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REPORT ON THE INVESTIGATION OF ORE DEPOSIT AT THE MACUCHI MINING DISTRICT IN COTOPAXI PROVINCE OF ECUADOR

1963

OVERSEAS TECHNICAL COOPERATION AGENCY

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Preface

Our Geological Survey Team of Japanese Government was despatched to Republic of Ecuador by Overseas Technical Cooperation Agency, and carried out the topographical and geological surveys at the Macuchi mining district in Cotopaxi Province of Ecuador from November in 1962 to March in 1963.

The objects of our work are to make the geological map based on the detailed topographical map and to study the occurrence of copper deposit in the Macuchi mining district.

The present report is described on the results of the field and laboratory investigations and precious datas presented from all concerned on the spot.

The Geological Survey Team should feel fortunate if the report would be useful to develop the mineral resources in Ecuador and to contribute the cooperation of mining industry between Ecuador and Japan in near future.

We wish to express our sincere thanks to the officials of Ministry of Works (Ministerio de Fomento) and many peoples in Ecuador for their valuable assistances in carring out our field investigation.

June 1st, 1963.

Geological Survey of Japan

Chief of the geological survey team

Dr. Hideo Takeda.

Report on the Investigation of Geology and Ore Deposit at the Macuchi Mining District in Cotopaxi Province of Ecuador.

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I. Introduction

The Republic of Ecuador is situated in the northwest corner of South America, bordering on the Pacific Ocean on the west.

In the central part of the Republic the Andes mountains stretch from north to south, then the country is divided into three provinces, Coastal province, Andean province and Oriental province, and the physiography and geology are varied in each province.

The geology of Ecuador was described by W. Sauer and by authors of "Ecuador in the Handbook of South American Geology", with maps and bibliographies.

The mineral resources in the Republic have been investigated by geologists of the South American Exploration Company, and by German geological mission in 1958, French geological mission in 1959 and Japanese geological mission in 1960.

In order to give the technical assistances and to find the possibility for mining, our Geological Survey Team investigated the geology and ore deposit at the Macuchi mining district in Cotopaxi Province of Ecuador.

The members of our survey team are as follows:

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Unfortunately, however, it was rainy season (from November to April) during the months of our field survey, and the land and geological surveys were disturbed by fog and rain.

We have to express our regret that the investigated area was limited because of the bad weather.

II. Outlines of Physiography and Geology

The outlines of physiography and geology in Ecuador were already published by many authors, then are briefly described in the present report.

Physiographically and geologically Ecuador is divided into three provinces; Coastal province (Costa), Andean province (Sierra) and Oriental province (Oriente), and the characteristics of physiography and geology are distinct in each province.

1. Coastal province

The province, comprising from the west foot of the Andes mountains to the coast of the Pacific Ocean, is mainly characterized by flat land under 300m of altitude, and coastal terraces are developed on the coast.

In the province the Guayaquil River, the greatest river on the coast of the Pacific Ocean of South America, winds through flat land, and falls into the Guayaquil Bay.

The tropical climate is prevailing here, and the land is covered with dense forest except plantations.

The geology of the province is composed mainly of Tertiary and Quaternary formations, but some basement rocks, Paleozoic sediments, Mesozoic volcanics and granodiorite, are also found. The stratigraphic column is indicated in Table 1.

According to the investigation by J. G. Marks (1956), the mollusks of Inoceramus are found in the Calentura member of the Callo formation, and it is said that the Callo formation belongs to Late Turonian, on the other hand, the entire Callo formation is appeared to range from Cenomanian to Senonian by the study of microfossils, and may be correlative to the Clavulina shales in Peru and the Palmira and Guadalupe cherts in Columbia.

As later described, the Piñon formation, underlying the Callo formation, is corresponded to the altered volcanic formation in the Macuchi mining district.

Table 1. Stratigraphic column for the Coastal province of Ecuador (by J. G. Marks, 1956)

Age and stratigraphic position (with map unit abbreviations)		Rock units	Thickness (meters)
Quaternary (Qc)	Recent	Andean piedmont, fluvial, and mangrove deposits	?
	Pleistocene	Tablazos, alluvial fans	?
Tertiary (T)	Pliocene	Puná fm., Jama fm., Canoa fm.	80
	U. Miocene	Borbón fm. (part), Punta Gorda fm., strata on Puná Island	?
	M. Miocene	Borbón fm. (part), Bahía fm., Daule fm., Progreso fm.	3000
	L. Miocene	Angostura fm., (part), Onzole shale, Charapotó shale, Subibaja fm.	600
	U. Oligocene	Angostura fm. (part), San Agustín sdst., Viche shale, Tosagua shale, Lacruz fm., Rodeo fm. (part)	650
	M. Oligocene	Chumundé ash beds, Zapotal sdst., Rodeo fm. (part)	?
	L. Oligocene	Playa Rica fm., San Mateo fm., (part) Ancón Point fm.	170
	U. Eocene	Zapallo shale, San Mateo fm. (part), Jusá shale, Salanguilo sdst., Seca shale, "Zapotal" fm. (subsurface), red-beds of El Morro	275
	M. Eocene	San Eduardo ls., Middle grits, Clay Pebble bed, Javita ls., Socorro fm.	500
Upper Cretaceous and Lower Eocene(Ku)	Paleocene	Estancia sandstone, San José sandstone, San José shale, Atlanta fm.	1300
	U. Cretaceous	Callo fm., Guayaquil chert	3000
Cretaceous Igneous (Ki)		Pascuales granodiorite	
Cretaceous or Jurassic?(Jv)		Piñon volcanics	1000
Paleozoic (Pal)		Punta Piedra rocks	

2. Andean province

The Andean province is characterized by high land over 3,000 m of altitude, and is made up of three divisions; Cordillera Oriental (or Cordillera Real), Intercordilleran Depression and Cordillera Occidental.

The mountains of Cordillera Oriental stretch from north to south parallel to of Cordillera Occidental, and there are many peaks, which rise to altitude greater than 4,500 m, the highest is El Chimborazo (6272 m), the second is El Cotopaxi (5896 m), and such magnificient summits are covered by glacier.

Between both Cordilleras Intercordilleran Depression is situated, and main cities in Ecuador, such as Quito, Latacunga, Ambato and Cuenca, are situated in the division.

The climate of the province is mild all the year round, and rainfall is scanty.

The geology of Cordillera Oriental consists mainly of metamorphic rocks, which are originated frpm sediments in the Paleozoic geosyncline, and the metamorphic belt is bounded by the great fault zone and Quaternary formation.

On the other hand, the Mesozoic altered volcanics and sediments are widely distributed in Cordillera Occidental. Stratigraphically the altered volcanic formation is corresponded to the Piñon formation of Jurassic or early Cretaceous in the Coastal province, and is widely developed in the Macuchi mining district. The upper Cretaceous formation, composed of andesite, tuff, siliceous shale and limestone, is also developed on the east side of the division, and granodiorite intrusives of late Cretaceous are observed in Cordillera Occidental.

Intercordilleran Depression is covered by Quaternary volcanic rocks, but Tertiary lake sediments are locally developed in the division.

3. Oriental province

The province is so-called "Oriente" in Ecuador, and the extent from the east slope of Andean province to the Amazon basin is comprised in the name of "Oriente".

The climate of the province, covered by extensive dense forest, is tropical and damp.

Prior to the serch for oil, the geology of jungle area remained unknown, but geological survey has been carried out by the geologists of oil companies recently.

The geology of the province is resembled to of the Coastal province, and consists of Tertiary and Quaternary formations, accompanied by Paleozoic and Mesozoic sediments and intrusives. The stratigraphic column is shown in Table 2.

The geological history of Ecuador can be deduced from the stratigraphy and geological structure as follows; the Sierra de Cutucú Paleozoic geosyncline during Pre-Cambrian or early Paleozoic was intensely compressed by the Caledonian movement, and the metamorphic rocks had occurred from the sediments and igneous rocks in the geosyncline.

Thereafter transgression and regression were repeated by crustal movements from Carboniferous to early Jurassic in the Andean province, and there was a great regression during Jurassic and early Cretaceous, because of severe orogenic movement during the same time, and the crustal movement revived during late Cretaceous.

The volcanic activities had been assumed from Paleogene to Neogene, and the glacier was widely distributed during Quaternary, thus the Andean province was extensively elevated after the glacial age (Fig. 1 & 2).

Table 2. Stratigraphic column in Upper Amazon Basin

(by H. J. Tschopp, 1956)

Age and stratigraphic position (with map unit abbreviations)			Rock units	Thickness (m)
Quaternary Qc			Piedmont and Mesa deposits	
Tertiary-Recent QMv			Volcanic rocks deposited by Tertiary to Recent volcanoes	
Tertiary		Miocene and Pliocene	Chambira and Ushpa formations Curaray formation Arajuno and upper Pastaza formations	about 2500-5000
		?Eocene--Oligocene	Chalcana, lower and middle Pastaza formations Tiyuyacu and Cuzutca formations	
		?Upper Cretaceous--Paleocene--?Lower Eocene	Tena formation	270-1000
Chiefly Cretaceeus Ki			Igneous rocks, chiefly intrusive	
Cretaceous K		Upper Cretaceous Middle Cretaceous	Napo formation	240-800
		Lower Cretaceous	Hollin formation	80-240
Upper, Middle and Lower Jurassic	Jv	Middle to Upper Jurassic	Chapiza formation: in upper part, Misahualli member, equivalent to porphyrites and subsequent granite intrusions (Topo granite, Ki)	
	J§	Lower Jurassic	Santiago formation	1500-2700
Paleozoic PAL		Carboniferous (Pennsylvanian)	Macuma formation	Upper, about 1250 Lower, about 150-200
		Early Paleozoic	Pumbuiza and Margajitas formations	1000 plus
Crystalline Metamorphic Basement pKm		Paleozoic and/or pre-Paleozoic	Ortho- and paragneisses, mica schists, and phyllites intruded by granitic rocks	

III. General View of Mining Industry

Hitherto, the mineral resources in Ecuador have not been developed except some gold and petroleum deposits. The great interest of mineral resources, however, has been aroused throughout Ecuador recently, and many informations of minerals are gathered and the localities of them are arranged by the Mining Office of Ecuador Government (Fig. 3).

The present situation of mining industry in Ecuador is about same as that in the report of Japanese geological survey team in 1960.

It appears that the inactive mining industry is caused by the following facts, (1) extensive area in Ecuador is covered by dense forest and volcanic tuff, which make exploration exceedingly difficult and mask the outcrop of mineral resources, (2) inspite of many investigations by geologists the surveys set limits in rough scale or in small area around mineral deposits, (3) the government of Ecuador has no facility of geological survey.

Gold In Ecuador small mines of alluvial gold and the Portovelo mine yield gold. The earlier history of mining is concerned mainly with gold, for instance, the Santiago river has produced placer gold since 16th century. Some companies in the U.S.A. and England tried to develop gold deposits on a large scale, but the efforts proved unprofitable, thus there were only native workings in production by 1919.

In 1892 the South American Development Company bought the Portovelo mine, and had developed until 1950, but ore reserve and grade were descend, and the mine was conveyed to the "Compania Industrial Mineral Asociada S. A.".

The Portovelo mine, however, is only the important metal mine in Ecuador, and monthly output of crude ore is about 5,000 tons, and grade of worked ore is 6-7 gramms gold per ton, 60-70 gramms silver per ton at present.

It is said that there are over 2,000 mines of gold placer in Ecuador.

<u>Silver</u> Silver was also produced in earlier age of Inca, and many Spaniards tried to explorate for silver deposit, but it was impossible to success in development of silver mine.

The Portovelo mine also yields silver now, and it is said that the possibility of mining at the Pilzhum mine in Cañar Province and the Molleturo mine in Azuay Province is worthy of notice.

<u>Copper</u> There are many copper showings in Ecuador, but the Macuchi mine has the only record of copper production. As later described, the Macuchi mine was worked from 1940 to 1950 by the Cotopaxi Exploration Company, and the total output was 25,750 tons of copper, but the deposit was worked out.

The La Plata mine in Pichincha Province was prospected by the same company in 1946, but the ore reserve were deemed insufficient to develop it.

Most of copper mineralization has been found in the Mesozoic altered volcanic formation associated with granodioritic intrusives along the west slope of Cordillera Occidental, but there is no profitable copper mine besides Macuchi mine for the high cost of road building and transportation.

Iron and Manganese The iron beach sands are known along the Ecuadorian coast, and the grade of refined ore is about 20% TiO_2. And small magnetite-hematite veins are found near Guayaquil, but it is said that the iron deposits are not enough to compensate.

Manganese deposits are known in some places, but have not been developed.

Lead and Zinc In Ecuador lead and zinc in small amounts have been produced, but there is no important deposit of them.

Petroleum and Coal At present petroleum deposits are worked at the Ancon oil field in the Penisula of Santa Elena, and the petroleum production is the most important as the mining industry of Ecuador.

Coal deposits are known in many parts of Andean region, but they cannot be developed on a large scale because of poor grades and high cost of transport.

Other minerals There are non-metallic and industrial mineral deposits, such as sulfur, kaoline, gypsum, magnesite, bentonite, limestone, perlite, and diatomite, on a small scale, and some cement factories are built.

IV. Geology and Ore Deposit in the Macuchi Mining District

1. Location of the Macuchi mine

The Macuchi mine is situated at about 1,600 m above the sea level on the west slope of Cordillera Occidental, and lies about 40 km east of Quevedo and about 60 km west of Latacunga.

A highway from Quito to Guayaquil via Latacunga passes through Macuchi village, and the ruins of mill and refinery of the Macuchi mine are found beside the good pavement of highway (see Pl. 1, Fig. 1 & 2).

It is convenient to drive to Macuchi village, because there are several buses at regular intervals on the highway.

2. Physiography

As the Macuchi mining district is located on the steep slope of Cordillera Occidental, the district is physiographically characterized by the young stage of the Andean mountains.

In the district the Pilalo river wanders northward, and the Amaya river, tributary to the Pilalo river, winds near the Mercedes deposit of Macuchi mine, and many falls are found in gorges.

The climate is mild, because the altitude of the district ranges from 1,500 m to 2,500 m, but rainfall is plentiful in the winter, and the land is covered by forest, and sugar-cane and banana are cultivated around houses in Macuchi village (see Pl. 2, Fig. 1 & 2, Pl. 3, Fig. 1 & 2).

3. Outline of geology

For the purpose of making the geological map, the topographical map on the scale of 1 : 10,000 was made by land survey was carried out based on the topographical map in the Macuchi mining district.

The geology of the district is composed mainly of altered volcanic rocks. According to some published papers, the altered volcanic formation may be corresponded to the Piñon formation underlying the Callo formation, in which the mollusks, Inoceramus plicatus d'Orbigny, I. striatoconcentricus Grübel and I. roemeri Karsten are found, so that the altered volcanic formation may belong to the Jurassic or early Cretaceous.

As later described, some microfossils, radiolaria and diatom (?), are found in the Macuchi district, then it is possible that the geologic age of the altered volcanic formation is determined more exactly by the correlation of microfossils between Macuchi and Piñon formation.

(1) Stratigraphy

The geology of the Macuchi mining district consists mainly of altered volcanic rocks, such as tuff, tuff breccia, agglomerate and lava flow, and sedimentary rocks, shale and sandstone. And some intrusives of plagio-porphyry, hornblende porphyrite and quartz diorite are found in the district.

From the results of route survey from Pilalo to Sanfrancisco, the stratigraphical relation is as follows; the alternation of shale and sandstone at the Pilalo anticline is the lower member, and is covered by the middle member of tuff and tuff breccia, which are widely distributed in the Macuchi district, and agglomerate associated with tuff and shale at the Macuchi syncline is the upper member (Fig. 4).

The stratigraphic column in the surrounding area of Macuchi mine is shown in Table 3 (Fig. 5).

It appears that, however, it should be necessary to investigate the geology in more wide area for study the stratigaphy, because the geologic structure is so complicated.

(2) Composed rocks

As above mentioned, the main composed rocks of the Macuchi mining district are altered volcanic rocks, originated from andesitic rocks in the Mesozoic geosyncline, and are affected by regional hydrothermal alteration, chloritization, epidotization and zeolitization.

<u>Tuff</u> According to the field observation, most of the rock is compact and massive, and of green in color, but the bedding structure is observed in some places (see Pl 4, Fig. 1 & 2).

Under the microscope, the main constituent minerals are quartz, chlorite and a carbonate mineral, sometimes accompanied by plagioclase, augite and glassy inclusion. Small grains of magnetite are arranged parallel to the lamination in some parts with bedding structure (see Pl. 8, Fig. 1 & 2).

Some microfossils, radiolaria and diatom (?), are observed in the tuff, located near the cross point

Table 3. Stratigraphic column in the surrounding area of Macuchi mine

Rock unit	Thickness (m)	References
Tuff	100 +	Intruded by plagio-porphyry
Alternation of agglomerate, tuff and shale	100	Composed mainly of agglomerate associated with tuff (40m in thick) and shale (0m to 20m in thick) in the lower part, and with shale (0m to 15m in thick) in the upper part. The Mercedes deposit lies in the alternation.
Alternation of agglomerate and tuff, and tuff brecoia	200	Interfingered relation between alternation of agglomerate and tuff, and tuff brecoia
Agglomerate and tuff	300	Interfingered relation between agglomerate (0m to 100m in thick) and tuff
Tuff breccia	100	
Tuff	200	
Alternation of tuff and shale	0 - 100	
Tuff	250	
Agglomerate	150	
Tuff	250	
Alternation of tuff breccia and tuff	600	Tuff breccia is characterized by red breccias, and the rock facies is different from of above tuff breccias.

Notice: Lava flows are intercalated in those tuffs.

highway and line of N4,000. It appears that the microfossils cannot immediately prove the geological age of altered volcanic formation, but they would be useful to determine the geological age in future (see Pl. 8, Fig. 3 & 4).

Tuff breccia In the Macuchi district various breccias in size and color are observed in the rock with hydrothermal alteration.

Under the microscope, most of breccia is andesitic rock, but siliceous shale is rarely found, and the matrix is composed of chlorite, epidote, quartz and a carbonate mineral, which are the products of hydrothermal alteration.

Lava flow The altered augite andesite is often found under the microscope, but it is difficult to distinguish the rock from tuff in the field observation, because the rock facies of them are very similar. It suggests that most of the rock may be lava flow interculated in tuff.

The phenocryst consists mainly of augite and plagioclase with zonal structure, accompanied by common hornblende locally, and the flow structure is often observed in the groundmass, composed of plagioclase, augite and magnetite (see Pl. 9, Fig. 1 & 2).

The rock is also altered by chloritization, epidotization and carbonatization.

In the district green rocks predominated in white spot are found, and they are proved to be lava flow in the microscopic observation. The white spot is composed of hydrothermal altered minerals, such as quartz, a carbonate mineral, chlorite and zeolite.

As later described, the white spot is also developed in some rounded blocks of agglomerate.

Agglomerate   Most of the rock is agglomeratic tuff, and rounded blocks of andesite are cemented by volcanic tuff (see Pl. 5, Fig. 1 & 2), and the alternation of agglomerate and tuff with bedding structure is sometimes observed in the district (see Pl. 6, Fig. 1 & 2).

Under the microscope, the rounded blocks in agglomerate consist mainly of augite andesite, and some blocks are predominant in the white spot, composed of hydrothermal altered minerals (see Pl. 9, Fig. 4).

Shale   The rock is interculated in volcanic rocks as thin layer, and the shale bed is not persistent in the Macuchi mining district.

Under the microscope, the rock is composed mainly of fine-grained quartz, plagioclase and a carbonate mineral.

Sandstone   The rock is found near Pilalo, and is alternated with shale (see Pl. 7, Fig. 1). The main constituents are quartz, plagioclase, common hornblende and biotite, and it suggests that the rock is thermal metamorphosed weakly.

And also a thin bed of tuffaceous sandstone is observed at the boundary between shale and tuff near the Mercedes deposit, and it is composed of quartz, plagioclase, a carbonate mineral and chloritized mafic mineral (see Pl. 7, Fig. 2, Pl. 10, Fig. 1 & 2).

In the Macuchi mining district some intrusives, such as plagio-porphyry, hornblende porphyrite and quartz diorite, are found.

Plagio-porphyry By the west side of Mercedes deposit the alternation of tuff and agglomerate is intruded by a sheet of plagio-porphyry, and some xenoliths of tuff are found in the intrusive body.

According to the field observation, the intrusive rock is fine-grained massive and compact, and of greyish white in color, and cannot be found phenocryst.

Under the microscope, however, the rock is composed of phenocryst and groundmass, and the main constituents of phenocryst are plagioclase with zonal structure and chloritized mafic mineral (hornblende ?) in small amounts, and of groundmass are fine-grained quartz and small amounts of plagioclase (see Pl. 10, Fig. 4).

Hornblende porphyrite A small intrusive of hornblende porphyrite is observed in agglomerate near the ruin of mill (Fig. 6).

The phenocryst and groundmass are composed of common hornblende, augite and plagioclase, and the rock is weakly altered by carbonatization (see Pl. 10, Fig. 3).

Quartz diorite In the Macuchi district small stocks of quartz diorite are found, but they cannot be examined under the microscope, because are decomposed.

Examined the hydrothermal alteration of composed rocks in the Macuchi mining district, the volcanics are regionally altered by chloritization, epidotization, zeolitization and carbonatization.

On the contrary, the regional hydrothermal alteration could not be observed in the intrusives, then it appears that the activities of intrusives had started later to the alteration.

As later described, the altered rock characterized by silicification and sericitization is developed near the ore deposit, and the rock may be related with metallization.

(3) Geologic structure

As above described, an anticlinal structure at Pilalo and a syncline or synclinorium at Macuchi are found in the Macuchi district.

The folding axes generally trend from north to south, and bedding planes on the wings of folding incline at steep angle of 50-70°.

The complicated folding, combined with anticline and syncline in a smaller scale, is observed near Macuchi mine, and the structure is appeared to be synclinorium, stretched from the syncline in the north side.

The folding axes may plunge to south, and the trend of axes turns from NNW to NNE near Minchua.

It appears that the geologic structure in the Macuchi mining district was mainly constructed by the intense folding movement during early or middle Cretaceous after the sedimentation of volcanic pyroclastics in the Mesozoic geosyncline.

4. Ore deposit

There are many copper showings in the Mesozoic altered volcanic belt, located on the west slope of Cordillera Occidental, but almost all deposits have not been developed besides Macuchi mine.

It seems that the inactivity of mining is due to the following facts; (1) the region of altered volcanic belt is characterized by steep mountains with dense forest, which make exploration, road building and transportation difficult, (2) there is no detailed topographical map, and the geological investigations set limits in rough scale.

(1) History of the Macuchi mine

The Macuchi mine was prospected for gold and silver by Mr. Saravia during the colonial period of Spain, and was developed by Mr. Carloo Seminario from 1930 to 1935. In 1936 the mine was bought by the Cotopaxi Exploration Co., a subsidiary of the South American Development Co., and was worked from 1940 to 1950. The total output was 25,750 tons of copper and 3,000 to 4,000 kg of gold. The copper produced in Ecuador during those years came from the Macuchi mine.

The mining at Macuchi mine was in a prosperous condition from 1940 to 1945, and the crude ore was treated by selective flotation and the concentrates were smelted at the Macuchi mine, producing copper matte containing all the gold, for shipment to a refinery in the U.S.A.

But the production had been inclined to restrict since 1946, and the efforts of exploration had failed to reveal additional commercial ore in the surrounding area. In 1950 the Mercedes deposit was worked out, and the mining was obliged to rest, and all equipments of mining, mill and refinery were withdrawn.

According to the reports of the Cotopaxi Exploration Co., submitted to the Mining Office of Ministry of Works, the hydroelectric plant and equipments for mining were completed in 1940, and the exploration was carried out on A-level by physical prospecting, and succeeded in finding of ore shoot by drilling near 1-level. And 6-level was developed for finding of new ore under the mineralized zone by the road from Macuchi to Quevedo, but the prospecting had failed.

In 1940 the total output of crude ore was 58,046 tons, 136 tons per day, and the total production from the Macuchi mine was 558 kg of gold, 2,600 kg of silver and 1,850 tons of copper, and the grade of crude ore was 3.2% Cu in average.

In 1942 the total output of crude ore increased to 90,950 tons, daily tonnage was 324 tons, and 912 kg of gold, 4,660 kg of silver and 3,800 tons of copper were produced, then the crude ore contained 4.2% Cu.

The scale of Mercedes deposit was investigated by drillings, the total length of which was 3,400 m, and the results suggested that the probable ore estimated by drillings was less than the possible ore in 1940, and the possibility of success in prospecting was limited in the surrounding area of Mercedes deposit.

According to the report in 1944, the total output of crude ore was 91,311 tons, 318.7 tons per day, and the average ore grade was 11.6 gramms gold per ton, 77 gramms silver per ton and 4.34 percent copper.

The prospecting by drilling was carried out on 2035- and 2170-levels, but some ore bodies in poor content of copper could be found.

There were 1385 workers of Ecuadorian besides 26 foreign engineers at the Macuchi mine, and salary of a worker was 25 to 30 Sucres (1$ ≑ 20 Sucres) per day.

The ore reserve, at the date of Jan. 1st in 1945, is shown in Table 4, and the total output in 1945 was 99,000 tons, daily tonnage was 345 tons, and the crude ore contained 12.6 gramms gold per ton, 67 gramms silver per ton and 4.8% Cu.

From 1946 to 1950 the ore deposit had been worked, but the production was inclined to restrict as Table 5.

Table 4. Ore reserve at Macuchi mine (Jan. 1st, 1945)

Level	Known ore reserve (t)	Output (t)	Average grade			Extant ore reserve (t)
			Au(gr/t)	Ag(gr/t)	Cu(%)	
B-1/3	11,451	10,883	12.2	68	2.35	568
A B	270,191	258,726	11.5	68	4.59	11,465
1 A	213,088	136,946	11.7	68	4.94	76,142
2 1	61,720	22,747	11.8	68	4.29	38,973
3 2	9,281	6,438	10.5	68	4.29	2,843
6 3	-	-	-	-	-	-
Total	564,731	435,740	11.6	68	4.67	129,991

Table 5. Output of copper from Macuchi mine

Year	Cu (t)	Year	Cu (t)	Year	Cu (t)
1940	1,850	1944	3,450	1948	350
1941	3,900	1945	4,000	1949	800
1942	3,800	1946	2,050	1950	600
1943	4,850	1947	100		

(Total) 25,750 tons of copper

At present the pit-mouths of Macuchi mine are closed by the iron gate or hidden under earth, and the temperature in pit is elevated by oxidation of sulfide ore, then underground survey is impossible.

(2) Ore deposit

The underground survey could not be carried out owing to destruction of pit at the Macuchi mine.

According to the datas of Cotopaxi Exploration Co., the ore body occurred as an irregular, steeply dipping lenses concordant with the bedding structure. The size of ore body was 100 m long on the strike, 125 m long on the plunge and 18 m thick in the thickest part.

From the results of our investigation, the stratigraphical position of Mercedes deposit lies in the upper member, composed of agglomerate associated with tuff and shale, and the deposit is situated on the west wing of anticline in synclinorium structurally.

The altered zone with metallization is developed near the deposit, and is characterized by bluish clay stone, and hard and compact rock with silicification, sericitization and sometimes hematitization. The altered rocks are often associated with impregnated sulfide minerals.

Under the microscope, the main constituent minerals of altered rocks are quartz, sericite and chlorite, and relic structure of volcanic rocks is often observed (see Pl. 11, Fig. 1 & 2).

(3) Ore minerals

There are some kinds of ores, such as compact pyritic ore, impregnated pyritic ore, chalcopyrite rich ore and sphalerite-galena ore, in the Mercedes deposit.

1) Compact pyritic ore

The ore is divided into fine-grained and course-grained ores.

Under the ore microscope, the coarse-grained ore is composed mainly of pyrite, chalcopyrite and sphalerite, associated with small amounts of tetrahedrite, galena, bornite and covelline.

Minute inclusion of chalcopyrite is observed in some crystals of sphalerite, and the texture is similar to an exsolution texture, but it appears that the texture is caused by replacement, because the minute inclusion of chalcopyrite is partially observed in the margin of sphalerite crystals.

Small veinlet of covelline may occur as secondary enrichment by oxidation of weathering, but bornite may be primary mineral (see Pl. 11, Fig. 4).

On the other hand, the fine-grained ore consists mainly of pyrite, accompanied by small amounts of chalcopyrite and sphalerite (see Pl. 11, Fig. 3).

2) Impregnated pyritic ore

Magascopically the ore is composed of many small grains of disseminated pyrite, but chalcopyrite, sphalerite and small amounts of galena are observed besides pyrite under the ore microscope.

3) Chalcopyrite rich ore

The ore is compact and massive. It seems that the chalcopyrite rich ore was copper source of Macuchi mine.

Under the ore microscope, the main constituent ore minerals are chalcopyrite, pyrite and sphalerite, accompanied by galena and tetrahedrite (see Pl. 12, Fig. 1).

Minute grains of native gold are observed in chalcopyrite under high magnified objective (see Pl. 12, Fig. 2). The silver mineral cannot be found, but silver may be contained in tetrahedrite.

4) Sphalerite-galena ore

Megascopically the ore is also compact and massive, and of black in color. The ore is very similar in appearance to the so-called "black ore (Kuroko in Japanese)", composed mainly of sphalerite and galena, from the "Kuroko deposits" in the "Green tuff" region in Japan.

Under the ore microscope, the ore consists of sphalerite, galena, pyrite and tetrahedrite, and crystal form of pyrite is sometimes resembled to a colloform texture (see Pl. 12, Fig. 3 & 4).

(4) Gangue minerals

Examined those ores under the microscope, the gangue minerals are quartz, sericite, a carbonate mineral, chlorite and barite, and there is no great difference among various ores concerning to the kind of gangue minerals.

(5) Ore reserve

According to the datas of Cotopaxi Exploration Co., the total quantity of ore mined from the Macuchi mine was 472,156 tons, and the average grade of crude ore was 4.7% Cu, 11.6 gramms gold per ton and 68 gramms silver per ton.

And the extant ore reserve is estimated at 139,000 tons, but it occurres at the marginal part of Mercedes deposit, then it may be poor content of copper.

V. Potentiality of the Macuchi mining district

In the report of Japanese geological survey team in 1960, it was described that the exploration in the Macuchi mining district was limited in the area, underlying the Mercedes deposit, then it should be possible to find new ore bodies if the prospecting would be made along the strike side of ore horizon.

Examined the underground map of Macuchi mine, however, the Cotopaxi Exploration Co. already made the prospecting along the strike side, and also tried to prospect with drillings at the altered zone by the west side of Mercedes deposit, but the efforts of prospecting had failed.

In view of the above results, we find it difficult to avoid the conclusion that the possibility in reference to the exploration may be exhausted in the surrounding area of Mercedes deposit.

The geology of the Minchua district is similar to of the Macuchi district, and the exploration with drillings was carried out at the altered zone by the Cotopaxi Exploration Co., but it could not success in the finding of new ore.

However, it is necessary to investigate in more detail by land and geological surveys with physical exploration and drilling in the Minchua district, because the altered zone with metallization is widely distributed in the Minchua district.

As above mentioned, there are many copper showings in the Mesozoic altered volcanic formation on the west slope of Cordillera Occidental, and it suggests that the geological survey should be carried out in the altered volcanic belt in near future, because the potentiality of mining would be admitted in the region.

We suggest the advisability of efforts being made to survey the geology and to develop the copper deposits in the Mesozoic altered volcanic belt by the Government of Ecuador.

And it seems that the vestment in mining is not attractive for foreigners, because the scale of copper deposits is not so large.

VI. Conclusion

Our survey was carried out for the purpose of making the geological map based on the detailed topographical map in the Macuchi mining district.

The geology of the Macuchi mining district is composed mainly of andesitic volcanic rocks, affected by regional hydrothermal alteration, and sediments in the orogenic belt of Mesozoic geosyncline. And also some intrusives, such as plagio-porphyry, hornblende porphyrite and quartz diorite, are found in the district.

The copper deposit of Macuchi mine lies in the upper member, composed of agglomerate with tuff and shale, and is situated on the west wing of anticline in synclinorium.

The Mercedes deposit is irregular, steeply dipping lenses in form, and is 125 m long on the plunge, 100 m long on the strike and 18 m thick in the thickest part in size.

There are some kinds of ores, such as pyritic ore, chalcopyrite rich ore and sphalerite-galena ore in the deposit, and the ore minerals are pyrite, chalcopyrite, sphalerite, galena and tetrahedrite, accompanied by small amounts of bornite, covelline and native gold, and quartz, sericite, chlorite, barite and a carbonate mineral are found as gangue minerals.

The altered zone with metallization, characterized by silicification, sericitization, chloritization and sometimes hematitization, is developed in the surrounding area of the deposit.

The total output of crude ore from Macuchi mine was 472,156 tons, and average ore grade was 4.7% Cu, 11.7 gramms gold per ton and 68 gramms silver per ton, and there were 1,350 workers at Macuchi mine in 1945.

The Mercedes deposit was worked out, and the efforts of exploration had failed, then the mining rested in 1950, but the extant ore reserve is estimated at 139,000 tons.

In the Macuchi mining district the possibility concerning to mining may be exhausted, but it is necessary to investigate in more detail by land and geological survey with physical exploration and drilling in the Minchua district.

It merits peculiar notice that the characteristics of geology and ore deposits in the Mesozoic altered volcanic formation are very similar to them in the "Green tuff" region, in which there are many great ore deposits, in Japan.

We suggest that the geological survey should be carried out in the Mesozoic altered volcanic belt on the west slope of Cordillera Occidental because of high potentiality for mining in near future.

References

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PLATE 1.

Fig. 1. General view of the Macuchi mining district.

Fig. 2 Ruins of the mill and refinery of Macuchi mine.

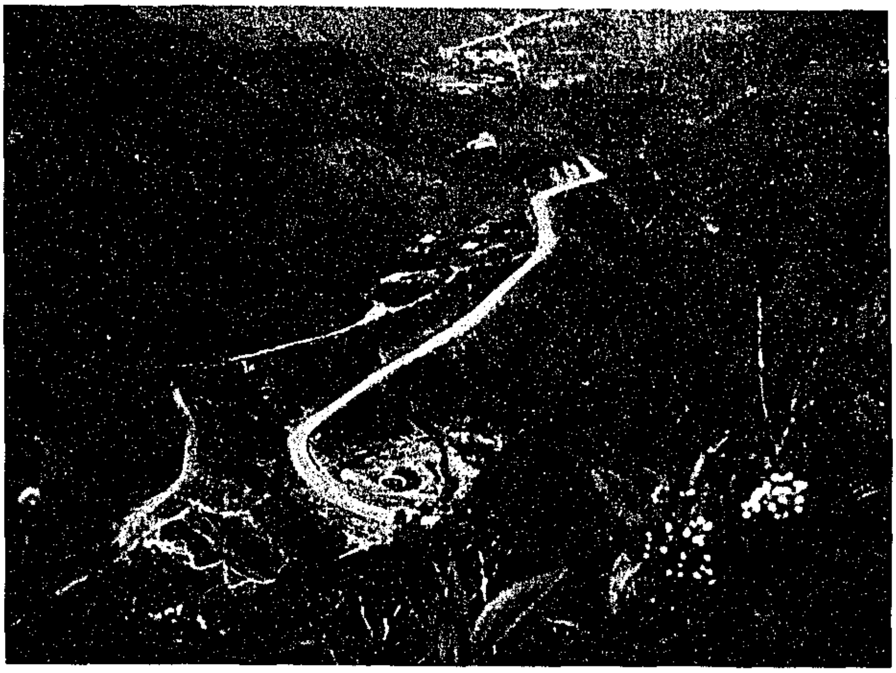


Fig. 1

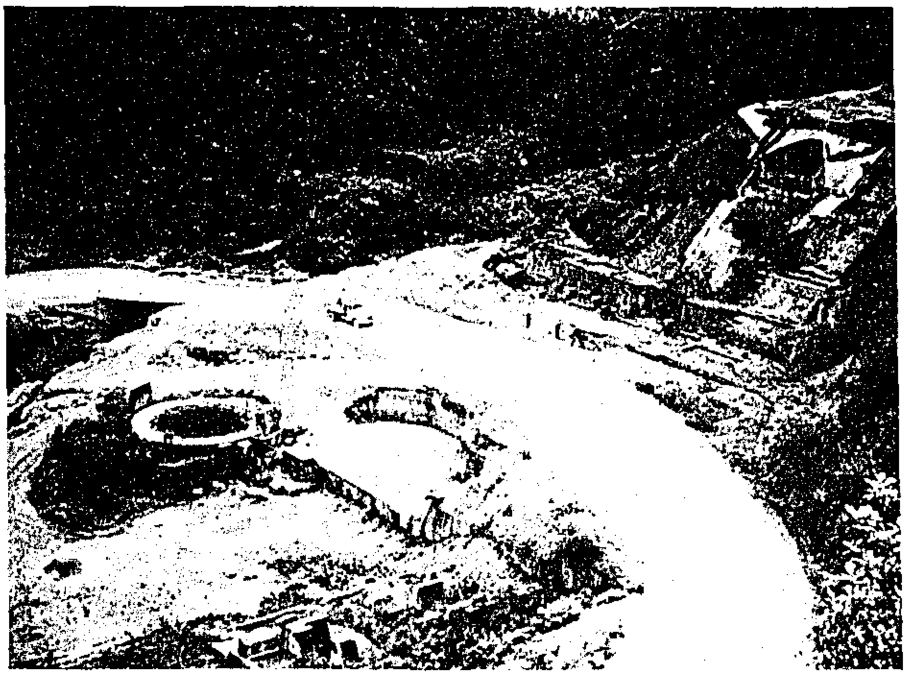


Fig. 2

PLATE 2.

Fig. 1. Sludge of Macuchi mine near Pilalo river.

Fig. 2. Land surveying in the forest.

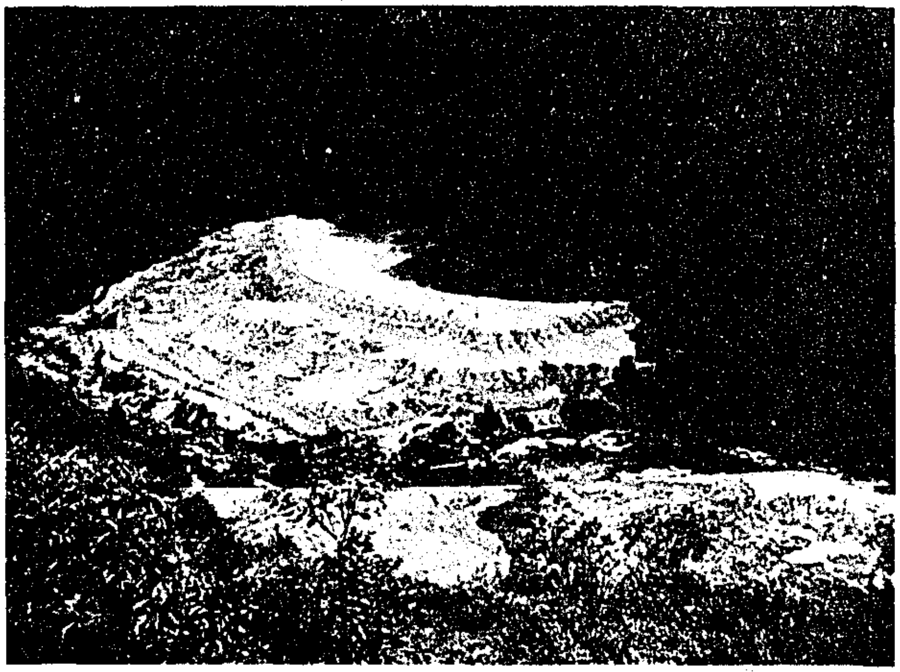


Fig. 1

Fig. 2

PLATE 3.

Fig. 1. The space near the pit mouth of A-level.

Fig. 2. Mountain and valley of the Macuchi mining district.
White part: Waste heap above A-level

Fig. 1

Fig. 2

PLATE 4.

Fig. 1. Green tuff with bedding structure by the side of mill of Macuchi mine.

Fig. 2. Ditto at the highway on N,6000.

Fig. 1

Fig. 2

PLATE 5.

Fig. 1. Agglomerate on the valley of Queb sn Uoaquin.

Fig. 2. Ditto near the pit mouth of 1-level.

Fig. 1

Fig. 2

PLATE 6.

Fig. 1. Alternation beds of agglomerate and tuff near Imagen de Maria.

Fig. 2. Ditto near Huella de Planta Electrica.

Fig. 1

Fig. 2

PLATE 7.

Fig. 1. Alternation beds of shale and sandstone near the town of Pilalo.

Fig. 2. Alternation beds of tuff and sandstone at the mouth of Queb sn Uoaquin.

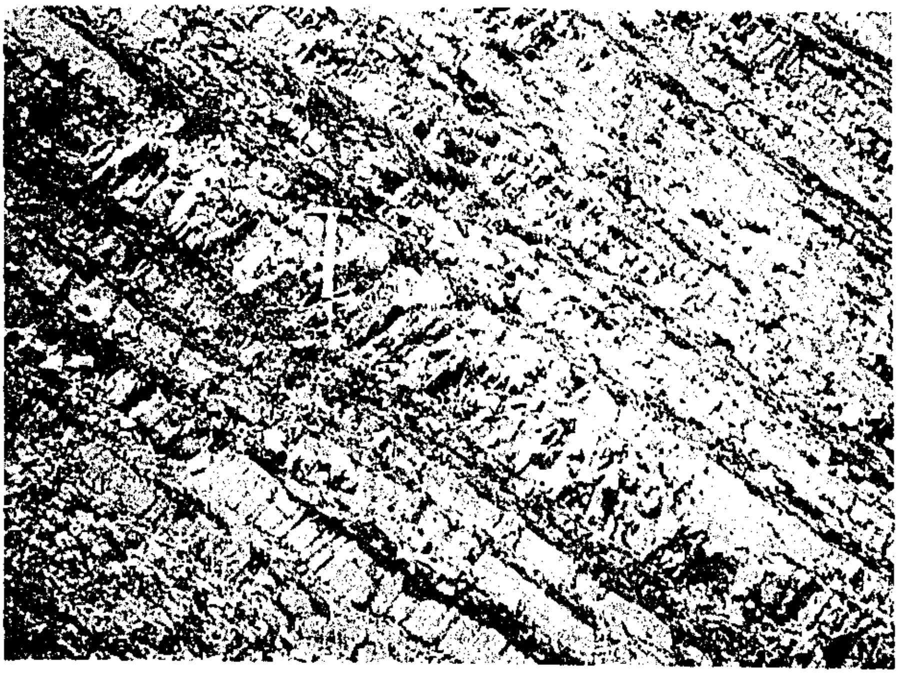


Fig. 1

Fig. 2

PLATE 8.

Photomicrographs.

Fig. 1. Tuff (62121502). One nicol.

X 40.

Fig. 2. Tuff with lamination (62121702). One nicol.

X 40.

Fig. 3. Radiolaria in tuff (63010814). Cross nicols.

X 90.

Fig. 4. Diatom in tuff (63010814). Cross nicols.

X 70.

Fig. 1

Fig. 2

Fig. 3

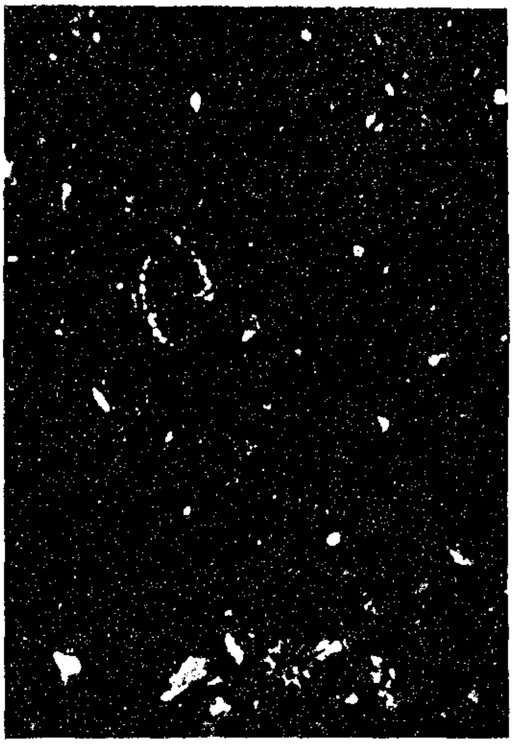


Fig. 4

PLATE 9.

Photomicrographs.

Fig. Lava flow of altered augite-andesite (62121801).

pl: plagioclase ag: augite

One nicol. X 40.

Fig. 2. Lava flow of altered andesite (62121905).

pl: plagioclase One nicol. X 40.

Fig. 3. Tuff-breccia (62121502). One nicol. X 40.

Fig. 4. Altered augite-andesite of rounded block in agglomerate (63010803).

chl: chlorite ag: augite

One nicol. X 40.

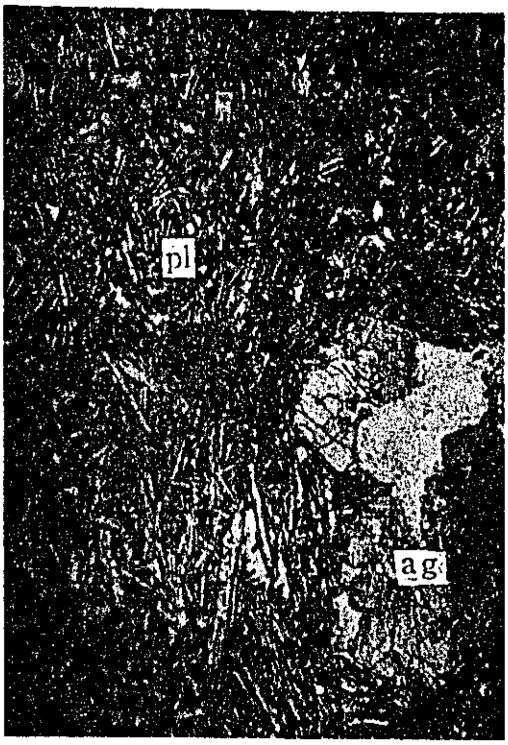


Fig. 1

Fig. 2

Fig. 3

Fig. 4

PLATE 10.

Photomicrographs.

Fig. 1. Taffaceous sandstone (62121708). One nicol. X 40.

Fig. 2. Ditto. Cross nicols. X 40.

Fig. 3. Brown hornblende-augite andesite (63010802).
hb: hornblende One nicol. X 40.

Fig. 4. Plagio-porphyry (63010902).
pl: plagioclase Cross nicols. X 40.

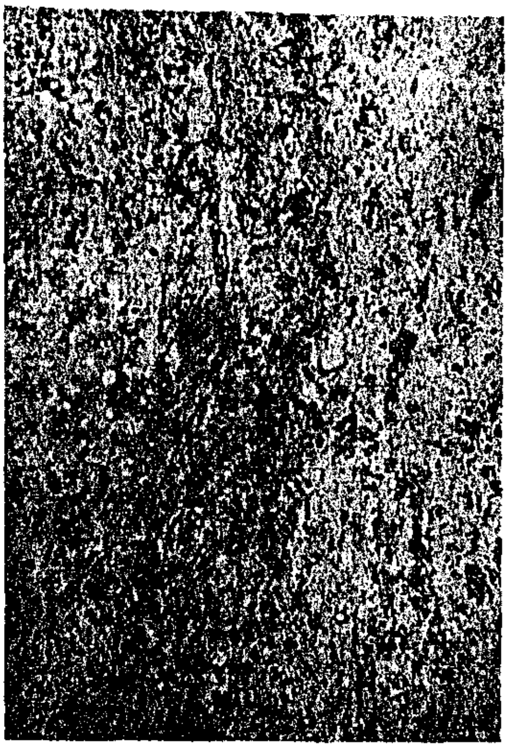


Fig. 1

Fig. 2

Fig. 3

Fig. 4

PLATE 11.

Photomicrographs.

Fig. 1. Altered rock with mineralization (63011002).

py: pyrite One nicol. X 40.

Fig. 2. Ditto, sr: sericite. Cross nicols. X 40.

Fig. 3. Fine-grained pyritic massive ore (Polished section-E).

py: pyrite X 110.

Fig. 4. Course-grained pyritic massive ore (Polished section-B).

py: pyrite sp: sphalerite cp: chalcopyrite gn: galena G: gangue mineral

X 110.

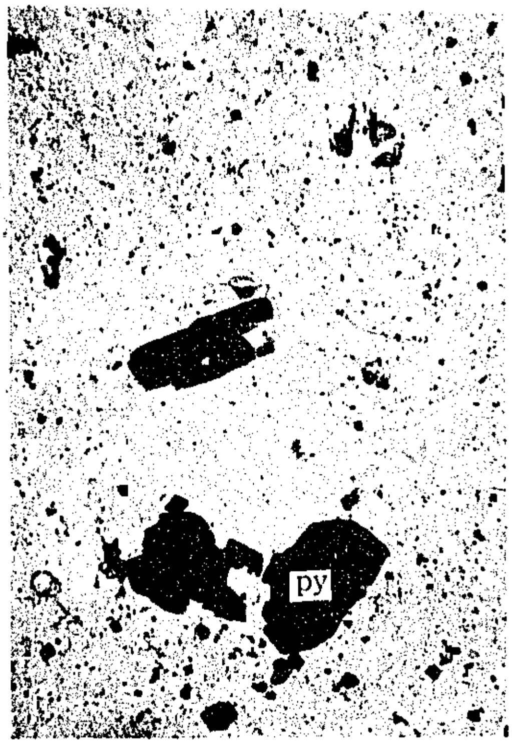


Fig. 1

Fig. 2

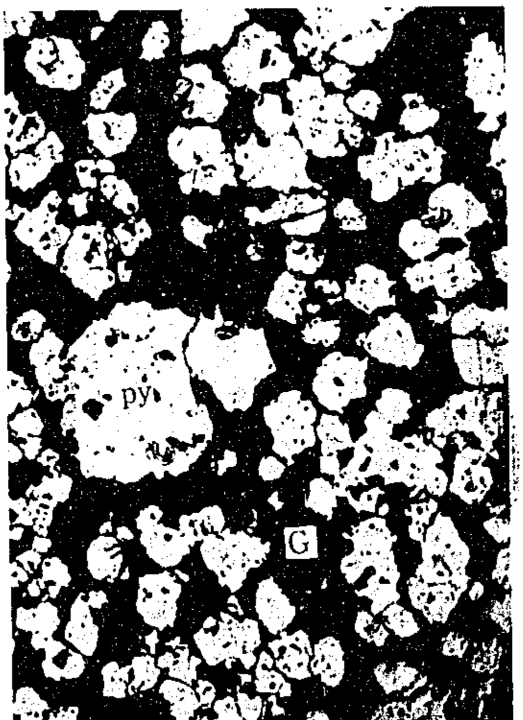


Fig. 3

Fig. 4

PLATE 12.

Photomicrographs.

Fig. 1. Chalcopyrite-rich ore (Polished section-A).

cp: chalcopyrite td: tetrahedrite

py: pyrite

X 110.

Fig. 2. Native gold in chalcopyrite of chalcopyrite-rich ore (Polished section-A).

au: native gold cp: chalcopyrite

G: gangue mineral

X 500.

Fig. 3. Sphalerite-galena ore (Polished section-D).

sp: sphalerite td: tetrahedrite

py: pyrite

X 110.

Fig. 4. Sphalerite-galena ore (Polished section-C).

py: pyrite sp: sphalerite

gn: galena G: gangue mineral

X 110.

Fig. 1

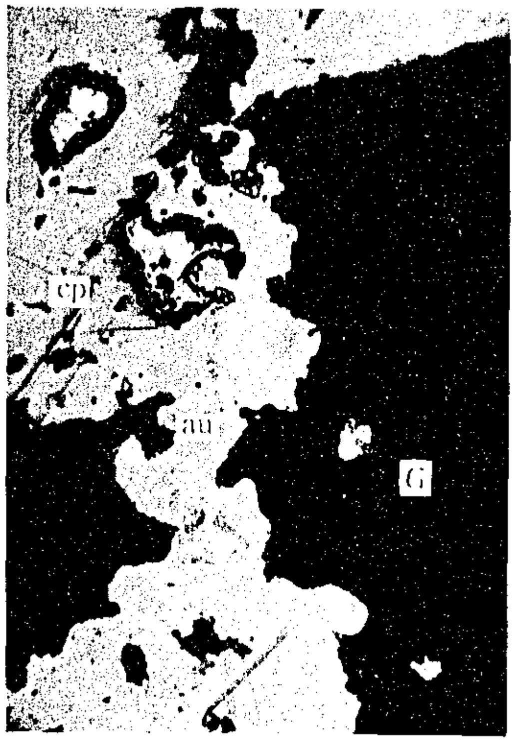


Fig 2

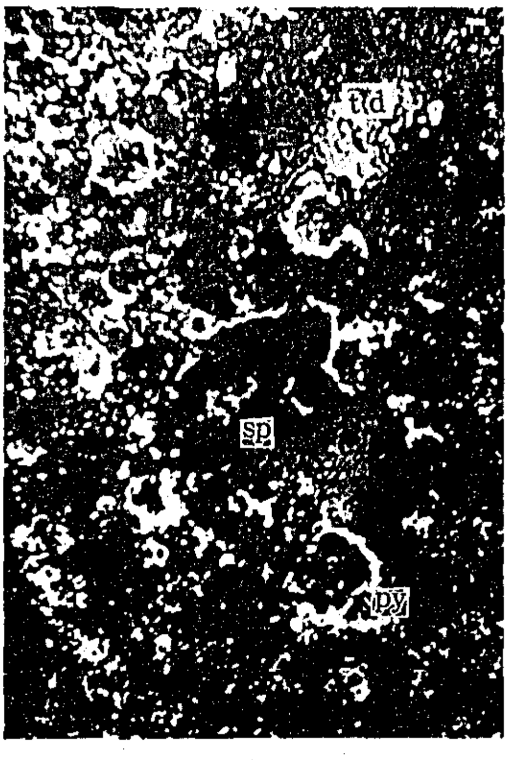


Fig. 3

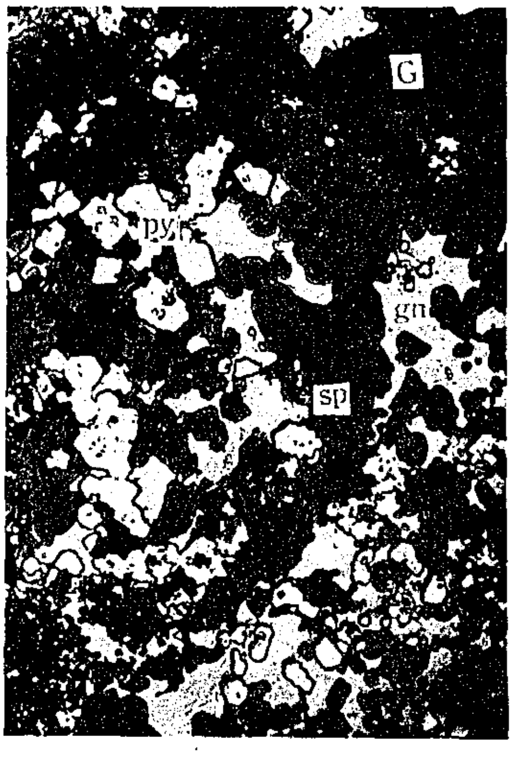


Fig. 4

Fig. 1

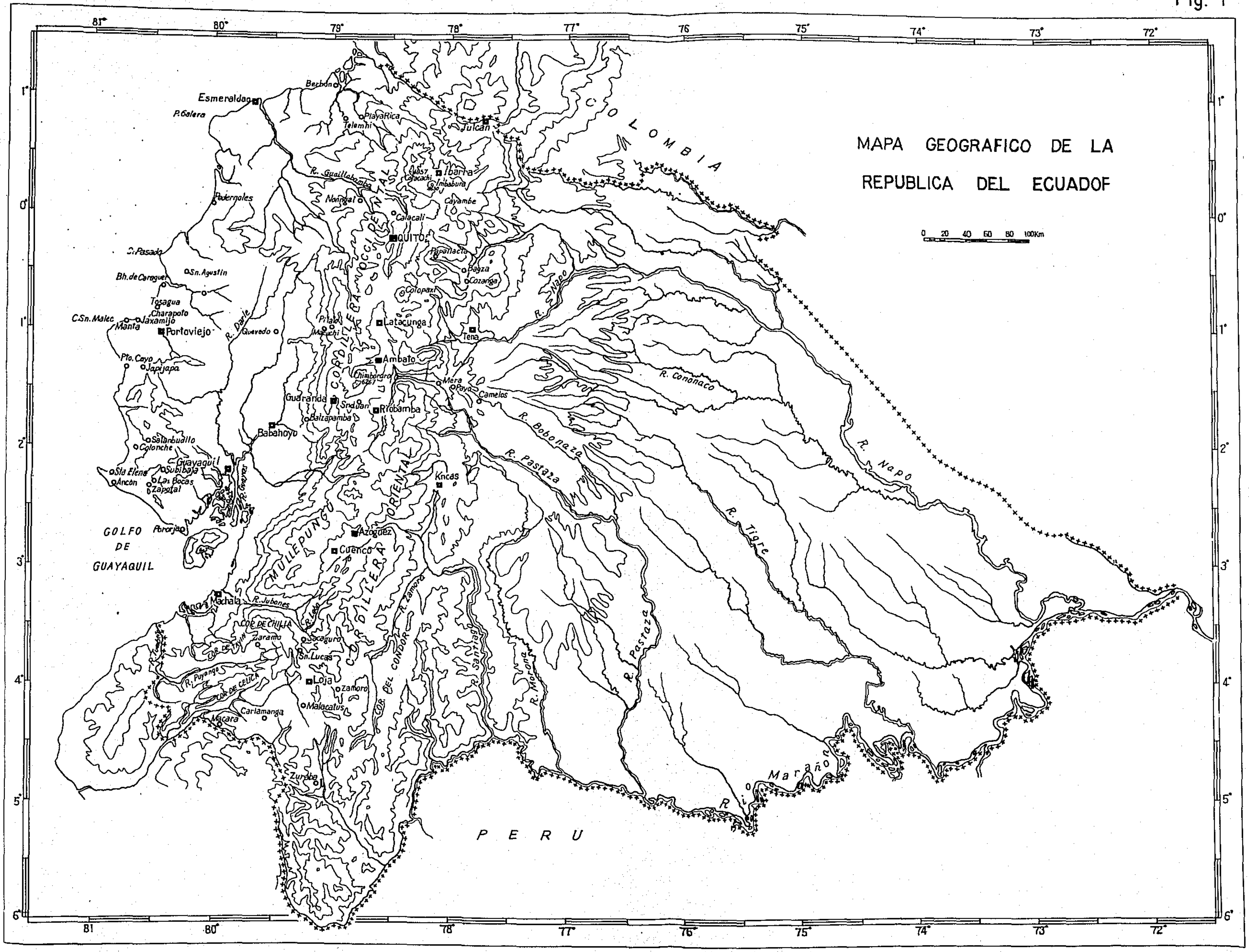

MAPA GEOGRAFICO DE LA
REPUBLICA DEL ECUADOF
0 20 40 60 80 100Km
COLOMBIA
PERU
GOLFO DE GUAYAQUIL
Esmeraldas
Julcan
Ibarra
QUITO
Latacunga
Ambato
Riobamba
Guaranda
Babahoyo
Guayaquil
Portoviejo
Manta
Tena
Azoguez
Cuenca
Machala
Loja
R. Napo
R. Curaray
R. Bobonaza
R. Pastaza
R. Tigre
R. Zamora
R. Jubones
R. Morona
Marañon
CORDILLERA OCCIDENTAL
CORDILLERA ORIENTAL
MULLEPUNGU
COR. DEL CONDOR

Fig. 2

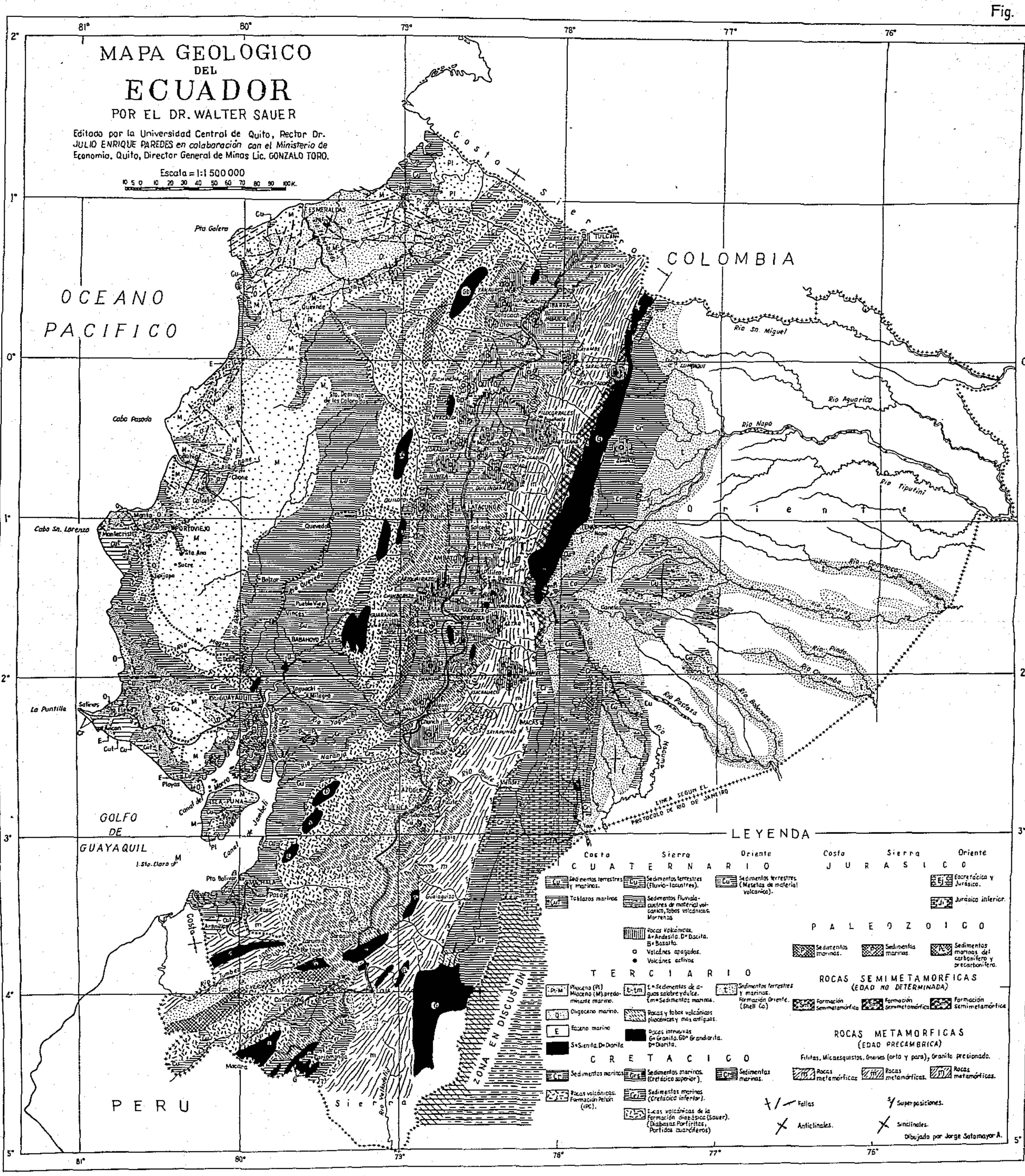
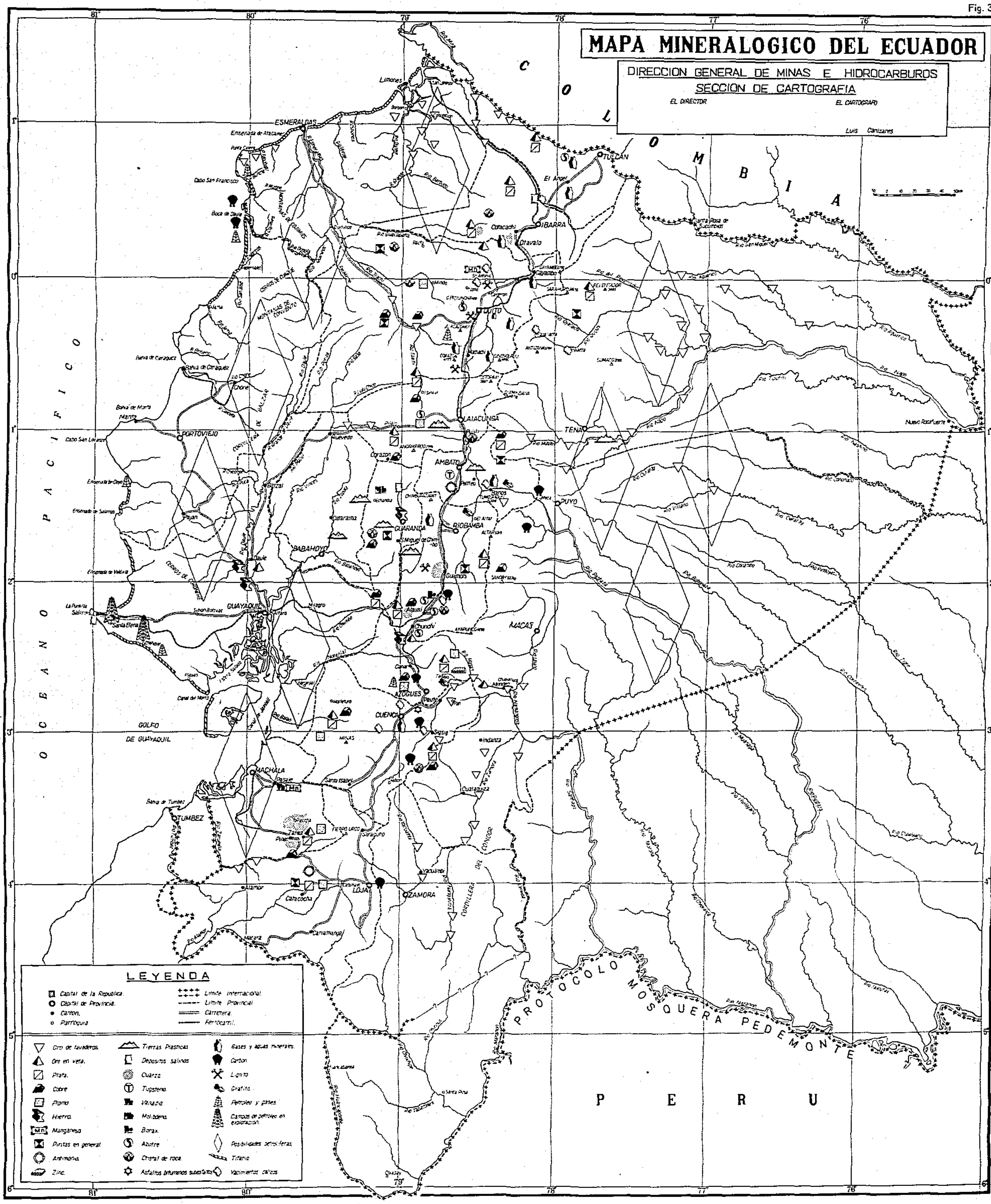

MAPA GEOLOGICO
DEL
ECUADOR
POR EL DR. WALTER SAUER
Editado por la Universidad Central de Quito, Rector Dr. JULIO ENRIQUE PAREDES en colaboración con el Ministerio de Economía. Quito, Director General de Minas Lic. GONZALO TORO.
Escala = 1:1 500 000
OCEANO PACIFICO
COLOMBIA
PERU
GOLFO DE GUAYAQUIL
ZONA EN DISCUSION
LINEA SEGUN EL PROTOCOLO DE RIO DE JANEIRO
Costa
Sierra
Oriente
Rio Sn. Miguel
Rio Aguarico
Rio Napo
Rio Tiputini
Rio Curaray
Rio Pindo
Rio Bobonaza
Rio Pastaza
Rio Nacuma
Cabo Pasado
Cabo Sn. Lorenzo
Pta Galera
La Puntilla
LEYENDA
Costa
Sierra
Oriente
CUATERNARIO
Sedimentos terrestres y marinos.
Sedimentos terrestres (Fluvio-lacustres).
Sedimentos terrestres (Mesetas de material volcanico).
Tablazos marinos
Sedimentos fluviolacustres de material volcanico, Tobas volcánicas, Morrenas
Rocas Volcánicas. A=Andesita. D=Dacita. B=Basalto.
Volcánes apagados.
Volcánes activos
TERCIARIO
Pliocena (Pl) Miocena (M). predominante marino.
t=Sedimentos de aguas salobre y dulce. tm=Sedimentos marinos.
Sedimentos terrestres y marinos. Formación Oriente. (Shell Co.)
Oligoceno marino.
Rocas y tobas volcánicos pliocénicas y mas antiguas.
Eoceno marino
Rocas intrusivas G=Granito. GD=Grandiorita. D=Diorita.
S=Sienita. D=Diorita
CRETACICO
Sedimentos marinos
Sedimentos marinos. (Cretácico superior).
Sedimentos marinos.
Rocas volcánicas. Formación Peñon (IPC).
Sedimentos marinos (Cretácico inferior).
Rocas volcánicas de la Formación diabásica (Sauer). (Diabasas-Porfiritas, Portidos cuarcíferos)
JURASICO
Eocretácico y Jurásico.
Jurásico inferior.
PALEOZOICO
Sedimentos marinos.
Sedimentos marinos.
Sedimentos marinos del carbonifero y precarbonifero.
ROCAS SEMIMETAMORFICAS
(EDAD NO DETERMINADA)
Formación Semimetamórfica
Formación Semimetamórfica
Formación Semimetamórfica
ROCAS METAMORFICAS
(EDAD PRECAMBRICA)
Filitas, Micaesquistos, Gneises (orto y para), Granito presionado.
Rocas metamórficas
Rocas metamórficas.
Rocas metamórficas.
Fallas
Superposiciones.
Anticlinales.
Sinclinales.
Dibujado por Jorge Sotomayor A.

Fig. 3



MAPA MINERALOGICO DEL ECUADOR
DIRECCION GENERAL DE MINAS E HIDROCARBUROS
SECCION DE CARTOGRAFIA
EL DIRECTOR
EL CARTOGRAFO
Luis Cañizares
COLOMBIA
PERU
PROTOCOLO MOSQUERA PEDEMONTE
OCEANO PACIFICO
GOLFO DE GUAYAQUIL
CORDILLERA DEL CONDOR
ESMERALDAS
TULCAN
IBARRA
QUITO
LATACUNGA
AMBATO
RIOBAMBA
GUARANDA
BABAHOYO
PORTOVIEJO
GUAYAQUIL
AZOGUES
CUENCA
MACHALA
LOJA
ZAMORA
TUMBEZ
TENA
PUYO
MACAS
LEYENDA
Capital de la Republica.
Capital de Provincia.
Canton.
Parroquia.
Limite Internacional.
Limite Provincial.
Carretera.
Ferrocarril.
Oro de lavaderos.
Oro en veta.
Plata.
Cobre.
Plomo.
Hierro.
Manganeso.
Piritas en general.
Antimonio.
Zinc.
Tierras Plasticas.
Depositos salinos.
Cuarzo.
Tugsteno.
Vanadio.
Molibdeno.
Borax.
Azufre.
Cristal de roca.
Asfaltos bituminosos sudestalles.
Gases y aguas minerales.
Carbon.
Lignito.
Grafito.
Petroleo y gases.
Campos de petroleo en exploracion.
Posibilidades petroliferas.
Titanio.
Yacimientos calizos.

Fig. 4

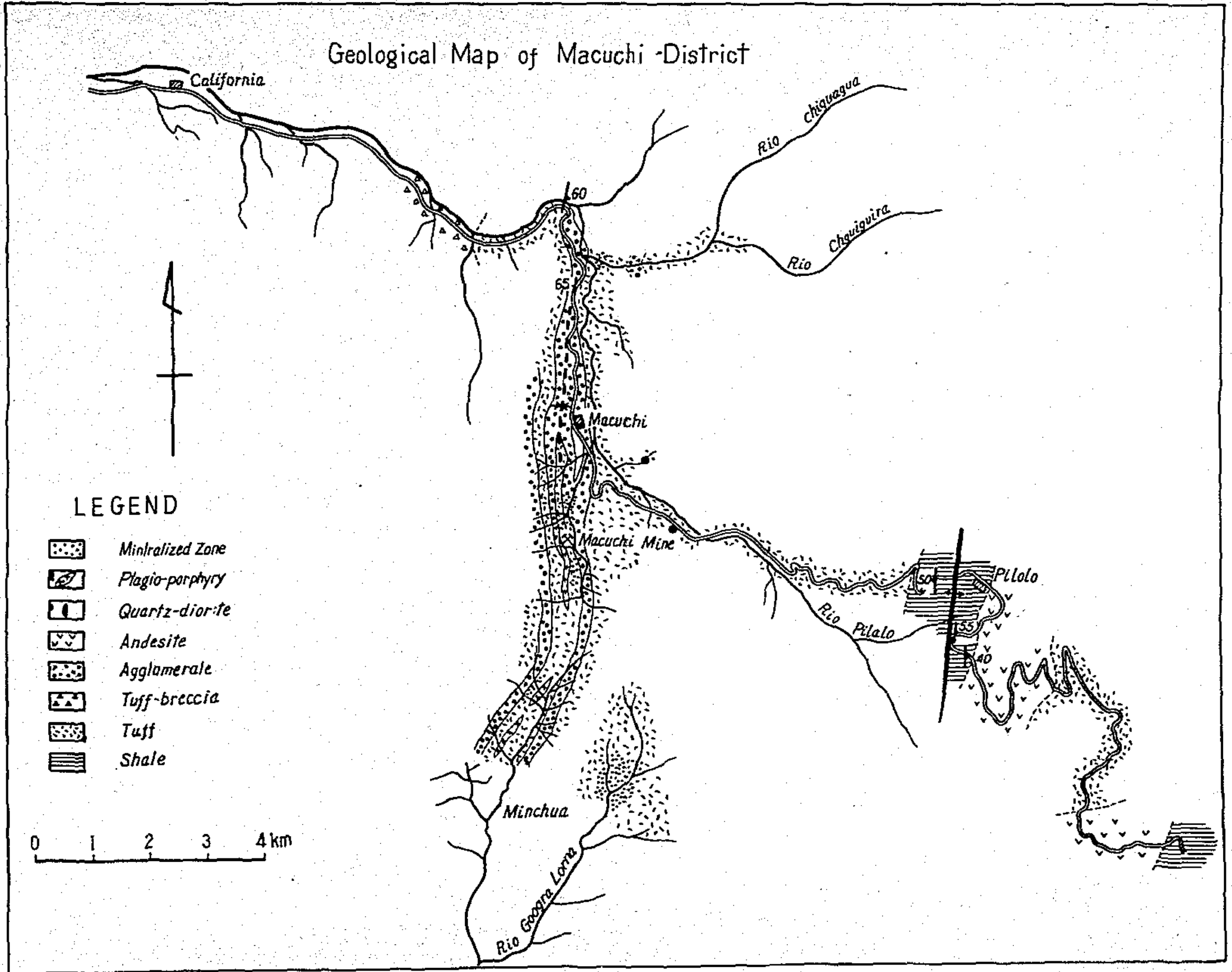
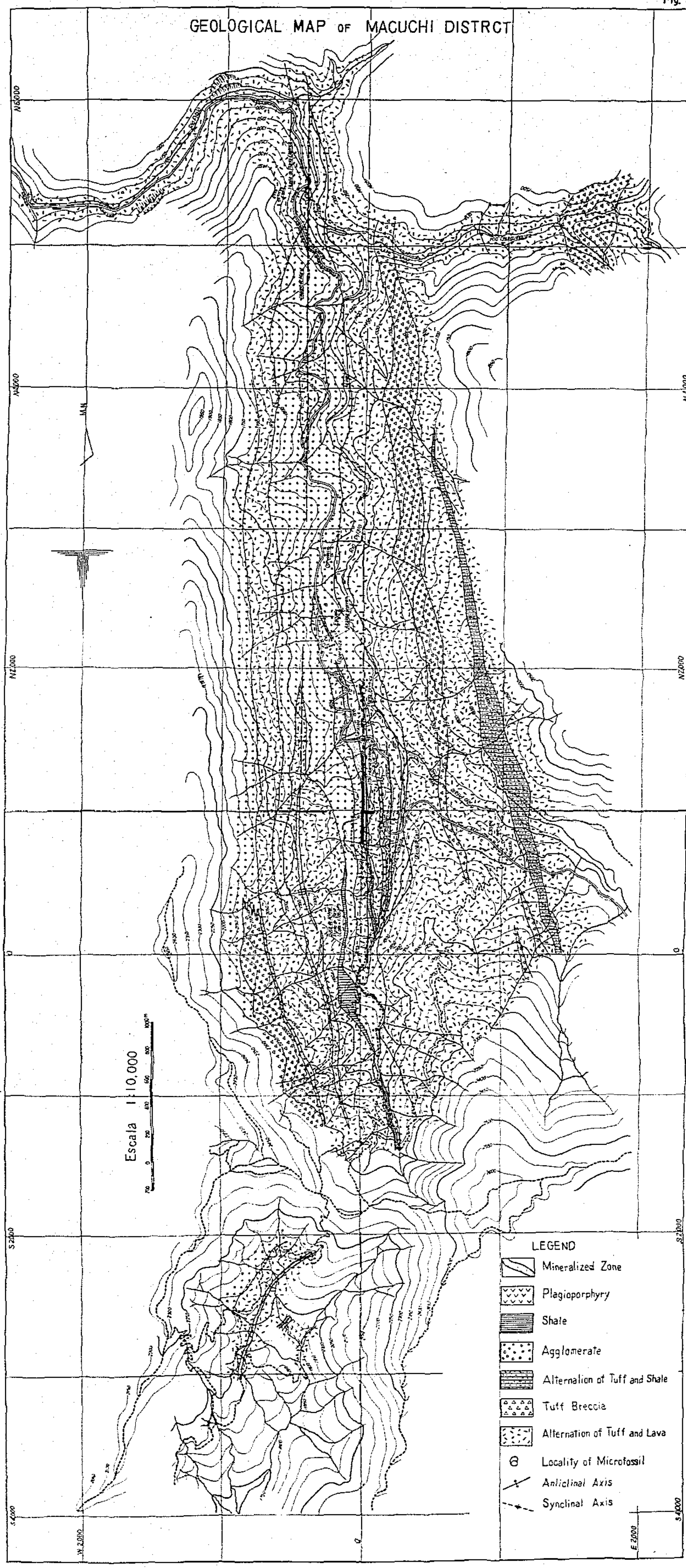
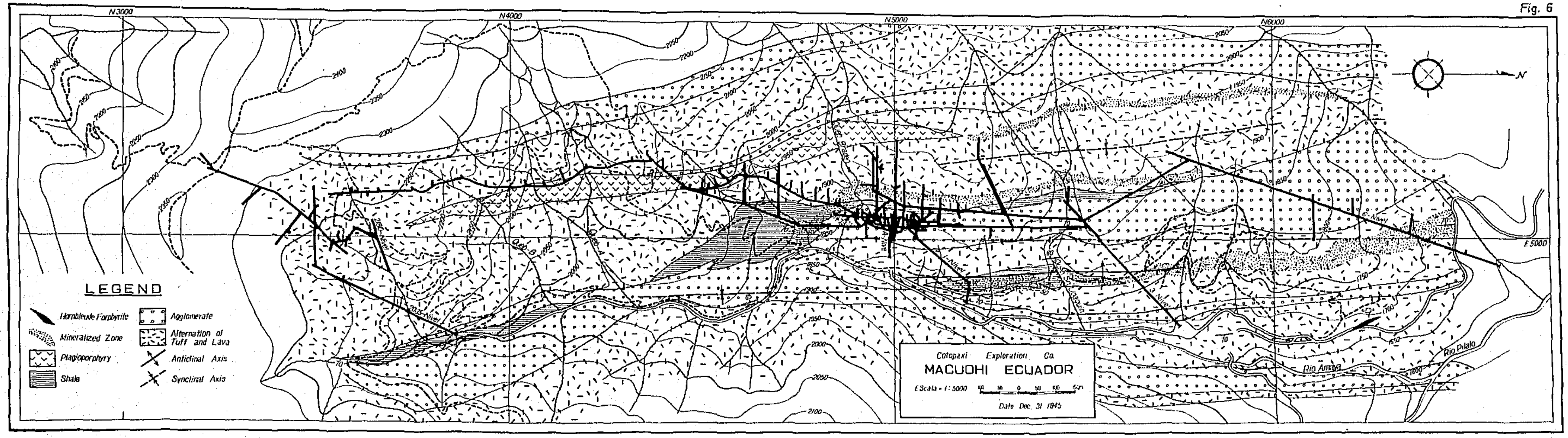

Geological Map of Macuchi -District
California
Rio Chiquagua
Rio Chguiguira
60
65
Macuchi
Macuchi Mine
Rio Pilalo
Pilolo
50
55
40
Minchua
Rio Googra Loma
LEGEND
Minlralized Zone
Plagio-porphyry
Quartz-diorite
Andesite
Agglomerale
Tuff-breccia
Tuff
Shale
0 1 2 3 4 km

Fig. 5



GEOLOGICAL MAP OF MACUCHI DISTRCT
N6000
N4000
N2000
0
S2000
S4000
W2000
E2000
M.N.
Escala 1:10,000
LEGEND
Mineralized Zone
Plagioporphyry
Shale
Agglomerate
Alternation of Tuff and Shale
Tuff Breccia
Alternation of Tuff and Lava
Locality of Microfossil
Anticlinal Axis
Synclinal Axis

Fig. 6



N3000
N4000
N5000
N6000
E5000
N
LEGEND
Hornbleude Forphyrite
Mineralized Zone
Plagioporphyry
Shale
Agglomerate
Alternation of Tuff and Lava
Anticlinal Axis
Synclinal Axis
Cotopaxi Exploration Co.
MACUOHI ECUADOR
EScala = 1:5000
Date Dec. 31 1945
Rio Pilalo
Rio Amina

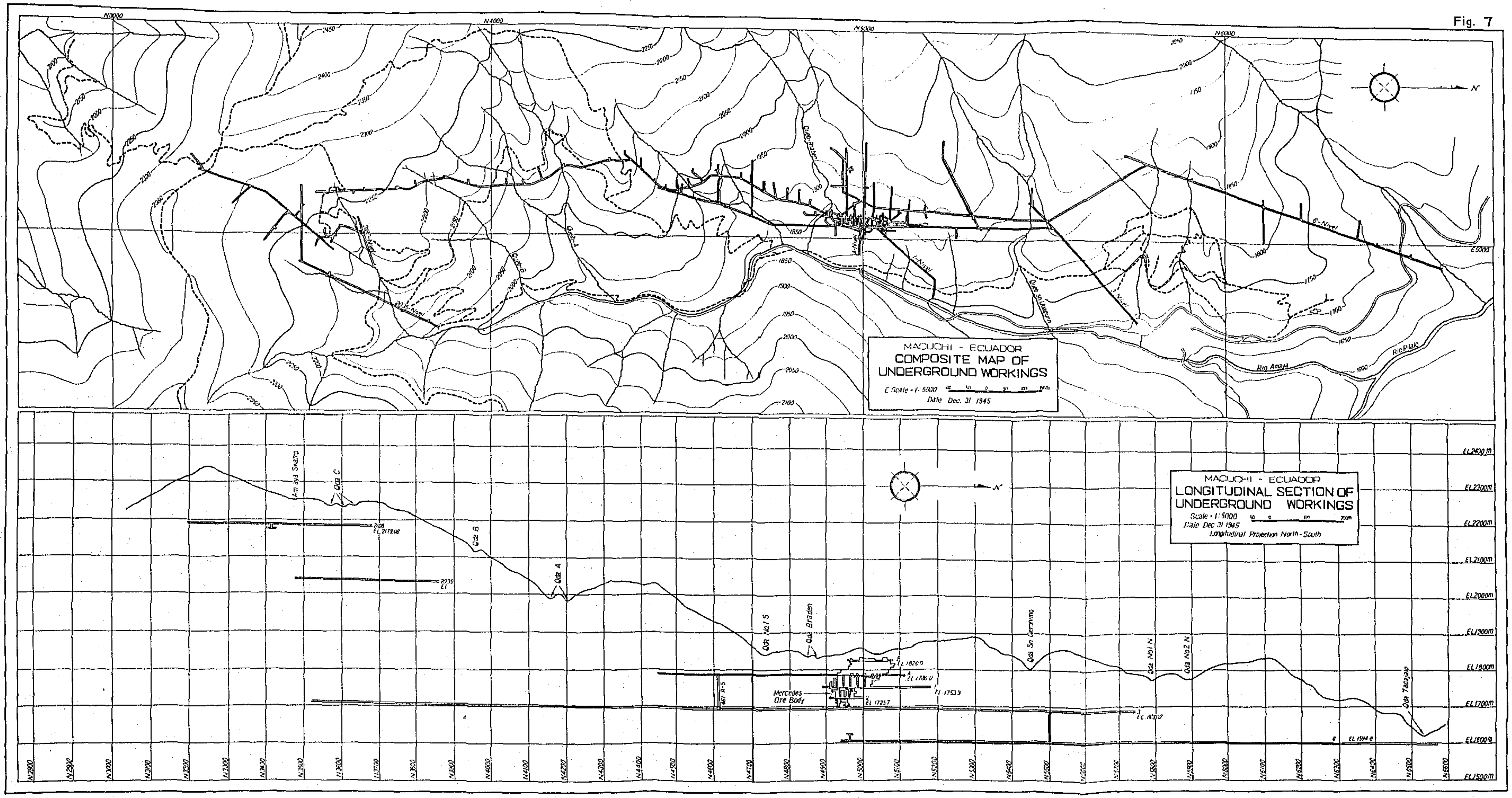
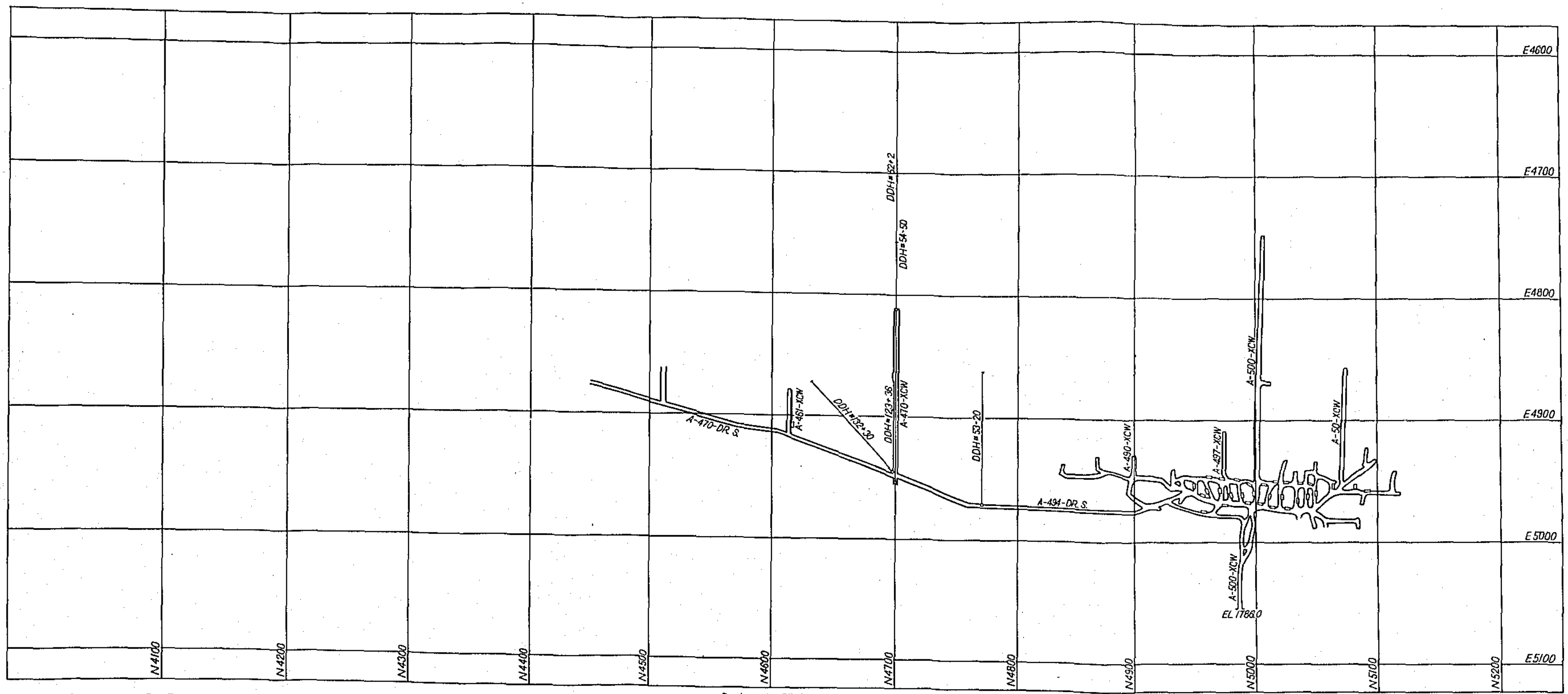

MACUCHI - ECUADOR
COMPOSITE MAP OF
UNDERGROUND WORKINGS
Scale - 1:5000
Date Dec. 31 1945
MACUCHI - ECUADOR
LONGITUDINAL SECTION OF
UNDERGROUND WORKINGS
Scale - 1:5000
Date Dec 31 1945
Longitudinal Projection North - South
Rio Amaya
Mercedes
Ore Body
Qda Braden
Qda Sn Geronimo
Qda A
Qda B
Qda C
EL 2400 m
EL 2300 m
EL 2200 m
EL 2100 m
EL 2000 m
EL 1900 m
EL 1800 m
EL 1700 m
EL 1600 m
EL 1500 m

Fig. 7

Fig. 8

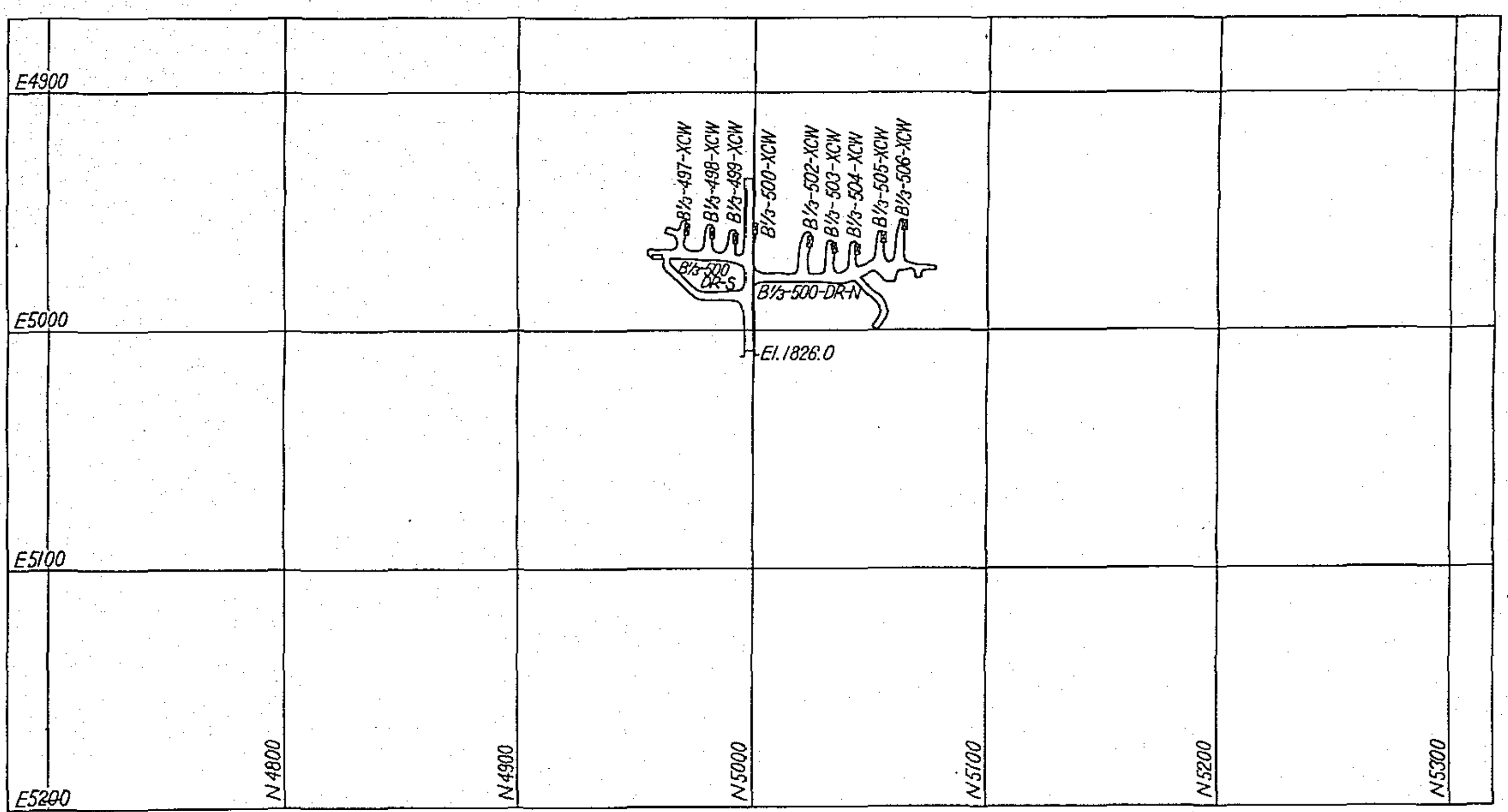


COTORAXI EXPLORATION Co.
MACUCHI - ECUADOR

Scale = 1 : 2500
By: Engineering Staff
Drafted By O.PMM
Date: Dec. 30 1945

MAP.
A LEVEL.

Fig. 9

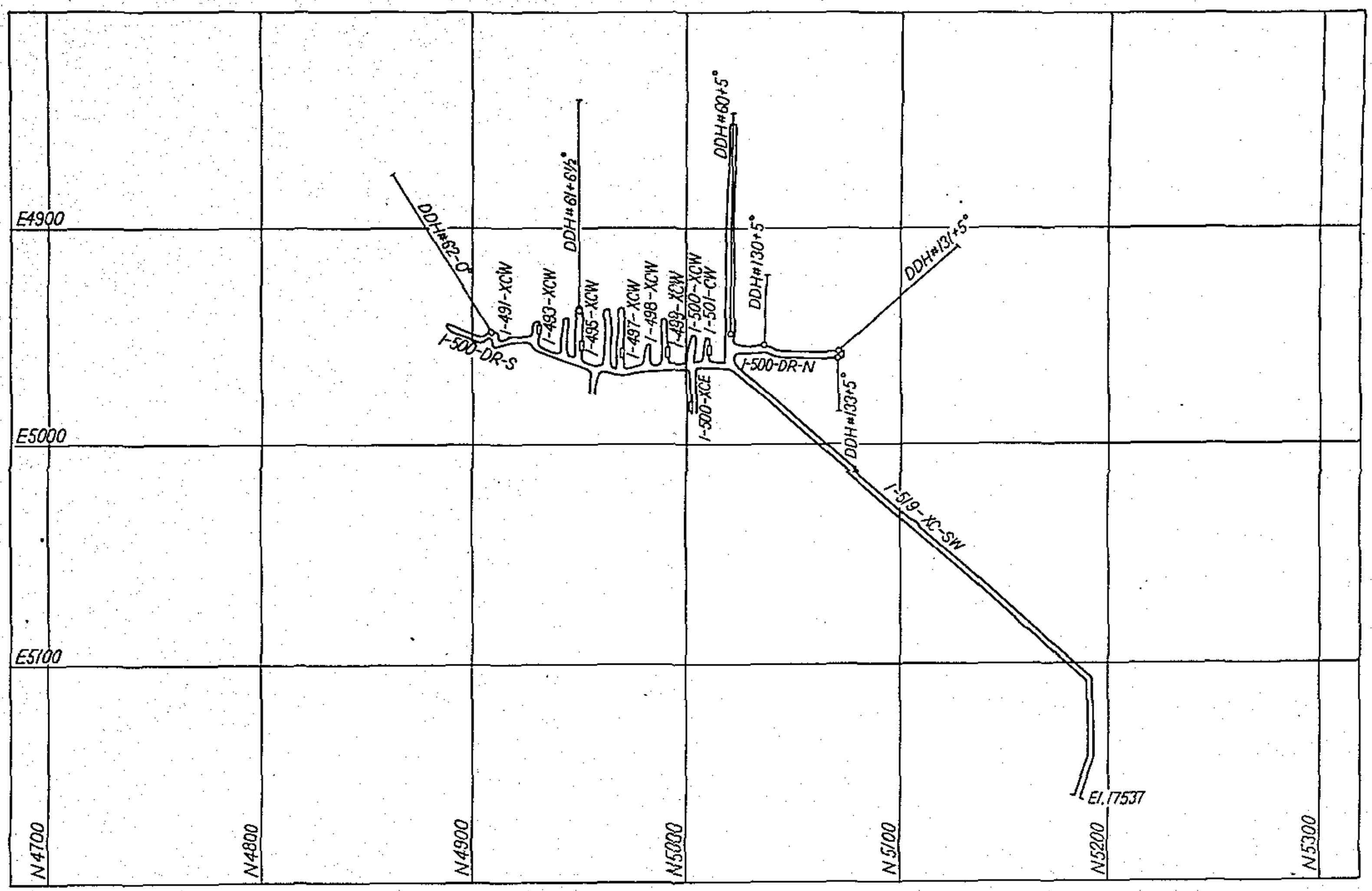


COTOPAXI EXPLORATION Co.
MACUCHI - ECUADOR

Scale 1:2500
By-Engineering Staff

PROGRESS MAP.
B⅓ LEVEL.

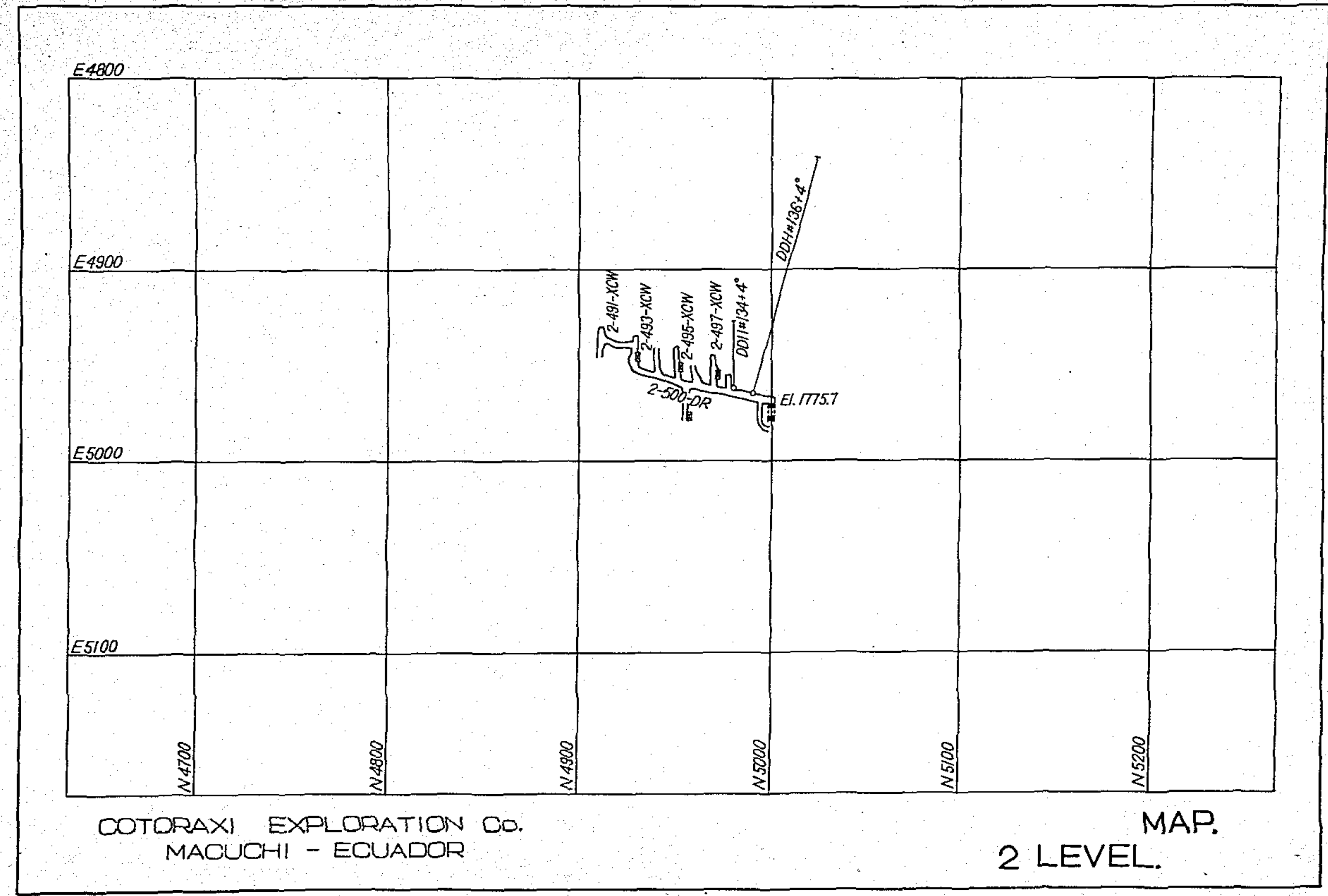
Fig.10



COTORAXI EXPLOPATION Co.
MACUCHI - ECUADOR

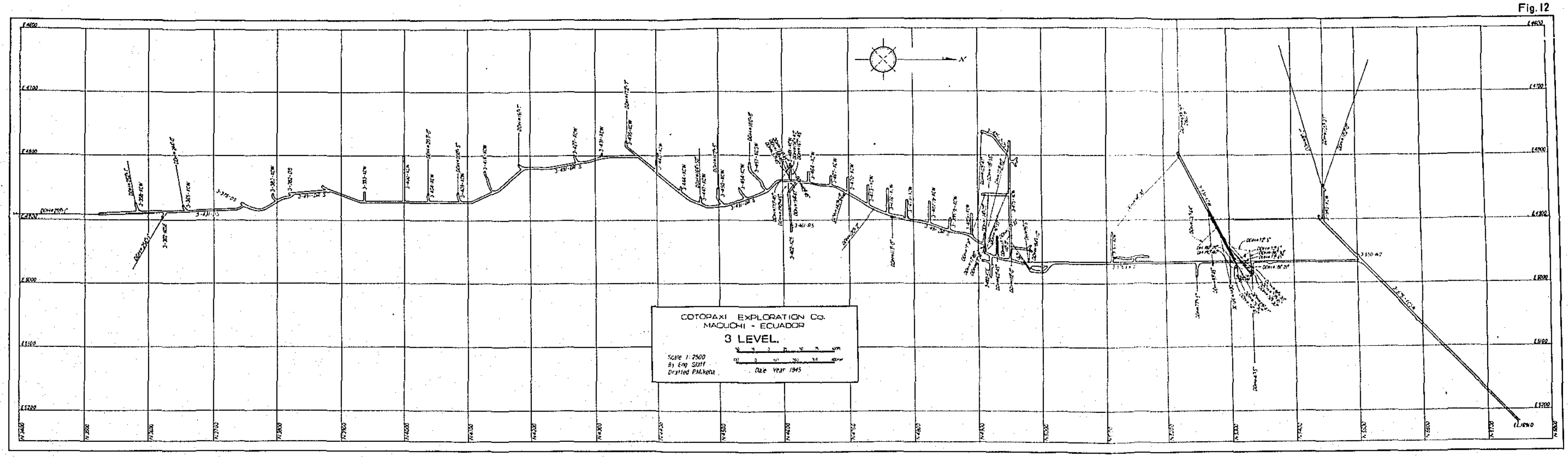
MAP.
1 LEVEL.

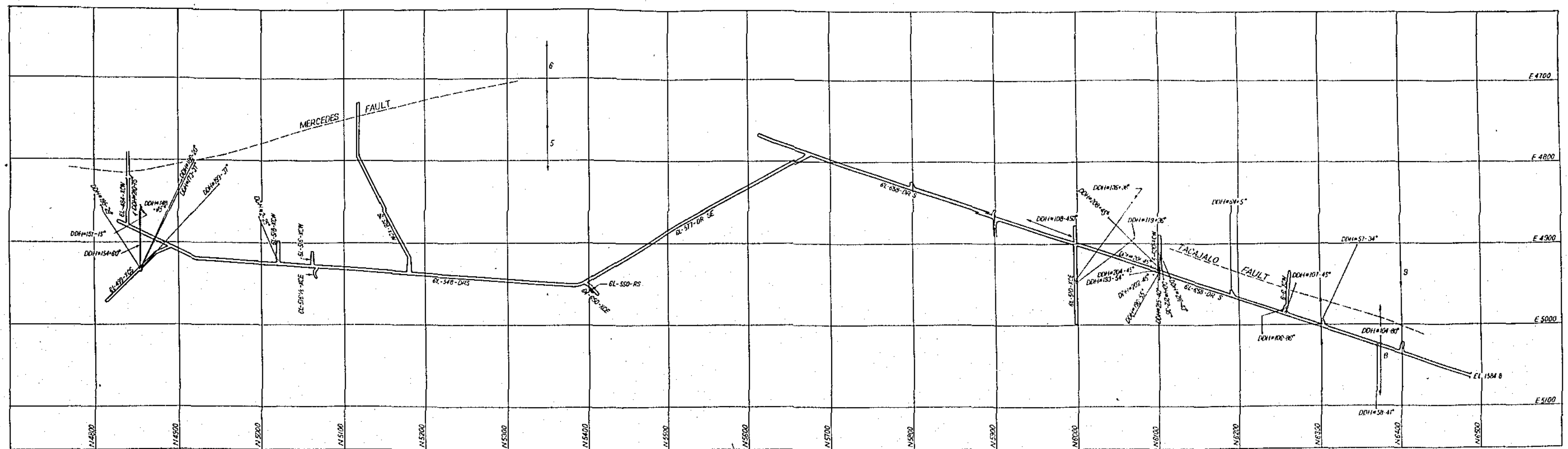
Fig. 11



E4800
E4900
E5000
E5100
N 4700
N 4800
N 4900
N 5000
N 5100
N 5200
2-491-XCW
2-493-XCW
2-495-XCW
2-497-XCW
DDH#134+4°
DDH#136+4°
2-500-DR
El. 1775.7
COTORAXI EXPLORATION Co.
MACUCHI - ECUADOR
MAP.
2 LEVEL.

Fig. 12


COTOPAXI EXPLORATION Co.
MACUCHI - ECUADOR
3 LEVEL.
Scale 1:2500
By Eng Staff
Drafted P.Mikeha
Date Year 1945

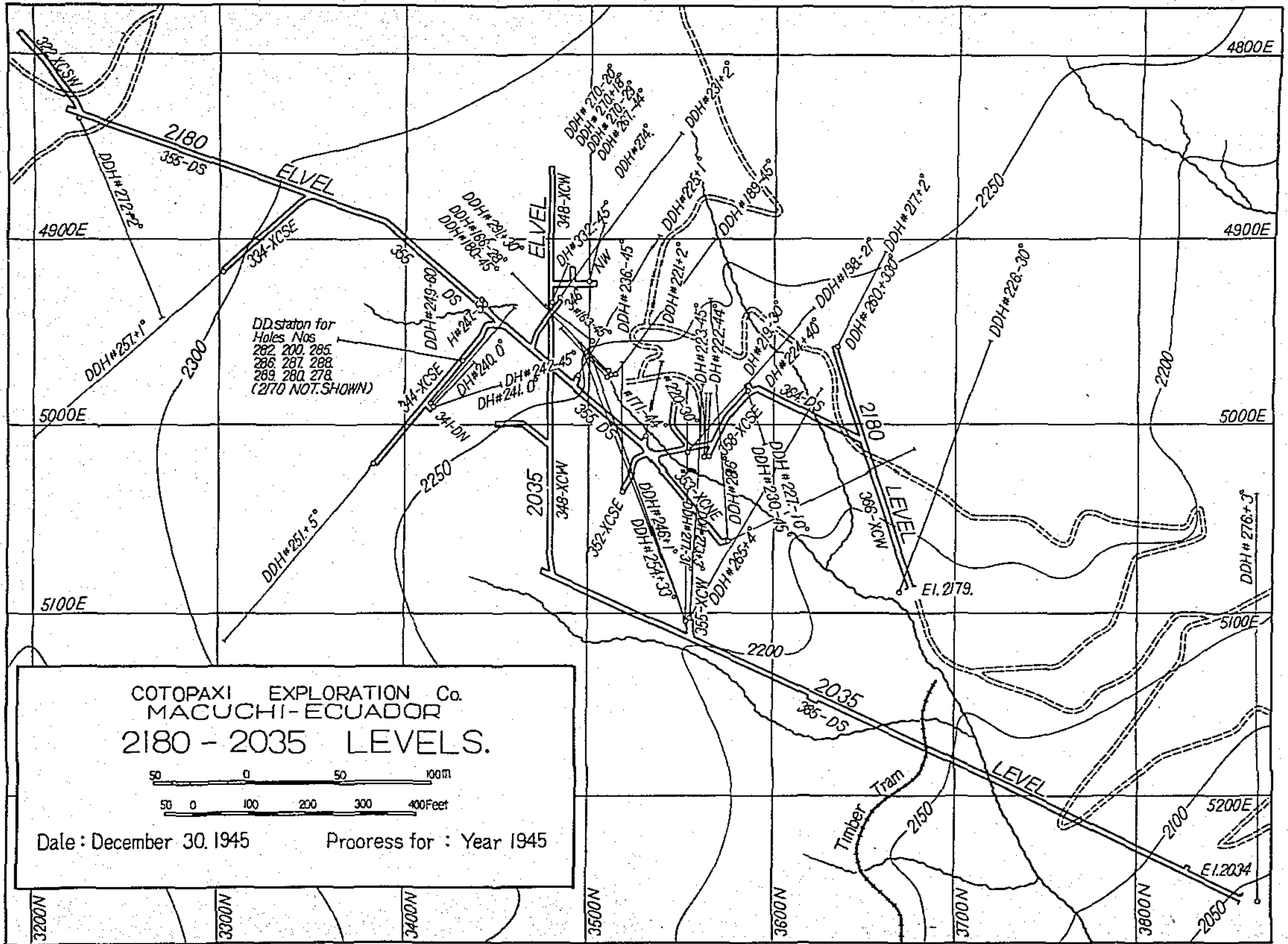


COTOPAXI EXPLORATION Co.
MACUCHI - ECUADOR

Scale - 1 : 500
By: Engineering Staff
Drafted By: A. Acosta F.
Date: Dec. 30 1945

MAP.
6 LEVEL.

Fig. 14


COTOPAXI EXPLORATION Co.
MACUCHI-ECUADOR
2180 - 2035 LEVELS.
50 0 50 100m
50 0 100 200 300 400Feet
Dale: December 30. 1945
Prooress for : Year 1945
2180 ELVEL
2180 LEVEL
2035 LEVEL
4800E
4900E
5000E
5100E
5200E
3200N
3300N
3400N
3500N
3600N
3700N
3800N
2050
2100
2150
2200
2250
2300
Timber Tram
El. 2179.
El. 2034
DD.staton for Holes Nos 282. 200. 285. 286. 287. 288. 289. 280. 278. (2170 NOT. SHOWN)
322-XCSW
334-XCSE
344-XCSE
348-XCW
352-XCSE
353-XCNE
355-XCW
366-XCW
355-DS
385-DS
364-DS
341-DN
DDH#272+2°
DDH#257+1°
DDH#251+5°
DDH#226-30°
DDH#276+3°

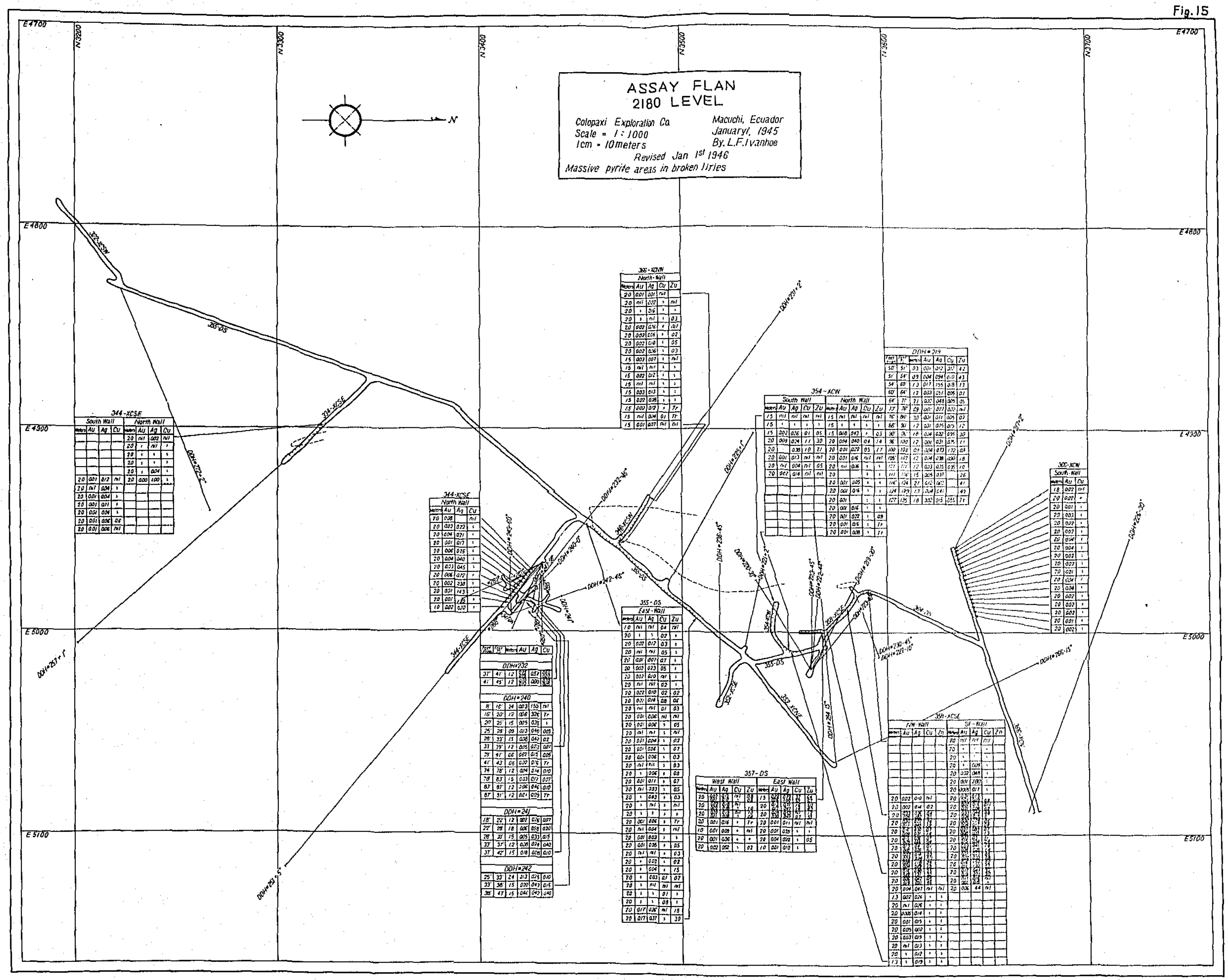
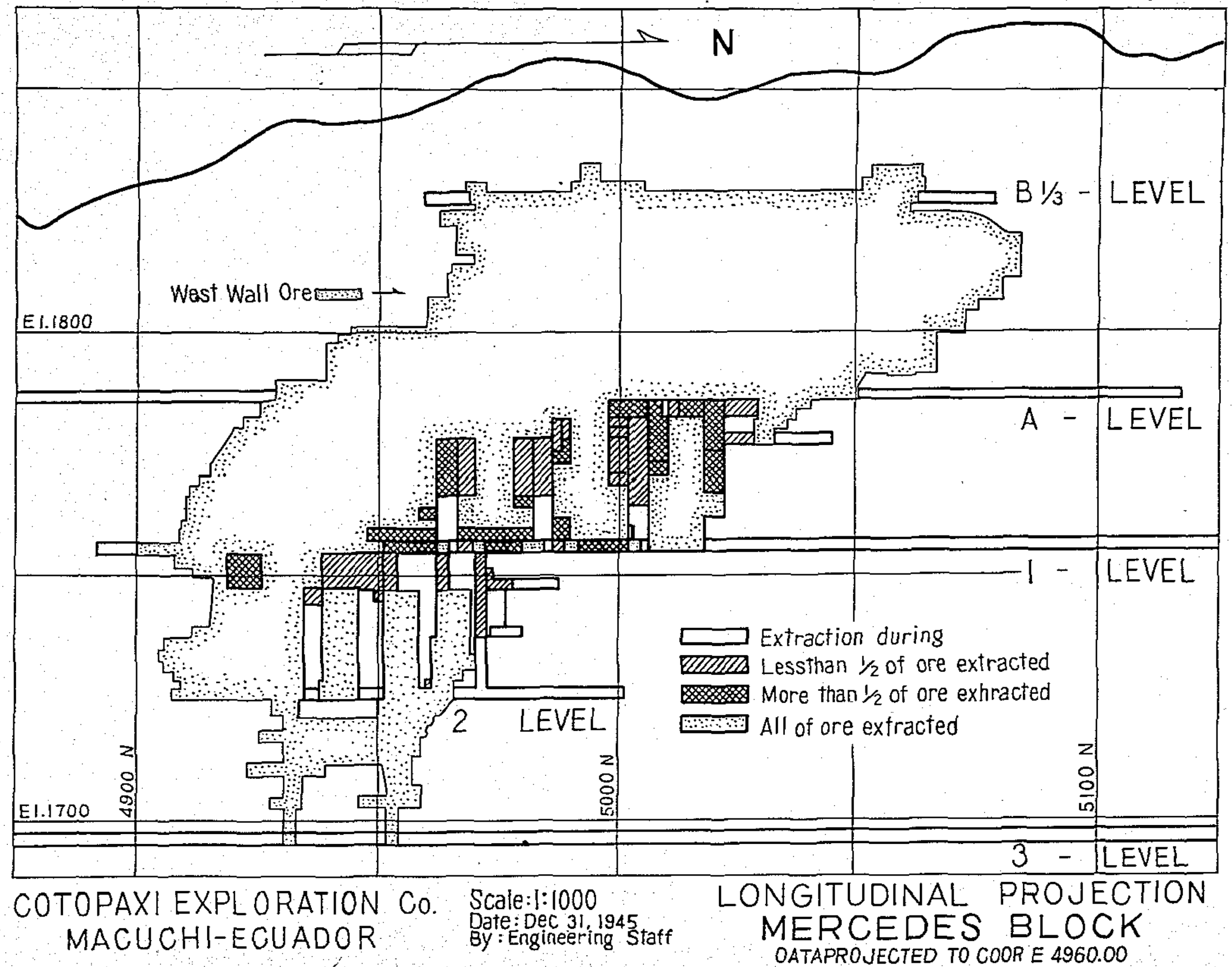

ASSAY PLAN
2180 LEVEL
Cotopaxi Exploration Co.
Scale = 1 : 1000
1cm = 10 meters
Macuchi, Ecuador
January 1, 1945
By L.F. Ivanhoe
Revised Jan 1st 1946
Massive pyrite areas in broken lines
N
E4700
E4800
E4900
E5000
E5100
N3200
N3300
N3400
N3500
N3600
N3700
344-XCSE
South Wall
North Wall
344-XCSE
North Wall
355-DS
East Wall
357-DS
West Wall
East Wall
354-XCW
South Wall
North Wall
DDH-232
DDH-240
DDH-241
DDH-242
DDH-219
Au
Ag
Cu
Zn

Fig. 15

Fig. 16


N
B 1/3 - LEVEL
West Wall Ore
El.1800
A - LEVEL
1 - LEVEL
Extraction during
Lessthan 1/2 of ore extracted
More than 1/2 of ore exhracted
All of ore extracted
2 LEVEL
4900 N
5000 N
5100 N
El.1700
3 - LEVEL
COTOPAXI EXPLORATION Co.
MACUCHI-ECUADOR
Scale: 1:1000
Date: Dec 31, 1945
By: Engineering Staff
LONGITUDINAL PROJECTION
MERCEDES BLOCK
DATAPROJECTED TO COOR E 4960.00