No. 55

The Mineral Exploration-
Mineral Deposits and Tectonics of Two Contrasting Geologic Environments in The Republic of the Philippines

Consolidated Report on Southern Sierra Madre Area

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Consolidated Report on Leyte•Dinagat•Siargao Area

(Attached the Results of Univariate Geochemical Analyses on Samar Area)

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Consolidated Report on Cebu • Bohol • Southwest Negros Area

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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Preface

In response to the request of the Government of the Philippines, the Government of Japan has decided to conduct a survey on the potential of mineral resources in the eastern Luzon, Visayas and the Palawan. The survey was entrusted to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

This Consolidated Report includes the results of synthesized regional analyses about the Southern Sierra Madre, Leyte · Dinagat · Siargao and Cebu · Bohol · Southwest Negros Areas which have been surveyed under the above-mentioned works.

We wish to express our deepest appreciation to the officials of the Government of the Philippines and the Ministries of Foreign Affairs and International Trade and Industry of Japan and the officials of the Embassy of Japan for their close cooperation for the survey.

February, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

Gen-ichi Fukuhara
President
Metal Mining Agency of Japan

Consolidated Report on Southern Sierra Madre - Polillo Area

SUMMARY

A total area of 4,770 km^2 in the Southern Sierra Madre · Polillo area was covered by geological and geochemical prospecting in 1985 as a part of "The Mineral Exploration - Mineral deposits and Tectonics of Two Contrasting Geologic Environments in the Republic of the Philippines" project.

The results were statistically processed and evaluated taking into considerations both local and regional geological perspectives, utilizing in the process all the relevant available results from the present geological survey and mineral prospecting in addition to the existing geoscientific data about the area.

The Southern Sierra Madre · Polillo area which is located in the central - eastern part of Luzon, is geologically divided into two tectonic zones namely, the Southern Sierra Madre and Polillo zones.

The Southern Sierra Madre zone occupies the major part of the Sierra Madre mountains extending to the Luzon Central Cordillera range while the Polillo zone lies at the northern marginal part of the East Philippine Arc.

The Philippine Fault traverses through the Polillo Strait, dividing the two tectonic zones in the process.

In the Southern Sierra Madre zone, Early Cretaceous metamorphic rocks and Late Cretaceous mafic complex form the geologic basement. Tertiary sedimentary rocks, volcanic flows and pyroclastic rocks and Pleistocene volcanic flows and pyroclastic formations cover these basement unit.

The major geologic units of the Polillo zone are the basement rock units composed of pre-Cretaceous metamorphic rocks, Cretaceous volcanic rocks and Cretaceous ophiolites. These rock units are in turn overlain by Tertiary sedimentary formations.

The Paleocene granodiorite and the Oligocene diorite bodies in the Southern Sierra Madre and the Eocene dioritic intrusives in the Polillo Island are the major intrusives in the survey area.

Movements associated with the left-lateral Philippine Fault and related steep dipping N-S, NNW and NNE trending faults resulted in intense block movement of the rock units of the area. Consequently, the structures in the survey area are dominated by N-S trending folds, with the geologic units elongated in the same direction.

Four types of mineralization were recognized in the Southern Sierra Madre namely; contact metasomatic iron, porphyry copper, vein type consisting mainly of hydrothermal auriferous quartz veins and massive sulfide types of mineralization.

On the other hand, two types of mineralization were found in Polillo Island namely; vein type of mineralization consisting mainly of hematite veinlets and disseminations and porphyry molybdenum mineralization.

The regional analyses and interpretations of the geochemical anomalies were carried out on ten (10) elements (Cu, Pb, Zn, Ag, As, Mn, Ni, Co, Mo, Hg) analysed from approximately 4,500 stream sediment samples (less than 0.175 mm in diameter) collected from the area.

The whole survey area was divided into 2 km × 2 km cells. Four types of statistical analyses were then carried out using the geometric means of each of the elements found in each cell. The four types of statistical analyses utilized were:

1. Univariate analyses of cell average values;
2. Univariate analyses of moving average data which determine the average value of nine cells that correspond to the value of the central cell. The frame is moved at two kilometer step throughout the survey area.
3. Univariate analyses of high-pass filter data which is the positive difference between each cell average values and moving average values.
4. Multivariate analyses (Factor Analyses) for the cell average values.

The results are shown in 1 : 1,000,000 scale maps (Attached Pl. 2-1-1 to Pl. 2-4-5).

The geological significance of the statistical results were then evaluated utilizing the data on the distribution of igneous bodies, geologic structures and observed alteration patterns associated with the inferred mineralization types.

Finally, the following five localities were selected as promising and warranting further study and prospecting. The localities are prioritized from I to V (Attached Pl. 8).

I. The upper reaches of Umiray River, central part of Southern Sierra Madre: This zone is located at the contact between the Paleogene andesite and the Oligocene diorite that had intruded the volcanic rocks. The copper mineral showings of Marcopper Matani and Lumbay Collosal can be found here.
Assumed type of major mineralization and associated commodities: porphyry type copper mineralization. Cu, Pb and Zn.

II The northeastern Montalban area located at the southeastern portion of Southern Sierra Madre: This zone is underlain by Cretaceous basaltic agglomerates that overlie the Mesozoic mafic complex. This zone includes the copper mineral showings of Puray.
Assumed type of major mineralization and associated commodities: massive sulphide type mineralization. Cu and Zn.

III The southeastern part of Polillo Island: In this zone, networks and disseminations of molybdenite and pyrite have been observed on the argillized parts of the Eocene diorite intrusive body. The Marcopper Polillo mineral showing is located in this zone.
Assumed type of major mineralization and associated commodites: porphyry type molybdenum mineralization. Cu and Mo.

IV. The western part of Tignoan, east coast of Southern Sierra Madre: Mineralization in this zone occurs in the Miocene andesitic volcanics as fissure-fillings. The gold mineral showings in the Tignoan River belong to this zone.
Assumed type of major mineralization and associated commodities: gold-bearing hydrothermal veins. Au, Ag and Cu.

V. The southwestern part of Burdeos, central-western part of Polillo: In this zone, hydrothermal mineralization occurs in Cretaceous pyroclastic rocks. Although the mineral showings are dominantly that of hematite veins, the results of the geochemical analyses suggest Cu mineralization.
Assumed type of major mineralization and the associated commodities: hydrothermal veins. Cu and Zn.

The Mineral Exploration-Mineral Deposits and Tectonics of two Contrasting Geologic Environments in The Republic of The Philippines

Consolidated Report on The Southern Sierra Madre・Polillo Area

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1. Introduction

1-1 Purpose and Scope

1-1-1 Background and Particulars

Pursuant to the Implementing Arrangement (I/A) entered into between the Government of Japan through the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ) and the Government of the Philippines through the Mines and Geo-Science Bureau (MGB) on September 26, 1984, a project officially titled "The Mineral Exploration-Mineral Deposits and Tectonics of two Contrasting Geologic Environments" was carried out in the Republic of the Philippines.

This report embodies the results of the synthetic evaluation on the areas of Southern Sierra Madre and Polillo which are included in the above-mentioned Project (Fig. 1). The field survey took place from April to July, 1985.

1-1-2 Objectives of the Report

The objectives of the report are to assess the mineral potential and to select promising localities in the Southern Sierra Madre and Polillo areas which are located in the middle eastern Luzon of the Philippines through analysing and correlating all acquired geological and geochemical survey data (JICA-MMAJ 1985) as well as various previous survey results.

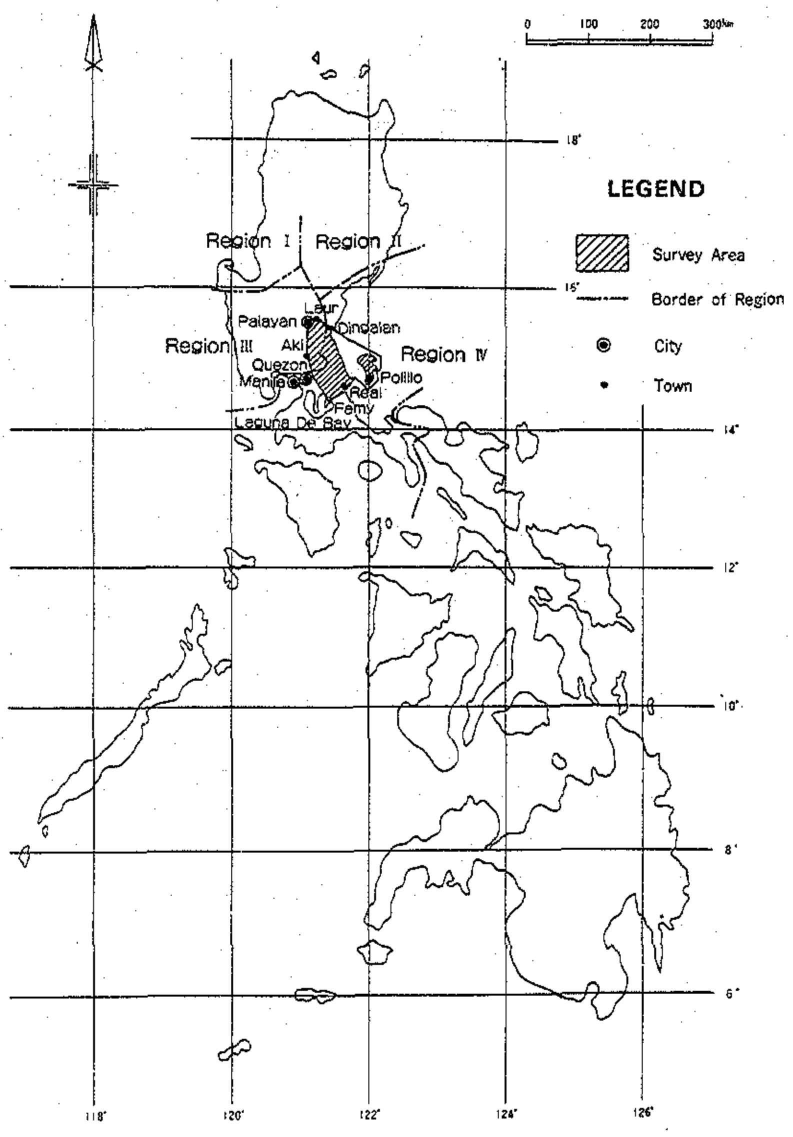


Fig. 1 Location Map of the Survey Area

1-2 Regional Setting

1-2-1 Location (Figs. 1, 2)

The survey area concerned is located in the middle eastern Luzon Island of the Republic of the Philippines. The Sierra Madre Mountains extend from north to south in the central part of the Southern Sierra Madre area forming steep mountainous zones with the highest peak of Mt. Cacanado (1739 m above sea level).

The Polillo Island has comparatively flat surface controlled by the geological units and the highest peak is Mt. Malolod (329 m above sea level).

The survey area in Southern Sierra Madre is bounded on the north by Laur-Dingalan Valley, on the south by road along the northern coast of Laguna De Bay, on the west by the eastern edge of the Luzon Central Plain near the long. 121° 05' E. line and on the east by the sea. Total area extends to 4,150 km^2. Polillo area is located to the eastern part of Polillo Strait covering an area of 620 km^2.

Southern Sierra Madre area comprises Nueva Ecija · Bulacan Provinces of Region III and Aurora · Quezon · Laguna · Rizal Provinces of Region IV administratively. Polillo area belongs to Quezon Province.

1-2-2 Access

The Southern Sierra Madre area is accessible by car from Manila via Daang-Maharlika Highway up to Cabanatuan city and further via Dingalan and south coastal roads up to Umiray. Southern parts can be reached by Manila East Road to Famy and further over gravel road to Infanta on the west coast. Interior parts can be reached from these main roads by municipal roads connecting wood trail networks. Parts along the east coast and large rivers are accessible together with banca boats.

The Polillo area is located 30 km east of Infanta and is accessible by launch from Port Real to Port Polillo (approximately 3 hours per one way). Interior parts can be reached only by a single road across the island connecting the towns of Polillo and Burdeos, other roads are poorly developed. Inland transports are mainly by manpower and by banca boat.

1-2-3 Climate

The survey area belongs to the tropical rain forest zone and is divided into the following three climate subzones by precipitation.

① Subzone of even rainfall throughout the year
Rainfall in western part of the Southern Sierra Madre area is evenly distributed throughout the year.

② Subzone with wet winter without particular dry season
Very pronounced rainfall from November to January is

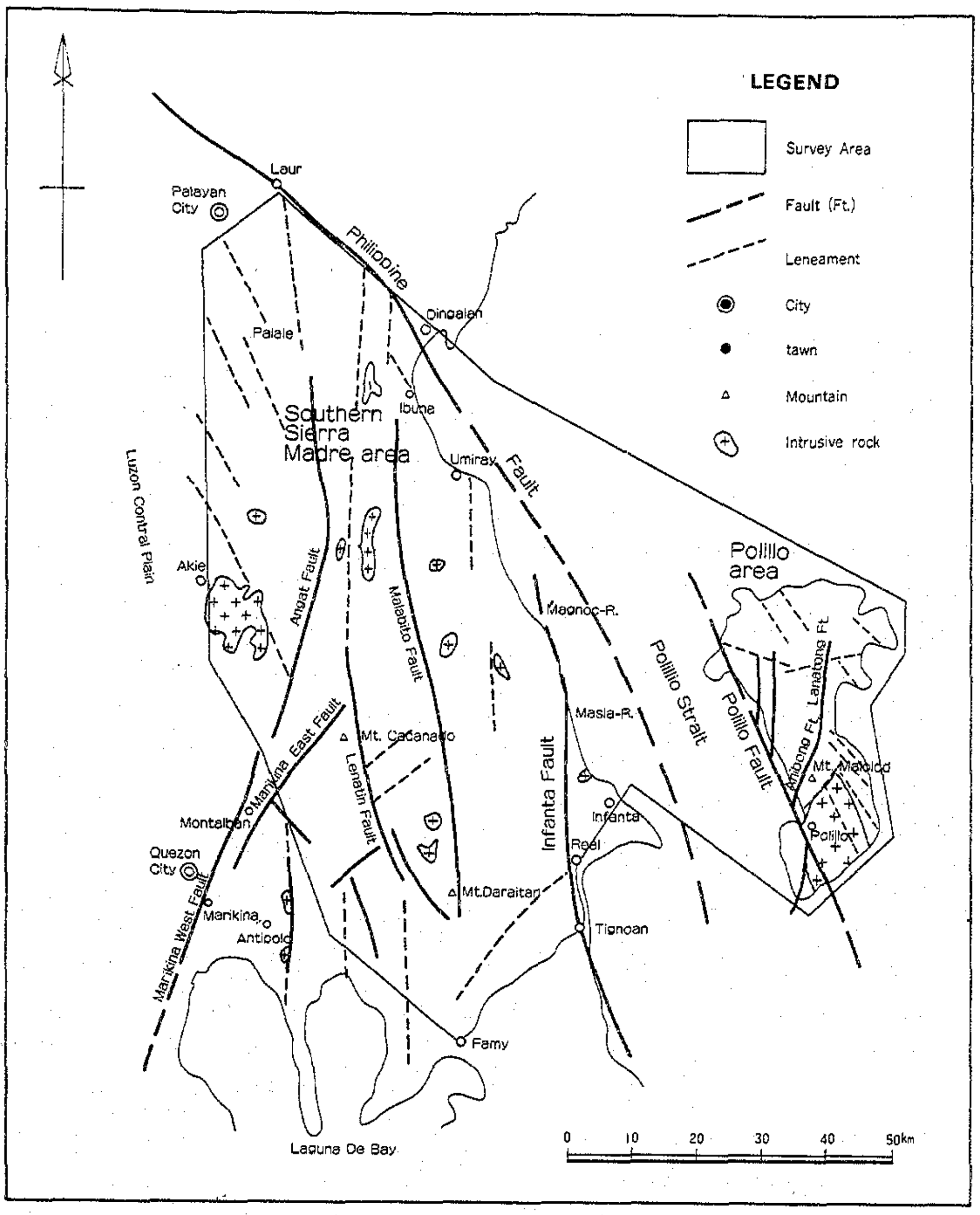


Fig. 2 Tectonic Division Map of the Southern Sierra Madre Area

observed in eastern part of the Southern Sierra Madre area.

③ Subzone with short dry season without particular wet season Climate in Polillo Island is characterized by three monthes of dry season from June to August and although it rains from September to May, there are no months with very heavy rain. Cyclones usually occur from September to December over the whole survey area.

Average temperature is 23°C and annual average precipitation is approximately 3,700 mm for the whole area.

1-2-4 Vegetation and Others

The area belongs to the tropical rain forest zone and the inland portions of the highlands are covered by primeval forest. Coastal plains and adjoining slopes are partly cultivated and planted with taro, rice, coconut and others, but most of the areas are covered with thick growth of shrubs and vines. Mangrove and nipa- palms grow in abundance at river mouths in tidal flats fringing the coasts.

1-3 Member of the Survey Team

1-3-1 Planning and Negotiations

Japanese Panel:

H. Shinokawa	Ministry of International Trade and Industry (MITI)
M. Aoyama	id.
H. Kainuma	Japan International Cooperation Agency (JICA)
H. Hirano	Metal Mining Agency of Japan (MMAJ)
N. Sato	Metal Mining Agency of Japan (MMAJ)

Philippines Panel:

R. D. San Juan	Department of Environment and Natural Resources (DENR)
P. C. Caleon	Mines and Geo-Sciences Bureau (MGB)
R. M. Luis	id.
R. L. Almeda	id.
A. Apostol	id.

1-3-2 Preparation of the Consolidated Report

Japanese Panel:

Y. Okubo	Overseas Mineral Resources Development Co., Ltd. (OMRD)
Y. Uehara	id.
Y. Shimazaki	id.

Philippines Panel:

R. M. Samaniego	Mines and Geo-Sciences Bureau (MGB)
M. V. Garcia	id.
B. S. Vargas	id.
R. M. Luis	id.
R. L. Almeda	id.
N. Y. Ferrer	id.
A. Apostol	id.
G. P. Revilla	id.
E. R. Malaca	id.
F. R. Zepeda	id.
D. C. Jagolino	id.

1-4 Methodology

Analysis and interpretation of the survey data were conducted as follows.

1-4-1 Survey Area (Figs. 1, 2)

For the convenience of geological description, the survey area was divided into two tectonic blocks-Southern Sierra Madre and Polillo. Philippines Fault running through Polillo Strait is the boundary between the two tectonic terranes.

1-4-2 Stratigraphy

In this report, a stratigraphic classification prepared through discussion at the Philippine and Japanese Workshop held in June, 1988 (Figs. 4, 5) is used. A geological map in the scale of 1:1,000,000 has been prepared in conformity with the above stratigraphic classification (Attached Pl. 1). Geological descriptions presented here were adopted from the Southern Sierra Madre (E.R. Malaca & G.P. Revilla, 1987) and Polillo (D.C. Jagolino & F.R. Zepeda) unpublished reports.

1-4-3 Geochemical Data

In terms of the geochemical data, the zones of anomalous values were identified by the following process.

The 4,588 samples (grains size under 0.175 mm) collected from the survey area were analysed for ten elements; Cu, Pb, Zn, Ag, As, Mn, Ni, Co, Mo and Hg.

The survey area was divided into 2 km × 2 km cells. Univariate and multivariate analyses of the average values of all the above cells were carried out. The univariate analyses of the moving average values of every nine cells (6 km × 6 km lattice) and of the high-pass filter values were also made. The high-pass filter values were calculated from the differences between the cell average and moving average values.

1-4-4 Heavy Mineral Samples

In addition to the stream samples, a total of 171 heavy mineral samples was collected by panning from the survey area. They were analysed for Au, Ag and Ga. These analytical data were treated by univariate analyses.

1-4-5 Existing Regional Survey Data

Available data on previous regional geological work of the survey area were compiled in the gravity map, lineament map, mineral showings distribution map and existing data index map in 1:1,000,000 scale to conform with the geological, geochemical and other maps of this project (Figs. 3, 4, 5, 6). List of the various survey data is attached in the Appendix.

1-5 Achievements of the Project

1-5-1 Conclusion

Four principal types of mineralization are found in the survey area. In the Southern Sierra Madre, they are as follows.

(1) Vein and dissemination type mineralization which occurs mainly as hydrothermal auriferous quartz veins in the Cretaceous Barenas-Baito Formation, Eocene to Oligocene Bayabas Formation and Miocene Tignoan Formation.

(2) Porphyry copper mineralization which occur in the vicinity of the contact zone of the Paleogene Bayabas Formation and the Oligocene Antipolo Diorite.

(3) Massive sulphide type mineralization, which is mainly related to the Cretaceous basaltic activity.

(4) Contact metasomatic iron mineralization, which occurs in the vicinity of contact zones of the Eocene to Early Oligocene formations (the Maybangain Formation and the Bayabas Formation) and diorite (the Antipolo Diorite) intruding the above sedimentary formations.

In Polillo two types of mineralization are observed as follows.

(1) Vein type mineralization consisting mainly of hydrothermal hematite occurs in Cretaceous andesitic volcanics and pyroclastics.

(2) Porphyry molybdenum type mineralization which occurs in the argillized zone of the Eocene Polillo Intrusives.

The regional analysis and the interpretation of the geochemical anomalies were carried out on 10 elements of approximately 4,600 stream sediment samples collected in the area.

The results of the geochemical analyses were, then, evaluated together with the distribution of igneous bodies, geologic structures and alteration associated with mineralization.

These studies resulted in the selection of following five promising areas with priorities listed below.

(I) The upper reaches of Umiray River, central part of Southern Sierra Madre.
This zone is located at the contact between the Paleogene andesite and the Oligocene diorite intruded into the volcanics. The assumed type of major mineralization and the associated commodities are porphyry copper mineralization and Cu, Pb and Zn.

(II) The northeastern Montalban, southwestern portion of Southern Sierra Madre.
This zone is located in the Cretaceous basaltic agglomerate of Barenas-Baito Formation overlying the Boso-boso Mafic Complex. The assumed type of major mineralization and associated commodities are massive sulphide type mineralization and Cu and Zn.

(III) The southeastern part of Polillo Island.
In this zone, network and dissemination with molybdenite and pyrite occur in argillized parts of Polillo Diorite. The assumed type of major mineralization and the associated commodities are porphyry molybdenum type mineralization and Cu and Mo.

(IV) The western part of Tignoan, east coast of Southern Sierra Madre
In this zone, mineralization occurs in the fissures of the Miocene andesitic volcanics of the Tignoan Formation. The assumed type of major mineralization and the associated commodities are gold-bearing hydrothermal veins and Au, Ag and Cu.

(V) The southwestern part of Burdeos, central-western part of Polillo
In this zone, hydrothermal mineralization occurs in Cretaceous pyroclastic rocks of Anawan Formation. Although the mineral showings are hematite veins, but the results of geochemical analyses suggest Cu mineralization. Assumed type of major mineralization and the associated commodities are hydrothermal veins and Cu and Zn.

2. Geology and Mineralization

2-1 Geologic Setting (Figs. 2, 3, 4 and Attached Pl. 1)

2-1-1 Regional Geology

The survey area belongs to the Eastern Physiographic Province of the Philippine Mobile Belt. It extends in N-S direction through the central portion of the Philippine Archipelago. The area is composed of two tectonic zones-Southern Sierra Madre and Polillo. The former occupies the major part of the Southern Sierra Madre Mountains and has geology basically similar to the Luzon Central Cordillera while the latter lies at the northern end of the East Philippine Arc.

The Philippine Fault traverses through the Laur-Dingalan Valley at the northern border of the Southern Sierra Madre and extends through the Polillo Strait dividing the Southern Sierra Madre and the Polillo tectonic terranes. The movements of the Philippine Fault and related steep dipping faults with N-S, NNW and NNE trends, resulted in intense block movement of the rock units of the area. Consequently, the structure of the area is dominated by N-S trending folds and the geologic units are elongated in the same direction. The intrusive bodies of the area are Lupa Granodiorite (Paleocene) and Antipolo Diorite (Oligocene) in the Southern Sierra Madre and Polillo Intrusives in the Polillo.

2-1-1-1 Southern Sierra Madre

This occupies the major part of the Southern Sierra Madre Mountains which trend in N-S direction. In this area, Early Cretaceous metamorphic rocks (Katablingan Metamorphics) and Late Cretaceous mafic complex (Boso-boso Mafic Complex and Barenas Baito Formation) form the geologic basement and Late Cretaceous to Paleocene, Late Eocene to Early Oligocene and Middle Miocene formations are the major overlying geologic units and they are distributed in most of the survey area.

The Late Cretaceous to Paleocene Kanan Formation occurs to the east and the Kinabuan Formation to the west of the survey area. Lupa Granodiorite intruded mainly into the Kanan Formation and Barenas Baito Formation. The Early Eocene Maybangain Formation overlies conformably the Kanan Formation and unconformably the Kinabuan Formation. The Late Eocene to Early Oligocene Bayabas Formation was intruded by the Early Oligocene Antipolo Diorite and is distributed widely in the central part of the survey area. The Middle Miocene units are the Angat Formation and the Tignoan Formation. The former occurs mainly at the western and the latter at the eastern parts of the area.

2-1-1-2 Polillo

The major geologic units of this area are the basement composed of pre-Cretaceous metamorphic rocks (Masisi Schist), the Cretaceous Anawan Formation comprising volcanic rocks, the Polillo Ophiolites and the overlying Tertiary sedimentary formations.

The metamorphic rocks (Masisi Schist) are regionally metamorphosed complex bodies mainly composed of green schist and phyllite. These occur in the western part of the island. The Anawan Formation occurs in the central part of the island. The ophiolite occurs in the northern and the southern parts of the island and is in accretion contact with both metamorphic rocks and Anawan Formation.

The Tertiary sedimentary rocks are the Late Eocene Babacolan Formation, Late Oligocene to Middle Miocene Burdeos Formation, Middle Miocene Langoyen Formation and the Pliocene Karlagan Formation. The Burdeos Formation and the Langoyen Formation extend from north to south in the eastern part of the island while the Karlagan Formation occupies most of the northern part.

The Polillo Diorite regarded as Paleocene occurs in the southern part of the island, intruding into the metamorphic rocks and the Anawan Formation. No igneous activity has been recognized in the area since Late Eocene period.

2-1-2 Stratigraphy

The stratigraphic column agreed upon during the RP-Japan Workshop in June, 1988 are presented in Figures 4 and 5.

2-1-2-1 Southern Sierra Madre

The Katablingan Metamorphics is the oldest rock unit noted in the area and occurs on the eastern side of Infanta Fault and extends from north to south along the coast. It consists of schist, gneiss and phyllite all of which are regarded as Mesozoic (Revilla and Malaca, ms. 1987).

The Boso-boso Mafic Complex consists of massive gabbro, sheeted diabase dyke complex and basalt. It occurs as NE - SW trending belt in the western part of the Sierra Madre Mountains. The Boso-boso Mafic Complex is overlain conformably by the Barenas-Baito Formation. Pillow basalt containing beds of silicious mudstone is included in the overlying Barenas Baito Formation. The age of the unit is believe to be the eariest Late Cretaceous or older based on fossils in the silicious mudstone.

The Barenas Baito Formation consists of pillow basalt, red chert, red silicious mudstone, shale and pyroclastics. It extends widely from north to south in the central part of the area. The age of this unit is assigned to be middle Late Cretaceous.

The Kinabuan Formation consists of lower clastic sedimentary rocks and upper limestone. It occurs as patches in south-central part of the area and conformably overlies the Barenas-Baito Formation. The unit was dated to be Late Cretaceous by studies of *foraminiferas (Reyes and Ordonez, 1970)*.

The Kanan Formation consists of andesitic to basaltic agglomerate/volcanic breccia, lapilli, lithic tuff and minor intercalated basalt flows. It extends from north to south in the

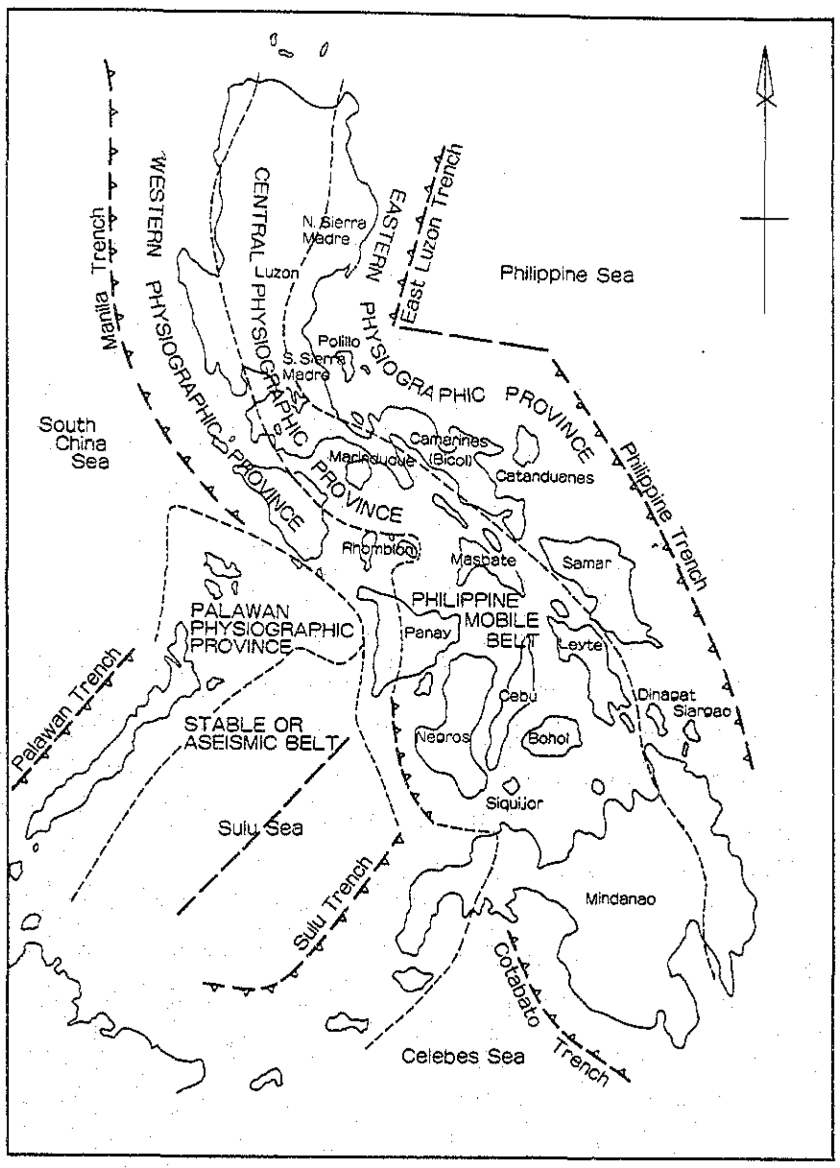


Fig. 3 Major Physiographic Elements in Philippines (Modified from G. R. Balce, et al., 1981)

eastern part of the area and conformably overlies the Barenas-Baito Formation. The age of the unit is from early Late Cretaceous to Paleocene.

The Maybangain Formation is massive to bedded dense limestone and highly fossiliferous. Small scale exposures occur scattered over the central and eastern parts of the area. It overlies the Kanan Formation conformably, but appears to be in unconformity with the Kinabuan Formation. The age of the unit is from Late Paleocene to Early Eocene.

The Bayabas Formation consists of andesitic to basaltic flows, agglomerate and tuff intercalated with siltstone, sandstone and conglomerate. It occurs widely as N-S trending belt in the central and northwestern parts of the area. It overlies the Maybangain Formation unconformably. The age of the unit is from Late Eocene to Early Oligocene.

The Binangonan Formation consists mostly of limestone with clastic sedimentary rocks and minor coal beds. It occurs as small N-S trending exposures in the central part of the area and overlies the Bayabas Formation unconformably.

This formation shows the characteristics of deposition under shallow marine and reefal environment together with coal beds formed under neritic conditions. The age of the unit is Late Oligocene.

The Angat Formation consists of upper limestone member and lower clastic member and extends in N-S direction at the southern part of the area. This formation overlies the Binagonan Formation conformably. The age of the unit is Early Miocene.

The Tignoan Formation consists of andesitic to basaltic agglomerate and tuff. It occurs extensively in southeastern part of the area. The unit is assumed to be of Middle Miocene as it includes limestone clasts of the Binangonan Formation dated as Late Oligocene to Miocene. It is correlated to the Madlum Formation in the Luzon Central Plain.

The Butete Formation consists mainly of conglomerate with minor amount of intercalated sandstone, shale and mudstone. Small scale exposures of the unit are scattered on the eastern side of the area. This formation unconformably overlies the Tignoan and Angat Formations and the Katablingan Metamorphic rocks. The age of the formation is Pliocene.

The Guadalupe Formation is the youngest formation in the area. It consists mainly of andesitic to basaltic flow, tuff and agglomerate, accompanied by tuffaceous clastics. It occurs widely in the southernmost part of the area. This formation has been assigned to Pleistocene (1.0 ~ 1.7 ma.) based on radiometric dating (Wolfe, 1981).

2-1-2-2 Polillo

the Masisi Schist consists of regionally metamorphosed rocks comprising green schist, phyllite and marble. Marble occurs as lenticular bodies within the phyllite. This unit is the oldest rock of the Polillo Island.

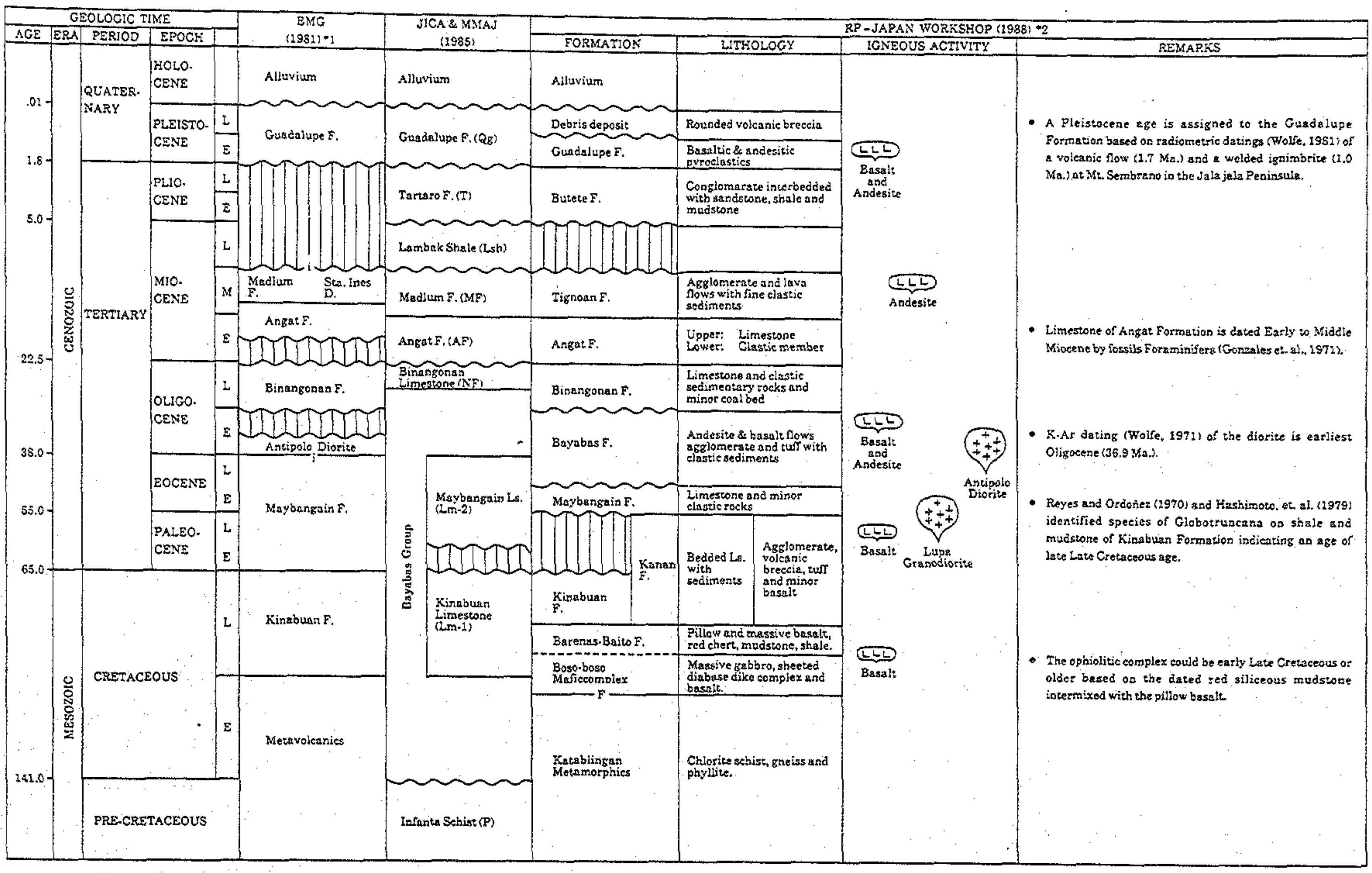
The Polillo Ultramafic Complex consists of intensely serpentinized periodotite and gabbro associated with amphibolite. It is in thrust contact to the northeast with the Cretaceous Anawan Formation, and in the vicinity of Agta, with the Masisi Formation. The amphibolite usually occurs as thrusted bodies between the Anawan Formation and the ultramafic rocks (Fernandez, 1967).

The Anawan Formation is composed of intercalation of sedimentary and volcanic rocks of basaltic to andesitic composition. It overlies the Masisi Schist unconformably and is widely distributed in the central part of the area. The volcanic member consists of flows and the sedimentary member of tuffaceous sandstone and shale. This formation yields no fossils and appears to have been formed during Cretaceous.

The Babacolan Formation consists of sandstone, shale and limestone. It occurs in long, thin lenticular shape at the upper reaches of Burdeos River and overlies unconformably the Anawan Formation. The exposures of this formation are very small. The lowest portion consists of sandstone while the middle portion consists of hard shale and the upper portion occurs as interbedded lenses within the sandstone/shale sequence. This formation was dated Late Eocene (BMG 1981).

The Burdeos Formation consists of conglomerate, sandstone, shale, limestone and coal beds. There seems to be a potential for coal exploration in this formation. It occurs as long narrow N-S trending belt in the eastern part of the island and overlies the Babacolan Formation unconformably. The conglomerate is mainly made up of rounded pebbles of volcanics and is poorly sorted but well consolidated. This member occupies most of the lower portion and are usually used as a guide for searching for coal deposits.

At the lower horizon of the unit, thin limestone beds containing abundant fossils are interlayered with black mudstone. The age of

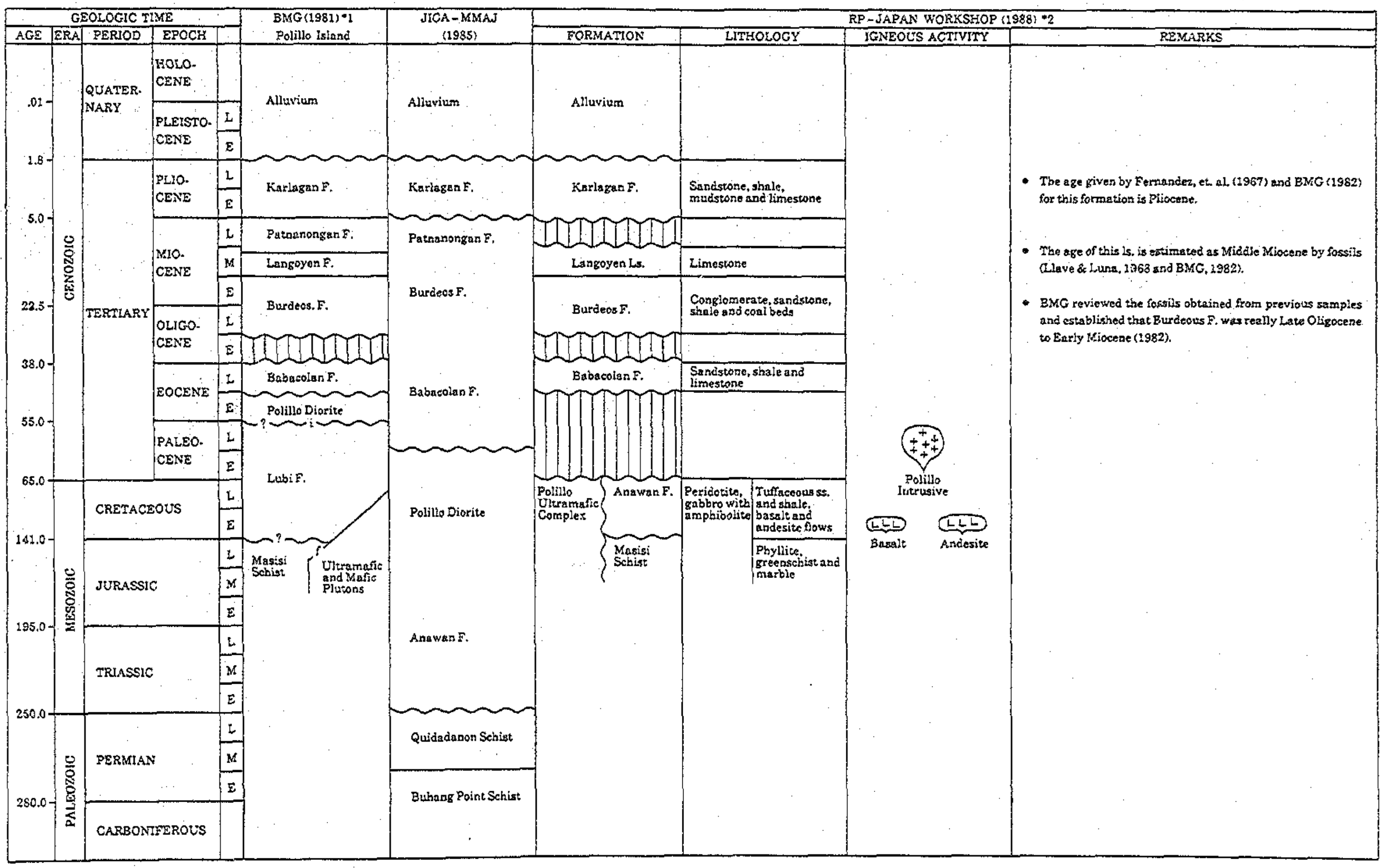


- A Pleistocene age is assigned to the Guadalupe Formation based on radiometric datings (Wolfe, 1981) of a volcanic flow (1.7 Ma.) and a welded ignimbrite (1.0 Ma.) at Mt. Sembrano in the Jala jala Peninsula.
- Limestone of Angat Formation is dated Early to Middle Miocene by fossils Foraminifera (Gonzales et. al., 1971).
- K-Ar dating (Wolfe, 1971) of the diorite is earliest Oligocene (36.9 Ma.).
- Reyes and Ordoñez (1970) and Hashimoto, et. al. (1979) identified species of Globotruncana on shale and mudstone of Kinabuan Formation indicating an age of late Late Cretaceous age.
- The ophiolitic complex could be early Late Cretaceous or older based on the dated red siliceous mudstone intermixed with the pillow basalt.

*1 BMG., 1981. "Geology and Mineral Resources of the Philippines" Volume I p.68 (Table II-31).

*2 Revilla and Malaca., ms., 1987. "Geology of Southern Sierra Madre Range".

Fig. 4 Stratigraphic Column of the Southern Sierra Madre



- The age given by Fernandez, et. al. (1967) and BMG (1982) for this formation is Pliocene.
- The age of this ls. is estimated as Middle Miocene by fossils (Llave & Luna, 1968 and BMG, 1982).
- BMG reviewed the fossils obtained from previous samples and established that Burdeous F. was really Late Oligocene to Early Miocene (1982).

*1 Geology and Mineral Resources of the Philippines. VI Geology P.68 (Table I-32) 1981.

*2 F.R. Zepeda & D.G. Jagolino, Reconnaissance Geological and Geochemical Survey of Polillo Island, ms. 1986.

Fig. 5 Stratigraphic Column in the Polillo the formation is from Late Oligocene to Middle Miocene (BMG, 1981).

The Langoyen Limestone is massive and dense and overlies the Burdeos Formation conformably. It occurs as scattered hills in alluvial sediments developed along the eastern coast. The limestone was dated early Middle Miocene (BMG, 1981).

The Karlagan Formation is composed of sandstone, shale, mudstone and limestone. It is exposed extensively in the northern part and is the youngest formation in the island. It lies gently dipping rarely exceeding 15 degrees. The upper shale and mudstone member is calcareous and marly and exhibit cross beddings indicating shallow depositional environment. The unit overlies the Langoyen Limestone unconformably. The unit is correlated to Pliocene (BMG, 1981).

2-1-3 Geologic Structure

The survey area is divided into Southern Sierra Madre and Polillo by the Philippine Fault. The area have undergone intense block movements due to the Philippine Fault and the related N-S and NNE-SSW/NNW-SSE trending steep-dipping faults.

2-1-3-1 Geologic structure in Southern Sierra Madre

Southern Sierra Madre is structurally bounded on the north by the Philippine Fault, on the east by Infanta Fault, on the southwest by Marikina Fault and on the west by Luzon Central Basin. Three major steep-dipping faults of Angat, Lenatin and Malabito Faults are observed in the central part. Folding and block movements were formed by these faults.

The Philippine Fault extends from Laur to Dingalan and runs northward up to Lingayen Gulf and is traceable southward over 1,200 km to Leyte Island via Polillo Strait. It is believed that the fault has a left-lateral displacement (Ruthland, 1967) andits movement started in Middle Miocene after the collision of the East Philippine Arc to the Sulu-Bohol-Masbate Arc and has continued to present (Mitchel et al., 1986). The Philippine Fault has displaced the Neogene formations for about 8 km in northern Leyte.

The N-S trending Infanta Fault is traceable from Magnoc to Masla along the eastern coast line and appears to run southward to the vicinity of Panay Island as Tablas Lineament. This fault is believed to be a right-lateral fault and to have produced the bending of the Philippine Fault at Polillo Strait (Revella and Malaca, 1987).

2-1-3-2 Geologic structure in Polillo

The Philippine Fault traverses along the Polillo Strait, to the west and the Philippine Trench is located in eastern offshore. Both structures played significant roles in the tectonic evolution of the area.

Polillo Fault which is parallel to the Philippine Fault extends along the western coast of the Polillo Island (Fernandez et al., 1967). It is a left lateral fault which cuts the Polillo Intrusives in the south and traverses through the Karlagan Formation in the north. N-S trending steeply dipping faults branching from the Polillo Fault are developed particularly on the eastern side of the Polillo Fault.

Structural elements of the area are N45°E trending high angled faults and NW trending fractures. Block movements were caused by displacements along these faults. The examples are Anibong Fault and Lanatong Fault which are high angle reverse faults (Delos Santos and Spencer, 1957).

2-1-4 Igneous Activities (Fig. 6)

Major igneous intrusive activities in the survey area are as follows. Paleocene to Eocene activities resulted in Lupa Granodiorite in Southern Sierra Madre and Polillo Intrusives in Polillo. Oligocene activities formed Antipolo Diorite in Southern Sierra Madre. In addition, igneous activities yielding basalt to andesite volcanic flows occurred in four intermittent times in Late Cretaceous, Eocene to Oligocene, Miocene and Pleistocene.

2-1-4-1 Igneous activities in Southern Sierra Madre

The following igneous activities are known in Southern Sierra Madre. The Late Cretaceous basalt flows of the Barenas-Baito Formation, the Poleocene intrusion of Lupa Granodiorite, the intrusion of Antipolo Diorite into the Bayabas Formation in 36.9 ma. (K-Ar dating Early Oligocene) (Wolfe, 1981), the Miocene andesitic and basaltic pyroclastics of the Tignoan Formation and the Pleistocene andesitic and basaltic volcanic flows of the Guadalupe Formation.

Of the above igneous bodies, many of the known mineral showings are associate with Antipolo Diorite.

2-1-4-2 Igneous activity in Polillo

The igneous activities of the island are andesitic and basaltic volcanic flows and Polillo Intrusives. The former occupies the main part of the Cretaceous Anawan Formation and the latter occurs widely in the central-southern part of the Polillo Island. No igneous rock after Late Eocene was observed in the island as the igneous activities shifted southeasterly to the Bicol Region after the above Polillo Intrusive activity.

2-2 Mineralization and Major Mineral Showings

The following five types of mineralization were recognized as the result of field survey of the area. Mineral showings investigated during the present survey (1985) are shown in Table 1. (Numbers indicate those of the mineral showings).

A) Contact metasomatic type mineralization

Iron mineralization occurs in the vicinity of contact zones of the Paleogene formations (the Maybangain Formation and the Bayabas Formation) and the diorite (the Antipolo Diorite) intruding them. Ore minerals are mainly magnetite accompanied by a small amount of hematite, pyrite and chalcopyrite (90 Santa Ines, 92 Angat and 93 Camaching).

B) Porphyry copper mineralization

Porphyry copper type mineralization occurs in the vicinity of contact zones of the Bayabas Formation of the central Southern Sierra Madre Range and the Oligocene Antipolo Diorite intruding the formation.

In Polillo, it occurs as molybdenite and chalcopyrite bearing quartz veinlets in the vicinity of marginal part of the Paleogene Polillo Diorite (17 Sumacbao, 27 Lumbay Collosal, 13 Marcopper Polillo).

C) Vein type mineralization

Vein type mineralization occurs mainly as hydrothermal auriferous quartz veins. In Polillo, veinlets and dissemination type mineralization consisting mainly of hematite is observed. Auriferous veins occur mainly in Cretaceous to Miocene basalt and propyrite. (18 Ibuna, 26 Marcopper Matani, 32 Tignoan, 36 Mount Malolod Iron Project).

D) Alluvial concentration

Alluvial gold enriched in river terrace sediments is often observed. It was reported that the basal part of terrace conglomerates at Papaya River in northwestern part of Southern Sierra Madre contained concentration of gold. (16 Papaya, 29 Boso-boso River).

E) Massive sulphide type mineralization

Massive sulphide type mineralization is mainly related to the Cretaceous basaltic agglomerate or pillow basalt. At Puray, lenticular deposit is observed in basic pyroclastics. The deposit is accompanied by dacite on the footwall and basaltic agglomerate on hanging wall. Ore minerals of the deposit are pyrite, chalcopyrite and bornite and its alteration comprises distinct chloritization on the hanging wall side (28 Puray).

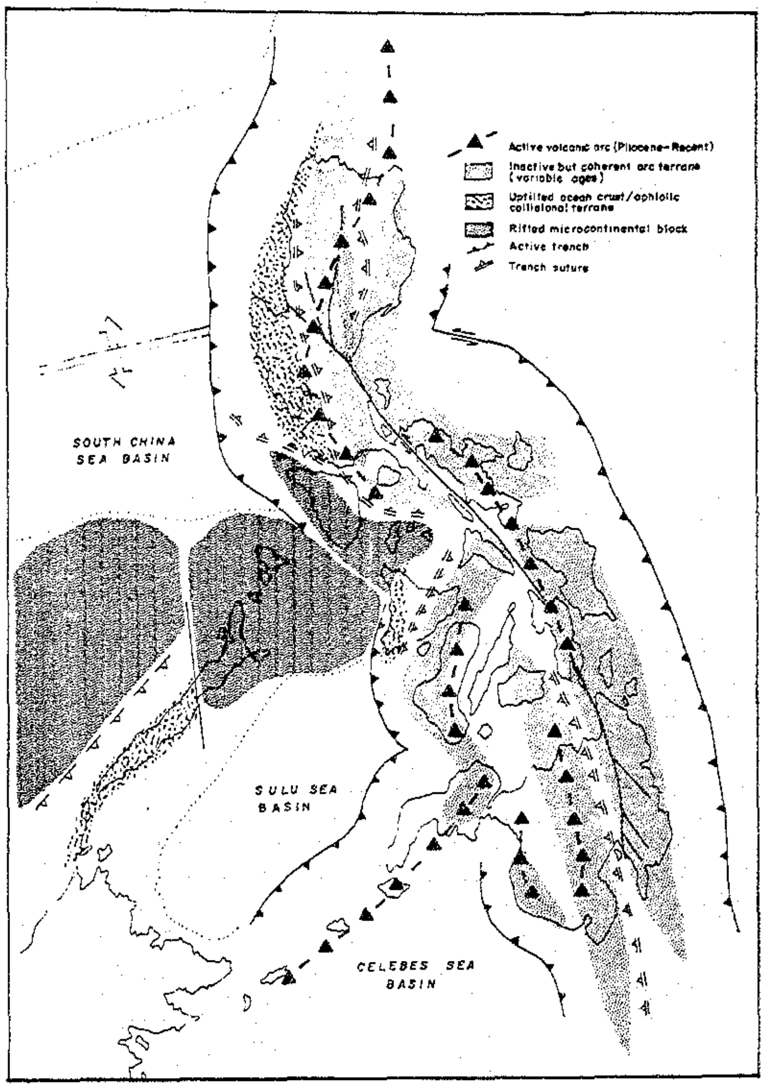


Fig. 6 Tectonic Terranes of Philippines
(After A. S. Zanoria, et al., 1984)

Table-1 Major Mineral Showings Investigated in the Southern Sierra Madre Area

*1 MINERAL SHOWING NAME	LOCATION	COMMODITY AND MINERALIZATION	AGE	TECTONIC PROVINCE	DESCRIPTION	
					OCCURRENCE	CHEMICAL ASSAY OF SAMPLE
16 Papaya	121° 10’ E 15° 25’ N	Au Placer	Pleistocene	Volcano-plutonic arc	Placer gold in terrace sediments	
17 Sumacbao River	121° 12’ E 15° 17’ N	Cu Au Porphyry copper	Paleogene	Volcano-plutonic arc	Dissemination and veinlets observed in and around intrusive rocks	Six (6) assay results; Cu 0.12~0.96%, Au tr-53 g/t, Ag tr-11 g/t
18 Ibuna	121° 22’ E 15° 18’ N	Cu Au Hydrothermal vein	Paleogene	Volcano-plutonic arc	Gold bearing quartz veins in basaltic pyroclastics	Cu 4.88%, Au 0.1 g/t
26 Marcopper Matani	121° 12’ E 14° 46’ N	Au Hydrothermal vein	Paleogene	Volcano-plutonic arc	Gold bearing quartz veins in andesite and basalt flows	(1) Cu 0.11%, Zn 0.12%, Ag 6.8 g/t, Au<0.1 g/t (2) Cu 0.34%, Zn 1.02%, Ag 15.9 g/t, Au 1.8 g/t
27 Lumbay Collosal	121° 24’ E 14° 51’ N	Cu Porphyry copper	Paleogene	Volcano-plutonic arc	Dissemination and veinlets observed in alteration zone in andesitic porphyry	Cu 0.02~0.07%, Au 0.1 g/t
28 Puray	121° 12’ E 14° 46’ N	Cu Au Massive sulfide	Cretaceous	Oceanic crust	Strate-bound massive sulphide in basaltic tuff breccia	Cu 13%, Zn 0.09%, Pb 0.03%, Au 3.2 g/t
29 Boso-boso River	121° 12’ E 14° 32’ N	Au Placer	Pleistocene	Volcano-plutonic arc	Placer gold in terrace sediments	
32 Tignoan	121° 33’ E 14° 35’ N	Au Hydrothermal vein	Oligocene-Miocene	Volcano-plutonic arc	Clay vein in basaltic pyroclastic rock small gold grain observed	(1) Cu 0.08%, Ag 1.3 g/t, Au 0.1 g/t (2) Cu 0.03%, Ag 2.7 g/t, Au<0.1 g/t
90 Sta. Ines	121° 19’ E 14° 44’ N	Fe Contact metasomatism	Oligocene-Miocene	Volcano-plutonic arc	Contact metasomatism between Bayabas Formation and Antipolo diorite	Fe 63.53%, Cu 0.11%, Au<0.1 g/t
92 Angat	121° 08’ E 14° 59’ N	Fe Contact metasomatism	Oligocene-Miocene	Volcano-plutonic arc	Contact metasomatism between Bayabas Formation and Antipolo diorite magnetite>hematite>pyrite>chalcopyrite observed	
93 Camaching	121° 08’ E 15° 05’ N	Fe Contact metasomatism	Oligocene-Miocene	Volcano-plutonic arc	Contact metasomatism between calcareous sedimentary rocks and diorite	
36 Mount Malolod	121° 57’ E 14° 50’ N	Fe Hydrothermal vein	Paleogene	Volcano-plutonic arc	Hydrothermal dissemination and veinlets in altered volcanics	
91 Marcopper Polillo	121° 59’ E 14° 47’ N	Mo Porphyry molybden	Oligocene-Miocene	Volcano-plutonic arc	Quartz veinlets in boundary zone of diorite, molybdenite and pyrite observed	Cu 0.13%, Mo 1.0%, Au 0.1 g/t

*1 These numbers correspond to those of in Attached Plate-6

3. Geochemical Sample Analyses and Data Processing

3-1 Analytical Methods and Precision

3-1-1 Analytical Methods

The whole survey area was divided into cells whose unit is a N-S 2 km, E-W 2 km grid and whose datum point is at longitude 121° 00'E, latitude 14°20'N. Geochemical analyses data of stream sediment samples (JICA - MMAJ, 1985) distributed in the cells were statistically analyzed in the following four kinds methods. All data are regarded as one population.

(1) Univariate analyses of the average values (hereinafter called cell average values) of the geochemical analysis data of each cell.

(2) Univariate analyses of the moving average values, where a frame consisting of nine cells (three cell in both N-S and E-W direction) is set and the average value of nine cells in taken to be the value of the central cell. The frame is moved one cell at two kilometer at one time step throughout the survey area and the average for every step is calculated.

(3) Univariate analyses of the high-pass filter values--the differences between the cell average values and the corresponding moving average values (only positive values)--(hereinafter called high-pass filter values)

(4) Multivariate analyses (factor analyses) of the cell average values.

The following are the numbers of samples, cells and chemical analysis components which were prepared for the above-mentioned analyses.

Table-2 Details of Sample and Cell

The Numbers of Sample	The Numbers of Cell	The Components for Analysis
4,588	1,257	Cu, Pb, Zn, Ag, As, Mn, Ni, Co, Mo, Hg

An IBM 3084Q computer and statistical analyses package BMD 08M (UCLA. developed) were utilized for statistical procedures. Computation was done in logarithmic values then subsequently converted into normal values. For the purpose of statistical procedure, 50 percent of the detection limit values was taken as the value of the sample below the detection limit. Chemical analyses were conducted by using AAS analyses in PETROLAB, the chemical analysis section of the MGB. Detection limit of AAS analysis are shown in Table-3.

Table-3 Detection Limits of AAS Analyses

(Unit: ppm)

Component	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Hg	Mo
Detection limit	2	10	2	1	0.5	50	3	3	0.04	2

3-1-2 Precision Check

Precision checks for the chemical analyses were carried out. The variance of the analyzed value at 95 percent confidence level is calculated, by the Thompson and Howarth method (1973) with the results of the batch test. A sample was chosen from each analysed batch (about 20 samples) and was analysed with another batch after which the variance was calculated statistically. The numbers of batch test samples for the entire RP-Japan project is approximately 1,000 for Cu, Pb, Zn, As, Mn and Hg, approximately 800 for Ni and Co.

Table-4 Dispersion of Batch Test Results

Component	Dispersion
Cu	±15%
Pb	±20%
Zn	±20%
As	±25%
Mn	±10%
Ni	±20%
Co	±20%
Hg	±25%

Variance for Ag and Mo values could not be determined because values in many samples were below detection limit.

3-2 Cell Average Values

As mentioned above, geometrical average values of geochemical analyses data in each cell were used in the analyses. For cells without sampling point (blank cell), the following gap filling was carried out.

(1) Geometrical average values of the eight cells around the blank cell is applied as the value of blank cells (when the numbers of the effective values are less than four, the supplement was not carried out).

(2) This procedure was done twice.

Table-5 Basic Statistical Values of the Cell Average Data

	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	As (ppm)	Mn (ppm)	Ni (ppm)	Co (ppm)	Mo (ppm)	Hg (ppb)
M value	49.73	-	94.52	-	1.30	998.84	23.46	22.68	-	-
M+1.0σ value	74.29	-	148.75	-	2.93	1,455.05	42.22	33.07	-	-
M+1.5σ value	90.79	-	186.61	-	4.39	1,756.18	56.64	39.92	-	-
M+2.0σ value	110.96	-	234.10	-	6.59	2,119.63	75.98	48.20	-	-
Maximum value	1,143.20	89.09	430.64	1.33	42.00	3,000.00	214.94	77.45	11.21	430.00
Minimum value	5.00	5.00	13.79	0.50	0.25	197.48	1.50	1.50	1.00	20.00
R. B. D.	0%	99%	0%	99%	11%	0%	0.6%	0.2%	99%	98%

M: mean value σ: standard deviation R. B. D.: ratio of cells below detection limit

Table-6 Basic Statistical Values for Original Analyses

	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	As (ppm)	Mn (ppm)	Ni (ppm)	Co (ppm)	Mo (ppm)	Hg (ppb)
M	49.44	-	92.30	-	1.42	969.35	23.95	22.31	-	-
M+1.0σ	82.29	-	163.66	-	4.09	1,586.12	48.25	34.95	-	-
M+1.5σ	107.29	-	217.92	-	6.96	2,028.91	68.51	43.75	-	-
M+2.0σ	138.90	-	290.18	-	11.82	2,595.31	97.27	54.76	-	-
Maximum	2,000.00	1,800.00	3,000.00	9.50	86.00	6,700.00	460.00	85.00	120.00	900.00
Minimum	3.00	5.00	4.00	0.50	0.25	25.00	1.50	1.50	1.00	20.00

M: mean value σ: standard deviation

Table-7 Details of Inflection Points of the Cumulative Frequency Curves (Cell Average Values)

Element	Cu	Zn	As	Mn	Ni	Co
Cumulative frequency	85%	93%	89%	94%	91%	85%
Cell averages	70 ppm	170 ppm	3.5 ppm	1,700 ppm	50 ppm	30 ppm

3-2-1 Basic Statistical Values

Basic statistical values of the cell average value for each element are shown in Table-5. Basic statistical values of the original analytical results are also shown in Table-6 for reference.

3-2-2 Histograms and Cumulative Frequency Curves

Histograms and cumulative frequency curves showing the frequency distribution of the cell average values for each element were drawn (Appendix data-1). Inflection point of the curve was selected by the method of Lepeltier (1969) and its corresponding cell average value was regarded as the lowest anomaly value (threshold value).

Inflection points for Pb, Mo and Hg could not be used because 98 to 99% of the cells for Pb, Mo and Hg contained values below the detection limits. Details of inflection point for each element are shown in Table-7.

3-2-3 Correlation Coefficients of Analysed Elements

Correlation coefficients among elements of the cell average values are shown in Table-8. Correlation coefficients among elements of the original analytical results are also shown in Table-9.

Table-8 Correlation Coefficients of Cell Average Data

	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg
Cu	1.000									
Pb	0.203	1.000								
Zn	0.549	0.141	1.000							
Ag	0.205	0.706	0.118	1.000						
As	0.124	0.231	0.077	0.186	1.000					
Mn	0.506	-0.001	0.822	-0.017	-0.136	1.000				
Ni	0.237	-0.039	0.123	0.006	0.139	0.023	1.000			
Co	0.554	0.010	0.610	0.056	-0.102	0.650	0.548	1.000		
Mo	0.105	0.217	-0.068	0.189	0.129	-0.148	-0.019	-0.103	1.000	
Hg	0.077	0.260	0.076	0.280	0.164	-0.015	0.050	0.037	0.078	1.000

Table-9 Correlation Coefficients of Original Analyses

	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg
Cu	1.000									
Pb	0.263	1.000								
Zn	0.525	0.271	1.000							
Ag	0.174	0.525	0.167	1.000						
As	0.131	0.232	0.124	0.106	1.000					
Mn	0.426	-0.002	0.712	-0.010	-0.114	1.000				
Ni	0.163	-0.026	0.099	0.009	0.065	0.027	1.000			
Co	0.486	0.004	0.525	0.020	-0.111	0.612	0.519	1.000		
Mo	0.050	0.116	-0.022	0.067	0.093	-0.148	-0.004	-0.124	1.000	
Hg	0.121	0.262	0.125	0.214	0.145	0.024	0.001	0.017	0.056	1.000

In the cell average values, positive correlations coefficients higher than 0.5 are observed among the following elements.

Cu — Zn Zn — Mn Mn — Co Ni — Co
Cu — Mn Zn — Co
Cu — Co

3-2-4 Areal Distribution of the Cell Average Values (Attached Plate 2-1 No. 1 ~ No. 9)

The cell average values of each element were classified into eleven ranks and were plotted on a 1:1,000,000 scale areal map with the corresponding rank color.

The classified ranks are as follows.

A	99% ≦ Z	G	40% ≦ Z < 50%
B	95% ≦ Z < 99%	H	30% ≦ Z < 40%
C	90% ≦ Z < 95%	I	20% ≦ Z < 30%
D	75% ≦ Z < 90%	J	Detection Limit ≦ Z < 20%
E	60% ≦ Z < 75%	K	Detection Limit > Z
F	50% ≦ Z < 60%		

The areal distribution of the anomalous cell average values are as follows (anomalous elements are shown in brackets). These localities are shown in Figure 7.

<u>Southern Sierra Madre</u>

A-1; Northwestern part; eastern side of Papaya (Cu, Ni)

A-2; Central east coast-inland (General Naker to Mt. Caladong); (Cu, Pb, Zn As, Mn, Ni, Co, Mo, Hg)

A-3; Central part of the western side of the area; northeastern side of Angat (Cu, Co)

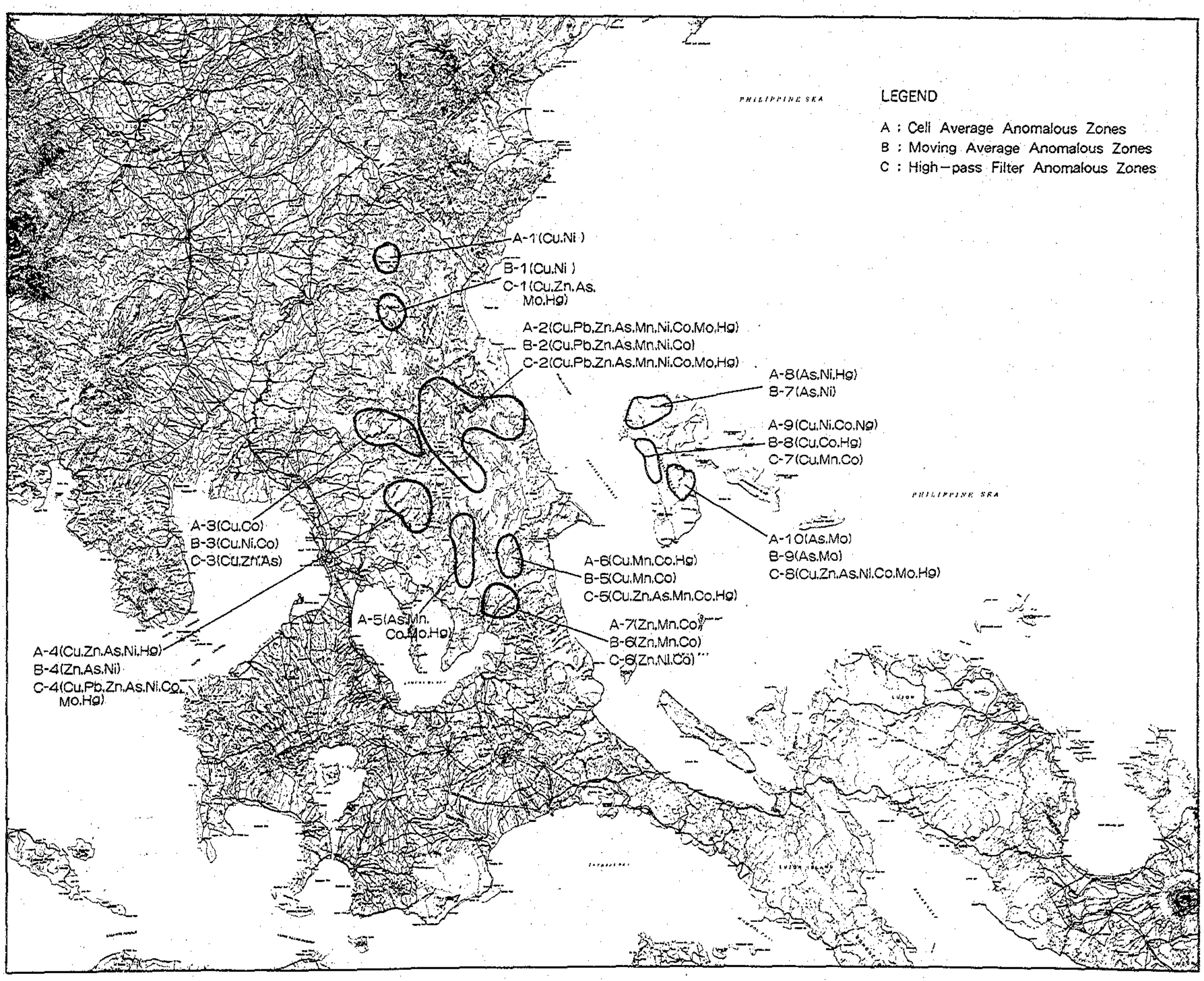


Fig. 7 Distribution Map of Anomalous Zones of Univariate Analyses

A-4; Southwestern part; northeastern side of Montalban (Cu, Zn, As, Ni, Hg)

A-5; Southern part; the vicinity of San Andres (As, Mn, Co, Mo, Hg)

A-6; Southeastern part; western side of Tignoan (Cu, Mn, Co, Hg)

A-7; Southern part; northeastern side of Santa Maria (Zn, Mn, Co)

Polillo

A-8; Northern Part; (As, Ni, Hg)

A-9; Central west coast: (Cu, Ni, Co, Hg)

A-10; Central part of the eastern side of the island; (As, Mo)

Of the above,the following anomalous zones can be understood by the present knowledge regarding geology, igneous activities and mineralizations.

(a) Central east coast to inland part of Southern Sierra Madre

This anomalous zone extends N-S direction through Southern Sierra Madre, where Cretaceous to Oligocene sediments occur, the Paleocene Lupa Granodiorite intruded in the northern and southern parts and the Oligocene Antipolo Diorite intruded in the central part. Anomalous cells for Cu, Pb, Zn, As and Mo are accompanied by the central eastern Lupa Granodiorite and the Cretaceous to Paleocene Kanan Formation of southern Umiray of the east coast.

The surveyed mineral showings are Marcopper Matani and Lumbai Colossal in the central southern part of the zone.

(b) Central part of western Southern Sierra Madre, vicinity of Angat

This anomalous zone is located in the eastern side of the Antipolo Diorite intrusives forming Mt. Maon. Anomalous cells for Cu are accompanied by diorite and those for Co are accompanied by the eastern Angat Ultramafic Complex. The surveyed mineral showing at Angat is located in this zone.

(c) Southwestern Part of Southern Sierra Madre, northeastern side of Montalban

In this anomalous zone, the Cretaceous Angat Ultramafic Complex occurs contemporaneous with basalt and Cu, Mn, Ni, Co and Hg anomalies are associated with ultramafic complex. Kuroko type mineral showings at Puray are associated with basalt.

(d) Southeastern part of Southern Sierra Madre, western side of Tignoan

The Tignoan Formation composed of Miocene pyroclastics and volcanic flow occurs in this anomalous zone. Aggregation of anomalous cells for various elements (Cu, Zn, As, Ni and Hg) is related to basic volcanic rocks and its accompanying hydrothermal mineralization. Gold showings at Tignoan River were investigated.

(e) Central part of the western coast of Polillo Island

The Mesozoic Masisi Schist, Anawan Formation including Cretaceous ultramafic volcanics, the Babacolan Formation composed of Eocene sediments and the Burdeos Formation composed of Oligocene-Miocene sediments occur in this anomalous zone. Aggregation of anomalous cells for various elements (Cu, Ni, Co and Hg) is related to these host rocks and to the hydrothermal mineralization associated with the Polillo Intrusives intruding into eastern part of the area.

3-3 Moving Average Data

As stated in 3-1-1, a geometrical average of every nine cells is defined as the value of the central cell and these values are calculated for movement in two kilometer steps. The gap filling procedure for a blank cell is done in a way that when more than half of five cells immediately surrounding the blank cell have effective values, the average of the each cell is regarded as the moving average value of the blank cell. This procedure is carried out twice. The moving average as stated above are suitable for finding the general trend and the geological change of the source areas as these values represent the average values of cells ranging 6 km × 6 km around each cell.

3-3-1 Basic Statistical Values

Basic statistical values for each element of the moving average values of Southern Sierra Madre Area are shown in Table-10. Regarding Ag, all cells contained values below detection limits, then omitted Ag from the statistical analyses.

Table-10 Basic Statistical Values for Moving Average Data

	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Mn (ppm)	Ni (ppm)	Co (ppm)	Mo (ppm)	Hg (ppb)
M	49.78	–	94.44	1.30	999.40	23.42	22.67	–	–
$M+1.0\sigma$	67.60	–	137.60	2.42	1,369.07	38.31	31.05	–	–
$M+1.5\sigma$	78.78	–	166.10	3.29	1,602.40	49.77	36.33	–	–
$M+2.0\sigma$	91.80	–	200.49	4.49	1,875.49	62.68	42.52	–	–
Maximum	123.93	16.81	207.30	7.42	1,991.50	76.29	50.67	2.32	50.58
Minimum	10.98	5.00	24.04	0.32	329.28	2.80	4.26	1.00	20.00
R. B. D.	0%	99%	0%	5%	0%	0.2%	0%	99.8%	99.7%

M: mean value σ: standard deviation R. B. D.: ratio of cells below detection limit

Table-11 Details of Inflection Points of the Cumulative Frequency Curve (Moving Average Data)

Element	Cu	Zn	As	Mn	Ni	Co
Cumulative frequency	85%	80%	77%	79%	97%	85%
Moving averages	62 ppm	120 ppm	2 ppm	1,200 ppm	55 ppm	29 ppm

3-3-2 Histograms and Cumulative Frequency Curves

Histograms and cumulative frequency curves of the moving average values were made for each element. Moving average values corresponding to inflection point of the cumulative frequency curve was regarded as the lowest value of anomaly (threshold) by Lepeltier's method (1969).

Inflection points and threshold values for Pb, Mo and Hg could not be determined because 99 percent of the cells contained Pb, Mo and Hg in amounts below the detection limit. Details of inflection point for each element are shown in Table-11.

3-3-3 Areal Distribution of the Moving Average Values (Attached Plate 2-1 No. 1 ~ No. 9)

The moving average values for each element were classified into eleven ranks and were plotted in a 1:1,000,000 scale areal map with the corresponding rank color as in the case of the cell average values.

Areal distribution of the anomalous moving average values of each clement are as follows (anomalous elements are shown in branckets). These localities are shown in Figure 7.

Southern Sierra Madre

B-1; Northwestern Part; eastern side of Papaya (Cu, Ni)
B-2; Central east coast (General Nakar -- Mt. Caladang); (Cu, Pb, Zn, As, Mn, Ni, Co, Mo, Hg)
B-3; Central part of western side of the area; northeastern side of Angat (Cu, Ni, Co)
B-4; Southwestern part; northeastern side of Montalban (Cu, Zn, As, Ni, Hg)
B-5; Southeastern part; western side of Tignoan (Cu, Mn, Co, Hg)
B-6; Southern part; northeastern side of Santa Maria (Zn, Mn, Co)

Polillo

B-7; Central part of western coast; (Cu, Co, Hg)
B-8; Northern Part; (As, Ni)
B-9; Central part of eastern side of the island; (As, Mo)

These anomalous zones correspond to that of the cell average values except for the vicinity of San Andres in southwestern part of the area. As for anomalous elements compared with cell average values, Mo and Hg are lacking at the central east coast to inland zone, Cu and Hg are lacking at the east side of Montalban in Southern Sierra Madre and Hg is lacking at the northern part. Ni is lacking at middle west cost in Polillo. While only Ni is added at northeastern side of Angat in Southern Sierra Madre.

Of the above, the following anomalous zones can be understood by the present knowledge regarding geology, igneous activities and mineralization.

(a) Central east coast to inland of South Sierra Madre
Details of this anomalous zone is similar of cell average values. Concentration of anomalous cells are clearer than in the case of cell average values, especially in the vicinity of intrusive bodies at middle to southern part of the zone A and B rank anomalous cells of Cu, Pb and As show clear concentration.

(b) Central part of western Southern Sierra Madre, vicinity of Angat
Details of this anomalous zone is similar to those of the cell average. Concentration of Ni, A and B rank anomalous cells is clearer than with cell average values.

(c) Southwestern part of Southern Sierra Madre, northeastern side of Montalban Details of this anomalous zone is the same as in the case of the cell average values.

(d) Southeastern part of Southern Sierra Madre, western side of Tignoan
Details of this anomalous zone is similar to the cell average values. Compared with cell average value, concentration of Cu, B rank cells at the western part, Mn, C rank cells at eastern part and Cu, B rank cells at southern part of the zone are clearer.

(e) Central part of the western coast of Polillo Island
Details of this anomalous zone is similar of cell average value. Compared with cell average values, concentration of Cu, A rank and Co, D rank cells at northern part of the zone are clearer.

3-4 High-Pass Filter Data

As stated in 3-1, the positive difference between the cell average values and the corresponding moving average values is defined as the high-pass filter value. These indicate the extent of the deviation of the individual cell averages from the flattened moving averages. Calculating the difference between the two values offsets the background value and thus the high-pass filter values indicate anomalous zones which were derived from added factors such as mineralization and secondary enrichment. These values provide guidelines regarding the locality, strength and priority of the geochemical anomalous zones.

3-4-1 Basic Statistical Values

Basic statistical values for each element of the high-pass filter values are shown in Table-12. (Ag values were omitted from the statistical analysis.)

3-4-2 Histograms and Cumulative Frequency Curves

Histograms and cumulative frequency curves showing frequency distribution of the high-pass filter values for each element were prepared. Inflection point of the curve was selected by the Lepeltier's method (1969) and its corresponding high-pass filter value was regarded as the lowest value of anomaly value (threshold value). Threshold for Pb, Mo and Hg could not be selected as more than 99 percent of the cells for Pb, Mo and Hg contained no effective value. Details of inflection points for the elements are shown in Table-13.

3-4-3 Areal Distribution of High-pass Filter Anomalous Values (Attached Pl. 2-3 No. 1 - No. 6)

Each anomalous value was classified based on the following formula for each element and was plotted on a 1:1,000,000 scale map with the corresponding rank colors, as all the threshold values selected were more than $M + 1.0\sigma$.

High-pass Filter Value Classification

Classificaiton Formula	Rank	Rank Color
$M + 2.0\sigma \leqq Z$	A	Red
$M + 1.5\sigma \leqq Z < M + 2.0\sigma$	B	Yellow
$M + 1.0\sigma \leqq Z < M + 1.5\sigma$	C	Blue

The following zones of anomalous high-pass filter values are related to anomalous zones of the cell averages and considered important. These localities are shown in Figure 7.

Southern Sierra Madre

C-1; Northwestern part; eastern side of Papaya (Cu, Zn, As, Mo, Hg)
C-2; Central east coast to inland (from General Nakar to Mt. Caladong); (Cu, Pb, Zn, As, Mn, Ni, Co, Mo, Hg)
C-3; Central part of the western side of the area; northeastern side of Angat (Cu, Zn, As)
C-4; Southwestern part; northeastern side of Montalban (Cu, Pb, Zn, As, Ni, Co, Mo, Hg)
C-5; Southeastern part; western side of Tignoan (Cu, Zn, As, Mn, Co, Hg)
C-6; Southern part; northeastern side of Santa Maria (Zn, Ni, Co)

Polillo

C-7; Central west coast; (Cu, Mn, Co)
C-8; Central east coast; (Cu, Zn, As, Mn, Co, Hg)

The above zones overlap those of cell averages, with the exception of the vicinity of San Andres. Regarding the concentrated elements, compared with the cell averages in Southern Sierra Madre; Zn, As, Mn and Hg are added at the southeast side of Papaya, Zn, As and Mn are added at the northeast side of Angat, Pb, Co and Mo are added at the northeast side of Montalban and Ni is added at the northeast side of Santa Maria. In Polillo, Cu, Zn, Ni, Co and Hg are added at the central west coast.

On the contrary, in Southern Sierra Madre, Ni anomalous cell is lacking at Papaya, Co anomalous cells are lacking at Angat and Ni and Hg anomalous cells are lacking at Santa Maria. In the Polillo, Ni and Hg anomalous cells are lacking at the central west coast.

Of the above, the following anomalous zones can be understood by the present knowledge regarding geology, igneous activity and mineralization.

Table-12 Basic Statistical Values for the High-pass Filter Data

	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Mn (ppm)	Ni (ppm)	Co (ppm)	Mo (ppm)	Hg (ppb)
M	3.59	1.09	8.07	0.37	64.10	3.04	1.70	0.34	2.66
$M+1.0\sigma$	14.87	4.25	35.17	1.56	272.89	12.14	5.79	0.91	12.81
$M+1.5\sigma$	30.26	8.37	73.43	2.58	563.06	24.29	10.69	1.49	28.10
$M+2.0\sigma$	61.57	16.51	153.31	4.27	1,161.79	48.59	19.72	2.44	61.65
Maximum	1,047.80	72.28	251.63	39.95	1,956.10	157.87	47.14	9.77	389.62
Minimum	0.10	0.11	0.10	0.10	0.38	0.11	0.10	0.10	0.10

M: mean value σ: standard deviation

Table-13 Details of Inflection Points of the Cumulative Frequency Curve (High-pass Filter Data)

Element	Cu	Zn	As	Mn	Ni	Co
Cumulative frequency	93%	78%	96%	93%	97%	78%
High-pass Filter	21 ppm	23 ppm	2.2 ppm	380 ppm	33 ppm	4.2 ppm

(a) Central east coast to inland of Southern Sierra Madre (A-1)
Details of this anomalous zone are similar to those of cell average values. Anomalous cells are recognized for all elements. Especially in the upper reaches of Umiray River in the southern part of the zone, A-rank cells are observed for Cu, Zn, As, Mo and Hg, it is inferred to have derived from strong mineralization. From the geological setting of the zone, the mineralization is believed to be related to diorite intrusive body.

(b) Central west Southern Sierra Madre, vicinity of Angat (A-2)
Details of this zone are similar to those of cell average values. Among the anomalous elements, Cu, Zn, As and Mn are associated with Antipolo Diorite of Mt. Maon, these anomalous cells are inferred to have derived from the mineralization related to with the diorite.

(c) Southwestern part of Southern Sierra Madre (A-4), northeastern side of Montalban
Details of this anomalous zone is similar to those of cell average value. Anomalous cells for many elements except Mn are observed, and A and B rank anomalous cells for Cu, Pb and Zn occur in basalt, hence the anomalous zone is inferred to have derived from the massive sulphide mineralization such as Puray Mineral Showing.

(d) Southeastern part of Southern Sierra Madre (A-6), western side of Tignoan
Details of this anomalous zone is similar to those of cell average values. Anomalous cells for many elements except Pb, Ni and Mo are observed andally A and B rank anomalous cells for Cu, Zn and Hg are recognized. It suggests the existence of hydrothermal mineralization.

(e) Western part of east coast of Polillo Island (A-10)
Details of this anomalous zone is similar to those of cell average values. Anomalous cells for many elements except Pb and Mn are observed and concentration of Cu, Zn, As, Mo and Hg anomalous cells suggests the existence of hydrothermal mineralization.

3-5 Factor Analyses of Cell Average Data

Factor analysis carried out on each cell average data using the Varimax rotation method.

The content of silver was below detection limit in 99.9% the cells and thus this element was excluded from this analysis. Therefore, the elements used for factor analysis amount to nine; they are Cu, Pb, Zn, As, Mn, Ni, Co, Mo, and Hg.

3-5-1 Extraction of Factors

Correlation matrix and eigenvalues (λ) taken from normalization and interpretation of the cell average values for elements are shown in Table-14 and Table-15.

Table-14 Correlation Matrix of Cell Average Values

	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg
Cu	1.000									
Pb	0.203	1.000								
Zn	0.549	0.141	1.000							
Ag	0.205	0.705	0.118	1.000						
As	0.124	0.231	0.077	0.186	1.000					
Mn	0.506	-0.001	0.822	-0.017	-0.135	1.000				
Ni	0.237	-0.039	0.123	0.007	0.139	0.024	1.000			
Co	0.554	0.010	0.610	0.056	-0.102	0.650	0.548	1.000		
Mo	0.105	0.216	-0.068	0.189	0.129	-0.148	-0.019	-0.104	1.000	
Hg	0.077	0.260	0.076	0.280	0164	0.014	0.050	0.037	0.078	1.000

$\lambda_2 = 2.114$ - - - and if those over 1 are taken, the factor value will be 3. However.as λ_4 and λ_5 are relatively large and the cumulative proportion of total variance reaches 81 percent up to λ_5 and covers most of the dispersion, the factors up to 5 are considered. On the other hand, when SMC (Squared multiple Correlation) diagonal factors are used as common estimate values, the eigenvalues will be $\lambda_1 = 2.669$, $\lambda_2 = 1.555$ - - -. The positive values are over factor of 5 and thus five factors were adopted for factor analyses.

3-5-2 Interpretation of Each Factor

Five factors and diagonal factors SMC (Squared Multiple Correlation) were adopted and the left half of Table-16 shows the factor loadings which were processed by main analysis. The right

Table-15 Eigenvalues and Cumulative Proportions of Variance

	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6	Factor-7
Eigenvalue (D.F. : 1)	3.023	2.114	1.193	0.941	0.869	0.794	0.457
C. P. T. V.	0.302	0.514	0.633	0.727	0.814	0.893	0.939
Eigenvalue (D.F. : S.M.C.)	2.699	1.555	0.763	0.243	0.099	-0.041	-0.100

D.F.: Diagonal factor C.P.T.V.: Cumulative proportion of total variance
S.M.C.: Squared multiple correlation

Table-16 Factor Loadings

Before Varimax Rotation						After Varimax Rotation					
Factor	1	2	3	4	5	Factor	1	2	3	4	5
Cu	0.663	0.129	0.047	0.106	0.169	Cu	0.605	0.164	0.243	0.079	0.200
Pb	0.189	0.753	-0.092	-0.106	-0.012	Pb	0.084	0.755	-0.058	0.100	0.181
Zn	0.838	-0.038	-0.235	0.160	-0.078	Zn	0.872	0.097	0.050	0.103	-0.098
Ag	0.197	0.736	-0.041	-0.172	-0.024	Ag	0.066	0.763	0.005	0.050	0.155
As	0.036	0.349	0.152	0.352	-0.070	As	-0.018	0.206	0.070	0.461	0.125
Mn	0.820	-0.255	-0.349	-0.022	-0.017	Mn	0.900	-0.046	-0.016	-0.159	-0.154
Ni	0.339	-0.044	0.679	0.002	-0.046	Ni	0.092	-0.010	0.748	0.123	-0.007
Co	0.825	-0.181	0.292	-0.176	0.016	Co	0.663	0.027	0.596	-0.169	-0.077
Mo	-0.043	0.308	0.037	0.097	0.205	Mo	-0.064	0.191	-0.022	0.116	0.308
Hg	0.099	0.334	0.041	0.026	-0.120	Hg	0.026	0.331	0.045	0.160	-0.004

half of Table-16 shows the factor loading safter adopting the Varimax rotation method.

Interpretation of each factor are as follows:

(a) Factor No. 1

Factor loadings before rotation except Mo are all positive and values for Zn, Mn, Co, and Cu are high. Those values after rotation have similar tendency as well, indicating factors related to mineralization of Zn, Mn, Co, and Cu.

(b) Factor No. 2

Factor loadings before rotation for Zn, Mn, Ni and Co are negative and those values for Ag, Pb, Hg and Mo are positive and high, indicating factors related to vein type Ag, Pb and Hg mineralization.

(c) Factor No. 3

Factor loadings before rotation for Pb, Zn, Ag and Mn are negative and those values for Ni and Co are positive and a little higher. Those values after rotation for Pb, Mn and Mo are negative and high, indicating factors related to Ni and Co concentration in host rock.

(d) Factor No. 4

Factor loadings before rotation for Pb, Ag, Mn and Co are negative and that value for As is positive and a little higher. Those values after rotation for Mn and Co are negative and that value for As is positive and a little higher. The factor hereby appears to be related to As concentration but the regarding mineralization type remains to be solved.

(e) Factor No. 5

Factor loadings before rotation for Pb, Zn, Ag, As, Mn, Ni and Hg are negative and those values for Cu and Mo are positive and a little higher. Those values after rotation for Zn, Mn, Ni, Co and Hg is negative and those value for Mo, Cu and Pb are positive and a little higher indicating factors related to porphyry type Cu, Mo mineralization.

3-5-3 Classification of Factor Scores

Factor score of each cell was calculated by multiplying the cell average value by factor score coefficient and summarizing them for each cell. After statistical procedure was done, these factor scores were classified into the following eight ranks and were plotted on a 1:1,000,000 scale map (Attached Pl. 2-4 Nos. 1 ~ 5).

Rank	Frequency	Rank	Frequency
A	$90\% \leqq Z < 100\%$	E	$30\% \leqq Z < 50\%$
B	$80\% \leqq Z < 90\%$	F	$20\% \leqq Z < 30\%$
C	$70\% \leqq Z < 80\%$	G	$10\% \leqq Z < 20\%$
D	$50\% \leqq Z < 70\%$	H	$0\% \leqq Z < 10\%$

3-5-4 Distribution of the Geochemical Anomalies (Factor Scores)

Attached plates (2-1 Nos. 1 ~ 5) and Figure 8 show areal distribution of the factor scores. The concentrated areas of high scored cells are as follows.

(A) Factor No. 1 (Closely related to Mn, Zn, Co and Cu)

D-1-1; The Cretaceous Kanan Formation from Umiray, east coast to Magnoc.

D-1-2; The Cretaceous Barenas Baito Formation and the Eocene-Oligocene Bayabas Formation at the upper reaches of Umiray River, central inland.

D-1-3; The Cretaceous Kanan Formation and the Lupa Granodiorite which intruded in the formation at the west side of Infanta, east coast.

D-1-4; The Pleistocene Guadalupe Formation at the northeastern part of Santa Monica in the south.

(B) Factor No. 2 (Closely related to Pb, Ag and Hg)

D-2-1; The Eocene-Oligocene Bayabas Formation at the upper reaches of Umiray River central inland.

D-2-2; The Antipolo Diorite in the vicinity of Mt. Maon central west and the above Bayabas Formation.

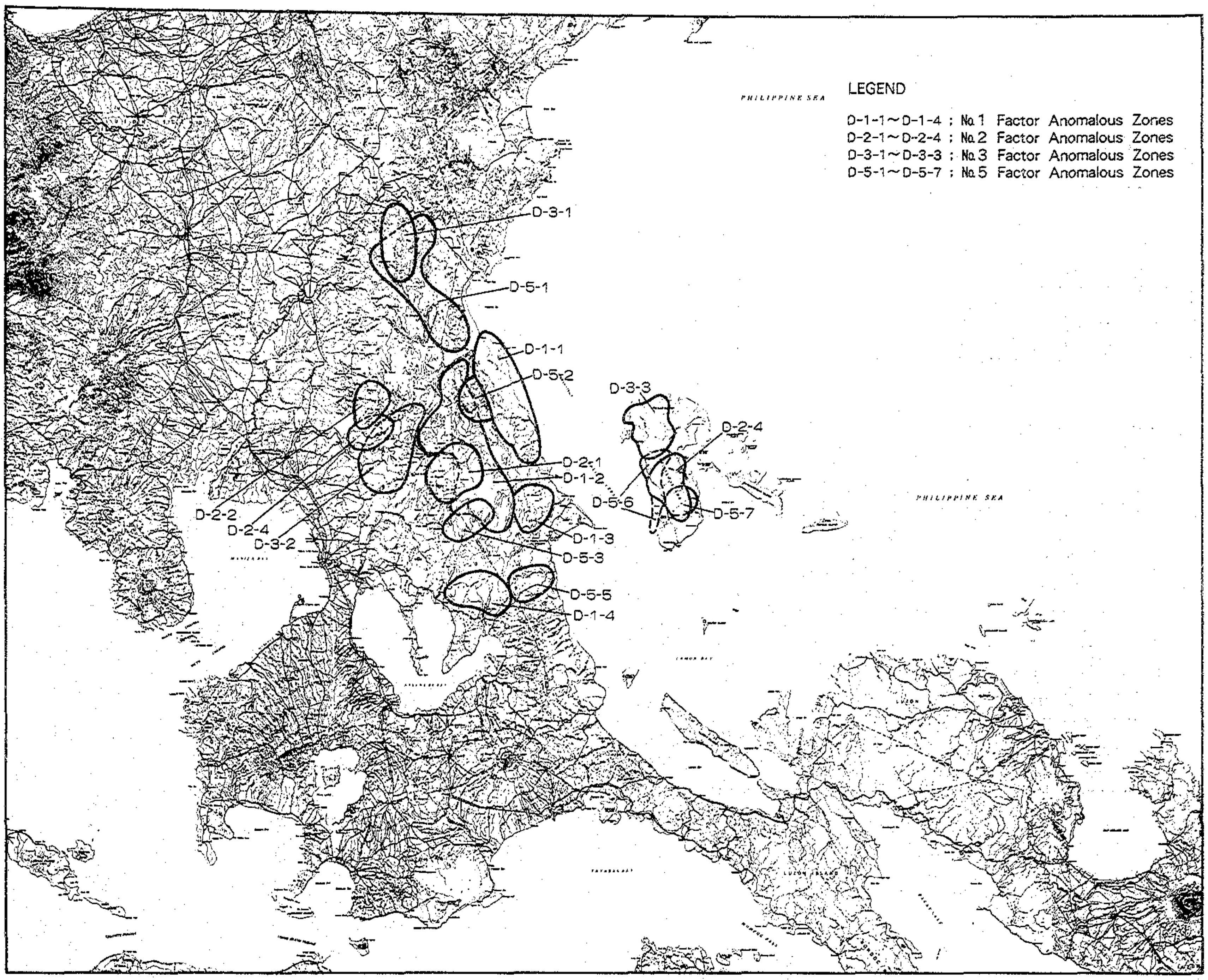


Fig. 8 Distribution Map of Anomalous Zones of Multivariate Analyses

D-2-3; The Cretaceous Boso-boso Mafic Complex and the Barenas Baito Formation at northern side of Montalban in the southwestern part of the area.

D-2-4; The Oligocene-Miocene Burdeos Formation and Eocene Polillo Intrusives at the central part of Polillo Island.

(C) Factor No. 3 (Closely related to Ni and Co in host rock)

D-3-1; The Cretaceous Barenas Baito Formation in the northern part.

D-3-2; The Cretaceous Boso-boso Mafic Complex and the Bayabas Formation in the central west part.

D-3-3; The Cretaceous Anawan Formation and the Pleistocene Karlagan Formation in the northern part of Polillo Island.

(D) Factor No. 4 (Possibly related to As)

Score was not plotted on the map as it had a possible relation to only As.

(E) Factor No. 5 (Possibly related to Mo, Cu and Pb)

D-5-1; The Cretaceous Barenas Baito Formation and the Boso-boso Mafic Complex in the northern part.

D-5-2; The Bayabas Formation at the upper reaches of Umiray River in the central part.

D-5-3; The Barenas Baito Formation at the upper reaches of Limutan River in the central southern part.

D-5-4; The Antipolo Diorite and Bayabas Formation at the southern part of Mt. Maon in the central west part.

D-5-5; The Miocene Tignoan Formation at western part of Tignoan in the south western part.

D-5-6; The Jurassic Masisi Schist and the Cretaceous Anawan Formation at the west coast of Polillo Island.

D-5-7; The Eocene Polillo Intrusives and the overlying Oligocene to Miocene Burdedos Formation at east coast of Polillo Island.

3-6 Univariate Analysis of Analytical Results of Panned Samples

A total of 171 panned samples were collected in Southern Sierra Madre and Polillo. Gold (ppb), Ag (ppb), Ga (ppm) were analyzed by AAS analyses at PETROLAB.

Univariate analyses of these results were carried out as follows.

Samples having values below detection limits were assigned and calculated by giving values corresponding to 1/2 of detection limit values of elements. Those values above $(M + 1.0\sigma)$ were classified into three ranks and were plotted on 1:1,000,000 scale map with corresponding rank symbol (Attached Pl.-3).

Table-17 Classified Ranks of Panned Samples

Rank	Classified Range	CODE		
		Au	Ag	Ga
A	$M+2.0\sigma \leqq Z$	◎	⟁	⧈
B	$M+1.5\sigma \leqq Z < M+2.0\sigma$	○	△	□
C	$M+1.0\sigma \leqq Z < M+1.5\sigma$	◦	▵	▫

Table-18 Basic Statistical Values of Panned Samples

	Au (ppb)	Ag (ppb)	Ga (ppm)
M	1,196	774	18
$M+1.0\sigma$	7,514	2,363	26
$M+1.5\sigma$	18,836	4,393	31
$M+2.0\sigma$	47,213	7,834	37
Maximum	64,000	19,000	52
Minimum	<20	<1,000	<4.0
Detection Limit	20	1,000	4.0
R. B. D. L.	89%	95%	3%

R. B. D. L.: Ratio of cells below detection limit

3-6-1 Areal Distribution of Anomalous Panned Samples (Ref. Attached Pl.-3)

All the anomalous panned samples for Au and Ag are concentrated in Southern Sierra Madre.

Central part:	Vicinity of Lumbay Collosal mineral showings at the upper reaches of Umiray River (Au; one B rank cell, Ag; two C rank cells).
East coast:	Western part of Tignoan (Au; each one B and C rank cell, Ag; each two A and C rank cells).
Central south:	At the middle reaches of Limutan River (Au; one A rank cell).

All the anomalous panned samples for Ga are concentrated in Southern Sierra Madre.

Central south:	In the Barenas Baito Formation (four A, B rank cells and nine C rank cells).
Eastern:	In the Cretaceous-Paleocene Kanan Formation (3 A, B rank cells).
East coast:	In the Miocene Tignoan Formation (one A rank cell and three C rank cells).

4. Correlation with Existing Regional Data

During data collection in Fiscal 1984, compilation of existing gravimetric maps and extraction of lineaments from LANDSAT images were carried out. These data, as presented in this report, were plotted on a 1:1,000,000 scalemap (Attached plate 5, 6) were analyzed in terms of significance and relationship with the results of the geological surveys.

4-1 Gravity Data

Gravimetric data (Bouguer anomaly) are available for Southern Sierra Madre. As shown in this plate, high Bouguer anomalies up to 70 mgal are recognized at the middle part of east coast where the Cretaceous Kanan Formation occurs. The anomaly decreases northward from Umiray to Dingalan and reach NW trending Philippine Fault extending along the equicontour line of 50 mgal. Towards south, these contours become lower and is 30 mgal at southern part. NNE-SSW trending high anomaly contours are recognized in the southeastern part at 90 mgal, the highest value in the area. The high contours are associated with the Cretaceous Barenas-Baito Formation with basaltic flows and pyroclastics and is elongated in NNE direction parallel with the Marikina West Fault.

In Polillo, Bouguer anomaly is relatively high (more than 60 mgal) in the southern part where the Mesozoic Masisi Schist and the Cretaceous Polillo Ultramafic Complex occur and is low (40-50 mgal) in the northeastern part where the Pleistocene Karlagan Formation occurs, forming a monoclinic structure.

4-2 Lineament Data

Plate-6 combines two lineament plates made by LANDSAT image analyses of JICA-MMAJ and NRMC (Natural Resources Management Center in Philippines). The former analyzed the image of Southern Sierra Madre in the first fiscal year and the latter analyzed the image combining various data of Southern Sierra Madre and Polillo in 1985. All of major faults which affected the structure of the Philippine Fault, Infanta Fault, Malabito Fault, Lenetin Fault, Marikina West Fault and Marikina East Fault are clearly observed with the N-S trending boundaries reflecting the N-S trend of the lineaments. Although of less importance many diagonal lineaments are also clearly identified. The Polillo Fault extending through the west coast of the island and the Anibong and Lanatong Faults which show diagonal trend to the above are confirmed by this lineament analyses.

5. Relationship between the Surveyed Mineral Showings and Geochemical Anomalies

Relationship between geochemical survey results and mineral showings in Southern Sierra Madre and Polillo Area is shown in Table 19.

According to Table-19, (26) Marcopper Matani and (27) Lumbay Collosal have anomalous cells for most of the elements followed by (28) Puray, (90) Santa Ines, (91) Marcopper Polillo and (32) Tignoan River which have many anomalous elements. In factor analyses, (16) Papaya, (27) Lumbay Collosal, (28) Puray, (32) Tignoan and (36) Mt. Malolod have anomalous cells for all factors followed by (17) Sumacbao, (26) Marcopper Matani and (90) Santa Ines have anomalous cells for three factors. Among the factors, a factor which is closely related to mineral showings is Factor No. 5 which likely suggests porphyry type Cu-Mo mineralization and the anomalous cells are accompanied by mineral showings except (18) Ibuna and (29) Bosoboso River.

Table-19 Relationship between Mineral Showings and Geochemical Anomalies

Index No.	Mineral Showing	Commodity	Cell Average										High-pass Filter										Factor Analysis				
			Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg	No. 1 Post	No. 2 Post	No. 3 Pre	No. 3 Post	No. 5 Pre
16	Papaya	Au	–	–	–	–	–	–	○	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	○	○	◎	○
17	Smacbao	Cu	–	–	–	–	–	–	◎	–	–	–	–	–	◎	–	–	–	–	–	◎	–	–	–	◎	◎	◎
18	Ibuna	Au	–	–	–	–	–	–	–	–	–	–	–	–	○	–	–	–	–	○	○	○	–	–	–	–	–
26	Marcopper Matani	Au	◎	◎	○	◎	◎	◎	–	◎	–	–	–	◎	◎	○	◎	○	–	–	–	–	◎	◎	–	–	◎
27	Lumbay Collosal	Cu	○	◎	○	–	◎	○	–	–	◎	–	◎	○	–	–	◎	◎	–	◎	◎	–	◎	◎	◎	○	◎
28	Puray	Cu-Au	◎	–	◎	–	◎	–	◎	◎	–	–	–	○	○	–	–	–	–	◎	–	–	◎	◎	◎	◎	○
29	Boso Boso River	Au	–	–	–	–	○	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	○	–	–	–	–
32	Tignoan	Au	○	–	–	–	–	○	–	○	–	◎	○	–	–	–	–	○	–	–	–	–	◎	◎	○	◎	◎
90	Sta. Ines	Fe	–	–	–	–	○	–	◎	–	◎	–	–	–	–	–	◎	◎	◎	–	○	–	–	–	◎	◎	◎
92	Angat	Fe	◎	–	○	–	–	–	–	–	–	–	◎	–	–	–	○	–	–	–	–	–	–	◎	–	–	◎
93	Camaching	Fe	◎	–	○	–	○	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	–	○	–	–	–	◎
36	Mt. Malolod	Fe	○	–	○	–	–	–	○	–	–	–	–	–	–	–	○	–	–	○	–	–	◎	◎	○	◎	◎
91	Marcopper Polillo	Mo	–	◎	–	–	–	–	–	–	◎	–	○	○	–	–	○	–	–	–	◎	◎	–	◎	–	–	◎

Pre: Before Varimax Rotation Post: After Varimax Rotation
◎: over M+1.5σ ○: between M+1.5σ and M+1.0σ –: below M+1.0σ

6. Evaluation and Conclusion

6-1 Consolidated Evaluation of the Survey Results

6-1-1 Geology and Structure

The Southern Sierra Madre and Polillo are located in the Eastern Physiographic Province in the east central part of Luzon Island. The survey area is divided by the Philippine Fault into two tectonic units, namely Southern Sierra Madre and Polillo.

6-1-1-1 Southern Sierra Madre

Southern Sierra Madre is structurally bonded on the north by the Philippine Fault, on the east by Infanta Fault, on the southwest by Marikina Fault and on the west by Luzon Central Basin.

The basement units consist of the pre-Cretaceous Katablingan metamorphic rocks, Cretaceous Boso-boso Mafic Complex and the overlying Barenas Baito Formation which includes pillow basalt and chert. The Late Cretaceous pyroclastic Kanan Formation and it's contemporaneous heterotopic facies, the Kinabuan Formation composed of limestone and sedimentary rocks overlie the basement units.

The Tertiary formations were deposited over these units and are distributed in the following parts of the area, namely, the Eocene Maybangain Formation consisted of limestone and minor clastic rocks in the northern part, the Eocene-Oligocene Bayabas Formation composed of lava flow and pyroclastics occurs in the central southern part. Oligocene Binagonan Formation composed of limestone and clastic sedimentary rocks is distributed in the central part. The Miocene Angat Formation comprising of limestone and clastic rocks occurs in the western part and the Middle Miocene Tignoan Formation containing pyroclastics and tuffaceous materials is developed in the southern part. The Pliocene Butete Formation consisting of sedimentary rocks occurs scattered as small exposures along the east coast, and the Pleistocene Guadalupe Formation consisting of lava flow and pyroclastics occurs around Laguna De Bay in the southern part.

As stated above, the volcanic activities occured four times from Late Cretaceous to Pleistocene while normal sediments were deposited at the intervals of the volcanic activities. These activities were regarded as a series of the island arc activities which formed the Philippine Archipelago.

Major intrusive bodies in the area are the Paleocene Lupa Granodiorite emplaced in basement units in the eastern part and the Oligocene Antipolo Diorite emplaced in the central western Bayabas Formation. Stocks of Antipolo Diorite are associated with many mineral showings and are related with Mineralization.

The Philippine Fault extends from Laur to Dingalan and runs northeastward up to Lingyaen Gulf and is traceable southward to over 1,200 km to Leyte Island through Polillo Strait. It is believed that the fault has left-lateral displacement (Ruthland, 1967) and it's movement started in Middle Miocene after the Collision of the East Philippine Arc to the Sulu-Bohol-Masbate Arc and has continued to present (Mitchel et al., 1986). The N-S trending Infanta Fault is traceable from Magnoc to Masla along the eastern coast line and appear to run southward to the vicinity of Panay Island. This fault is believed to be a right-lateral fault and to have produced the bending of the Philippine Fault at Polillo Strait. Three N-S trending and steep dipping fault of Angat, Lenetin, and Malabito occur in the central part. Foldings and block movements affected by these faulting are distinctly observed in the area.

6-1-1-2 Polillo

The evolution of the geology and structure of the Polillo Island are intimately associated with the Philippine Trench, the Philippine Fault traversing along the Polillo Strait and the Polillo Fault which is a branch of the Philippine Fault.

The lower units of the island consist of Jurassic Masisi Metamorphic Rocks and the Polillo Ultramafic Complex which is thrusted over the Masisi. They both are exposed on the west coast. The Cretaceous Anawan Formation overlies the Jurassic units unconformably with intercalations of volcanic ashes and sedimentary rocks.

Tertiary sedimentary rocks consist of the Eocene sedimentary Babacolan Formation, Oligocene-Miocene Burdeos Formation which is an alternation of conglomerate, sandstone and shale and the Miocene Langoyen Limestone and the Pliocene Karlagan Formation is ascending order. The Burdeous Formation and Langoyen Formation extend from north to south in the eastern part of the island. The Pliocene Karlagan Formation consisting of sandstone, shale, mudstone and limestone overlies the above formations and is exposed extensively in the northern part.

As for intrusive rocks in the area, the Early Eocene Polillo Intrusives occurs in the southern part. Igneous activities known in the area are andesitic and basaltic flows in the Cretaceous Anawan Formation and the Early Eocene Polillo Intrusives as mentioned above, contrary to the Southern Sierra Madre, no igneous activity after Eocene was recognized in Polillo Island.

The Polillo Fault extending along the west coast is a left lateral fault and is parallel to the Philippine Fault. In the southern part, it cuts the Polillo intrusives and in the northern part, it traverses the Karlagan Formation. North-southerly trending and steeply dipping faults branching from the Polillo Fault were developed on the eastern side. In addition, NS-SW trending steeply dipping faults (Anibong, Lanatong Faults) occurs in the central eastern part. These fault activities accelerated the block movements in the area.

6-1-2 Mineralization

Four kinds of mineralization investigated in Southern Sierra Madre area s follows.

(1) Vein type mineralization in the Cretaceous Barenas Baito Formation, Eocene-Oligocene Bayabas Formation and the Miocene andesitic volcanics or pyroclastics (Example; Ibuna, Marcopper Matani, and Tignoan).

(2) Porphyry copper mineralization which occurs in the vicinity of the contact zone of the Eocene-Oligocene Bayabas Formation and the Oligocene Antipolo Diorite (Example; Lumbay Collosal).

(3) Contact metasomatic mineralization in the Eocene-Oligocene Maybangain and Bayabas Formations and at its contact with the intruded Oligocene Antipolo Diorite (Example; Sumacbao, Santa Ines, Angat and Camaching).

(4) Massive sulphide mineralization in basalt of the Cretaceous Barenas Baito Formation (Example; Puray).

Two kinds of mineralization in Polillo Island are as follows.

(1) Vein and dissemination type mineralization in Cretaceous andesitic volcanics or pyroclastics (Example; Mt. Malolod).

(2) Porphyry molybdenum type mineralization with pyrite and molybdenite dissemination in the altered part of the Paleocene Polillo intrusives (Example; Marcopper Polillo).

6-1-3 Geochemical Analyses

For the purpose of synthesis and interpretation on geochemical results, analytical values of each cell were statistically analyzed by the following four methods.

(1) Univarate analyses of the average values of the geochemical analysis data in each cell (cell average value).

(2) Univariate analyses of the moving average data, where a frame consisting of nine cells (three cell in both N-S and E-W direction) is set and the average value of nine cells is taken to be the value of the central cell. The frame is moved at two kilometer step throughout the survey area.

(3) Univariate analyses of the high-pass filter data, the differences between the cell average values and the corresponding moving average values (only positive values).

(4) Multivariate analyses (factor analyses) of the cell average values.

Anomalous zones were extracted from the above analyses by the following standards.

A) Each anomalous zone should more or less be defined by two detected element anomalous values.

B) Each anomalous zone should at least the suggested by more than two methods of geochemical analyses.

C) In addition to satisfy above two items, alteration associated with mineralization should be observed in the zone.

Table-20 and Attached Plate-9 show the anomalous zones selected based on standards and relevant features of each anomalous zone.

Evaluation of the anomalous zones are as follows.

No. 1 The middle reaches of Umiray River, Southern Sierra Madre
Overlapping anomalous cells for Cu, Pb, Zn and Mn are observed in the Eocene-Oligocene Bayabas Formation. It

Table-20 Relation between the Extracted Anomalous Zones and Geological Setting

Geochemical Anomalous Zone		Cell Average										High-pass Filter										Factor Analysis					Geological Setting and Mineralization
Area No.	Location	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg	Cu	Pb	Zn	Ag	As	Mn	Ni	Co	Mo	Hg	No. 1	No. 2	No. 3	No. 3	No. 5	
1	Middle reaches of Umiray River 121°21'E 15°00'N	○		○		○	○					○		○		○	○	○	○			Post ○	Post ○	Pre ○	Post ○	Pre ○	Anomalous zone in Eocene~Oligocene volcanic rocks.
2	Upper reaches of Umiray River 121°22'E 14°51'N	○	○	○	○	○	○		○	○		○	○	○	○	○	○		○	○		○	○	○	○	○	Anomalous zone in Eocene~Oligocene volcanic rocks accompanied with mineral showings (Marcopper Matani, Lumbay Collosal).
3	Northeast of Montalban 121°12'E 14°46'N	○		○		○		○	○				○	○					○			○	○	○	○	○	Anomalous zone in Cretaceous basaltic flow accompanied with mineral showing (Puray).
4	Vicinity of Santa Ines 121°19'E 14°44'N					○		○								○	○	○		○				○	○	○	Anomalous zone in Oligocene diorite stock accompanied with mineral showing (Sta. Ines).
5	Western side of Tignoan 121°33'E 14°35'N	○					○		○		○	○					○					○	○	○	○	○	Anomalous zone in Miocene volcanic rocks accompanied with mineral showing (Tignoan).
6	Southeastern part of Burdeos 121°57'E 14°50'N	○		○				○								○			○			○	○	○	○	○	Anomalous zone in Cretaceous basaltic rocks accompanied with mineral showing (Mt. Malolod).
7	Southeastern part of Polillo 121°59'E 14°47'N		○							○		○	○			○				○	○		○			○	Anomalous zone in alteration zone of Eocene diorite accompanied with mineral showing (Marcopper Polillo).

○: Overlapped over M + 1.0 σ cell
Pre: Before Varimax Rotation　Post: After Varimax Rotation

appears to be associated with andesitic flows in the sediments and is a significant anomalous zone with fairly large area extent. However, it was not selected as promising area for lack of both mineral showing and alteration associated with mineralization.

No. 2 The upper reaches of Umiray River, Southern Sierra Madre
In this zone, anomalous cells for all elements except Ni and Hg overlap. This zone is occurs in the Eocene-Oligocene Bayabas Formation. It includes many high ranking anomalous cells associated with the mineral showings of Marcopper Matani and Lumbay Collsal with vein type mineralization are observed as well as with the diorite intrusive bodies. It was, therefore, selected as promising area (I).

No. 3 The northeastern Montalban
There are overlapping anomalous cells for Cu, Zn, As, Ni and Co in this zone. It occurs in basaltic tuff breccia of the Cretaceous Barenas Baito Formation and is associated with mineral showing of massive sulphide, Puray. This zone selected as promising Area II because it includes many high ranking anomalous cells and the mineral showing exhibits intense mineralization.

No. 4 The northeastern part of San Andres, central southern part of Southern Sierra Madre
In this zone, anomalous cells for As and Ni overlap each other at the contact zone of Bayabas Formation and Antipolo Diorite and is accompanied by contact metasomatic type mineral showing, Santa Ines.
It was excluded from promising areas because this zone locates near the Santa Ines Iron Mine which mined out and anomalous elements assembledge (As and Ni) is not attractive for further exploration.

No. 5 The western part of Tignoan
There are overlapping anomalous cells for Cu, Mo, Co and Hg in this zone. It occurs in the andesite of the Tignoan Formation and accompanies the vein type mineral showing, Tignoan. It was selected as promising area IV with lower priority, because two heavy mineral samples collected show high content for Au and Ag but high ranking anomalous cells are scarce.

No. 6 The southwestern part of Burdeous, central western part of Polillo Island
There are overlapping anomalous cells for Cu, Zn, As and Co in this zone. It occurs in sedimentary rocks and pyroclastics of the Anawan Formation and accompanies with dissemination type mineral showing, Mt. Malolod. It was selected as promising area V with lower priority, because, diorite intrusive bodies and distinct alteration were observed in the vicinity of the mineral showing, though high ranking anomalous cells are scarce.

No. 7 Southeastern part of Polillo Island
Paleocene Polillo Intrusives occurs in this zone. There are overlapping anomalous cells for Cu, Pb, As, Mn and Hg in this zone. It occurs in argillized zone of Polillo Intrusive and is accompanied by dissemination type mineral showing, Marcopper Polillo. It was selected as promising area III because it was regarded as porphyry molybdenum type mineralization.

6-2 Conclusions

As a result of the consideration of the above five promising areas are selected with the following priorities.

(I) The upper reaches of Umiray River, Southern Sierra Madre
Porphyry copper type mineralization is expected in this zone. The Antipolo Diorite intruded into the Bayabas Formation and porphyry copper type Lumbay Collosal mineral showing is found in this zone.
Assumed commodities are Cu, Pb and Zn.

(II) The northeastern side of Montalban
Massive sulphide type mineralization is observed in this zone. Massive sulphide mineral showing, Puray occurs in the Cretaceous basaltic agglomerate of Barenas Baito Formation of this zone.
Assumed commodities are Cu and Zn.

(III) Southeastern part of Polillo Island
Porphyry molybdenum type mineralization zone in the Polillo intrusives. Mineralization occurs as dissemination with molybdenite and pyrite in argillized and pyritized quartz diorite.
Assumed commodities are Cu and Mo.

(IV) The western part of Tignoan
Vein type mineralized zone in Miocene andesite of Tignoan Formation. The Tignoan River mineral showing is auriferous fissure filling veins in andesite.
Assumed commodities are Cu, Au and Ag.

(V) The southwestern part of Burdeos
Vein type mineralized zone in Cretaceous pyroclastics of Anawan Formation. Although the mineral showings are hematite veins, results of geochemical analyses suggest Cu-mineralization.
Assumed commodities are Cu and Zn.

References

Southern Sierra Madre

Abiog, D. B., 1970, unpub*[1]., Geology of portion of Eastern Sierra Madre Range in Quezon and Nueva Ecija Provinces: Bureau of Mines.

Agadier, M. A., 1986, unpub., A re-evaluation of the Cretaceous-Paleogene sediments of a portion of the Sierra Madre in the Baras, Quadrangle, Rizal: Bureau of Mines and Geo-Sciences.

Allen, C. R., 1962, Circum-Pacific faulting in the Philippines-Taiwan Region: The Philippine Geologist, vol. 16, No. 4, p. 122-143.

Alvir, A. D., 1929, A geological study of the Angat-Novaliches Region: Philippine Journal of Science, vol. 40, No. 3.

Antonio, L. R., 1967, Geology of Sta. Ines Iron Deposits, Antipolo, Rizal, Philippines: Proceedings of the Second Geological Convention and First Symposium of the Geology of the Mineral Resources of the Philippines and Neighboring Countries, vol. 1, p. 121-136.

Avila, Jr., E. T., 1975, unpub., Report on the geology and mineral resources of southern Batangas covering Lobo, Batangas City, Malabrigo and San Juan Quadrangles: Bureau of Mines.

Balce, G. R. and Contreras, P. V., 1970, unpub., Geological verification of mining claims in Torrijos and Sta. Cruz, Marinduque for Marinduque Exploration Company: Bureau of Mines.

Blome, C. D., 1985, U. S. Geological Survey - Report on Referred Fossils, shipment No. 0-85-10D, 6 p.

Bureau of Mines, 1963, Geological map of the Philippines, Scale 1:1,000,000.

Bureau of Mines and Geo-Sciences, 1981, Geology and Mineral Resources of the Philippines, vol. 1, 406 p.

Bureau of Mines and Geo-Sciences, 1983, Geological map of Manila and Quezon City Quadrangle, Scale 1:50,000.

Bureau of Mines and Geo-Sciences, 1983, Geological map of Montalban Quadrangle, Scale 1:50,000.

Bureau of Mines and Geo-Sciences, 1983, Geological map of Norzagaray Quadrangle, Scale, 1:50,000.

Bureau of Mines and Geo-Sciences, 1983, Geological map of Umiray River Quadrangle, Scale 1:50,000.

Bureau of Mines and Geo-Sciences, 1983, Geological map of Umpacan Quadrangle, Scale 1:50,000.

Bureau of Mines and Geo-Sciences, 1986, Geology and Mineral Resources of the Philippines, vol. II, p. 259-260.

Corby, G. W. et al, 1951, Geology and oil possibilities of the Philippines: Department of Agriculture and Natural Resources, Technical Bulletin No. 21, p. 99-100.

Cruz, A. J., 1969, unpub., Reconnaissance geologic survey of the Maybakong, Paliparan, Kalinawan area of Northeastern Tanay, Rizal for Marble: Bureau of Mines.

Cruz, A. J., and Cusi, E. G., 1966, unpub., Geologic investigation of the four Sidling Placer Claims and vicinity, Antipolo-Teresa area, Rizal for cement raw materials: Bureau of Mines.

Cruz, A. J., and Lingat, P. H., 1964, unpub., Geologic investigation of Tanay, Rizal for cement raw materials and location of plant site: Bureau of Mines.

De la Rosa, S. C. et al., 1978, unpub., Geology and mineral resources of Dofia Remedies Trinidad Municipality, Bulacan: Bureau of Mines and Geo-Sciences (Region IV).

De la Rosa, S. C. et al., 1978, unpub., The Geology of Real Quadrangle: Bureau of Mines and Geo-Sciences (Region IV) .

Espiritu, E. A. et al., 1968, Biostratigraphy of Bondoc Peninsula: The Philippine Geologists, vol. 22, No. 2, p. 73 & 83,

Fernandez, J. C., 1970, unpub., Geological investigation of the Ruby, Buna, Stercom, and Ontegon copper prospects, Barrio Ligaya, Gabalson, Nueva Ecija: Bureau of Mines.

Fernandez, M. V., 1986, unpub., Sedimentary environment and facies analysis of a portion in Tanay, area, Rizal Province: Up sedimentology class.

Fuller, M. D. et al., 1982, Paleomagnetism of Luzon: Philippine Seatar Committee Special Publication No. 1, p. 131-156.

Gervacio, F. C., 1970, Geological map of Marinduque Island: Bureau of Mines, Scale 1:50,000.

Grey, R. R., 1967, Time stratigraphic correlation of Tertiary rocks in the Philippines: The Philippine Geologist, vol. 21, No. 1, p. 19-20.

Hashimoto, Wataru and Matsumaru, Kuniteru, 1981, Larger Foraminifera from the Philippines, Part XII, Eocene Limestone from Southeastern Luzon: Contribution to the Geology and Paleontology of Southeast Asia, vol. 22, p. 65-66.

Hashimoto, W., et al., 1975, Cretaceous System of Southeast Asia: Geology and Paleontology of Southeast Asia, vol. 15, p. 219-220.

Hashimoto, W., 1977, Larger foraminiferal assemblages useful for the correlation of Cenozoic marine sediments in the mobile belt of the Philippines: Geology and Paleontology of Southeast Asia, vol. 18, p. 105-110.

Hashimoto, W.,1978, Larger Foraminifera from the Philippines, Part VI, Larger foraminifera found from the Pinugay Hill limestone, Tanay, Rizal, Central Luzon: Contribution to the Geology and Paleontology of Southeast Asia, vol. 19, p. 65-71.

Hashimoto, W., 1979, Larger Foraminifera from the Philippines, Part X. Stratigraphic and faunal break between the Maybangain and Kinabuan Formations in the Tanay Region, Rizal, Philippines: Contribution to the Geology and Paleontology of Southeast Asia, vol. 20, p. 143-157.

Jagolino, R. B. and Gorriceta, A. J., 1965, unpub., A geologic investigation of cement raw materials in Sto. Niño-San Andres - Laiban area, Tanay, Rizal: Bureau of Mines.

JICA-MMAJ., 1985, Report on the Mineral Exploration-Mineral Deposits and Tectonics of two Contrasting Geologic Environments in the Republic of the Philippines. Phase I Southern Sierra Madre-Polillo Area.

Karig, D. E., 1982, Accreted terranes in the northern part of the Philippine Archipelago: Philippine Seatar Committee Special Publication No. 1, p. 67-79.

Mars Mining Corporation, unpub., Geologic map of Alabat Island, Quezon Province, Scale 1:50,000.

McCabe, Robert et al., 1985, Terranes in the Central Philippines: The Philippine Geologist, vol. 39, No. 1, p. 9-11.

Melendres Jr., M. M. and Verzosa, R. E., 1960, unpub., Reconnaissance geology and oil possibilities of the Southeastern Luzon Central Valley: San Jose Oil Company, Inc.

Miranda, E. F. and Mantaring, J. M., 1973, unpub., Geological-geochemical investigation of the Unisan Quadrangle, Quezon Province: Bureau of Mines.

Mitchell, A. H. G. et al., 1984, Geology of Southwestern Panay: UNDP Internal Technical Report GLR/84/3, p. 45-53.

Mitchell, A. H. G. et al., 1986, Cenozoic Evolution of the Philippine Archipelago: Journal of Southeast Asian Earth Sciences, vol. 1, No. 1, p. 3-22.

Ocampo, V. P. and Martin, S. G., 1967, unpub., Report on the geology and section measurements in Southeastern Luzon Central Valley, Philippines: Bureau of Mines.

Ondovilla, R. N., 1981, unpub., Geological-geochemical investigation of the Mauban Quadrangle, Quezon Province: Bureau of Mines and Geo-Sciences.

Ordoñez, E. P., 1970, Notes on the Upper Cretaceous Radiolaria of Tanay, Rizal: Journal of the Geological Society of the Philippines, vol. 24, No. 2, p. 120-121.

Pascual, R. D. and Revilla, G. P., 1984, unpub., Final Report on the geological appraisal and assessment of the limestone deposit of Makaira-Dayapa area, Lungsod Silangan: Bureau of Mines and Geo-Sciences (Region IV).

Pelayo, A. M., 1981, unpub., Stratigraphy of a portion of the Sierra Madre in the Norzagaray Quadrangle, Bulacan: Bureau of Mines and Geo-Sciences.

Pelayo, A. M., 1983, Stratigraphy of a portion of the Sierra Madre in the Norzagaray Quadrangle, Bulacan (ABSTRACT): The Philippine Geologist, vol. 37, No. 2, p. 35.

Revilla, G. P., 1986, unpub., Report on the Kagsa white clayey sand deposit, Real, Quezon: Bureau of Mines and Geo-Sciences (Region IV).

Revilla, G. P. and Malaca, E. R., 1987, ms*2, Geology of southern Sierra Madre Range.

Reyes, M.V. and Ordoñez, E.P., 1970, Philippine Cretaceous smaller Foraminifera: Journal of the Geological Society of the Philippines, vol. 24, No. 2, p. 1-13.

Ronan, J. N., 1976, unpub., Memorandum report on the geological verification of two (2) placer claims for aggregate material in Barrio San Roque, Angono, Rizal: Bureau of Mines.

Ruthland, F. W. R., 1967, Preliminary report on the geology of the Laur-Dingalan Fault Zone, Luzon, Philippines: Bureau of Mines Report of Investigation No. 63, 58 p.

Santiago, P. D., 1982, unpub., Paleocene planktonic Foraminifera (reworked) in Maysawa Creek, Lenatin River, Tanay, Rizal: Bureau of Mines and Geo-Sciences.

Santiago, P. D., and Alcantara, P. M., 1982, Bureau of Mines and Geo-Sciences Paleontological Report, Rep. Pl. No. 53-81, sample submitted by Aristeo M. Pelayo.

Sliter, W. V., 1985, U. S. Geological Survey - Report on Referred Fossils, shipment No. 0-85-8M, 4p.

Sonido, E. P., 1977, A review of the gravity data on the Central Valley Basin, Luzon, Philippines: Journal of the Geological Society of the Philippines, vol. 31, No. 2, p. 4-5.

Taylor, B. and Hayes, D. E., 1980, The tectonic evolution of the South China Basin: AGU Geophysical Monograph No. 23, p. 89-104.

Tamesis, E. V. et al., 1982, Stratigraphy and geologic structures of the Central Valley Basin, Luzon, Philippines: Philippine Seatar Committee Special Publication No. 1, p. 83-114.

Tumanda, F. P. et al., 1984, unpub., Notes on the Paleontology of Northern Marinduque: Bureau of Mines and Geo-Sciences.

Van Eysinga, F. W. B., 1981, Geological time table, 3rd edition.

Walther, H. W. et al., 1981, Early Cretaceous porphyry copper mineralization on Cebu Island, Philippines: Hannover, Geol. Jb., D48, p. 21-35.

Wolfe, J. A., 1981. Philippine geochronology: Journal of the Geological Society of the Philippines, vol. 35, No. 1 p. 16-24.

Wolfe, J. A., et al., 1980, The Taysan porphyry copper deposit, Southern Luzon Island, Philippines: Journal of the Geological Society of the Philippines, vol. 34, No. 1, p. 1-21.

Yumul Jr., G. P., 1985, unpub., Geology and petrography of the Angat Ophiolite - A Preliminary Report (ABSTRACT): Bureau of Mines and Geo-Sciences.

Polillo

Alberding, H., 1939, unpub., Report on the coal resources of the Polillo District: BMG.

Argaño, W. 1978, unpub., Geological investigation of forty Lode claims applied for mining lease in Pinaglugayan and Canicanian, Polillo, Quezon: BMG.

BMG, 1981, Geology and mineral resources of the Philippines, vol. 1, p. 69.

Crispin, O., and Buangan, A., 1964, unpub., Memorandum report on the geological investigation of the Malolod Iron prospect. Mt. Malolod, Polillo, Quezon province: BMG.

Celenk, O., Florendo F., and Santos, F., unpub., Reconnaissance Geochemical Survey of SW Panay: BMG.

Delos Santos and Abiog, D., 1956, unpub., Report on the geological investigation of coal claims in Anibawan, Burdeos (Polillo Island), Quezon for Commonwealth Ceramics Corporation: BMG.

Delos Santos, V., and Spencer, F., 1957, Geology and coal resources of Central Polillo Island, Quezon: BMG Special project series No. 15.

Fernandez, J., Vera Cruz, B., Estupigan, P., and Aberquez, O., 1967, unpub., Preliminary report on the regional geology of Polillo Island Group, Quezon: BMG.

Ferrera, L., and Francisco, F., 1957, unpub., Report on the coal property under coal lease No. 29, Burdeos Coal area in Bo. Burdeos, Municipality of Polillo, Island of Polillo, Province of Quezon: BMG.

Ickis, H., 1906, Polillo Coal deposits report concerning the coal fields of Polillo. 17 pages.

Karamata, S., 1978, Metamorphism beneath obsducted ophiolites, Ophiolite Symposium. p. 219-227.

Karig, D., 1982, Accreted terrains in the northern part of the Philippine archipelago: Geology and tectonics of the Luzon-Marianas region. p. 67-79.

Llave, C., and De Luna, R., 1968, unpub., Report on the geological investigation of limestone deposit in Sitios Pangasinan and Tingtingon, BO. Cabalungan, Burdeos, Quezon: BMG.

Malicse, J., and Letargo, 1985, unpub., Metamorphic aureole at the base of Mindoro Ophiolite along Bongabong River, East-Southeast Mindoro: BMG.

Melendres, M., 1954, unpub., The geology and coal resources of sourthern Burdeos coal area, Polillo, Quezon Province, Philippines: BMG.

Miranda, F., and Caleon, P., 1979, unpub., Geology and mineral resources of Camarines Norte and part of Quezon Province: BMG.

Mitchell, A. H., Estupiga, P., Hernandez, F., and Dela Cruz, A., 1984, unpub., Cenozoic evolution of the Philippine Archipelago: BMG.

Smith, W., 1924, Geology and Mineral resources of the Philippine Islands: Bureau of Science, Pub. No. 19.

Uyeda, S., and McCabe R., 1982, A possible mechanism of episodic spreading of the Philippine sea: Geology and tectonics of the Luzon-Marianas region. p. 53-66

Zepeda, F. R. and Jagolino, D. C., ms., Reconnaissance Geological and Geochemical Survey of Polillo Island.

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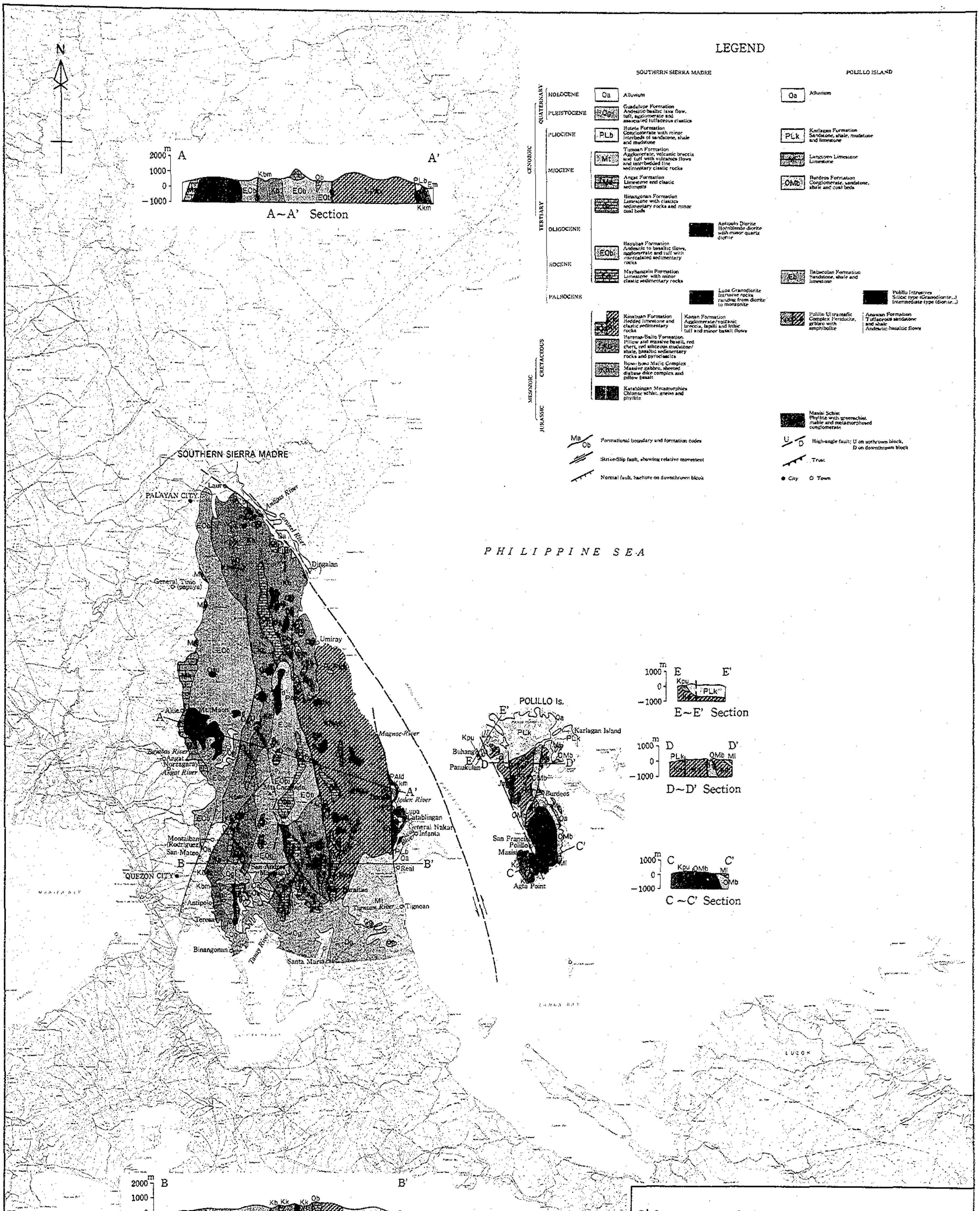
*1 unpub. ; unpublished

*2 ms. ; manuscript

Pl.1 Geological Map and Section (1:1,000,000)



Pl.1 GEOLOGICAL MAP

CONSOLIDATED REPORT ON SOUTHERN SIERRA MADRE AND POLILLO ISLAND

THE MINERAL EXPLORATION-
MINERAL DEPOSITS AND TECTONICS OF
TWO CONTRASTING GEOLOGIC ENVIRONMENTS
IN
THE REPUBLIC OF THE PHILIPPINES