slightly weaker near the collar. Biotitization is recognized very rarely and pink feldspar is also minor in amount. The distinct fissures are observed between 3.6 and 3.7 m, and 111.2 and 111.55 m, filled up with gray clay. Copper minerals are chalcopyrite, chalcocite, and covellite, and other ore minerals are pyrite, hematite, magnetite, and molybdenite. Disseminated chalcopyrite is dominant, and pyrite in veinlets is dominant near the collar, which is gradually taken place by the disseminated pyrite towards the bottom of the hole. Molybdenite entirely occurs in quartz veinlets, and chalcocite and colvellite occur in veinlets as coating films over chalcopyrite, but they cover the disseminated chlacopyrite near the bottom of the hole and their amount is also increased. Most of magnetite and hematite are found included in the relicts after biotite, which are considered to have been produced by the alteration of biotite.

TABLE 7-5

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 5

AVERAGE T-Cu 1.06 % S-Cu 0.23% MoS2 0.002%

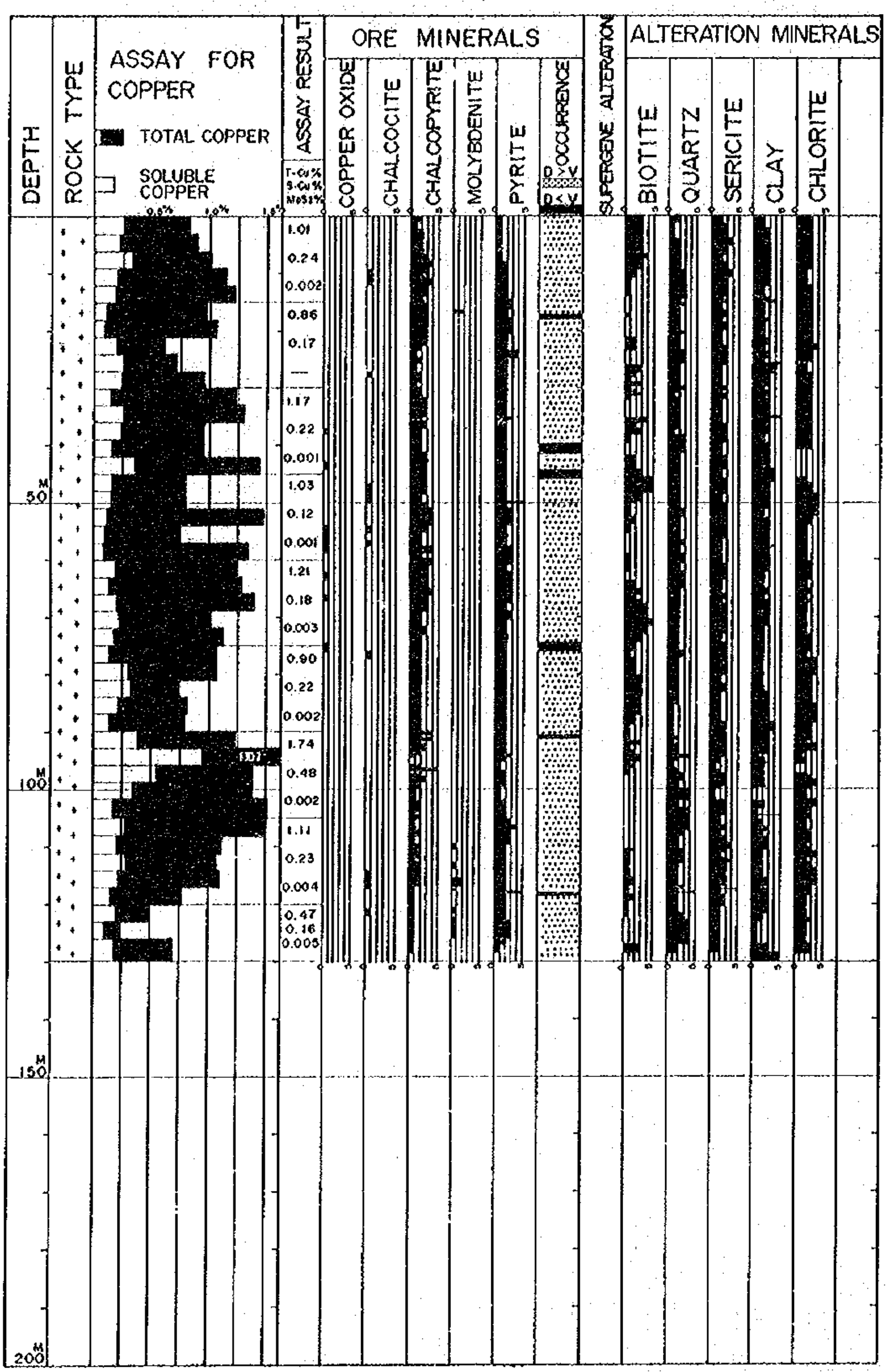
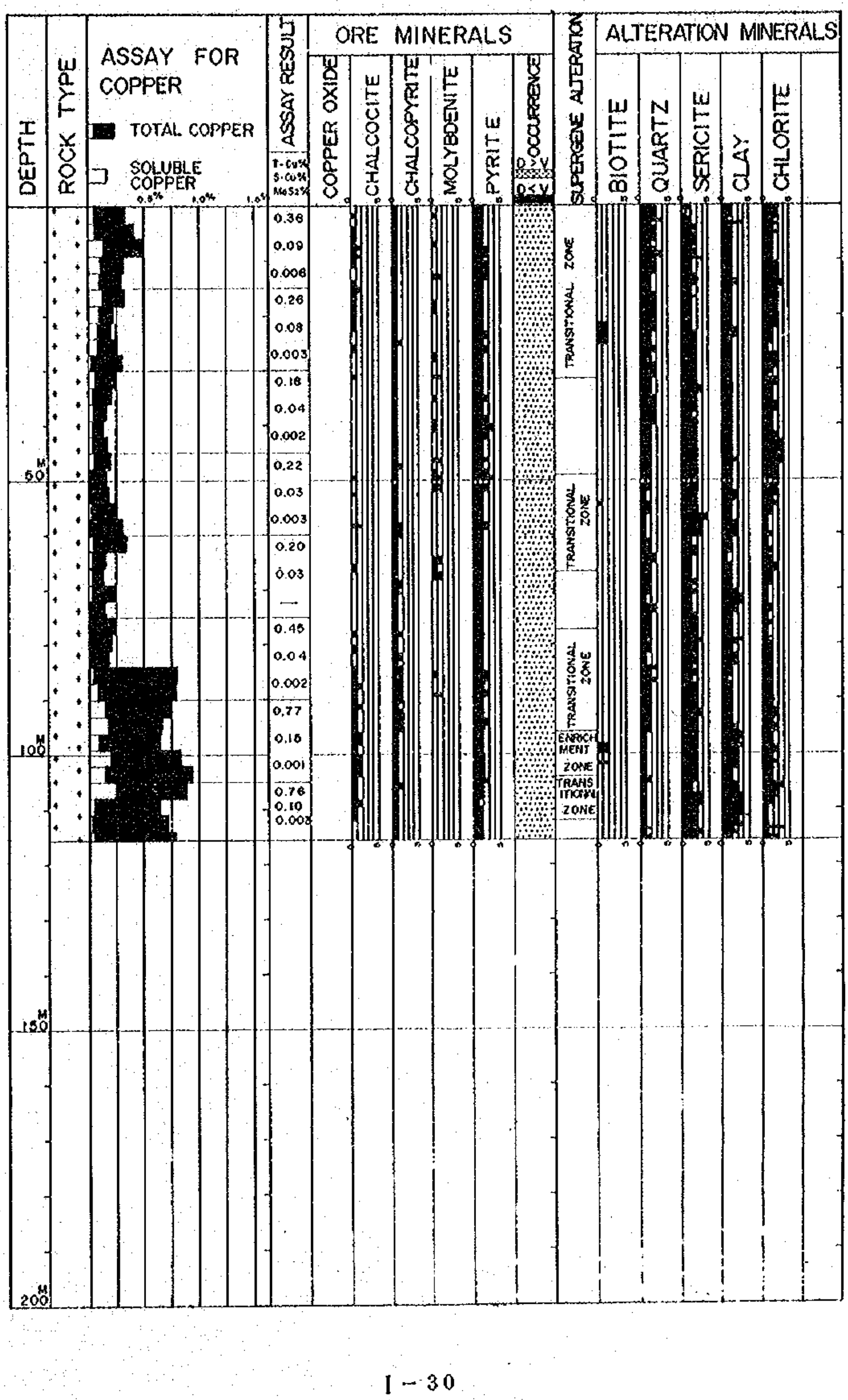


TABLE 7-6

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 6

AVERAGE T-Cu 0.39%
S-Cu 0.07%
MoS2 0.003%



3-7 Underground Drill Hole No. 7 (cf. Table 7-7)

Position of Collar; 9,221,690.03 N, 796,274.49 E

Direction; 337° 30', horizontal

Drilled Length; 72.15 meters.

The hole is entirely composed of monzonite porphyry with very minor and localized occurrence of quartz (1. x 1.5 mm). The phenocrysts are plagioclase (max. 5 x 7 mm, ave. 2 x 5 mm) and biotite (max. 6.5 x 7 mm, ave. 1.5 x 2 mm). Biotitization and chloritization are very distinct, while sericitization and argillization are generally feeble. Silicification increases from the collar towards the bottom. Distinct fissure are observed between 27.2 and 27.4 m, 28.5 and 28.75 m, 29.15 and 29.35m, 33.2 and 34.4 m, 35.9 and 36.05 m, 36.4 and 36.6 m, 37.3 and 37.9 m, 47.8 and 49.0 m, 56.45 and 58.65 m, 61.5 and 61.85 m, and 62.55 and 62.65 m, containing gray or white clay. Copper minerals are chalcopyrite and enargite which is determined microscopically. Other ore minerals are pyrite, magnetite, and hematite. Chalcopyrite dominantly occurs as disseminated, and disseminated pyrite also a little exceeds to the one in veinlets. Most of magnetite and hematite occur in the relicts after biotite, but they occur in veinlets too at the bottom. Under the microscope, the sizes of chalcopyrite is about 0.4 mm max., averagely about 0.1 mm in diam., many of which show irregular shapes like net-work.

3-8 Underground Drill Hole No. 9 (cf. Table 7-8)

Position of Collar; 9,221,447.46 N, 796,022.91 E

Direction; 0° 30', horizontal

Drilled Length; 200 meters

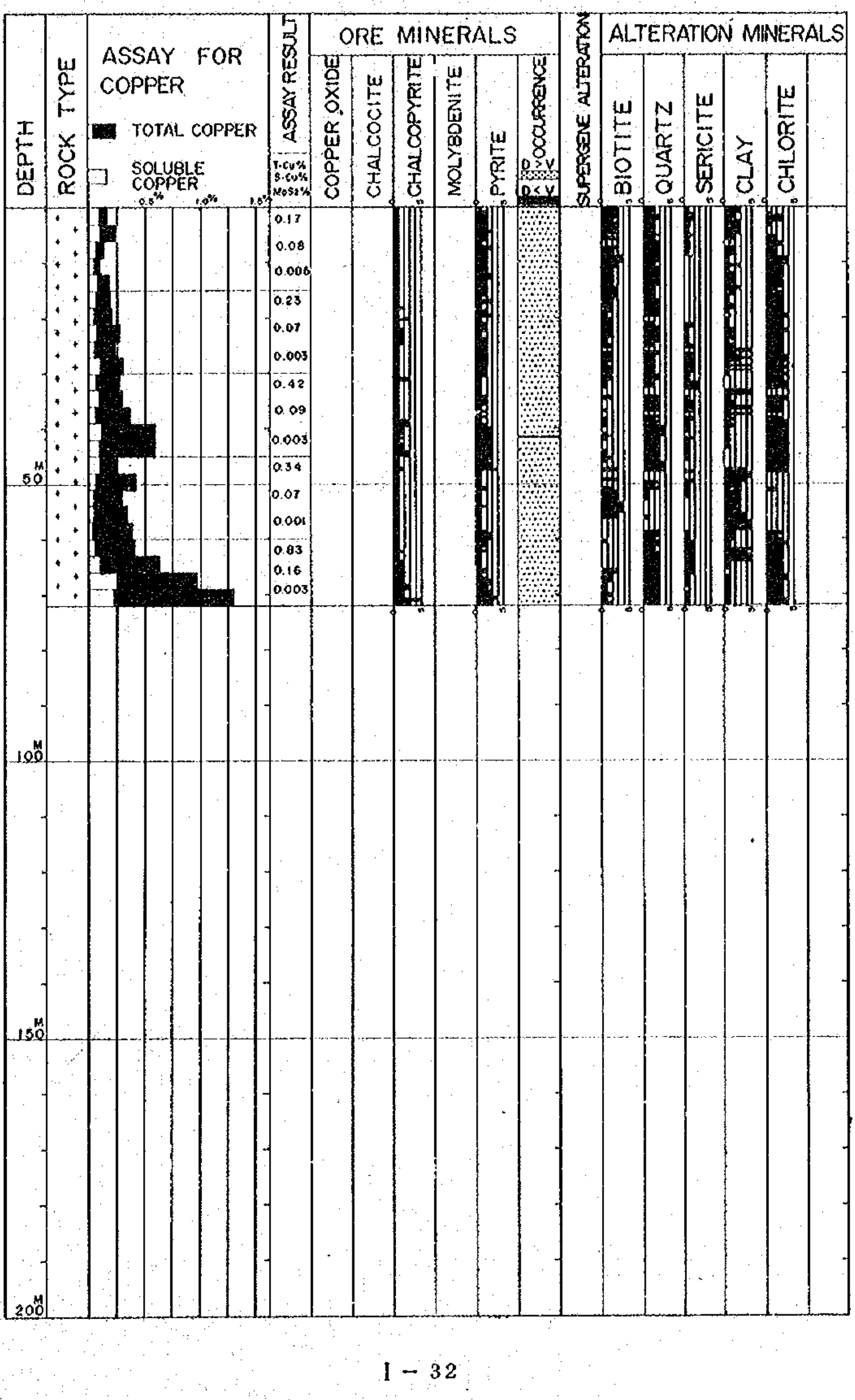
Monzonite porphyry composes the entire hole, although it contains the

TABLE 7-7

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 7

AVERAGE T-Cu 0.38% S-Cu 0.09% MoS2 0.003%



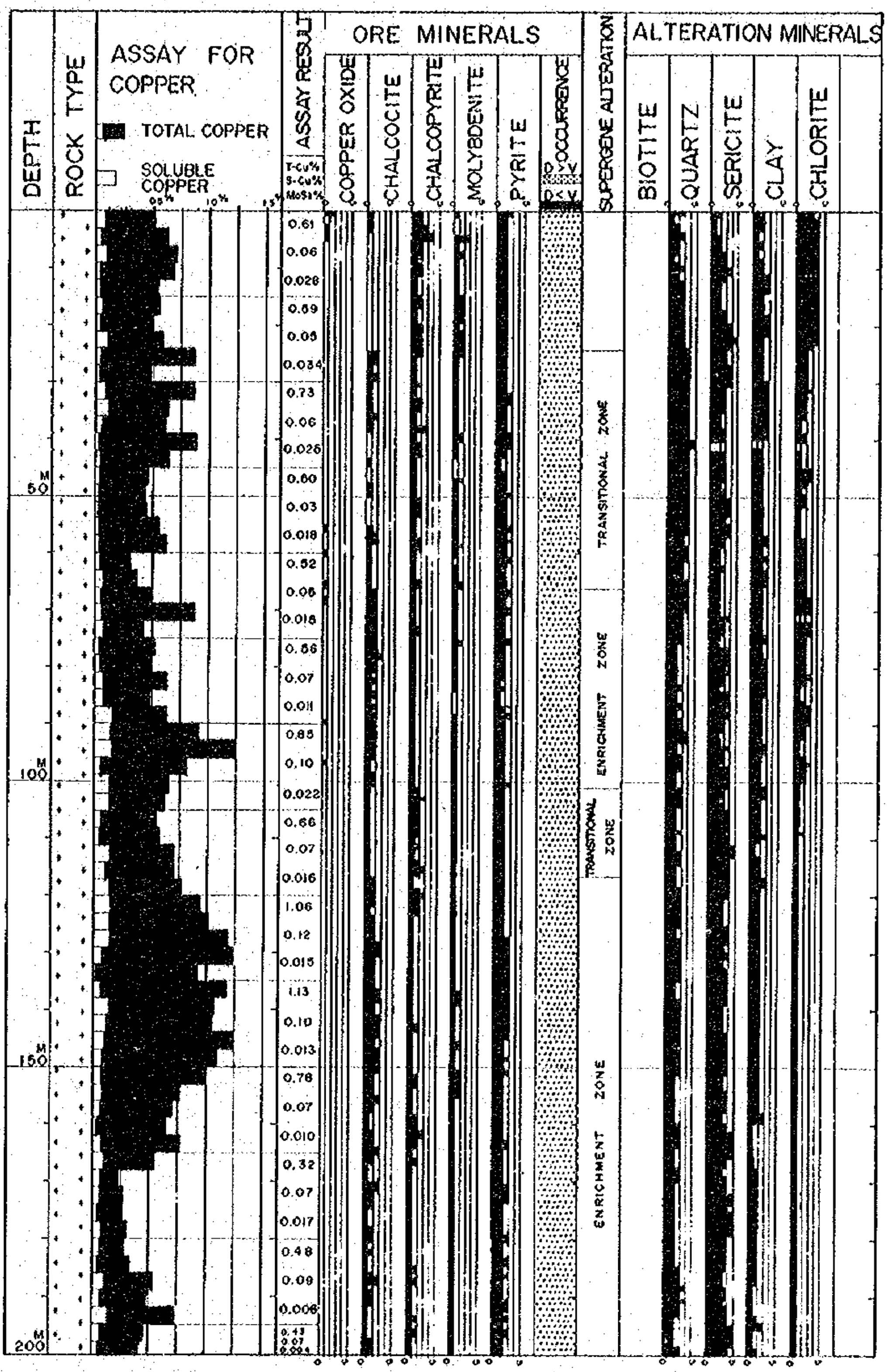
phenocrysts of quartz (max. 2.5 x 3 mm, ave, 1 x 1 mm) locally. The main phenocrysts are plagioclase (max. 5 x 8.5 mm, ave. 3 x 5 mm) and biotite (max. 3 x 3 mm, ave. 1 x 1 mm). Biotite is entirely altered into sericite and phlogopite, and some of the plagioclase phenocrysts are so intensely altered that the porphyritic texture is undistinguishable. Intensity of silicification, argillization, and chloritization gradually decreases towards the bottom from the collar, while sericitization is generally stronger and especially so towards the bottom. Any distinct fissure can not be recognized. Copper minerals are chalcopyrite, chalcocite, bornite, covellite, enargite, and green copper oxides, and other ore minerals are pyrite, molybdenite, magnetite, galena, spharelite, and pyrrhotite. Occurence of chalcopyrite as disseminated and that of pyrite in veinlets are predominant. Enargite, spharelite, galena, and pyrrhotite occur in veinlets. Green copper oxides mainly form a halo surrounding pyrite and chalcopyrite. Chalcocite, bornite, and covellite, are coating films over chalcopyrite and their amount is increased towards the bottom.

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

TABLE 7-8

No. 9

AVERAGE T-Cu 0.67% S-Cu 0.07% MoS_2 0.017%



3-9 Underground Drill Hole No. 10 (cf. Table 7-9)

Position of Collar; 9,221,472.89 N, 796,075.68 E

Direction; 169° 00', horizontal

Drilled Length; 154.96 meters

The entire hole is occupied by quartz monzonite porphyry containing the phenocrysts of quartz (max. 5 x 6 mm, ave. 1 x 1 mm), and plagioclase (max. 4.5 x 8 mm, ave. 2 x 3 mm). Silicification and argillization are stronger near the bottom but weaker near the collar. Sericitizztion is stronger near the collar and weaker near the bottom. Chloritization is stronger near the collar and bottom, but scarcely recognized between the depths of 105 and 135 m. Distinct fissures are recognized as gray or white clay zones appearing between 84.15 and 84.65 m, 109.1 and 109.85 m, 133.8 and 133.95 m, and 143.05 and 143.25 m. Characteristic is to contain abundant xenoliths of quartzite. Copper minerals are chalcopyrite, bornite, chalcocite, and covellite, and other ore minerals are pyrite, molybdenite, spharelite, and hematite. Disseminated chalcopyrite and pyrite are predominnant, and most of molybdenite occur in quartz veinlets though some shows disseminated occurrence. Spharelite occurs in pyrite veinlets. Chalcocite, bornite, and covellite, are coating films over chalcopyrite.

3-10 Underground Drill Hole No. 11 (cf. Table 7-10)

Position of Collar; 9,221,461.12 N, 796,225.91 E

Direction; 87° 45', horizental

Drilled Length; 126.52 meters

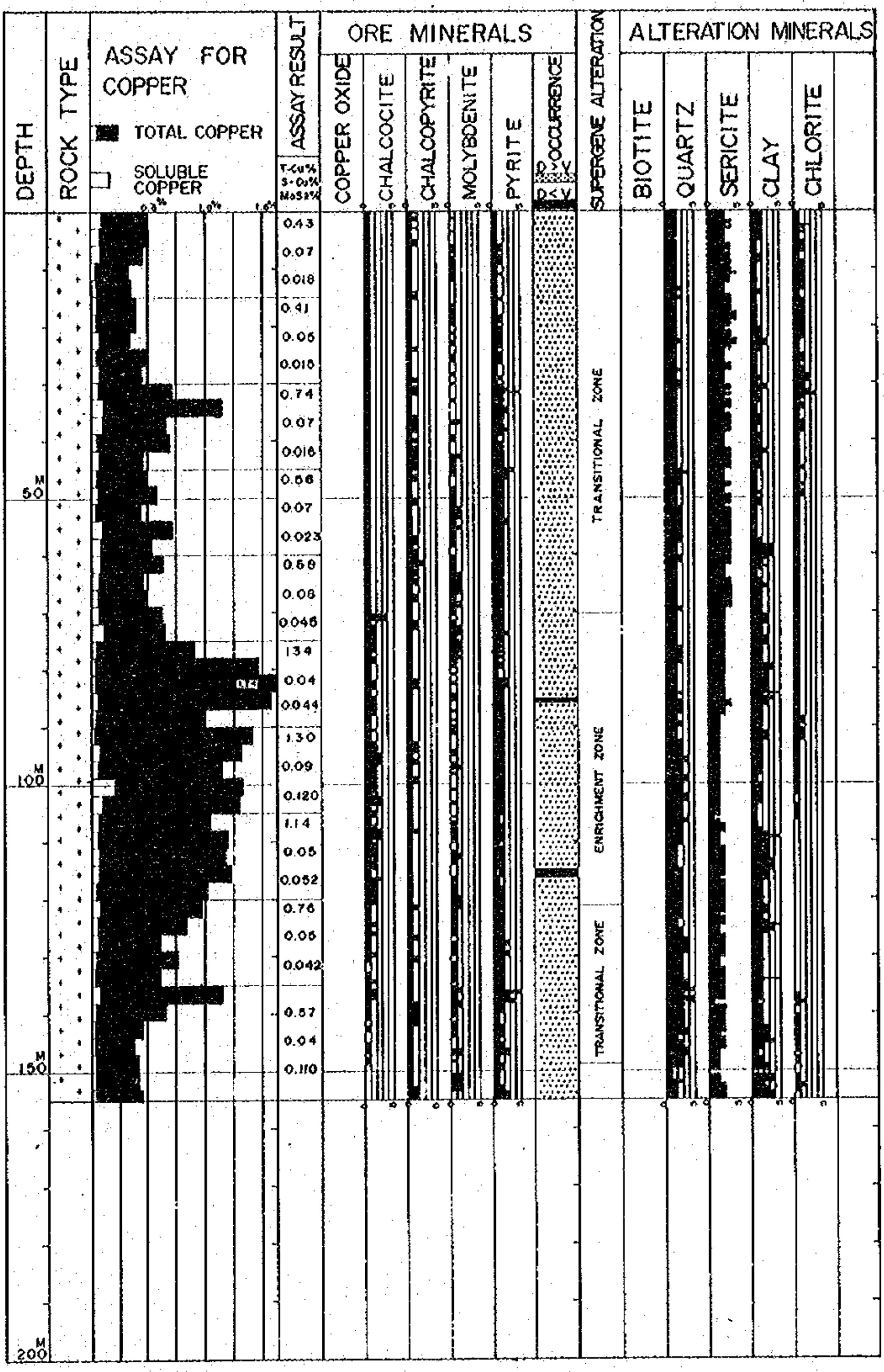
Almost throughout the hole is composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 4 x 7 mm, ave. 3 x 3 mm), plagioclase (max. 5 x 7 mm, ave. 3 x 5 mm), and biotite (max. 5 x 5 mm, ave.

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

TABLE 7-9

No. 10

AVERAGE T-Cu 0.78% S-Cu 0.06% MoS_2 0.050%



3 x 3 mm). Silicification is stronger near the collar and weaker near the bottom. Sericitization is widely observed with association of weak argillization. The euhedral biotite is altered into chlorite and sericite, of which relicts are only remained. As for the distinct fissure, only white clay is observed between 103.1 and 103.5 m. Copper minerals are chalcopyrite, chalcocite, bornite, enargite, and green copper oxides, and other ore minerals are pyrite, molybdenite, hematite, and magnetite. Disseminated chalcopyrite is predominant, and disseminated pyrite is about equal to that in veinlets. Enargite, molybdenite, and green copper oxides are almost entirely found in veinlets. Chalcocite and bornite are coating films over chalcopyrite and pyrite. Supergene enrichment indicates the hole as transitional zone.

3-11 Underground Drill Hole No. 12 (cf. Table 7-11)

Position of Collar; 9,221,639.67 N, 796.388.63 E

Direction; 160° 45', horizontal

Drilled Length; 121.74 meters

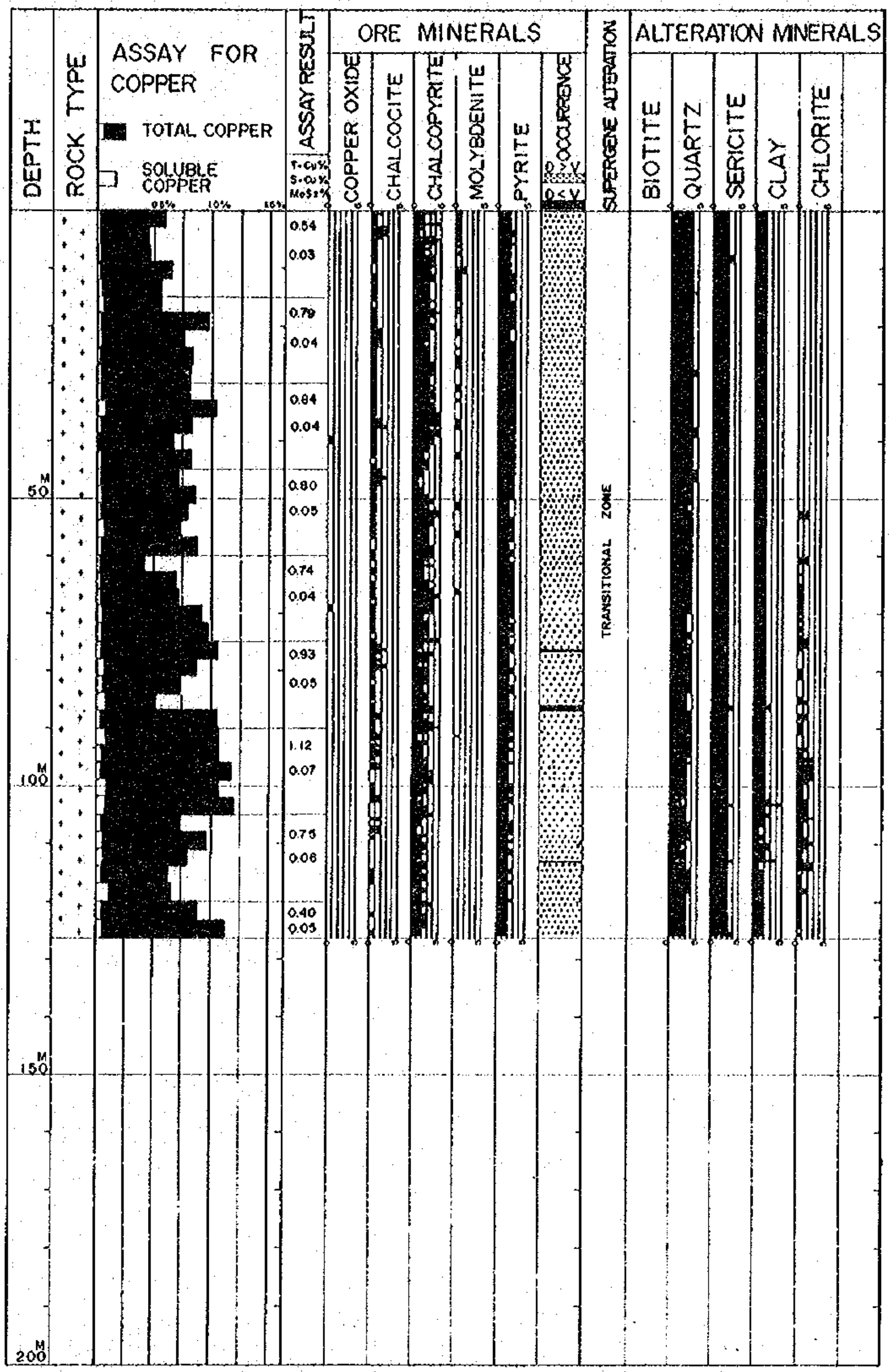
The hole has penetrated entirely quartz monzonite porphyry containing the phenocrysts of quartz (max. 5 x 6 mm, ave. 2 x 2 mm), plagioclase (max. 6 x 8 mm, ave. 4 x 6 mm), and biotite (max. 6 x 4 mm, ave. 3.5 x 4 mm), and they are generally larger in sizes than others. Xenoliths of metadiabasic rock, quartzite, and silicified shale are recognized. Biotitization and chloritization are generally distinct, while silicification and sericitization are comparatively weak. Argillization is only as much as observable in plagioclase phenocrysts. Pink feldspar is observed comparatively conspicuous. As the distinct fissures, the zones of gray clay are observed between 10.05 and 10.25 m, 61.25 and 61.35 m, 67.35 and 67.55 m, 109.35 and 110.05 m, and 113.1 and 113.35 m, and a zone of gray clay

TABLE 7-10

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 11

AVERAGE T-Cu 0.82% S-Cu 0.08% MoS2 0.003%



between 104.7 and 106.6 m containing breccias of quartz monzonite porphyry (diam. 1 cm ±). Copper minerals are chalcopyrite, chalcocite, and very little of bornite, and other ore minerals are pyrite, magnetite, and molybdenite. Copper minerals occur mostly as disseminated, and pyrite and molybdenite are found in veinlets. Chalcocite and bornite are coating films over chalcopyrite, indicating transitional zone of supergene enrichment.

3-12 Underground Drill Hole No. 13 (cf. Table 7-12)

Position of Collar; 9,221,600.62 N, 795,945.78 E

Direction; 5^{o} 15', horizontal

Drilled Length; 95.95 meters

The entire length is composed of quartz monzonite porphry containing the phenocrysts of quartz (max. 5 x 5 mm, ave. 2 x 2 mm), plagioclase (max. 5 x 7 mm, ave. 2 x 3 mm), and biotite which is entirely altered into sericite or phlogopite. As for alterations, sericitization is most intense, while others decrease their intensity in order of silicification and argillization. Pink feldspar is locally observed. None of distinct fissure is recognized. Copper minerals are chalcocite,chalcopyrite, enargite, and green copper oxides, and other ore minerals are pyrite, molybdenite, and hematite. Chalcopyrite and pyrite dominantly occur as disseminated, while the disseminated pyrite becomes more prevalent from the collar towards the bottom against that in veinlets. Enargite is concentrated where pyrite in veinlets is well concentrated, and molydenite is found in quartz veinlets. Chalcocite forms coating film over chalcopyrite. Supergene enrichment is very distinct, forming the enriched zone or transitional zone.

TABLE 7-11

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 12

AVERAGE T-Cu 0.78% S-Cu 0.09% MoS2 0.004%

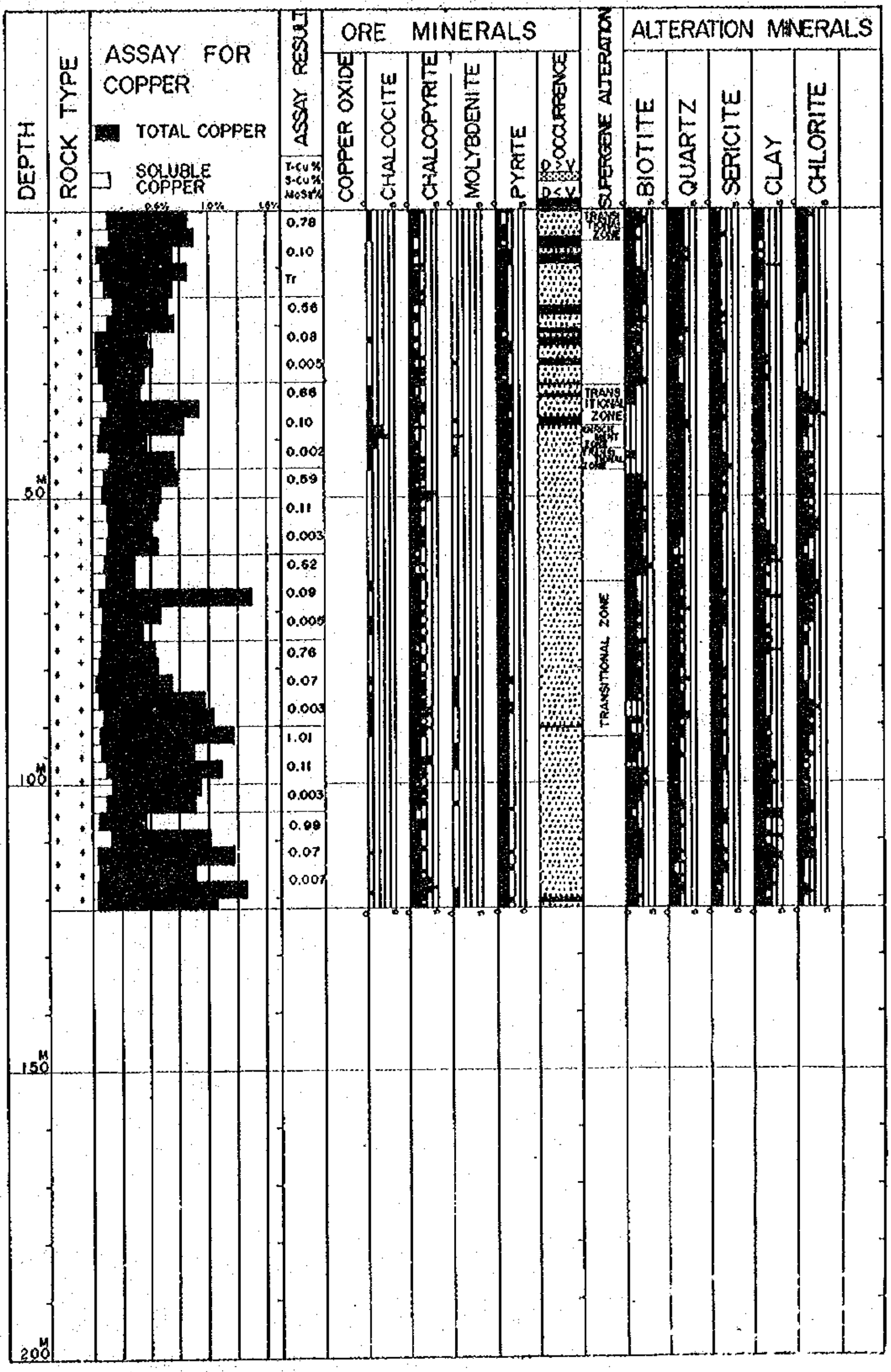
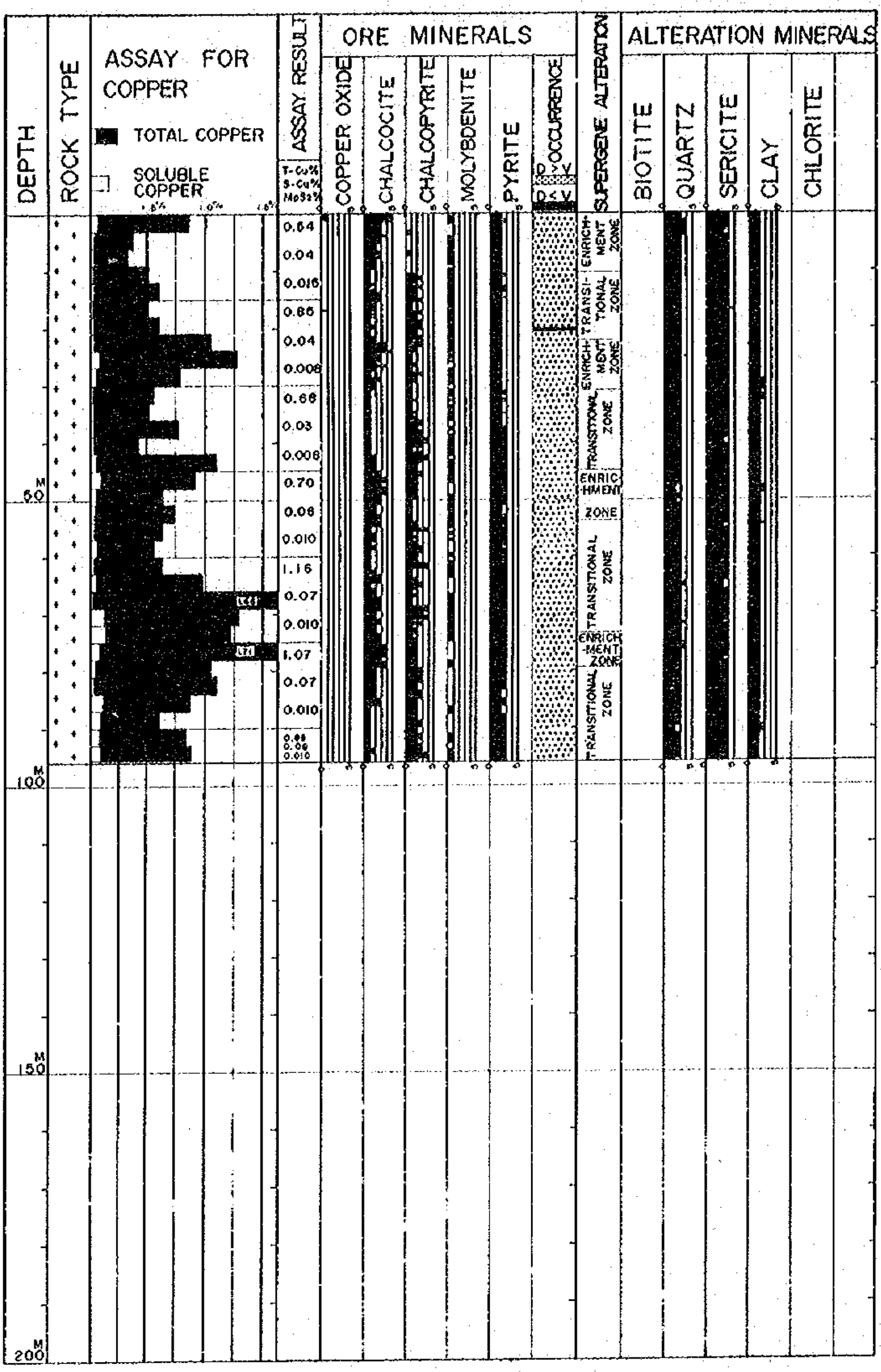


TABLE 7-12

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 13

AVERAGE
T-Cu 0.83%
S-Cu 0.05%
MoS2 0.010%



3-13 Underground Drill Hole No. 14 (cf. Tablo 7-13)

Position of Collar; 9,221,949.56 N, 796,325.24 E

Direction; 245^{o} 30', horizontal

Drilled Length; 123.20 meters

Quartz monzonite porphyry occupies the whole length, which contains the phenocrysts of quartz (max. 3 x 3.5 mm, ave. 1 x 1 mm), plagioclase (max. 8 x 11 mm, ave. 3 x 5 mm), and biotite (max. 9.5 x 9.5 mm, ave. 3 x 3 mm). Biotitization and chloritization are very strong, while sericitization and argillization are comparatively weak. Silicification is observalbe all over but it increases slightly towards the bottom. No distinct fissure is recognized. Copper minerals are chalcopyrite, chalcocite, and bornite, and other ore minerals are pyrite, magnetite, molybdenite, and hematite. Disseminated chalcopyrite is predominant, but its occurrence in veinlets is also distinct as compared to other locations. Pyrite is generally less in amount and mostly in disseminated occurrence. Magnetite and hematite are surrounding biotite or included in it. Molybdenite is found in quartz veinlets, but rarely occurs in disseminated state. Chalcocite and bornite are coating films over chalcopyrite and pyrite but a little in amount.

3-14 Underground Drill Hole No. 15 (cf. Table 7-14)

Position of Collar: 9,221,715.95 N, 796,092.40 E

Direction; 287^{o} 15', horizontal

Drilled Length; 121.95 meters

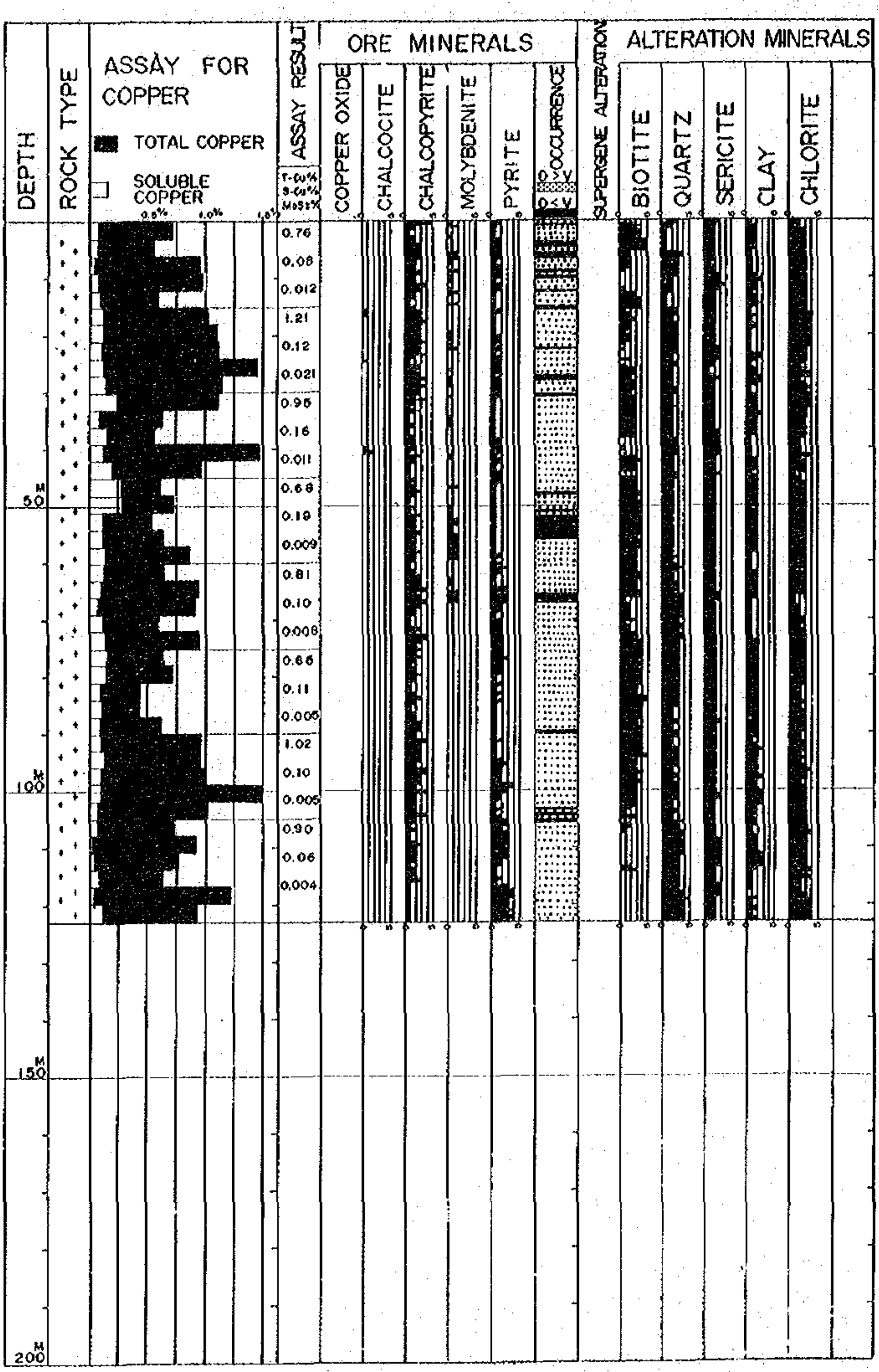
The hole is almost entirely composed of monzonite porphyry except near the bottom where it contains quartz phenocrysts (max. 4 x 4.5 mm, ave. 2 x 2 mm). The porphyry contains the phenocrysts of plagioclase (max. 4.5 x 7 mm, ave. 3 x 5 mm), and biotite. Sericitization and silicification are

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

TABLE 7-13

No. 14

AVERAGE T-Cu 0.87 % S-Cu 0.11 % MoS2 0.009 %



so predominant that plagioclase phenocrysts are affected by argillization, and biotite phenocrysts are altered into sericite and phlogopite, and chloritized near the collar, leaving only their relic outlines. The distinct fissures are represented by white clay zones observed between 44.6 and 45.4 m, 49.45 and 50.20 m, 50.7 and 51.3 m, 56.4 and 56.95 m, 57.1 and 58.65 m, and 102.7 and 103.0 m., which contain the breccias of quartzite (1--3 cm in diam.) and of monzonite porphyry or quartz monzonite porphyry (1--3 cm in diam.). Copper minerals are chalcopyrite, chalcocite, enargite, bornite, and green copper oxides, and other ore minerals are pyrite, molybdenite, and sphare-lite. Chalcopyrite is found mostly disseminated, while chalcocite, bornite, and green copper oxides are mostly in veinlets. Enargite is associated with pyrite stringers in quartz veinlets, in which spharelite is contained, too. The pyrite as disseminated is about equal in amount to that in veinlets, but the latter is a little more dominant near the collar. Molybdenite, though minor in amount, are observed throughout the hole.

3-15 Underground Drill Hole No. 16 (cf. Table 7-15)

Position of Collar; 9,221,716.96 N, 796,102.03 E

Direction; 52° 15', horizontal

Drilled Length; 67.67 meters

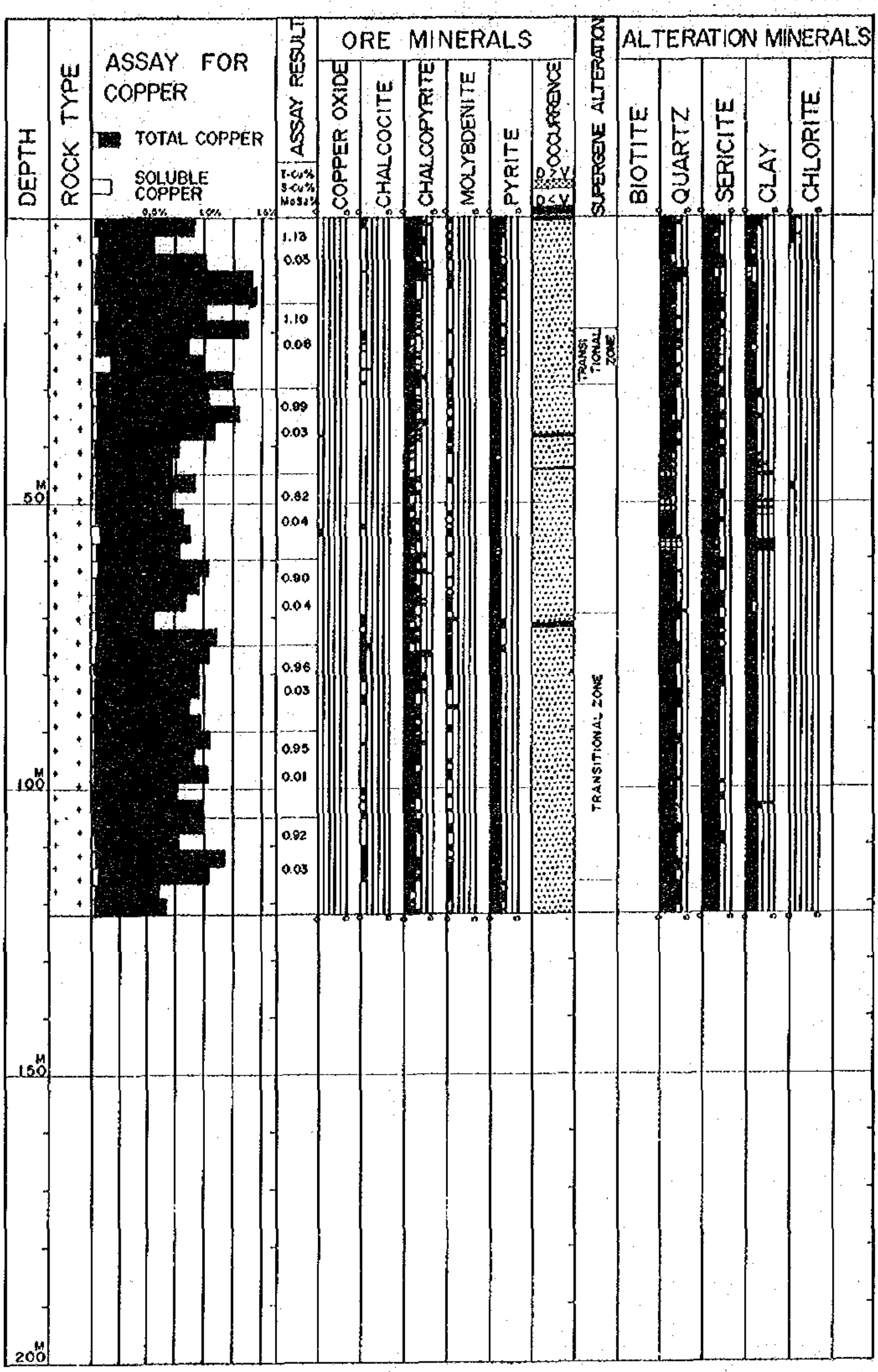
The rock appearing in this hole is entirely monzonite porphyry containing the phenocrysts of plagioclase (max. 5 x 7 mm, ave. 4 x 5 mm) and biotite (max. 7 x 7 mm, ave. 3 x 4 mm). Sericitization and silicification are intense but argillization is weaker. Biotitization increases gradually towards the bottom. Chloritization is also stronger at the bottom. Very rarely epidote is found. Distinct fissure is only represented by a grayish clay zone appearing between 56.0 and 56,35 meters. Copper minerals are

TABLE 7-14

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 15

AVERAGE T-Cu 0.97% S-Cu 0.03% MoS2 0.006%



chalcopyrite, chalcocite,and bornite, and other ore minerals are pyrite, molybdenite, magnetite, and hematite. Chalcopyrite mostly occur as disseminated and pyrite is fairly abundant occurring either disseminated or in veinlets. Molybdenite is observed almost throughout the hole. Magnetite and hematite occur partly overlapped each other, but they show a distinct tendency that hematite is stronger near the collar, while magnetite near the bottom. These iron oxide ores often occur along (001) plane, perpendicular to c-axis, of biotite or in its outer periphery. Bornite and chalcocite are coating films over chalcopyrite, indicating the transitional zone by supergene enrichment.

3-16 Underground Drill Hole No. 17 (cf. Table 7-16)

Position of Collar; 9,221,507.36 N, 795,847.73 E

Direction; 289^{o} 30', horizontal

Drilled Length; 25.7 meters

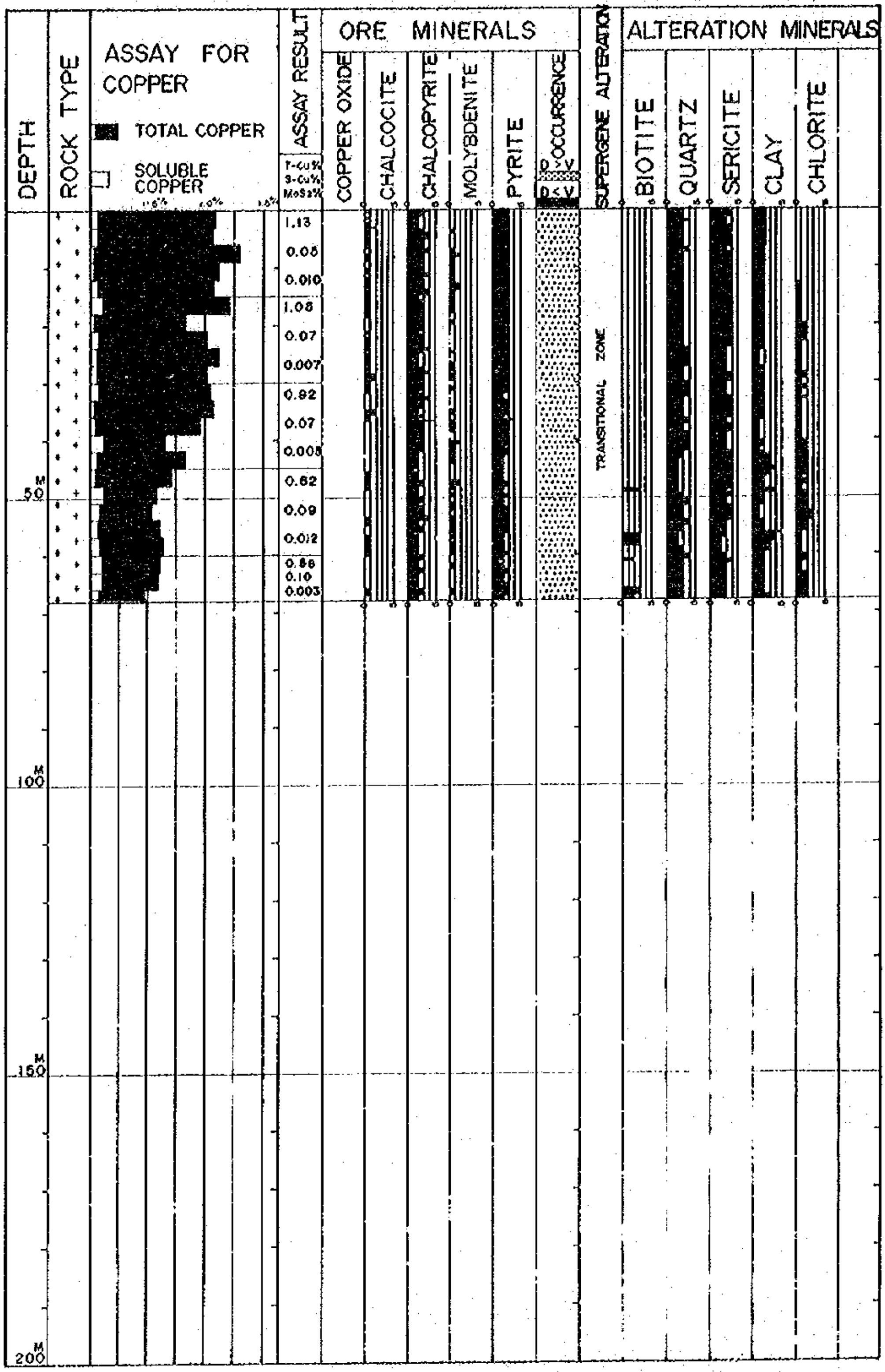
The hole is entirely composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 6.5 x 7 mm, ave. 1.5 x 2 mm) and plagioclase (max. 4 x 6 mm, ave. 3 x 4 mm). Sericitization is very remarkable and is associated with argillization and silicification. Chloritization is mostly observed around the network quartz veinlets. Due to these alterations, the outlines of plagioclase are so obliterated that the porphyritic texture can hardly be distinguished in some portion of the rock. No significant fissure is found in this hole. Copper minerals are chalcocite and chalcopyrite with occasional bornite, and other ore minerals are pyrite, molybdenite, and hematite. Chalcocite, chalcopyrite, and bornite are extremely disseminated in occurrence, being scattered as specks forming the "pepper and salt" patterns in the grayish white ground of quartz monzonite

TABLE 7-15

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 16

AVERAGE	
T-Cu	0.89%
S-Cu	0.07%
MoS2	0.008%



porphyry. Domiant is pyrite in veinlets. Molybdenite is found mostly in veinlets almost throughout the hole. The supergene enrichment indicates the enriched zone near the collar and the transitional zone near the bottom.

3-17 Surface Drill Hole No. 1

Position of Collar;	9,221,024.89 N, 797,142.15 E
Collar Elevation;	3,657.77 m SL
Direction;	vertical
Drilled Length;	200 meters

The altenation of sandstone and shale of the Inca Formation occupies from the collar to the depth of 35 meters, thence the upper zone of the Goyallisquizga Formation to the bottom. Porphyrite dykes of the later intrusion are observed between 179.3 and 180.3, and betwen 182.55 and 190.2 m in depth. The distinct fissures are recognized at the depths of 17.0--19.5 m, 52,3--52.5 m, and 131.6--133.25 m, which are represented by clay zones of gray or pale gray in color.

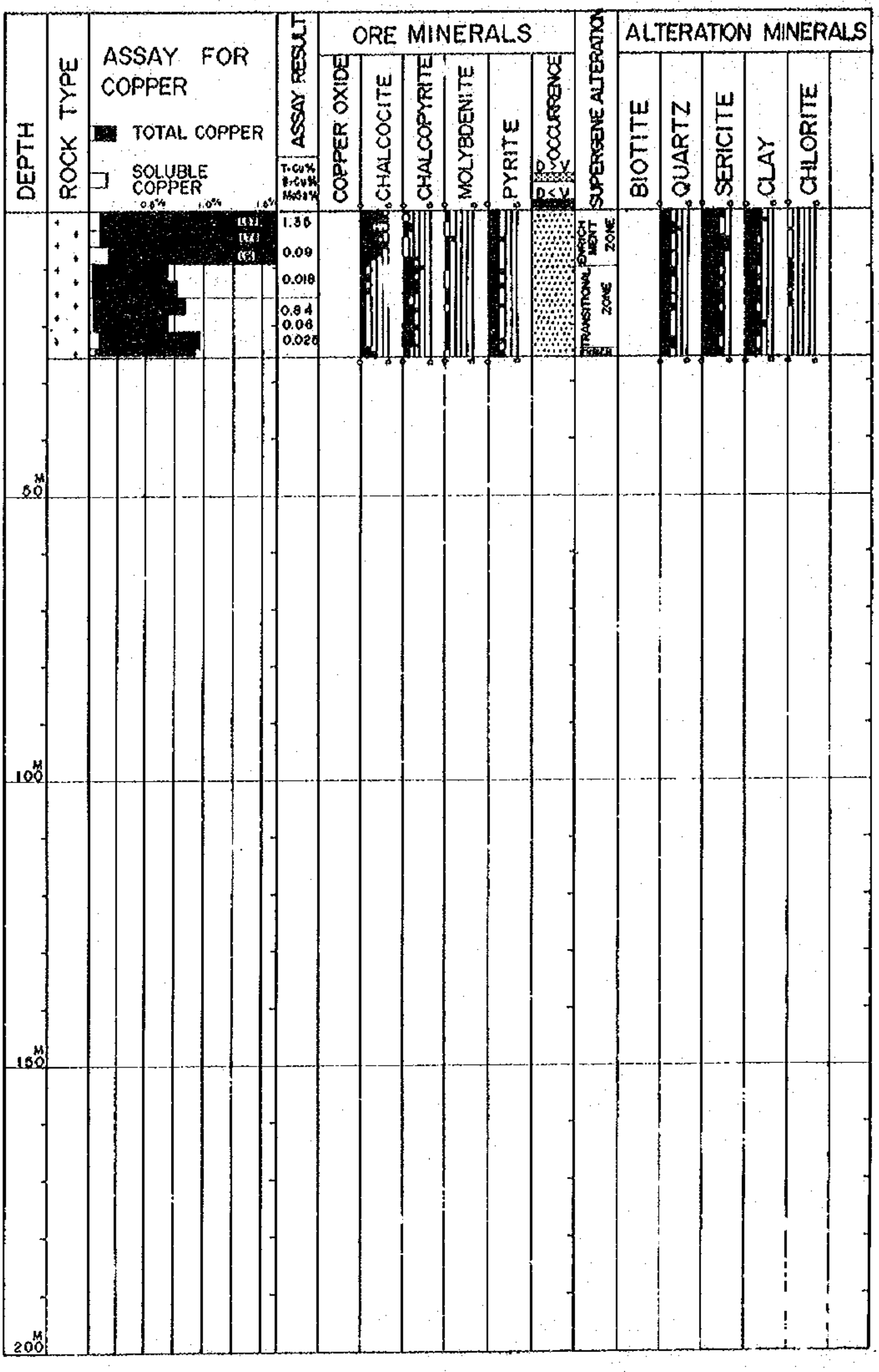
In the vicinity of the Michiquillay Deposit, hematite and magnetite are deposited in the calcareous layer of the lowermost Inca Formation, which are confirmed to appear in this hole at the depths of 14.5--17.0 m and 29.15--33.95 m. Moreover, the gossans are recognized at the depths of 38.7--47.0 m and 75.25--75.55 m in quartzite of the Goyallisquizga Formation, magnetite is recognized between 96.1 and 96.35 m, and chalcocite, bornite, and covellite, coating over chalcopyrite, between 135.15 and 142.2 m in depth.

TABLE 7-16

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 17

AVERAGE T-Cu 1.16%, S-Cu 0.07%, MoS2 0.021%



3-18 Surface Drill Hole No. 2

Position of Collar; 9,200,322.08 N, 798,208.05 E

Collar Elevation: 3,592.64 m SL.

Direction; vertical

Drilled Length; 150.55 meters

The rock formations appearing in this hole are, in descending order, (1) shale formation to the depth of 16.65 m,

(2) limestone formation containing fragnental shell fossils to the depth of 65.65 m, thence

(3) tuffaceous sandstone formation to the bottom, and

(4) porphyrite dykes penetrating the above formation, in which (1) and (3) may be co-related to the Inca Formation, (2) to the Chulec Formation, and the dykes may be later of all. The zones of gray clay appearing at the depths of 18.3--19.3 m and 20.4--21.7 m, containing sub-breccias of limestone (1--3 cm in diam.), must be reverse faults with considerable displacements. Another fissure is recognized between 65.65 and 74.0 m in depth, containing breccias or sub-breccias of quartzite and black sandy limestone (1--3 cm in diam.). In the said zone, the section from 68.9 to 74.0 m is composed of unconsolidated sandy material, possibly indicating a fractured zone.

Mineralization is generally poor, with pyrite being recognized very seldomly, but it is characteristic that the porphyrite dykes contain magnetite in considerable amount.

3-19 Surface Drill Hole No. 3

Position of Collar; 9,222,029.25 N, 794,622.36 E

Collar Elevation; 3,493.91 m SL.

Direction; vertical

Drilled Length; 201.50 meters

The rock formations appearing in this hole are, in descending order,

(1) sedimentary formation to the depth of 136.85 m, in which limestone is the main,

(2) quartz monzonite porphyry containing hornblende to the bottom,

and (3) porphyrite dykes penetrating the sediments and porphyry above mentioned.

The upper portion of the sedimentary formation is composed of the alternation of limestone containing fragmental shell fossibls, marl, and gray massive limestone, but below the depth of 98 m, the formation is turned into limestones having the partings of dark gray shale and andesitic tuffs. They may be co-related to the lower Chulec Formation.

Quartz monzonite porphyry is intruding into the said sediments, having a chilled margin or about 3 cm at the contact. Calcite is conspicuously observed in the porphyry near the contact, which is replacing not only plagioclase and orthoclase, but also mafic minerals. The mafic minerals are so intensely altered into chlorite and epidote as well as into calcite, that hornblende and biotite are made undistinguishable. As apart from the contact, fresher hornblende comes to appear, but biotite, as minor in amount, only remains as relict. The porphyry gives the contact metamorphism though weak as it is, yielding garnet locally.

The phenocryst of porphyrite is mostly plagioclace, and the mafic minerals are scarcely recognized. The groundmass is essentially composed of lath-shaped plagioclase (ave. 0.1 x 0.2 cm).

The distinct fissures observed in this hole are the clay zones of black or gray, containing the breccias of limestone (1--3 cm in diam.) and shale (1--2 cm in diam.), at the depths of 25.3--25.7 m, 26.25--26.4 m, 49.7--50.3 m, 92.85--93.5 m, and 175.5--176.2 m.

At the depth of 25.7 to 26.25 in the limestone, an ore zone of replacement type is recognized, where galena and spharelite occur as disseminated in a zone of pyrite.

3-20 Surface Drill Hole No. 8 (cf. Table 7-17)

Position of Collar; 9,221,845.46 N, 795,827.91 E

Collar Elevation; 3,527.16 m SL.

Direction; vertical

Drilled Length; 154.23 meters

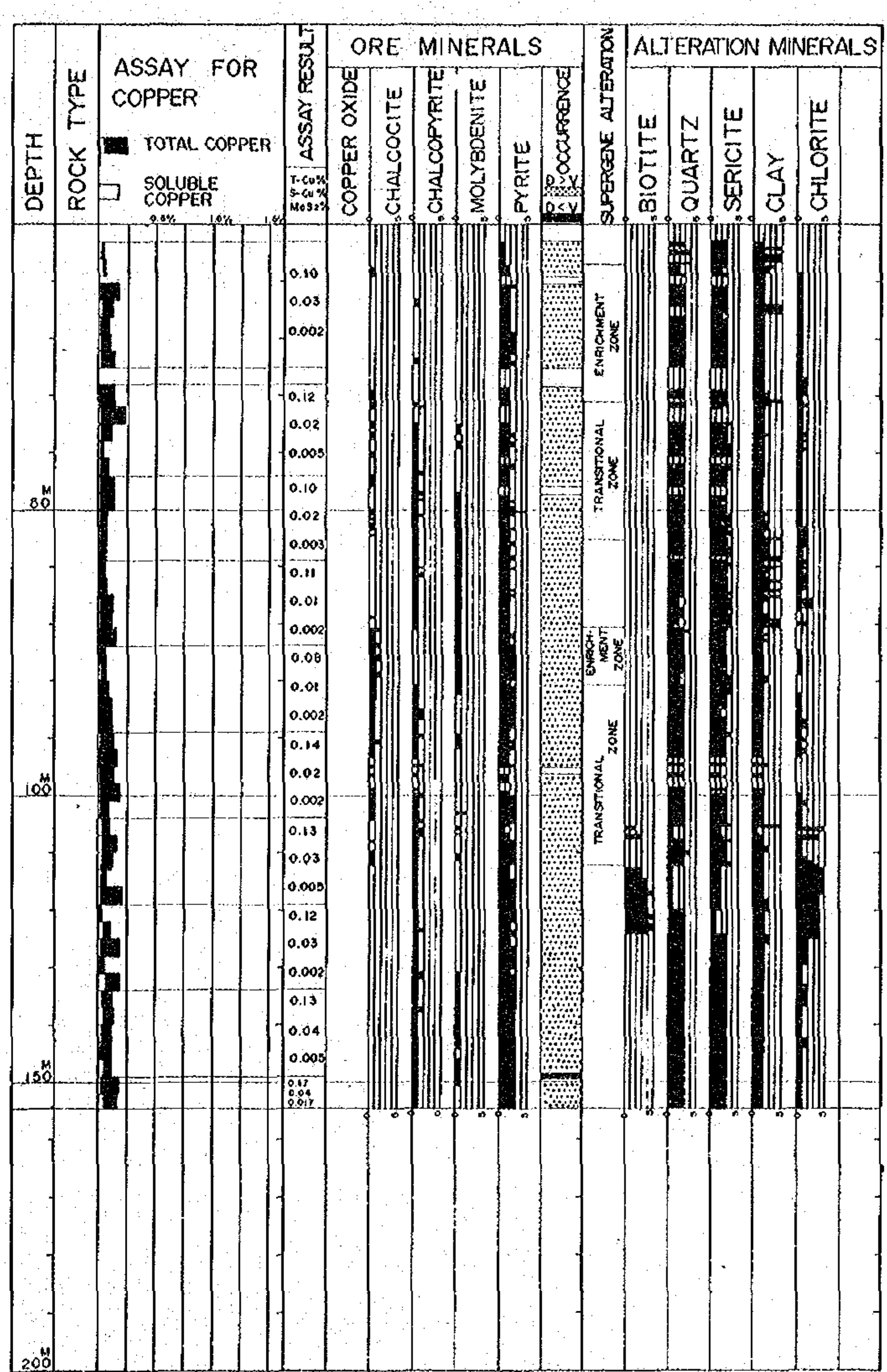
The hole is entirely composed of quartz monzonite porphyry containing the phenocrysts of quartz (max. 6 x 7.5 mm, ave. 3 x 3 mm), plagioclase (max. 7 x 8.5 mm, ave. 2.5 x 3.5 mm), and biotite is contained at the depth betwen 105.5 and 124.0 meters. Silicification, sericitization, and argillization are distinctly recognized almost throughout the length, and chloritization is also fairly intense. Biotite, under the microscope, is almost perfectly altered into chlorite, epidote, zoisite, clinozoisite, and siderite. Pink feldspars are only observed between 77 and 78 meters in depth. The distinct fissures are the zones of white or grayish white clay containing the breccias of quartz monzonite porphyry, appearing at the depths of 3.85--4.55 m, 5.35--6.5 m, 14.4--16.1 m, 30.5--31.0 m, 57.95--58.65 m, 59.5--59.75 m, 62.1--62.5 m, 64.05--64.45 m, 65.0--65.55 m, 80.0--80.4 m, and 105.1--105.5 m. Copper minerals are chalcopyrite and chalcocite, and other ore minerals are pyrite, molybdenite, and magnetite. Chalcopyrite mostly occurs as disseminated, and some one included in the phenocryst of biotite reaches as big as 1.2 x 0.5 mm, while the one in the groudmass is generally less than 0.2 mm. Pyrite also occur as disseminated mostly, some reaching as big as 0.5 mm maximum, but generally is 0.1 mm in average diameter with subhedral form. Most of molybdenite occur in veinlets, and magnetite is surrounding the periphery of biotite or formed along the plane of (001). Chalcocite occurs as coating film over chalcopyrite, partaking to compose the enriched and transitional zones.

TABLE 7-17

HISTOGRAM OF MINERALIZATION AND ALTERATION GRADE

No. 8

AVERAGE T-Cu 0.12% S-Cu 0.02% MoS_2 0.004%



PART II TUNNELLING OPERATION

PART II Tunnelling Operation

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Part II Tunnelling Operation

Chapter 1 Outline of the Operation

This operation was aimed to investigate the geological features of the Michiquillay Ore Deposit and its surroundings. The amounts of works performed during the operation are the advances of tunnels of 56.95 meters in the preparation of underground diamond drilling chambers, 1,070 meters of cross cuts, and 170 meters of raises. (cf. Fig. 2-1)

These works were performed by the Peruvian supervisors and local laborers under the guidance by the engineers from Minero Peru and Japan on two-shift basis. One cycle of the work had been standardised as to make one blasting per shift by means of the combination of a jack-hammer with leg and a shovel loader, and its standard advance was aimed at 1.2 meters per cycle.

Special care was taken in raising works from the point of mine safety so as the raise to be partitioned into ore passage and manway, in which the stagings were installed at every three meters advance together with ladders.

As the run of mine was expected mostly ore, and in view of the scarcity of proper dumping site near the adit, the wooden ore bins were installed at the adit area, through which the ore was extracted and loaded on dump trucks to be hauled to the mine air strip where the ore was stock-piled. Some casual irregularity of the truck trips made it inevitable for the ore bins to be over-filled from time to time.

The progress of the works was apt to be delayed due to the local

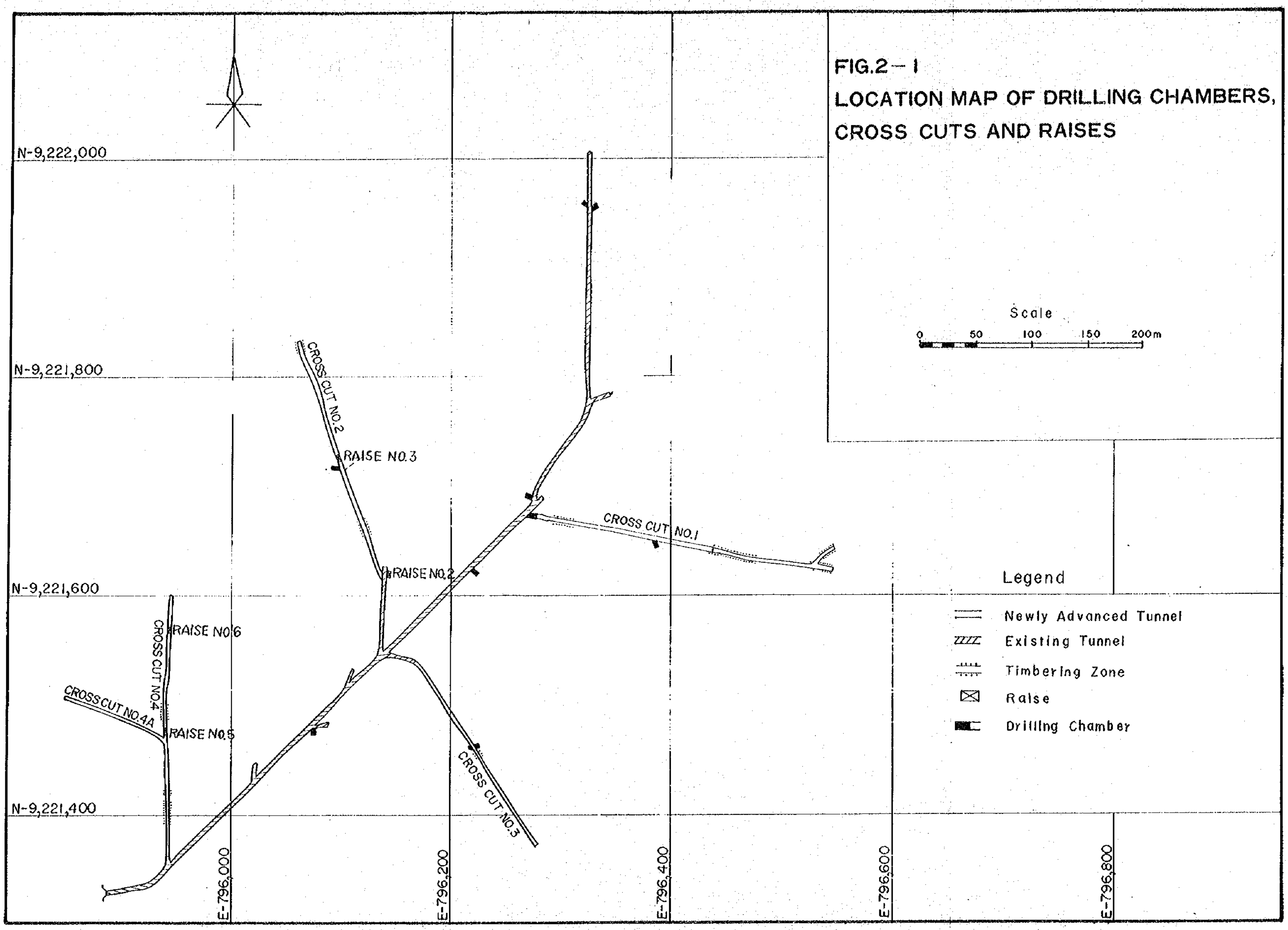


FIG.2-1
LOCATION MAP OF DRILLING CHAMBERS, CROSS CUTS AND RAISES

difficulties of advance caused by water, soft ground, etc., as well as to the necessity of technical training for the Peruvian supervisors and laborers.

The operation was begun with the installations and tentative housings, which were succeeded by the tunnelling works. The total manshifts required are shown as follows;

Works	Total manshifts
Supervisors	208
Capatazos	633
Office workers	429
Rock drillers	1,884
Bodegueros	547
Compressor operators	266
Miscellaneous	4,594
Timbermens	51
Total	8,612

Chapter 2 Machineries Used and Materials Consumed

The machineries and their spare parts used and the materials consumed in the tunnelling works are shown on Tables 2-1, 2-2, and 2-3.

Table 2-1. Main Machineries Used

Item	Model	Quantity	Specification
Air Compressor	DK-600	3	Discharge; 11 m^3/min. Diesel Engine; T-928 120 PS. Air-cooled, portable type.
	DT-4-ARR	1	Discharge; 18 m^3/min. Diesel Engine; D-100 B 145 PS. Water-cooled, stationary type.
Shovel Loader	EIMCO-12B	3	Bucket Capacity; 0.16 m^3
Rock Drill	TY-280LD TY-280JS	7 2	Cylinder Diameter; 76 mm. Air Consumption; 3.4 m^3/min.
Mine Car		10	Volume; 0.9 m^3 Hand-operated, Side-dumping.
Bit-grinder	LSD61	1	Air-driven, 4,200 r.p.m.

Table 2-2. Spare Parts Used

Machinerie	Spare Part	Quantity
Rock Drill	Rifle Bar	13
	Rifle Nut	12
	Water Tube	66
	Water Valve Retainer Ring	12
	Water Valve Spring	9
	Rotation Pawl	28
	Steel Holder	1
	Steel Holder Spring	10
	Steel Holder Nut	12
	Through Bolt	14
	Through Bolt Nut	10
	Cup Rubber	40
	Pawl Spring	24
Air Compressore	Air Cleaner Filter	3
	Fuel Filter	8
	Oil Filter	12
	Diaphragm Valve Sheet	14
Shovel Loader	King Bolt	2
	King Bolt Nut	2
	Rocker Cable (long)	10
	Rocker Cable (short)	8
	Bucket Chain	2
	Bumper Spring	6
	Handle Spring	14
	Turntable Ball	10

Table 2-3. Consumption of Material

Material	Quantity	Material	Quantity
Grinding Stone	20 pcs.		
Nail 6"	355 kg	Picking Steel Bar	29 pcs.
Nail 4"	130 "	Pick	15 "
Nail 2"	30 "	Trimming Hand Axe	2 "
Wire	800 "	Hand Saw 60 cm	3 "
Manila Rope 19 m/m	350 m	Hand Saw 30 cm	1 pce.
Manila Rope 12 m/m	100 "	Japanese Hand Saw	5 pcs.
Wire Rope 12 m/m	90 "	Heavy Hammer 15 lbs.	4 "
Wire Rope 21 m/m	180 "	Hand Hammer 4 kg	2 "
Carbide	2,450 kg	Pipe Wrenche 18"	4 "
Tamping Rod 2 m	90 pcs.	Pipe Wrenche 21"	2 "
Oil for Drill	375 ℓ	Pipe Wrenche 24"	2 "
Oil for Shovel Loader	500 "	Adjustable Spanner 8"	8 "
Right Oil	96,495 "	Adjustable Spanner 12"	8 "
Lubricant	900 "	Pinche 6"	4 "
Grease	185 kg	Measuring Tape 50 m	1 "
Safety Cap	73 pcs.	Measuring Tape 10 m	1 "
Glove	80 prs.	Rubber Hose 1"	120 m
Rubber Coat	75 pcs.	Rubber Hose 1/2"	120 "
Rubber Pant	75 "	Valve 4"	1 pce.
Rubber Boot	116 prs.	Valve 2"	6 pcs.
Carbide Lamp (L)	44 pcs.	Valve 1"	14 "
Carbide Lamp (S)	43 "	Dynamite	13,037.2 kg
Drill Rod, Hex. Hol.		Blasting Cap No. 6	22,412 pcs.
22 m/m x 0.9 m	22 pcs.	Safety Fuse	55,822 m
22 m/m x 1.2 m	21 "	"Kühlen" (Drill Hole Cleaner)	14 pcs.
22 m/m x 1.8 m	161 "		
22 m/m x 2.4 m	21 "		

Material	Qunatity	Material	Quantity
Timber & Lumber		For Ore Bin	
For Raise		Log ∅ 25cm x 3m	72 pcs.
Log ∅ 25cm x 3m	360 pcs.	" ∅ 30cm x 3m	22 "
Plate 5cm x 20cm x 3m	591 "	" ∅ 20cm x 3m	20 "
Ladder	91 "	Square Lumber	
For Drift		30cm x 30cm x 8m	3 "
Log ∅ 25cm x 3m	400 "	25cm x 25cm x 8m	5 "
Plate 5cm x 20cm x 3m	759 "	25cm x 25cm x 6m	3 "
For Ore Bin		25cm x 25cm x 4m	2 "
Log ∅ 30cm x 8m	4 "	Plate	
" ∅ 25cm x 5m	2 "	5cm x 20cm x4m	80 "
" ∅ 25cm x 3.5m	7 "	5cm x 20cm x 3m	619 "
		5cm x 20cm x 2.5m	25 "

Chapter 3 Tunnelling

3-1 Installation

3-1-1 Piping and Track Laying

The preparatory works were begun on March 17, 1974 with the installation of 4 units of air compressors in the adit area of Level 3,500 m and piping of 4" pipes for the delivery of air to the underground working heads. Water for the rock drills was supplied by inviting water of the River Michiquillay through an open raise formerly driven from the said Level to the surface, along which 2" pipes were installed this time. The tracking was done by laying 10 kg steel rails at the gage of 500 m/m and a split switch was installed at every entrance of the cross cut newly driven.

3-1-2 Housing

Each one of mine office, bodega, and repairing house were constructed. The distribution of labors required in this work is shown on the following table.

Works	Total Manshifts	Total Hours
Installation of air compressors and piping	32	256
Transportation and surface installation of rails and pipes	75	600
Construction of bodega, office, etc., at mine site	38	304
Ore bin construction, 2 x 16 m^3	100	903
2 x 80 m^3	59	684
1 x 10 m^3	38	456
Underground track laying and piping	67	512
Total	409	3,715

The existing magazine was used for the storage of explosives.

The layout of the mine office, bodega, compressor rooms are shown by Fig. 2-2.

3-1-3 Construction of Ore Bins

In view of the lack of proper stockyard for the run of mine near the adit, the wooden ore bins were installed adjacent to the adit. They were constructed on the slope of about 37° gradient in front of the adit, and consisted of one of 10 cubic meters capacity, two of 16, and another two of 80 cubic meters capacities.

The ore was extracted and hauled by dump trucks to the mine air strip. The ore was piled at every 8 meters advance of tunnelling (corresponding to 100 tons), and the piles were classified according to the work heads of tunnelling.

Explanatory diagrams of the ore bins are attached as Fig. 2-3.

3-2 Tunnelling

3-2-1 Preparation of Diamond Drilling Chambers

The works were performed as shown on the following table.

For Drill Holes	Total Days Worked	Advances	Timberings Required
		(m)	(sets)
No. 2	5	4.20	
No. 3	6	6.20	
No. 4	5	6.40	
No. 6	6	8.45	
No. 7	4	4.35	2
No. 10	5	4.85	
No. 11	3	6.00	
No. 12	8	8.00	
No. 15	4	8.50	
Total		56.95	2

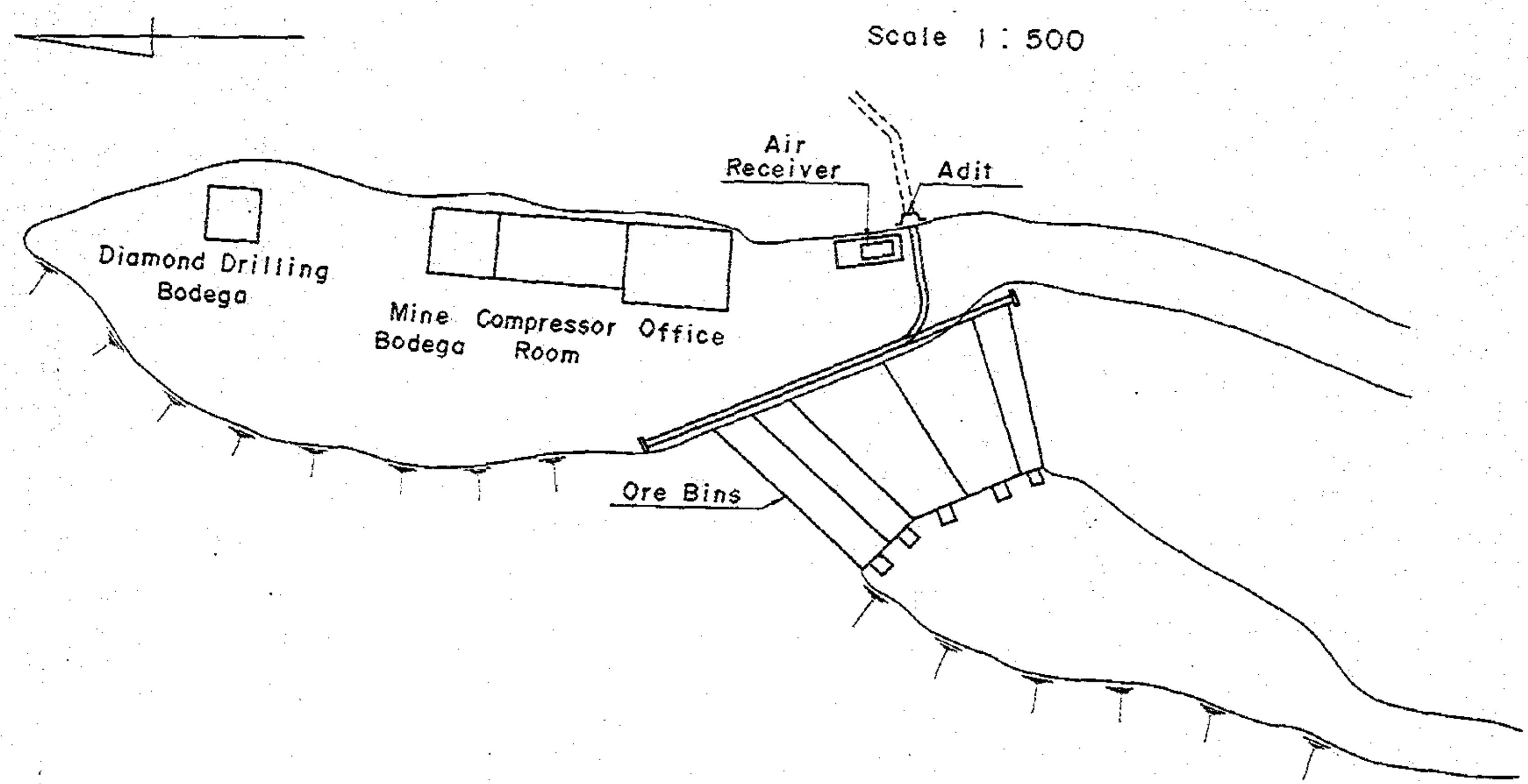


FIG.2-2 LAYOUT MAP OF MINE OFFICE, BODEGA, COMPRESSOR ROOM, AND ORE BINS

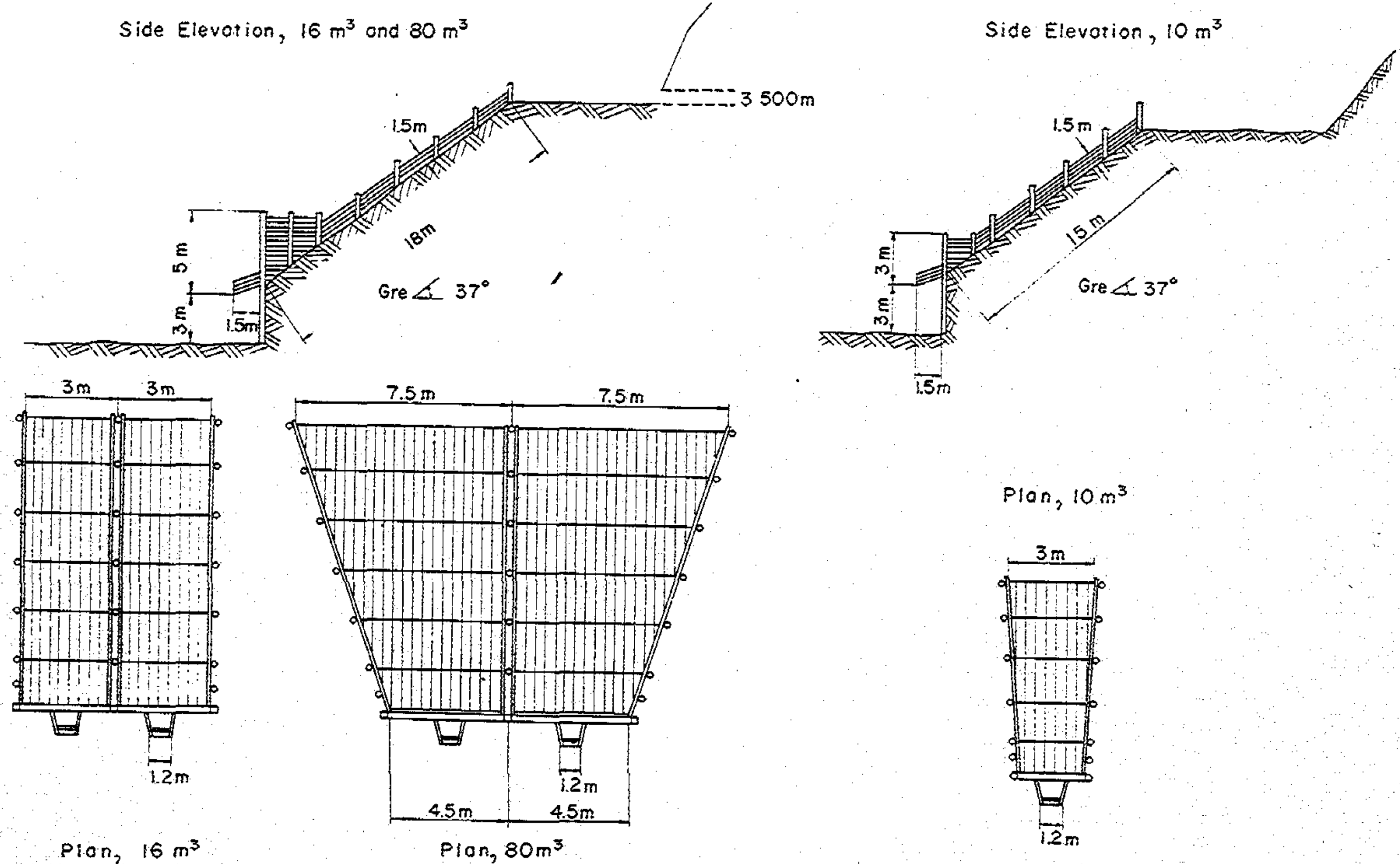


FIG.2-3 ILLUSTRATIONS OF WOODEN ORE BINS

The rest of the drilling sites were located by making use of the available spaces in the existing tunnel. Mucking was done by hands.

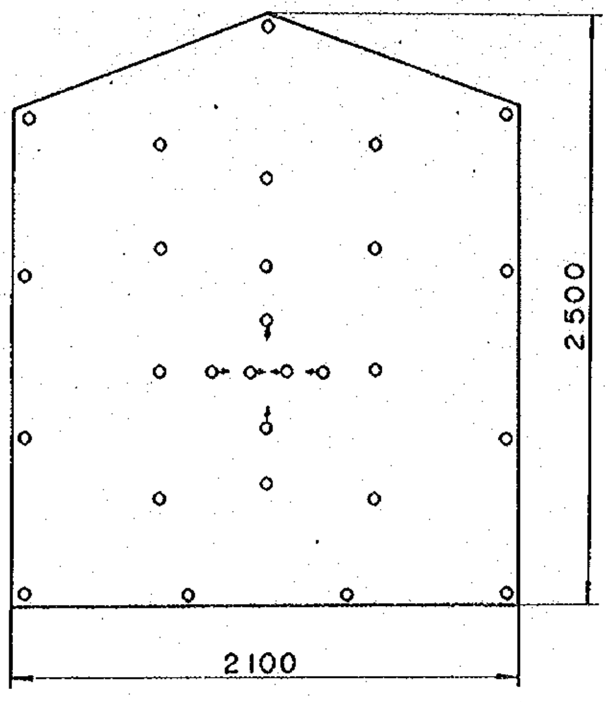
3-2-2 Drifting

Three mucking machines, EIMCO 12 B, were provided, but a part of the mucking was done by hands. The muck was hauled by 0.9 m^3 mine cars of side-dumping type. Dimension of the tunnel was 2.1 m in width and 2.5 m in height with the gradient of 1/200. The standard drill round is shown by Fig. 2-4 and the cross sections of the tunnel are shown by Figs. 2-5 and 2-6. The locations of the cross cuts newly driven are shown on Fig. 2-1.

(1) Cross cut No. 1 (scheduled advance; 300 m)

After the advance of 24.50 m in the direction of S 70° E, the work was suspended. The work was resumed from the point of 24.50 m and completed the scheduled advance of 300 m. Total days required were 154.

From the start to 19.35 m, the ground was rather jointy but the work progressed more or less in good order. But 14 sets of timbering were required in the next section to 33.50 m, due to such a bad ground as the monzonite porphyry was fairly argillized along the fissures, from which water was coming out at the rate of 10 l/min. After passing through the fairly improved ground from there to 161 m, it encountered another difficulty to advance in the section from 161 m to 204 m due to the intensely fractured zone by fissures and associated fractures from which water was rushing out at the rate of 10 l/min, by which 36 sets of spiling were required. From 204 m to 262 m it was advanced in a good speed without care for any timbering in spite of the fractured ground with some water. In the succeeding section from 262 m to 273 m, 11 sets of spiling were



Numbers of Drill Holes	28
Type of Center Cut	Pyramid Cut
Blasting Caps Used	NO. 6
Explosives Used	SEMEXA 45% 82 g/stick

Safety fuses were used.

FIG.2-4 STANDARD DRILL ROUND OF DRIFTING

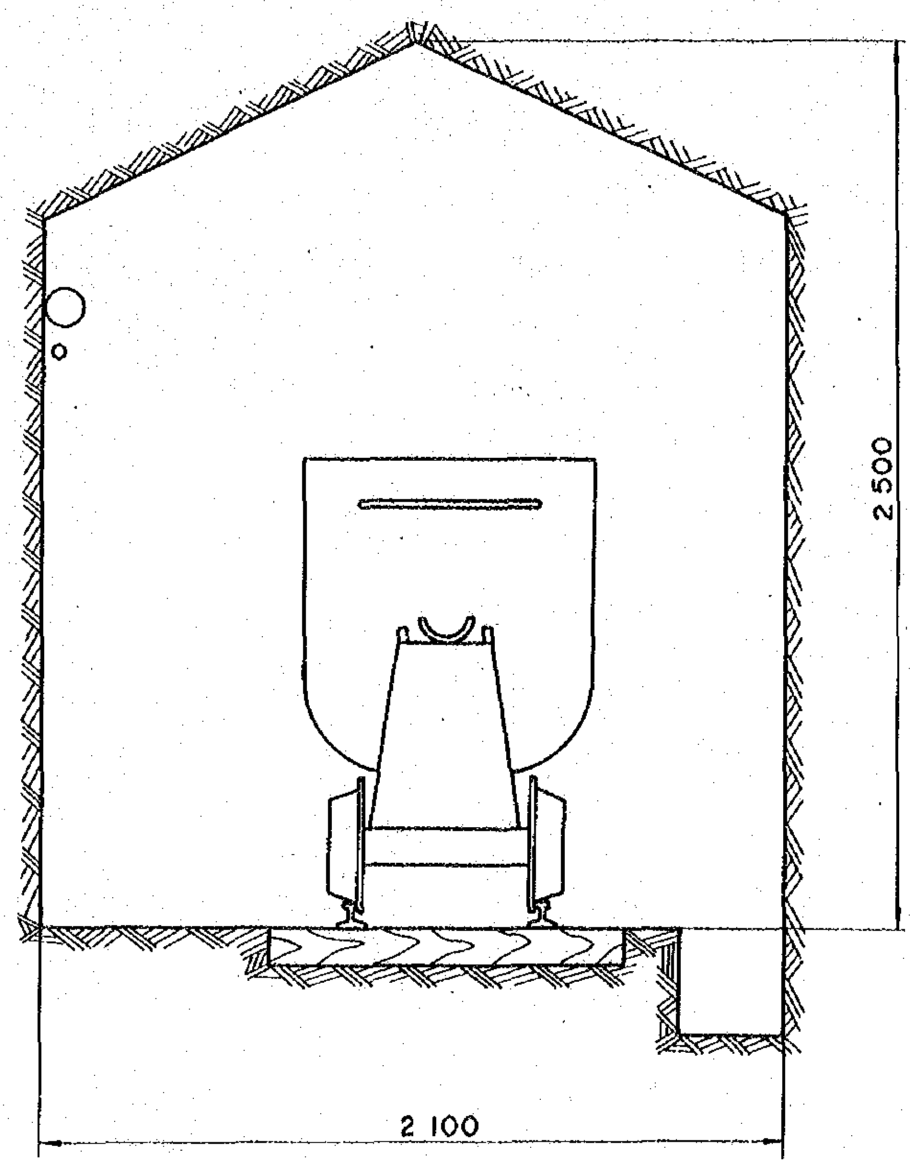


FIG.2-5 CROSS SECTION OF DRIFT

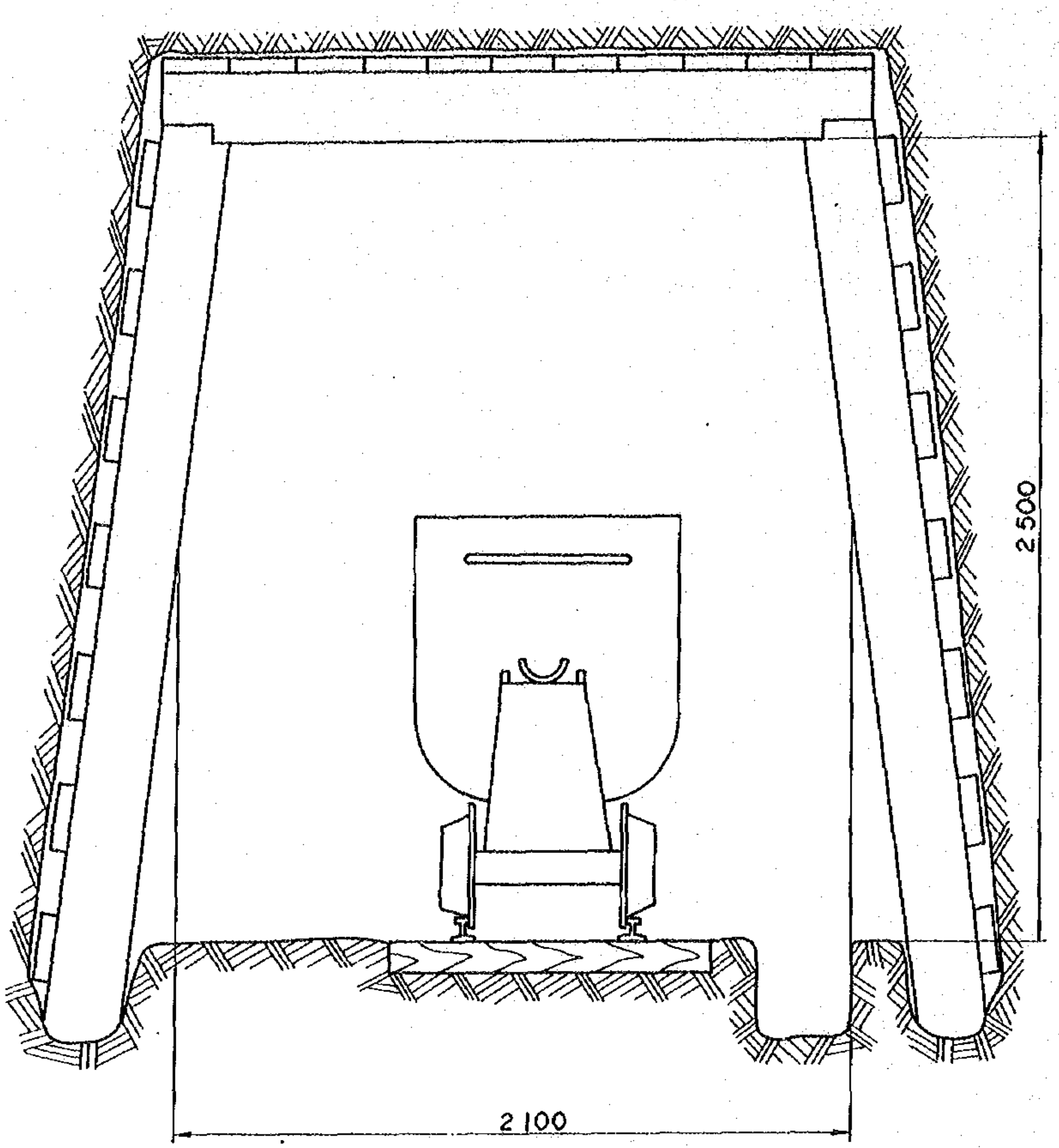


FIG. 2-6 CROSS SECTION OF TIMBERED DRIFT

required due to the caving by the well-developed fissures and fractures with gushing water at the rate of 20 l/min ~ 30 l/min. It was felt inadequate to advance any farther not only technically but also from the point of mine safety, as it was found that the spiling lags at the head of 273 m were heavyly loaded, which necessitated to drive a by-pass leftwardly from the point of 258 m. After advancing this by-pass for 27 meters, the scheduled advance of 300 meters was attained, in which 14 sets of timbering were required due to the well developed fissures and fractures with outcoming water of about 10 l/min. In the meanwhile, 2 sets and 3 sets of reinforcement timbering were given at the points of about 30 m and 175 m respectively as the maintenance of tunnel was endangered.

(2) Corss cut No. 2 (scheduled advance; 250 m)

It was started in the direction of N 20° W but the work was suspended after the advance of 171.50 meters. It was resumed from the point of 171.50 m but the work was abandoned with the over-all advance of 231.5 m, below scheduled advance, due to the bad ground. 126 days were required in all.

It was advanced in good condition in the initial 41.9 m, but 9 sets of timbering were required in the succeeding section from 41.90 m to 54.40 m, due to a shattered zone along fissures. In the next section to 148.50 m, the ground was found improved without outcoming of water. In the section from 148.50 m to 156.10 m, 7 sets of timbering were required. But from 156.10 m to 219 m, the work was favored by better condition, in spite of the jointy ground. After this section, it entered into another shattered zone to 231.50 m, where 10 sets of spiling were necessitated, with gushing water at the rate of 20 l/min ~ 25 l/min.

The work was quitted at this point, as it was judged inadequate to proceed any farther, not only technically but also in view of mine safety, as the spiling lags at this heading were found severely loaded.

(3) Cross cut No. 3 (scheduled advance; 200 m)

The work was commenced in the direction of S 35° E but it was suspended after the advance of 170.40 m. The work was resumed from the point of 170.40 m and the scheduled work of 200 m advance was attained. The total days worked were 102.

In the initial 92.70 m the work was carried out in more or less favored condition in spite of the jointy ground. But 4 sets of timbering were required from 92.70 m to 103.20 m, due to the fractured ground with water. The water momentarily amounted as much as 40 l/min ~ 200 l/min, but it decreased as the heading was advanced. The abundance of water caused some of the explosives miss-fired, which made the performance of the work very difficult. However, the work was carried on quite smoothly hereafter to 200 m, being favored by good ground without water.

(4) Corss cut No. 4 (scheduled advance; 220 m)

It was started in the direction of due north but the work was suspended after accomplishing the advance of 133.60 m. The work was resumed from the point of 133.6 m and attained the over-all advance of 238.50 m with the total days worked of 114.

In the initial 31.50 m, it was driven more or less in better condition without being hampered by water, but 12 sets of timbering were required in the next section from 31.50 m to 52.50 m, due to the argillized monzonite porphyry. Another 2 sets of timbering were again required from 58.60 m to 62.10 m, where the cross cut encountered a big gougy zone. In spite of somewhat soft ground from 62.10 m to 127 m, the work was carried out rather smoothly without being hampered by water. The ground turned jointy with a little water from 127 m to 142.30 m, which necessitated 13 sets of timbering. The advance was improved in the next section from 142.30 m to 238.50 m without being bothered by water in spite of the jointy ground.

In the meanwhile, 3 sets of reinforcement timbering were given at the point of about 31.50 m, where the maintenance of the tunnel was felt endangered by rushing water. Another 2 sets of reinforcement were also required near 35 m point, where the posts were broken by unusual pressure from the left side wall and the maintenance was felt endangered.

(5) Cross cut No. 4A (scheduled advance; 100 m)

It was commenced from the point 107 m north along Cross cut No. 4 in the direction of N 70° W and attained the scheduled advance of 100 m, with the total days of 31. The advance was attained rather smoothly without being hampered by water, although the ground was jointy.

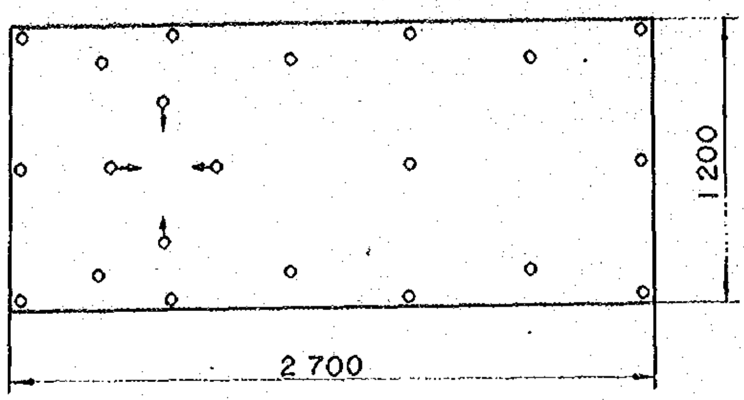
3-2-3 Raising

The raise was designed as follows;

Dimension	2.7 m x 1.2 m
Crib interval	1.5 m
Inclination	vertical
Standard drill round;	as shown on Fig. 2-7
Chute and footholds ;	wooden built as shown on Fig. 2-8
Locations ;	as shown on Fig. 2-1

(1) Raise No. 2 (scheduled advance; 60 m)

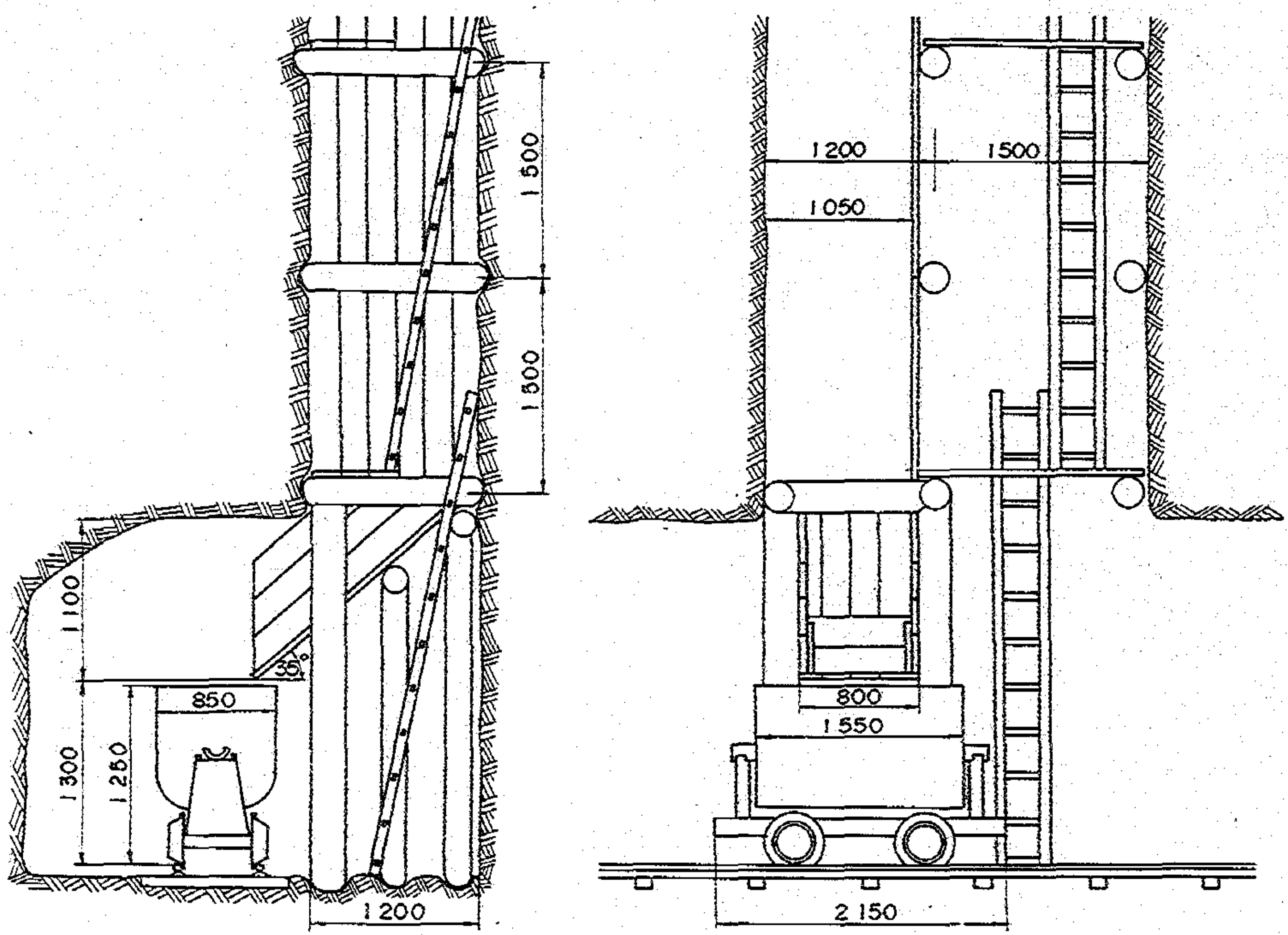
The work was suspended when the advance of 54 meters was reached. The work was resumed from the point of 54 meters and was accomplished as scheduled.



Numbers of Drill Holes	21
Type of Center Cut	Pyramid Cut
Blasting Caps Used	NO. 6
Explosives Used	SEMEXA 45% 82 g/stick

Safety fuses were used.

FIG. 2-7 STANDARD DRILL ROUND OF RAISE



Side View

Front View

FIG.2-8 WOODEN CHUTE FOR RAISE

After the initial advance of 7.90 meters by using temporary platform and installing wooden chute, the advance was made after the normal procedure. Drilling was hampered at 40 m due to the fractured ground but the work progressed more or less smoothly due to the scarcety of water. 78 days were consumed in all for the completion.

(2) Raise No. 3 (scheduled advance; 60 m)

The work was suspended after the accomplishment of the advance of 36 meters. The work was resumed from the point of 36 meters and completed the scheduled advance of 60 meters.

After the intial advance of 5.30 meters by using temporary platform and installing wooden chute, the advance was made after the normal procedure. Although the drilling work was often hampered by the fractured ground, the advance was made rather in good condition without encountering water. Total days required were 73.

(3) Raise No. 5 (scheduled advance; 20 m)

The work accomplished the scheduled advance of 20 meters.

Being favored by a fair ground condition without water, it was worked out quite smoothly with 23 days for the completion.

(4) Raise No. 6 (scheduled advance; 30 m)

The work accomplished the scheduled advance of 30 meters.

The advance was made smoothly due to the fair ground condition without water. 31 days were required in all for the completion.

3-3 Withdrawal Operation

3-3-1 Removal of Pipe and Rails

The operation was started on May 21, 1975 by removing the said materials from the finished cross cuts, and completed the work on May 31, 1975.

3-3-2 Removal of Air Compressors and Pipings

Starting on May 23, this work was completed on May 31, 1975.

3-3-3 Removal of Office and Bodega

They were removed from May 26 to May 31, 1975

3-3-4 Removal of Miscellaneous Materials

All were accomplished from May 28 to May 31, 1975.

Total manshifts required in the withdrawal operation are shown on the following table.

Works	Total Manshifts	Total Hours Worked
Removal of Air Compressors and Pipings	24	288
Removal of Office and Bodega	24	288
Removal of Underground Steel Rails and Pipes	120	1,440
Removal of Miscellaneous Materials	16	192
Total	184	2,208

3-4 Statistical Data of the Works

The statistical data such as the hours worked, the rate of works, unit consumption of materials, and so forth, obtained through the works of preparation of diamond drilling chambers, driftings, and raisings are summarized on Tables from 2-4 to 2-18.

Table 2-4 Operational Data in the Preparation of Diamond Drilling Chambers

Items \ Headings, Drill Sites		No.2	No.3	No.4	No.6	No.7	No.10	No.11	No.12	No.15	Total
Total Days Worked		5	6	5	6	4	5	3	8	4	32
Total Advance (m)		4.20	6.20	6.40	8.45	4.35	4.85	6.00	8.00	8.50	56.95
Advance per Day (m)		0.84	1.03	1.28	1.41	1.09	0.97	2.00	1.00	2.13	1.78
Total Manshifts		18	38	26	40	25	15	16	32	24	234
Advance per Manshift (m)		0.23	0.16	0.26	0.21	0.17	0.32	0.38	0.25	0.35	0.24
Nos. of Cycles		4	8	4	7	5	3	4	8	8	51
Advance per Cycle (m)		1.05	0.78	1.60	1.21	0.87	1.62	1.50	1.00	1.06	1.12
Drilled Length per Hole (m)		1.63	1.06	1.60	1.41	1.19	1.60	1.60	1.20	1.20	1.39
Rate of Advance against Drilled Length (%)		64.4	73.6	100	86.4	73.1	101.3	93.8	83.3	88.3	80.6
Explosives Consumed	Total Am't. (kg)	30.4	38.0	43.5	64.1	35.4	44.0	47.2	75.3	77.3	455.2
	Am't. per m. Adv. (kg)	7.2	6.1	6.8	7.6	8.1	9.1	7.9	9.4	9.1	8.0
Blasting Caps Consumed	Total Am't. (pcs.)	68	88	103	131	79	81	102	183	143	978
	Am't. per m. Adv. (pcs.)	16.2	14.2	16.1	15.5	18.2	16.7	17.0	23.0	17.0	17.2
Fuses Consumed	Total Am't. (m)	145	188	182	277	161	187	249	447	349	2,185
	Am't. per m. Adv. (m)	34.5	30.3	28.4	32.8	37.0	38.6	41.5	55.9	41.1	38.4
Nos. of Timbered (sets)		-	-	-	2	-	-	-	-	-	2
Nos. of Inserted Bits Used (pcs.)		-	-	-	-	-	-	-	-	-	-

Table 2-5 Operational Data in the Preparation of Diamond Drilling Chambers

	No.2	No.3	No.4	No.6	No.7	No.10	No.11	No.12	No.15	Total
Drilling Time (hrs.)	39 (16%)	57 (12%)	52 (20%)	66 (15%)	47 (18%)	27 (19%)	48 (25%)	96 (25%)	96 (33%)	528 (19%)
Blasting Time (hrs.)	19 (8%)	74 (15%)	20 (8%)	31 (7%)	17 (7%)	17 (12%)	24 (13%)	64 (17%)	48 (17%)	314 (12%)
Mucking Time (hrs.)	137 (56%)	222 (45%)	163 (62%)	241 (53%)	159 (61%)	60 (42%)	104 (54%)	192 (50%)	120 (42%)	1,398 (51%)
Timbering Time (hrs.)	-	-	-	16 (4%)	-	-	-	-	-	16 (17%)
Track Lay'g Time (hrs.)	-	-	-	-	-	-	-	-	-	-
Misc. Time (hrs.)	49 (20%)	139 (28%)	26 (10%)	99 (21%)	37 (14%)	38 (27%)	16 (8%)	32 (8%)	24 (8%)	460 (17%)
Total Time (hrs.)	244 (100%)	492 (100%)	261 (100%)	453 (100%)	260 (100%)	142 (100%)	192 (100%)	384 (100%)	288 (100%)	2,716 (100%)

Table 2-6 Operational Data in the Drifting

General Summary

Items \ Headings		Cross-Cut No.1	Cross-Cut No.2	Cross-Cut No.3	Cross-Cut No.4	Cross-Cut No.4A	Total
Total Days Worked		154	126	102	114	31	229
Total Advance (m)		300	231.5	200	238.5	100	1,070
Advance per Day (m)		1.95	1.83	1.96	2.09	3.23	4.67
Total Manshifts		1,398	978	814	913	305	4,408
Advance per Manshift (m)		0.21	0.24	0.25	0.26	0.33	0.24
Nos. of Cycles		209	163	149	167	61	749
Advance per Cycle		1.44	1.42	1.34	1.43	1.64	1.43
Drilled Length per Hole (m)		1.66	1.60	1.60	1.59	1.70	1.62
Rate of Advance against Drilled Length (%)		86.7	88.8	83.8	89.9	96.5	88.3
Explosives Consumed	Total Am't. (kg)	2,946.2	2,372.7	2,280.0	2,441.0	987.8	11,027.7
	Am't. per m. Adv.(kg)	9.8	10.2	11.4	10.2	9.9	10.3
Blasting caps consumed	Total Am't. (pcs.)	4,916	4,056	4,072	4,069	1,637	18,750.
	Am't. per m. Adv.(pcs.)	16.4	17.5	20.4	17.1	16.4	17.5
Fuses Consumed	Total Am't. (m)	12,015	10,050	10,029	9,304	4,613	46,011
	Am't. per m. Adv.(m)	40.1	43.4	50.1	39.0	46.1	43.0
Nos. of Timbored (Sets)		80	26	4	32	-	142
Nos. of Inserted Bits Used (pcs.)		48	41	35	40	16	180

Table 2-7 Operational Data in the Drifting

General Summary

Items \ Headings	Cross Cut No.1	Cross Cut No.2	Cross Cut No.3	Cross Cut No.4	Cross Cut No.4A	Total
Drilling Time (hrs.)	3,682 (22%)	2,731 (23%)	2,637 (27%)	2,871 (26%)	1,169 (32%)	13,090 (25%)
Blasting Time (hrs.)	1,791 (11%)	1,337 (11%)	1,334 (14%)	1,318 (12%)	580 (16%)	6,360 (12%)
Mucking Time (hrs.)	4,845 (29%)	4,599 (40%)	4,225 (44%)	4,085 (37)	1,316 (36%)	19,070 (36%)
Timbering Time (hrs.)	4,472 (27%)	1,234 (11%)	47 (1%)	1,093 (10%)	-	6,846 (13%)
Track Lay'g Time (hrs.)	448 (3%)	468 (4%)	245 (3%)	297 (3%)	188 (5%)	1,646 (3%)
Misc. Time (hrs.)	1,417 (8%)	1,272 (11%)	1,045 (11%)	1,257 (12%)	407 (11%)	5,398 (11%)
Total Time (hrs.)	16,655 (100%)	11,641 (100%)	9,533 (100%)	10,921 (100%)	3,660 (100%)	52,410 (100%)

Table 2-8 Operational Data in the Drifting by Heading

Cross cut No.1

Items \ Months		1st	2nd	3rd	4th	5th	6th	7th	8th	Total
Drilling Time (hrs.)		157	120	88	813	966	290	693	555	3,682
Blasting Time (hrs.)		70	60	42	358	468	153	365	275	1,791
Mucking Time (hrs.)		327	289	189	891	1,056	575	803	715	4,845
Timboring Time (hrs.)		-	259	77	495	-	1,505	895	1,241	4,472
Track Lay'g Time (hrs.)		75	60	-	74	99	30	85	25	448
Misc. Time (hrs.)		139	80	36	249	230	142	280	261	1,417
Total Time (hrs.)		768	868	432	2,880	2,819	2,695	3,121	3,072	16,655
Total Manshifts		64	72	36	240	234	236	260	256	1,398
Advance per manshift (m)		0.21	0.15	0.26	0.21	0.29	0.11	0.26	0.20	0.21
Total Advance (m)		13.70	10.80	9.50	51.30	70.20	26.20	68.30	50.00	300.00
Explosives Consumed	Total Am't. (kg)	147.0	112.8	66.0	664.7	1,068.5	199.3	443.0	244.9	2,946.2
	Am't. per m. Adv. (kg)	10.7	10.4	6.9	13.0	15.2	7.6	6.5	4.9	9.8
Blasting Caps Consumed	Total Am't. (pcs.)	233	172	108	1,065	1,516	388	881	553	4,916
	Am't. per m. Adv. (pcs.)	17.0	15.9	11.4	20.8	21.6	14.8	12.9	11.1	16.4
Fuses Consumed	Total Am't. (m)	568	420	264	2,599	3,687	977	2,151	1,349	12,015
	Am't. per m. Adv. (m)	41.5	38.8	27.8	50.7	52.5	37.3	31.5	27.0	40.1
Nos. of Timbered (Sets)		-	4	4	6	-	18	18	30	80
Nos. of Inserted Bits Used (pcs.)		-	4	2	8	11	4	11	8	48

Table 2-9 Operational Data in the Drifting by Heading

Cross cut No.2

Items \ Months		1st	2nd	3rd	4th	5th	6th	7th	8th	Total
Drilling Time (hrs.)		36	500	515	744	144	196	520	76	2,731
Blasting Time (hrs.)		17	233	235	316	70	123	291	52	1,337
Mucking Time (hrs.)		256	1,046	865	1,042	217	245	677	251	4,599
Timbering Time (hrs.)		10	32	267	-	230	-	-	695	1,234
Track Lay'g Time (hrs.)		25	74	94	89	12	-	96	78	468
Misc. Time (hrs.)		145	251	224	477	71	29	40	35	1,272
Total Time (hrs.)		489	2,136	2,200	2,668	744	593	1,624	1,187	11,641
Total Manshifts		46	182	185	230	62	49	117	107	978
Advance per manshift (m)		0.07	0.26	0.25	0.27	0.22	0.33	0.32	0.06	0.24
Total Advance (m)		3.20	46.50	47.00	61.30	13.50	16.10	37.30	6.60	231.5
Explosives Consumed	Total Am't. (kg)	46.5	343.8	465.9	628.4	139.2	192.5	485.1	71.3	2,372.7
	Am't. per m. Adv. (kg)	14.5	7.4	9.9	10.3	10.3	12.0	13.0	10.8	10.2
Blasting Caps Consumed	Total Am't. (pos.)	93	726	834	1,043	249	295	709	107	4,056
	Am't. per m. Adv. (pos.)	29.1	15.6	17.7	17.0	18.4	18.3	19.0	16.2	17.5
Fuses Consumed	Total Am't (m)	197	1,838	2,086	2,625	588	705	1,674	337	10,050
	Am't. per m. Adv. (m)	61.6	39.5	44.4	42.8	43.6	43.9	44.9	51.1	43.4
Nos. of Timbered (sets)		-	-	10	-	6	-	-	10	26
Nos. of inserted Bits Used (pos.)		-	7	7	9	8	3	6	1	41

Table 2-10 Operational Data in the Drifting by Heading

Cross cut No.3

Items \ Months		1st	2nd	3rd	4th	5th	6th	7th	Total
Drilling Time (hrs.)		57	476	682	740	395	180	107	2,637
Blasting Time (hrs.)		27	290	291	338	185	129	74	1,334
Mucking Time (hrs.)		181	1,017	1,063	936	505	341	182	4,225
Timbering Time (hrs.)		-	-	-	47	-	-	-	47
Track Layg Time (hrs.)		35	69	51	63	15	12	-	245
Misc. Time (hrs.)		73	154	277	366	100	38	37	1,045
Total Time (hrs.)		373	2,006	2,364	2,490	1,200	700	400	9,533
Total Manshifts		37	175	197	210	100	59	36	814
Advance per manshift (m)		0.14	0.18	0.25	0.27	0.29	0.38	0.20	0.25
Total Advance (m)		5.30	31.00	49.20	55.70	29.20	22.40	7.20	200.00
Explosives Consumed	Total Am't. (kg)	68.3	417.9	541.8	565.6	377.2	216.0	93.2	2,280.0
	Am't. per m. Adv. (kg)	12.9	13.5	11.0	10.2	12.9	9.6	12.9	11.4
Blasting Caps Consumed	Total Am't. (pcs.)	137	731	975	1,040	649	369	171	4,072
	Am't. per m. Adv. (pcs.)	25.8	23.6	19.8	18.7	22.2	16.5	23.8	20.4
Fuses Consumed	Total Am't. (m)	290	1,841	2,443	2,547	1,583	901	424	10,029
	Am't. per m. Adv. (m)	54.7	59.4	49.7	45.7	54.2	40.2	58.9	50.1
Nos. of Timbered (sets)		-	-	-	4	-	-	-	4
Nos. of Inserted Bits Used (pcs.)		-	5	10	10	5	4	1	35

Table 2-11 Operational Data in the Drifting by Heading

Cross cut No.4

Items \ Months		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	Total
Drilling Time (hrs.)		16	487	643	398	72	679	376	200	-	2,871
Blasting Time (hrs.)		-	209	276	180	28	339	188	98	-	1,318
Mucking Time (hrs.)		-	861	921	468	122	932	535	246	-	4,085
Timbering Time (hrs.)		-	228	280	-	281	228	32	-	44	1,093
Track Lay'g Time (hrs.)		16	92	49	12	-	70	38	20	-	297
Misc. Time (hrs.)		-	234	327	106	61	224	163	138	4	1,257
Total Time (hrs.)		32	2,111	2,496	1,164	564	2,472	1,332	702	48	10,921
Total Manshifts		4	176	209	97	47	206	111	59	4	913
Advance per manshift (m)		-	0.25	0.26	0.37	0.11	0.25	0.27	0.31	-	0.26
Total Advance (m)		-	44.5	53.50	35.60	5.30	51.10	30.00	18.50	-	238.50
Explosives Consumed	Total Am't. (kg)	-	436.3	543.6	397.1	46.1	553.9	287.3	176.7	-	2,441.0
	Am't. per m. Adv. (kg)	-	9.8	10.2	11.2	8.7	10.8	9.6	9.6	-	10.2
Blasting Caps Consumed	Total Am't. (pcs.)	-	720	918	655	72	921	485	298	-	4,069
	Am't. per m. Adv. (pcs.)	-	16.2	17.2	18.4	13.6	18.0	16.2	16.1	-	17.1
Fuses Consumed	Total Am't. (m)	-	1,809	2,231	1,600	149	1,895	1,004	616	-	9,304
	Am't. per m. Adv. (m)	-	40.7	41.7	44.9	28.1	37.1	33.5	33.3	-	39.0
Nos. of Timbered (Sets)		-	7	10	-	6	6	1	-	2	32
Nos. of Inserted Bits Used (pcs.)		-	5	5	13	1	8	5	3	-	40

Table 2-12 Operational Data in the Drifting by Heading

Cross-cut No.4A

Items \ Months		1st	2nd	Total
Drilling Time (hrs.)		432	737	1,169
Blasting Time (hrs.)		216	364	580
Mucking Time (hrs.)		485	831	1,316
Timbering Time (hrs.)		-	-	-
Track Lay'g Time (hrs.)		132	56	188
Misc. Time (hrs.)		115	292	407
Total Time (hrs.)		1,380	2,280	3,660
Total Manshifts		115	190	305
Advance per manshift (m)		0.35	0.32	0.33
Total Advance (m)		40.00	60.00	100.00
Explosives Consumed	Total Am't. (kg)	346.5	641.3	987.8
	Am't. per m. Adv. (kg)	8.7	10.7	9.9
Blasting Caps Consumed	Total Am't. (pcs.)	580	1,057	1,637
	Am't. per m. Adv. (pcs.)	14.5	17.6	16.4
Fuses Consumed	Total Am't. (m)	2,027	2,586	4,613
	Am't. per m. Adv. (m)	50.7	43.1	46.1
Nos. of Timbered (Sets)		-	-	-
Nos. of Inserted Bits Used (pcs.)		6	10	16

Table 2-13 Operational Data in the Raising

General Summary

Items \ Headings		Raise No. 2	Raise No. 3	Raise No. 5	Raise No. 6	Total
Total Days Worked		78	73	23	31	133
Total Advance (m)		60	60	20	30	170
Advance per Day (m)		0.77	0.82	0.87	0.97	1.28
Total Manshifts		257	246	73	121	697
Advance per Manshift (m)		0.23	0.24	0.27	0.25	0.24
Nos. of Cycles		48	50	15	24	137
Advance per Cycle (m)		1.25	1.20	1.33	1.25	1.24
Drilled Length per Hole (m)		1.40	1.40	1.40	1.40	1.40
Rate of Advance against Drilled Length (%)		89.3	85.7	95.0	89.3	88.6
Explosives Consumed	Total Am't. (kg)	608.2	562.6	166.9	216.6	1,554.3
	Am't. per m. Adv. (kg)	10.1	9.4	8.3	7.2	9.1
Blasting Caps Consumed	Total Am't. (pcs.)	1,025	987	302	370	2,684
	Am't. per m. Adv. (pcs.)	17.1	16.5	15.1	12.3	15.
Fuses Consumed	Total Am't. (m)	2,743	2,981	876	1,026	7,626
	Am't. per m. Adv. (m)	45.7	49.7	43.8	34.2	44.9
Nos. of Timbered (sets)		44	40	14	20	118
Nos. of Inserted Bits Used (pcs.)		13	18	11	3	45

Table 2-14 Operational Data in the Raising
General Summary

Items \ Headings	Raise No. 2	Raise No. 3	Raise No. 5	Raise No. 6	Total
Drilling Time (hrs.)	667 (22%)	660 (23%)	170 (19%)	322 (22%)	1,819 (21%)
Blasting Time (hrs.)	194 (6%)	214 (7%)	58 (7%)	96 (7%)	562 (7%)
Mucking Time (hrs.)	328 (11%)	328 (11%)	125 (14%)	293 (20%)	1,074 (13%)
Timbering Time (hrs.)	1,505 (48%)	1,300 (44%)	444 (51%)	602 (42%)	3,851 (46%)
Track Lay'g Time (hrs.)	14 (1%)	-	-	-	14 (1%)
Misc. Time (hrs.)	372 (12%)	428 (15%)	79 (9%)	135 (9%)	1,014 (12%)
Total Time (hrs.)	3,080 (100%)	2,930 (100%)	876 (100%)	1,448 (100%)	8,334 (100%)

Table 2-15 Operational Data in the Raising by Heading

Raise No. 2

Items \ Months		1st	2nd	3rd	4th	5th	6th	Total
Drilling Time (hrs.)		153	216	146	88	14	50	667
Blasting Time (hrs.)		46	64	40	24	4	16	194
Mucking Time (hrs.)		80	84	70	70	4	20	328
Timbering Time (hrs.)		282	465	194	155	319	90	1,505
Track Lay'g Time (hrs.)		-	14	-	-	-	-	14
Misc. Time (hrs.)		51	129	110	35	31	16	372
Total Time (hrs.)		612	972	560	372	372	192	3,080
Total Manshifts		51	81	47	31	31	16	257
Advance per manshift (m)		0.31	0.23	0.24	0.21	0.05	0.38	0.23
Total Advance (m)		16.00	18.90	11.20	6.40	1.50	6.00	60.00
Explosives Consumed	Total Am't. (kg)	159.2	210.9	122.2	58.9	9.8	47.2	608.2
	Am't. per m. Adv. (kg)	10.0	11.2	10.9	9.2	6.5	7.9	10.1
Blasting Caps Consumed	Total Am't (pcs.)	254	342	230	98	20	81	1,025
	Am't. per m. Adv. (pcs.)	15.9	18.1	20.5	15.3	13.3	13.5	17.1
Fuses Consumed	Total Am't. (m)	620	834	626	324	67	272	2,743
	Am't. per m. Adv. (m)	38.8	44.1	55.9	50.	44.7	45.3	45.7
Nos. of Timbered (sets)		8	16	4	4	8	4	44
Nos. of Inserted Bits Used (pcs.)		7	-	-	3	-	3	13

Table 2-16 Operational Data in the Raising by Heading

Raise No. 3

Items \ Months		1st	2nd	3rd	4th	5th	6th	7th	Total
Drilling Time (hrs.)		56	218	166	-	126	94	-	660
Blasting Time (hrs.)		24	68	48	-	36	38	-	214
Mucking Time (hrs.)		2	124	98	-	54	50	-	328
Timbering Time (hrs.)		55	320	113	286	70	368	88	1,300
Track Lay'g Time (hrs.)		-	-	-	-	-	-	-	-
Misc. Time (hrs.)		19	256	43	26	26	50	8	428
Total Time (hrs.)		156	986	468	312	312	600	96	2,930
Total Manshifts		13	84	39	26	26	50	8	246
Advance per manshift (m)		0.41	0.21	0.33	-	0.46	0.21	-	0.24
Total Advance (m)		5.30	18.00	12.70	-	12.00	12.00	-	60.00
Explosives Consumed	Total Am't. (kg)	54.5	198.6	110.2	-	101.8	97.5	-	562.6
	Am't. per m. Adv. (kg)	10.3	11.0	8.7	-	8.5	8.1	-	9.4
Blasting Caps Consumed	Total Am't. (pcs.)	85	346	188	-	180	188	-	987
	Am't. per m. Adv. (pcs.)	16.0	19.2	14.8	-	15.0	15.7	-	16.5
Fuses Consumed	Total Am't (m)	207	943	611	-	604	616	-	2,981
	Am't. per m. Adv. (m)	39.1	52.4	48.1	-	50.3	51.3	-	49.7
Nos. of Timbered (Sets)		-	8	2	13	-	13	4	40
Nos. of Inserted Bits Used (pcs.)		-	-	6	-	6	6	-	18

Table 2-17 Operational Data in the Raising by Heading

Raise No. 5

Items \ Months		1st	2nd					Total
Drilling Time (hrs.)		138	32					170
Blasting Time (hrs.)		46	12					58
Mucking Time (hrs.)		58	67					125
Timbering Time (hrs.)		60	384					444
Track Lay'g Time (hrs.)		-	-					-
Misc. Time (hrs.)		34	45					79
Total Time (hrs.)		336	540					876
Total Manshifts		28	45					73
Advance per manshift (m)		0.61	0.07					0.27
Total Advance (m)		17.00	3.00					20.00
Explosives Consumed	Total Am't. (kg)	133.0	33.9					166.9
	Am't. per m. Adv. (kg)	7.8	11.3					8.3
Blasting Caps Consumed	Total Am't. (pcs.)	234	68					302
	Am't. per m. Adv. (pcs.)	13.8	22.7					15.1
Fuses Consumed	Total Am't. (m)	653	223					876
	Am't. per m. Adv. (m)	38.4	74.3					43.8
Nos. of Timbered (Sets)		-	14					14
Nos. of Inserted Bits Used (pcs.)		9	2					11

Table 2-18 Operatinoal Data in the Raising by Heading

Raise No. 6

Items \ Months		1st	2nd					Total
Drilling Time (hrs.)		322	-					322
Blasting Time (hrs.)		96	-					96
Mucking Time (hrs.)		293	-					293
Timbering Time (hrs.)		118	484					602
Track Lay'g Time (hrs.)		-	-					-
Misc. Time (hrs.)		91	44					135
Total Time (hrs.)		920	528					1,448
Total Manshifts		77	44					121
Advance per manshift (m)		0.39	-					0.25
Total Advance (m)		30.00	-					30.00
Explosives Consumed	Total Am't. (kg)	216.6	-					216.6
	Am't. per m. Adv. (kg)	7.2	-					7.2
Blasting Caps Consumed	Total Am't. (pcs.)	370	-					370
	Am't. per m. Adv. (pcs.)	12.3	-					12.3
Fuses Consumed	Total Am't (m)	1,026	-					1,026
	Am't. per m. Adv. (m)	34.2	-					34.2
Nos. of Timbered (Sets)		-	20					20
Nos. of Inserted Bits Used (pcs.)		3	-					3