# REPORT

ON

# THE MINERAL EXPLORATION

IN

# THE SOUTHERN AREA, REPUBLIC OF MADAGASCAR

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# THE MINERAL EXPLORATION
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## (CONSOLIDATED REPORT)



MARCH 1994

JAPAN INTERNATIONAL COOPERATION AGENCY

METAL MINING AGENCY OF JAPAN

# PREFACE

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

The survey and investigation of the Southern Area of Madagascar were carried out over three years from 1991 to 1993 and completed on schedule under close cooperation with the Government of the Republic of Madagascar and its authorities.

This report summarizes results of the survey and investigation executed during three years.

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

March, 1994

Kensuke Yanagiya
President
Japan International Cooperation Agency

Takashi Ishikawa
President
Metal Mining Agency of Japan

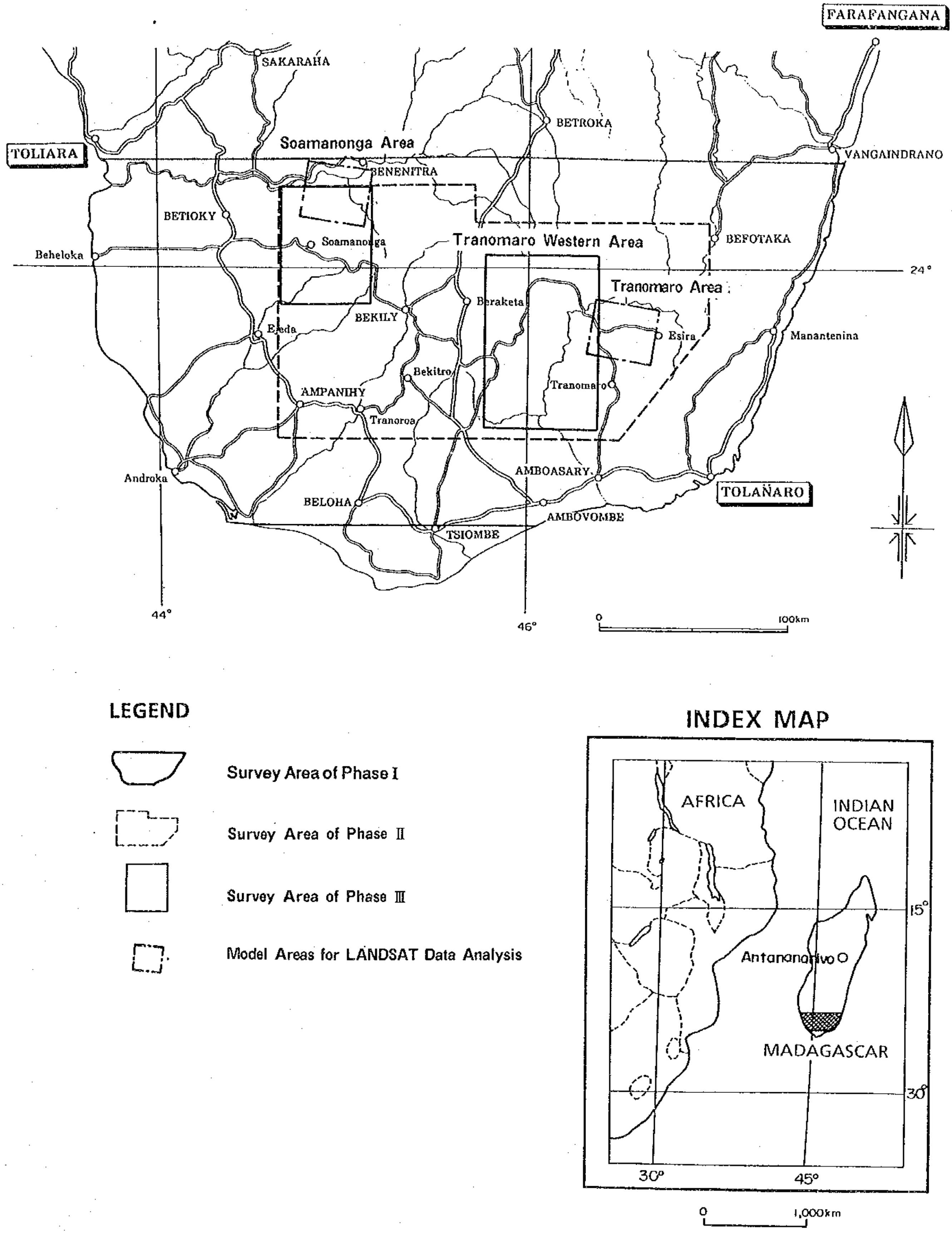


Fig. I-1 . Location Map of Survey Area

# Résumé

Ce rapport fait la synthèse des résultats d'une étude fondamentale effectuée dans la partie sud de la République de Madagascar durant trois ans, entre 1991 et 1993. Cette étude qui s'inscrit dans le cadre de la coopération au développement de ressources naturelles a été menée avec les objectifs suivants : déterminer les conditions géologiques de la zone ainsi que les caractérisques des gisements minéraux, et étudier la présence éventuelle de ressources minières. Voici quelles ont été les trois phases annuelles du projet :

Première année : compilation et examen des données existantes
lecture des images satellite/
Superficie : 66 300 km²

Deuxième année : analyse spectrale des données satellite/
Superficie : 30 000 km²

Troisième année : Sondages géologiques in situ
zone de Soamanonga : 2 000 km²
zone occidentale de Tranomaro : 5 000 km²

Ci-suit la synthèse des études et analyses effectuées.

(1) Images satellite

Les images satellite qui reflètent bien la structure géologique de vastes étendues constituent un outil très précieux non seulement au stade des études préliminaires mais aussi au stade des études détaillées. Cependant, l'identification des roches nécessite le recours à des moyens rectificatifs ou complémentaires tels que l'analyse spectrale ou les sondages de contrôle in situ car le couvert végétal modifie grandement les caractéristiques spectrales.

(2) Zone de Soamanonga

La zone de Soamanonga comporte du gneiss appartenant au système de Vihibory (1 890 Ma), couche supérieure du précambrien. Dans la partie nord-ouest de la zone se trouvent des roches sédimentaires continentales du système de Karroo formé entre la fin du permien et le jurassique moyen. Dans la partie nord de la zone, à proximité de Varahina, on relève dans le gneiss et le système de Karroo l'existence de gisements aurifères, argentifères et cuprifères. Ces gisements qui se trouvent au sein de veines de quartz ou dans leur périphérie se présentent sous forme de veines ou de disséminations. Ils trouvent vraisemblablement leur origine dans les mouvements tectoniques nord/nord-

est -- sud/sud-ouest du crétacé. Bien que fragmentaires et de taille réduite, les minerais qui forment des bandes de 10cm X plusieurs dizaines de cm comportent dans leurs parties les plus denses 15% de cuivre, 3 g/t d'or et 120 g/t d'argent.

(3) Zone occidentale de Tranomaro

La partie occidentale de la zone de Tranomaro comporte du gneiss appartenant au système d'audroyen (3 000 Ma), couche inférieure du précambrien. La partie centrale de la zone se caractérise par sa structure annulaire creuse constituée de roches volcaniques du crétacé. Ces roches volcaniques comportent essentiellement des laves basaltiques ainsi que des laves et des dykes de rhyolithes. A certains endroits, on remarque aussi la présence de micro-granit vraisemblablement de nature intrusive. Une telle activité magmatique s'explique vraisemblablement par l'existence d'un point chaud apparu dans la croûte continentale stable. Il serait intéressant d'étudier les rapports de cette activité avec une éventuelle minéralisation.

(4) Ressources minières

Le sud de Madagascar est susceptible de receler des ressources minières très diverses telles que des pierres précieuses, des minerais non-métallifères et métallifères. Si les ressources minières de cette région sont presque toutes situées dans le gneiss du précambrien, la période de formation diffère selon les gisements. Le processus de formation s'étale sur un temps extrêment long : sédimentation du gneiss et orogénèse du précambrien, activité magmatique du cambrien, mouvements tectoniques et activité volcanique du crétacé, mouvemements tectoniques et activité volcanique du tertiaire, érosion et mouvements sableux du quaternaire.

(5) Suites à donner à cette étude

1) Si les gisements aurifères, argentifères et cuprifères de la la zone de Varahina sont de taille réduite et de localisation dispersée, certaines parties sont d'une qualité extrêmement haute. Par conséquent, il est souhaitable de multiplier les études fondamentales en englobant les zones périphériques qui présentent des traces de l'existence de gisements cuprifères.

2) La nature, l'origine et la période de formation des ressources

minières de la zone sont très diverses. Outre un examen de la qualité, de la taille, de la localisation, des conditions d'exploitation et des débouchés, il est donc souhaitable d'établir une classification des gisements selon leur date de formation et leur origine afin de sélectionner un projet prioritaire.

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# Part I GENERAL REMARKS

# Chapter 1　OUTLINE OF THE SURVEY

## 1-1　Survey Area and Survey Objective

The survey area is, as shown in Fig. I-1, situated between the latitudes of 23°27' S and 25°22' S, covering an area of 66,300 km².

The objective of this survey is to clarify the geological environment and mineralization and to investigate possibilities of the occurrence of ore deposits.

## 1-2　Survey Method and Survey Quantity

The survey was carried out during three years. The survey methods and the survey quantity in each phase are shown in Fig. I-2.

In the Phase I survey, the existing data compilation and the satellite image photointerpretation were conducted and in the Phase II survey, the satellite data spectral analysis was carried out. In the Phase III survey, the field geological check survey totalling 280 km in surveyed route was performed for the two areas, the Soamanonga area of 2,000 km² and Tranomaro western area of 5,000 km², both of which were extracted by the photointerpretation and spectral analysis of the satellite data.

## 1-3　Survey Period and Survey Member

(1) Survey period

| | 1991<br>7 8 9 10 11 12 | 1992<br>1 2 3～12 | 1993<br>1 2 3 4 5 6 7 8 9 10 11 12 | 1994<br>1 2 |
|---|---|---|---|---|
| Existing Data Compilation | 7/26 ― 12/31 | | | |
| LANDSAT TM Image Interpretation | 7/26 ― 12/31 | | | |
| LANDSAT TM Image Spectral Analysis | | | 1/28 ― 2/20 | |
| Field Check Survey | | | 9/26 ― 11/11 | |
| Indor Test and Preparation of Report | 11/6 ― | ― 2/20 | 2/21 ― 3/1<br>11/12 ― | ― 2/25 |

(2) Planning and negotiation member

| | Japan Side | | Madagascar Side | |
|---|---|---|---|---|
| Phase I | Yoichi YAMAGUCHI | (MMAJ) | D. ANDRIAMBOLOLONA | (MEM) |
| | Kyoichi KOYAMA | (MMAJ) | J. RASOANAIVO | (DMG/MEM) |
| | Hiroshi ASAHI | (MITI) | A. FITAHINTSOA | (DMG/MEM) |
| | Nario NAKANO | (MFA) | R. ANDRIAMANANANTENA | (DMG/MEM) |
| | Haruhisa MOROZUMI | (MMAJ) | V. RAKOTONOMENJANAHARY | (DMG/MEM) |
| | Nobuyuki OKAMOTO | (JICA) | | |
| | Takahisa YAMAMOTO | (MMAJ) | | |
| Phase Ⅲ | Nobuyuki MASUDA | (MMAJ) | J.R. RATSIMBAZAFY | (DMG/MEM) |

MMAJ: Metal Mining Agency of Japan
MITI: Ministry of International Trade and Industry
MFA : Ministry of Foreign Affairs
JICA: Japan International Cooperation Agency
MEM : Ministry of Energy and Mines
DMG : Department of Mines and Geology

(3) Survey team member

1) Japan Side

| | | | |
|---|---|---|---|
| Phase I | Katsuji FUKUMOTO | (MINDECO) | Leader, Compilation |
| | Itoshi KOHNO | (MINDECO) | Compilation, Photointerpretation |
| | Kiyohisa SHIBATA | (MINDECO) | Compilation of Existing Data |
| | Koji YASHIRO | (MINDECO) | Photointerpretation |
| | Kazuhiro ADACHI | (MINDECO) | Photointerpretation |
| | Haruo HARADA | (MINDECO) | Compilation of Existing Data |
| Phase II | Itoshi KOHNO | (MINDECO) | Leader, Spectral analysis |
| | Koji YASHIRO | (MINDECO) | Spectral Analysis |
| | Kazuhiro ADACHI | (MINDECO) | Spectral Analysis |
| | Hidehisa WATANABE | (MINDECO) | Spectral Analysis |
| Phase Ⅲ | Jiniichi NAKAMURA | (MINDECO) | Leader, Field Survey |
| | Haruo HARADA | (MINDECO) | Field Survey |

MINDECO: Mitsui Mineral Development Engineering Co. Ltd.

2) Madagascar Side

| | | | |
|---|---|---|---|
| Phase Ⅲ | J.R. RATSIMBAZAFY | (DMG/MEM) | Overall |
| | J. ANDRIANARIMANANA | (DMG/MEM) | General |
| | R. ANDUAMANANTENA | (DMG/MEM) | Field Survey |

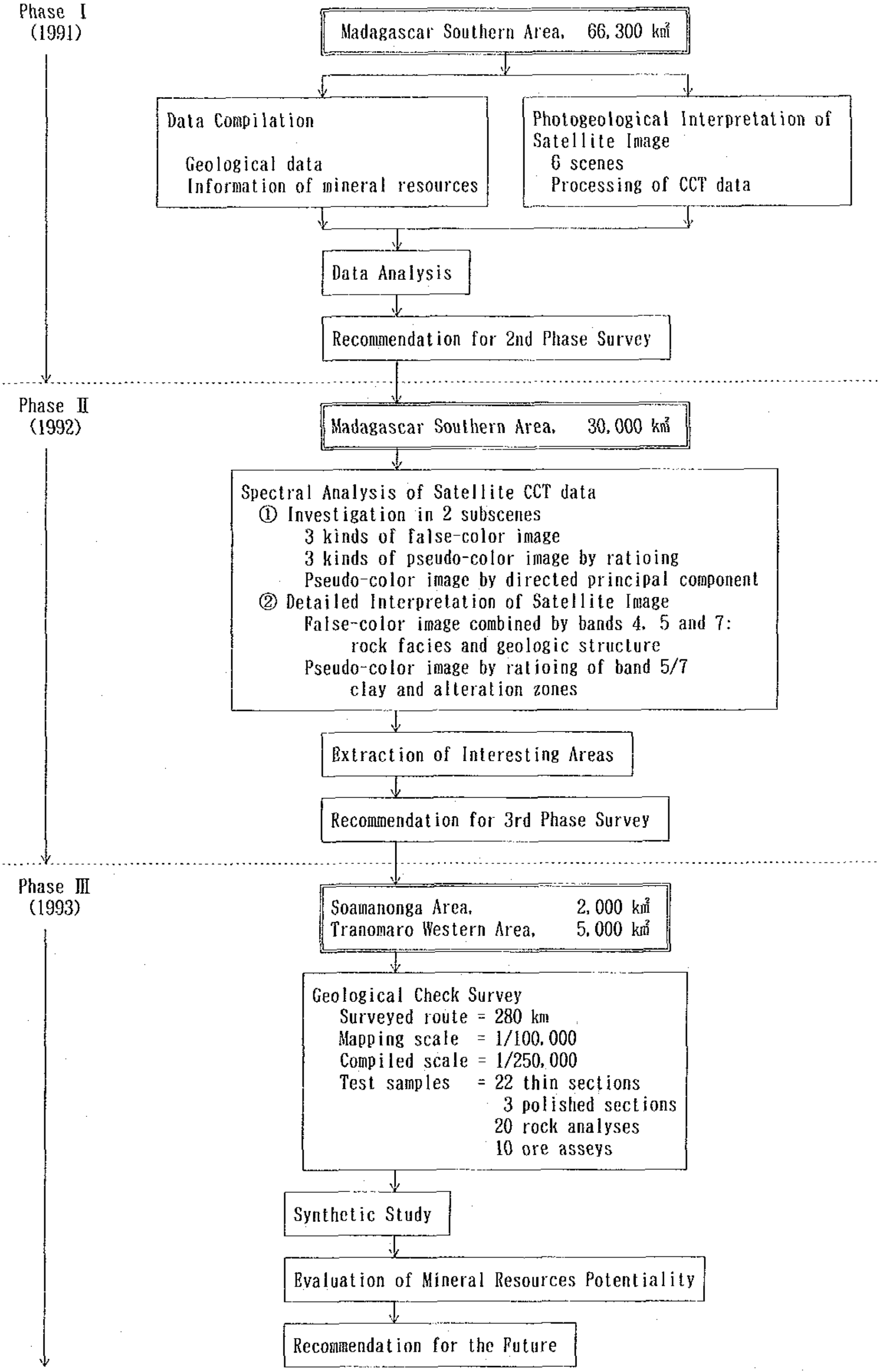



Fig. I-2 Flow Chart of Survey Progress

## Chapter 2 PREVIOUS SURVEY

A regular geological survey of the sorthern part of Madagascar was carried out from 1940's to 1960's. The results were summarized by H. Besairie (1963, 1964) in the Geological Maps on the scales of 1:500,000 and 1:250,000.

General geological structure of the whole Madagascar island were described in the Geology of Africa by R. Furon (1963) and in the Geology of Madagascar by H. Besaire and M. Coillignon (1972). Outline of the ore deposits and the mineral indications of Madagascar were reported by J. Behier (1960) and H. Besairie (1966).

As for the surveys of mineral resources by Japan, the basic survey of mineral resources in Madagascar by OTCA (Overseas Technical Cooperation Agency, 1964) and the overseas geological survey for chromite resources in the central part of Madagascar by MMAJ (1974) were conducted.

## Chapter 3 GENERAL GEOLOGY OF MADAGASCAR

The basement of the Madagascar island is the Precambrian metamorphic rocks composed mainly of gneiss. The basement rocks are located to the eastern part of the Congo Craton of the African continent and form a part of the Mozambique Orogenic Belt which suffered the Pan African Orogeny in the late Cambrian to the early Paleozoic age. In that time, the gneissic rocks were intruded by granite, syenite and gabbro.

In the western part of the Madagascar island, there appeared an epiorogeny condition from late Paleozoic to early Mesozoic age and continental sediments correlated to the Karroo System were piled covering the Precambrian basement. In the middle of Mesozoic age, the continental sedimentary environment turned to transgressive and marine sediments were piled to the west.

In the late Mesozoic age, there formed graben zones on both sides of the island and there occurred a volcanic activity of basaltic and rhyolitic rocks. At the end of Mesozoic age, the Madagascar island was separated from the African continent and formed the present figure. The volcanic activity characterized by basalt and rhyolite has been repeated in the Tertiary age. These volcanisms occurred mainly along the graben zones but also occasionally as spots in the Precambrian basement rocks.

Summarized straligraphy of the Madagascar island is shown in Table I-1. A geological map of the southern part of Madagascar compiled by H. Besairie (1963) is shown in Fig. I-3.

Table I-1 Stratigraphy of Madagascar Island

| Time (Ma) | Era | System (Igneous Activity) | Rock Facies | Ore Deposits | Tectonics | Dis. Area |
|---|---|---|---|---|---|---|
| 1.6 | | Holocene-Pleistocene / Volcanic Rocks | Sand, Mud / Basalt, Rhyolite | Placer(Monazite, Ilmenite, Zircon) Kaolinite, Lignite, Bitsand | | E, W, S |
| | | Neogene-Paleogene | Limestone, Marl | Limestone | | W |
| 65 | | Cretaceous / Volcanic Rocks | Marl, Sandstone / Basalt, Rhyolite | | Rift System Tectonics | W |
| | | Jurassic | Marl, Limestone | Limestone | | W |
| | | Karroo System (Permian-Jurassic) — Isalo Group | Sandstone, Shale | Bituminous sand | | W |
| | | Sakamena Group | Shale, Marl | | | |
| 250 | | Sakoa Group | Shale, Sandstone, Tillite | Coal | | |
| | | | | Unconformity | | |
| 570 | | Cambrian / Intrusive Rocks | Granite, Syenite, Gabbro Charnockite, Pegmatite | Quartz, Beryle, Gernet Columbite-Tantalite U, Th, Be, Li | Pan African Orogeny | C, W |
| | | Vohibory System (1900Ma) | Gneiss, Leptinite, Amphibolite, Marble | Ni, Cr, Fe, Barite, Asbest, Chrysotite, Cu, Zn, Au | | W |
| 2500 | | Graphite System (2400Ma) | Gneiss, Migmatite, Leptinite | Graphite, Fe, Al, Garnet | | C-W, S |
| | | Androyen System (3000Ma) | Gneiss, Leptinite, Pyroxenite | U, Th, Phlogopite, Al, Sn | | E, C |

C:Central, W=Western, B=Eastern, S=Southern

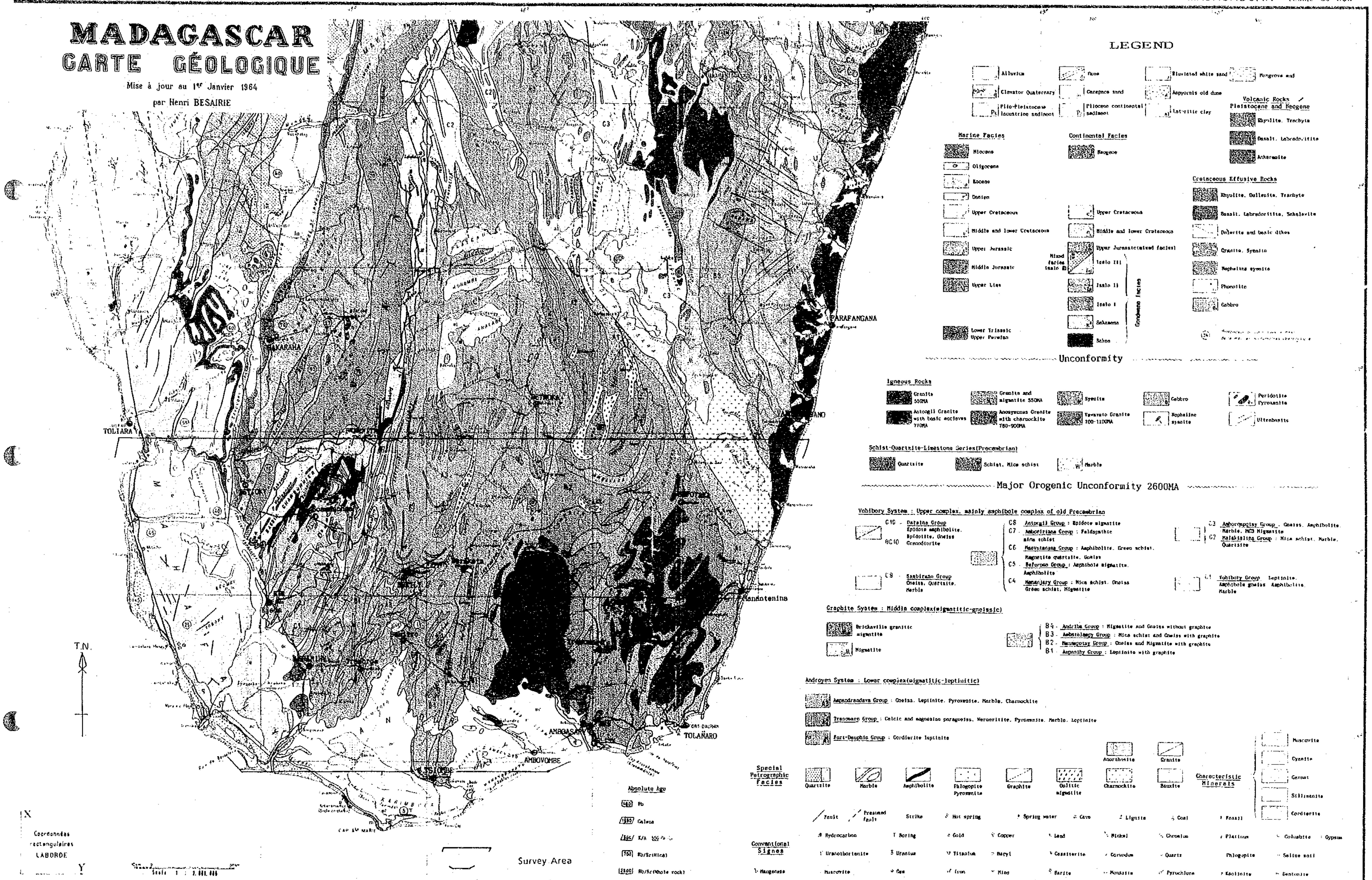



Fig. I-3 Geological Map of Southern Part of Madagascar

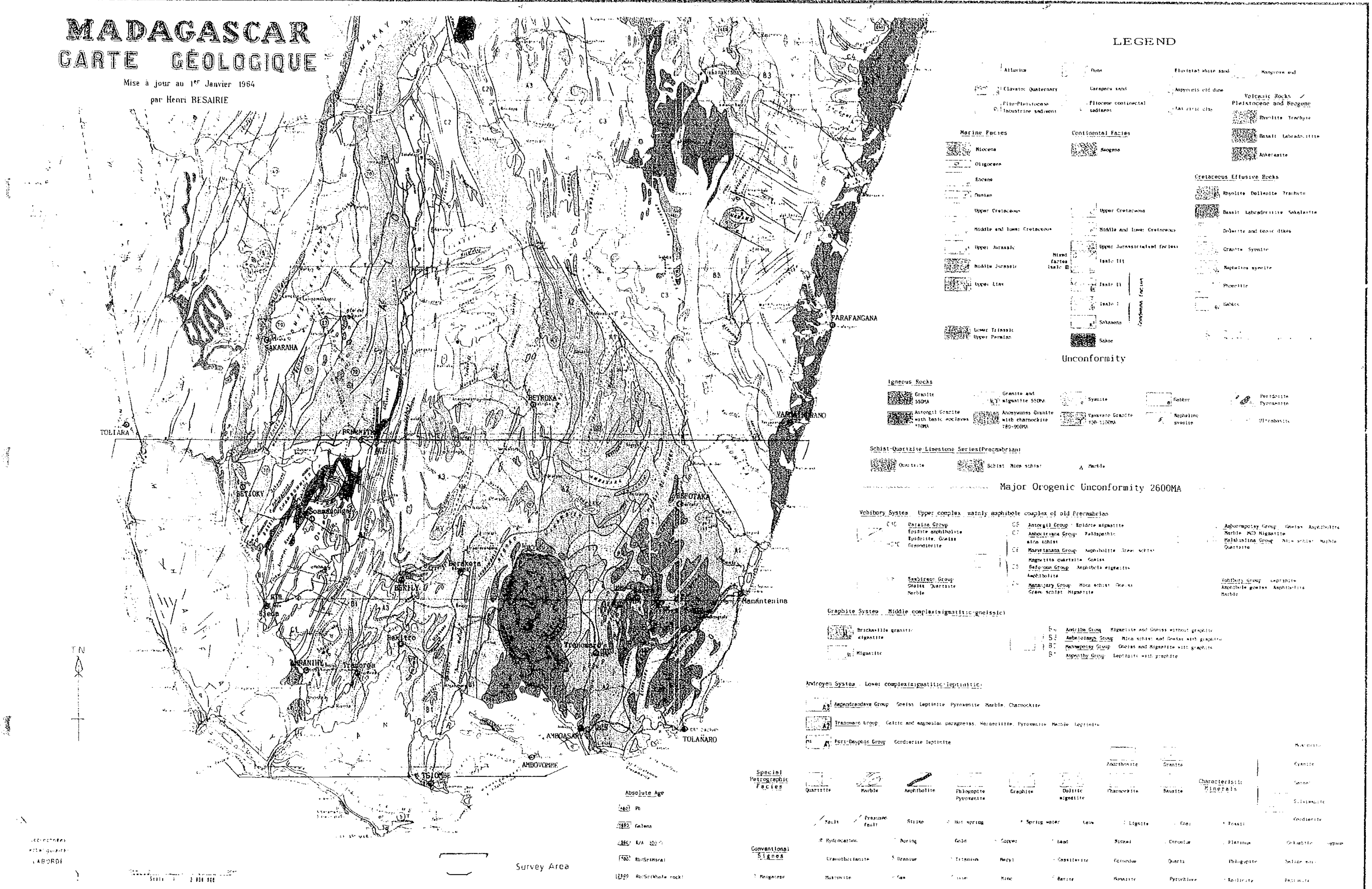



Fig. I-3 Geological Map of Southern Part of Madagascar

# Chapter 4 OUTLINE OF THE SURVEY AREA

## 4-1 Accessibility

The Madagascar island covers an area of about 590,000 $km^2$, 1.6 times of that of Japan, located in the tropical zone on the tropic of Capricorn.

The southern part of Madagascar is particularly under-developed area in the island. Main modernized sites are Toliara city to the west and Tolanaro city to the east of the area.

Five flights a week are operated between Antananarivo, the metropolis and Toliara or Tolanaro cities. It takes one or two days to reach the survey area by car from both cities.

## 4-2 Environment of Survey Area

### (1) General Circumstances

This area is situated in under-developed areas and the environment for living and sanitary conditions are very wrong. The inhabitants are living in primitive self-sufficiency. All materials for living, such as camping tools, drinking water, foods, and fuels must be prepared at Toliara or Tolanaro cities. 4WD vehicles are necessary even in the dry season because of bad road conditions.

### (2) Topography and Drainage System

The western part including Soamanonga area is located at a gentle plateau drainaged of NNE-SSW direction. The eastern part including the Tranomaro western area is located in a rugged mountainous range developed of NS and EW drainage system. The central part is located at an uneven highland.

The Madagascar island is divided into three topographical zones, that is, eastern coastal plain, central plateau and western coastal plain. The eastern coastal plain is a narrow lowland stretching in NNE-SSW direction along coastal line. The central plateau is 800 m to 1,500 m above sea level and occupies more than half of the island. The eastern side is a steep cliff and toward the west it decreases the elevation. The western coastal plain is a wide hilly zone continuous to the coastal lowland.

(3) Climate and Vegetation

The Meteorology of the Madagascar island is divided into two seasons: dry season from April to October and rainy season from November to March. In the rainy season, the climate is of high temperature and very wet due to the south east trade winds as well as the north east seasonal wind, and also due to the influence of the cyclone. As a rule, it is warm all the year because the island is located on the tropic of Capricorn. However, in the western coastal area, it become very dry and hot in summer.

Annual rainfalls are more than 3,000 mm in the eastern coastal plain, about 1,000 mm to 2,000 mm in the central plateau and less than 500 mm in the western coastal plain. The vegetations are characterized by tropical rain forest in the eastern coastal plain, savanna in the central plateau and the western coastal plain, and especial thorny plants in the south western dry land.

## Chapter 5 CONCLUSION AND RECOMMENDATION

### 5-1 Conclusion

(1) Satellite images

Satellite images, in which regional geological structure is reflected clearly, are very useful tools for geological survey not only in the stage of reconnaissance but in the stage of detailed survey. However, it needs some adjustment means or some suplimentary means for the judgment of rock facies, because the spectral data are disturbed by the radiation of vegetation on the surface.

(2) Soamanonga area

The Soamanonga area is composed of the Vihibory System (1.890 Ma), the upper most member of the Precambrian metamorphic rocks. And in the north western part of the area, late Permian to middle Triassic Karroo System which is of continental sedimentary rocks covers unconformably the Precambrian basement.

In the neighborhood of Varahina located at the northern part of the area, gold-silver-copper deposits occur in the Vihibory System and also in the Karroo System. The ore deposits are of vein type or dissemination type in quartz veins and their surroundings, and are inferred to be formed in close relation to the Cretaceous tectonic movement. According to the assay results of this survey, the grades at the parts of high grade ore show around 15% copper, 3 g/t gold, and 120 g/t silver, although the orebodies are usually sporadic and of small size about 10 cm × 1 m.

(3) Tranomaro western area

In the Tranomaro western area which is composed of the Androyen System (3,000 Ma), the lowest member of the Precambrian metamorphic rocks, there develops a remarkable caved ring structure formed by Cretaceous volcanic rocks that are mainly of basalt lava, and rhyolite lava and dykes. Moreover, microgranite is found to be intruded in the Precambrian basement along the outer side of the ring structure. The microgranite is seemed to be an intrusive facies of the Cretaceous volcanic activity that is thought to be an igneous activity originated in a hot-spot in the stable continental crust. A possibility of mineralization accompanied with this type of igneous activity is a very interesting subject in the future.

(4) Mineral resources

Various mineral resources, that are precious stones, non-metallic minerals, metallic resources, are expected to be existing in the southern part of Madagascar. Although almost all of the minerals occurred in the Precambrian gneissic rocks, the genetic ages of the minerals are estimated to extend over a long time, comprising the periods of Precambrian sedimentation of gneiss forming original materials, Precambrian orgeny and metamorphism, Cambrian igneous activity, volcanism and tectonic movement from Cretaceous to Tertiary age and Quaternary weathering and drifting.

## 5-2 Recommendation for the Future

1) The gold-silver-copper orebodies in the Varahina area shows partly very high grade in Au, Ag and Cu assays, though the bodies are of small scale and fragmentary. It is recommended to accumulate basic surveys for the mineralizations and indications in the Varahina area.

2) Mineral resources in the southern part of Madagascar are registered by various types of minerals, genesis and genetic age. In order to select a preferential target for the future, it is advisable to study and classify each ore deposit according to the genesis and genetic age, in addition to the considerations to be given on its grade, scale, occurring features, and conditions of operation and market.

# Part Ⅱ PARTICULARS

# Chapter 1 EXISTING DATA COMPILATION

## 1-1 General Geology

### (1) Precambrian and Cambrian rocks

The Precambrian rocks exposed in the survey area consist of the three systems, Androyen System, Graphite System and Vohivory System, which are correlated with the lower to middle Proterozoic (2,650±200 Ma to 1,100±200 Ma), based on radiometric dating on galena, monazite, uraninite, thorianite and zircon.

Intruding the Precambrian rocks, granite, charnockite, syenite and pegmatite occur as sheets in the Precambrian gneiss. Radiometric ages of these intrusives range from 550 Ma to 485 Ma, indicating intrusions of the Cambrian to early Ordovician age. These ages are consistent with that of thorianite mineralization (485 Ma; Furon, 1963).

### (2) Karroo System

The Permian to Jurassic sediments in the Madagascar Island are called the Karroo System based upon their similarities to those of the Karroo System in South Africa. This system is mainly made of continental sediments and divided into the three groups, Sakoa Group (lower Permian), Sakamena Group (upper Permian to lower Triassic) and Isalo Group (upper Triassic to middle Jurassic) and intercalated of marine sediments in the upper parts. The Karroo System is distributed to the west of this area.

### (3) Cretaceous System

To the west of Tranomaro in the southeastern part of this area, basalt and rhyolite form an elliptical composite igneous mass, measuring about 70 km in N-S and about 45 km in E-W.

## 1-2 Outline of Mineral Resources

Although various kinds of mineralizations have been discovered in Madagascar, only a few of them have been exploited as mines, because of small-scale, incomplete exploration and unsufficient ore reserves.

Mineral resources mined at present are mainly chromite, phlogopite, graphite and precious stones, although ore indications of iron, coal, uranium, nickel, bauxite, ilmenite, niobium, tantalium, copper, lead, zinc, etc. are known.

Pegmatites (precious stones), gold, iron, phlogopite, copper, nickel, etc. have been explored by the MIEM (Ministry of Industry Energy & Mines) and OMNIS (Office Militaire National pour les Industries Strategique) with the aids of France, Italy, former USSR, UK, and other countries.

In the survey area, the occurrence of ore deposits and indications of black sand (monazite, ilmenite, rutile, zircon), graphite, phlogopite, precious stones (garnet, corundum, beryl, etc.), uranothorianite, gold, silver, copper, zinc, iron, chromium, kaolin, and bauxite are known. The ore deposits and indications of each district are described below.

(1) Tolanaro (Fort-Dauphin) district

A number of deposits of black sands which contain monazite, ilmenite, rutile and zircon are formed in the sand-dune sediments and in the present littoral sediments along the coast line, facing the Indian Ocean. These are secondary placer deposits, which were originally transported by rivers derived from the Precambrian Androyen System and then concentrated by an ocean current along the coast line in this district. The Antete and the Vohibarika deposits are located 25 km southwest and 100 km north of Tolanaro, respectively. Other small-scaled deposits are ubiquitous. In the district, 1,750 t of monazite was produced from 1959 to 1963 by the SOTRASSUM, French Pechiney-CEA (Commissariat á l'Energie Atomique) joint venture. After 1965, however, the production has been stopped. Proved reserves of black sands (1970) in the district is 2.7 mil. tons of black sands. Grade of crude ores of the Antete deposit is as follows: 0.53~2.80% monazite; 0.57~2.60% zircon; 14.2~42.0% ilmenite. Production of the black sands around Tolanaro is scheduled to start from 1992 by the OMNIS-Canadian QIT (Quebec Iron & Titanium) joint venture. Bauxite deposit (120 mil. tons with average grade of 30% $Al_2O_3$) occurs at Manantenina located about 120 km north of Tolanaro.

(2) Tranomaro district

Ore deposits and showings of precious stones (corundum), phlogopite, uranothorianite, cassiterite, etc. are known. At present, only phlogopite is mined on a small scale. Uranothorianite was mined actively at the Marosohy, Androtsabo and Amboanemba mines by CEA (Commissariat a l'Energie Atomique) from 1954 to 1964. Uranothorianite is distributed within a district measuring about 60 km in N-S and about 20 km in E-W along the Manamboro river. The ore deposits occur as lenticular or pipe-like bodies within pyroxenite of the Androyen System. It is said that uranothorianite ores with U grade higher than 12% were mined and the main deposits were almost mined out.

(3) Bekitro district

Ore showings such as phlogopite, manganese, precious stones (beryl and garnet), ilmenite, etc. are known. Phlogopite deposits occur as stratiform or lenticular bodies of pegmatite within pyroxenite of the Androyen System.

(4) Ampanihy district

Although ore showings such as precious stones (ruby, garnet, etc.), graphite, phlogopite, ilmenite, copper, manganese, etc. have been known, only precious stones are mined now. Graphite, in particular, is expected to be worked in this district. Garnet (spessartine) is mined where garnet-bearing leptinite of the Graphite System has been subjected to lateritization. Graphite was worked where graphite-bearing leptinite had been lateritized. About 4 km southeast of Ampanihy, a kaolin deposit is exposed almost horizontally in the semidesert area. It occurs near the boundary between hornblende schist of the Graphite System and red sandstone of the Sakoa Group of the Upper Karroo system. Drillings have proved their thickness to be about 10 m.

(5) Northern Beraketa district

Ore deposits and showings of phlogopite were known. Phlogopite deposits were mined at the Marovala, Ampandramdava, Ambararata and other mines from the beginning of 1900's to about 1940. They occur as stratiform or lenticular bodies of pegmatite within pyroxenite of the Androyen System. Calcite, diopside, apatite, gypsum, pyrite, molybdenite, etc. are associated with phlogopite. In addition to the phlogopite deposits, ore showings of graphite, uranothorianite and beryl are distributed in this district.

(6) Soamanonga district (Vohibory district)

Ore showings of gold, silver, copper, zinc and manganese have been known. They were mined at the Besakoa mine in the colonial time. Copper mineralization in this district is recognized as oxide copper or as quartz vein in the Vohibory System with a small amount of gold and silver (Lanapera and Besakoa deposits). Zinc-rich copper-zinc mineralization occurs at the Besakoa deposit. In addition, disseminated or lenticular copper ore is recognized in the red sandstone bed of the Karroo System (Bevalaha deposit). The Sakoa Group of the Karroo System in the district contains coal seams, which were explored by the British BB-C Coal Co. in Ankinany along the Sakoa river. There occur iron-bearing sandstones with average thickness of 30 cm in southern Betioky situated to the west of this district. According to BRGM (Bureau de Recherches Geologiques et Minieres, 1959-1960), probable reserves are estimated as follows: 6 mil. tons (10~14% Fe) or 1.5 mil. tons (24% Fe) or 0.6 mil. tons (29% Fe). According to Besairie (1966), possible reserves are estimated to be 130 mil. tons (10~14% Fe) or 30 mil. tons (24% Fe).

## Chapter 2 PHOTOINTERPRETATION OF LANDSAT IMAGES

### 2-1 Interpretation Method

Six false color images in a scale of 1:500,000 displayed by blue, green and red to each bands 2, 3, and 4 were prepared after linear stretch and edge enhancement process using TM data in a form of CCT. The used LANDSAT data are shown in Table II-2-1, and the location of each image is in Fig. II-2-1. Mosaic of images covering the Madagascar southern area is shown in Fig. II-2-2.

By the photointerpretation, 29 photogeologic units (Table II-2-2) were classified and correlated to the geological map by Besairie. The results of photointerpretation is summarized in Fig. II-2-3.

### 2-2 Photogeologic Units

1) Unit PCa

This unit, showing pale brownish on the false color images, is distributed to the east in the northern part of the survey area, forming mountain ranges with steep peaks. The resistivity against erosion is high. On the geological map, this unit is correlated with the cordierite zone of the Precambrian metamorphic rocks.

2) Unit PCb

This unit, showing yellow ocher and hard feature on the images, is distributed in contact with the PCa to the east in the northern part of the area, forming a mountainous topography. On the geological map, it is correlated with the cordierite zone of the Precambrian metamorphic rocks.

3) Unit PCc

This unit is widely distributed throughout the survey area showing bluish green or white tone on the images. Since mountain range and valley appear alternately, this area is inferred to be composed of rhythmic alternation of soft and hard rocks. A complicated regional folding is recognized from the curved schistosity and stratified bedding. On the geological map, this unit is correlated with the Precambrian metamorphic rocks.

4) Unit J1

This unit, being deep green on the images, shows a long and narrow distribution in the northwestern part of the survey area, forming a cuesta or plateau-like landform. Therefore, this unit is considered to be composed of relatively homogeneous and somewhat hard sedimentary rocks. On the geological map, it is correlated with the Lower Permian continental formations.

5) Unit J2

This unit, being deep green on the images, shows a long and narrow distribution in the northwestern part of the area, forming a cuesta or hogback-like landform composed mainly of soft sedimentary rocks with some intercalation of hard rocks. On the geological map, this unit is correlated with the Lower Permian to Lower Triassic continental formations.

6) Unit J3

This unit, being grayish green on the images, shows a zonal distribution in the northwestern part of the area, forming a cuesta-like landform composed mainly of hard sedimentary rocks. On the geological map, this unit is correlated with the Upper Permian to Lower Triassic continental formations.

7) Unit J4

This unit, being reddish brown on the images and in contact with the unit J3, shows a zonal distribution in the northwestern part of the area. Since this unit forms a flat lowland and its sedimentary structure is obscure, it is considered to be composed mainly of soft sedimentary rocks. On the geological map, this unit is correlated with the Upper Permian to Lower Triassic continental formations.

8) Unit J5

This unit being reddish brown on the images, shows an irregular distribution cut by faults in the northwestern part of the area, forming a plain or cuesta composed mainly of somewhat hard sedimentary rocks. On the geological map, this unit is correlated with the Middle to Upper Jurassic marine formations.

9) Unit K

This unit, being bluish green or reddish brown on the images, shows a somewhat irregular distribution in the northwestern part of the survey area, forming a cuesta composed mainly of somewhat hard sedimentary rocks. On the geological map, this unit is correlated with the Lower to Middle Cretaceous marine formations.

10) Unit Kva

This unit, being dark green on the images, shows a concentric distribution in the margin of the ring-like structure, forming a well-continued U-shaped valley. On the geological map, this unit is correlated with the Cretaceous basalts.

11) Unit Kvb

This unit, being bluish green on the images and soft, forms a ring-like structure along with the units Kva and Kvr somewhat east in the center of the area. It also forms a U-shaped valley. On the geological map, this unit is correlated with the Cretaceous basalts.

12) Unit Kvc

This unit, being deep green on the images, shows a zonal distribution in the northwestern part of the survey area, forming a low hilly landform. It has a moderate resistance with an obscure sedimentary structure. On the geological map, this unit is correlated with the Cretaceous basalts.

13) Unit Kvr

This unit, being grayish white to yellowish brown on the images, is distributed in the center and margin of the ring-like structure, forming a roundish ridge, mesa or monadnock. On the geological map, this unit is correlated with the Cretaceous rhyolites.

14) Unit Ta

This unit, being dark green or dark red on the images and showing stratification and moderate resistance, is surrounded by the Unit Tb and forms a plain or mesa-like landform. The presence of hollows, considered to be sinkholes, leads to an interpretation that this unit consists of carbonate rock-dominant formation composed mainly of marl. On the geological map, it is correlated with the Eocene marine formations.

15) Unit Tb

This unit, being bluish green tint with white patch on the images, is distributed in the western part of the survey area. It resists erosion. The presence of a stratification and hollows considered to be sinkholes leads to an interpretation that this unit consists of carbonate rock-dominant formation composed mainly of limestone. On the geological map, this unit is correlated with the Eocene marine formations.

16) Unit Tc

This unit, being dark bluish green on the images and showing somewhat coarse surface texture and abundant ups and downs, is distributed in the western flat plain of the survey area. The presence of stratification and moderate resistance leads to an interpretation that this unit is composed mainly of carbonate rocks. The coarse texture of the surface is considered to represent a karst topography. On the geological map, this unit is correlated with the Eocene marine formations.

17) Unit Q1

This unit, being dark brown or dark red on the images, is distributed irregularly in the lowland in the southwest of the survey area, forming a flat plain with monadnock. It is considered to be composed mainly of soft sedimentary rocks.

18) Unit Q2

This unit, being white on the images and having very coarse surface texture, shows an irregular distribution in the flat lowland in the south of the area. it is considered to be composed mainly of somewhat soft sedimentary rocks. On the geological map, this unit is correlated with the eluviated white sand bed.

19) Unit Q3

This unit, being dark gray or dark green on the images, is distributed along the coast from east to south of the survey area. The presence of a coarse surface texture and sand waves leads to an interpretation that this is an eolian sediment. On the geological map, this unit is correlated mainly with the aepyornis old dune sediments.

20) Unit Q4

This unit, being white on the images, is distributed along the coast, outside the unit Q3, from east to south of the area. The presence of somewhat fine surface texture and sand waves leads to an interpretation that it is an eolian sediment younger than the unit Q3. On the geological map, this unit is correlated with the sand-dune sediments and alluvium.

21) Unit Q5

This unit, showing variously colored tone on the images, is distributed along the rivers in the survey area. This unit is correlated with the alluvium.

22) Unit Gra

This unit, being reddish brown on the images, is distributed widely in the eastern part of the area. The presence of the well-developed lattice-like joints and the hard mountainous landform leads to an interpretation that it consists of granitic rocks. On the geological map, this unit is correlated with the Anosyennes granites.

23) Unit Grb

This unit, being white to pale pink on the images, shows a vein-like or lenticular distribution in the center of the area. It is hard and forms a hilly landform as blocks. On the geological map, this unit is correlated with the granites and hybrid rocks.

24) Unit A

This unit, being milky white or bluish white and having smooth surface texture on the images, is distributed as an eyeball in the folded belt in the center of the area. It is somewhat hard, forming a hilly landform as blocks. On the geological map, this unit is correlated with the anorthosite.

25) Unit L

This unit, being bluish white on the images, is included in the unit PCc and shows a vein-like to lenticular distribution. It is somewhat hard and has a ridge parallel to the structure. On the geological map, this unit is correlated with the marble.

26) Unit S

This unit, being white on the images, is included in the unit PCc and shows a vein-like to lenticular distribution. It is very hard and forms a ridge parallel to the structure. This unit is inferred to be the Precambrian quartzite.

27) Unit TA1 (tonal anomaly)

This unit, being deep green on the images, is included in the Unit PCc and shows a vein-like to lenticular distribution parallel to the structure. It is somewhat hard and forms a ridge.

28) Unit TA2 (tonal anomaly)

This unit, being bluish green on the images, is included in the unit PCc and shows a zonal arrangement parallel to the structure. It is somewhat soft and forms an elongated depression.

29) Unit TA3 (tonal anomaly)

This unit, being pinkish white on the images, is distributed irregularly in the southern part of the center of the area. It is somewhat soft and forms a gentle hilly landform.

## 2-3 Geological Structure

The major geologic structures interpreted on the satellite images are mentioned below. The interpretation units of PCa to J5 have the general strike of N-S to NNE-SSW and younger formations are distributed from east toward west. Complex folded structures found in the units PCc to J3 are recognized clearly on the images, resulting in an extraction of some anticlinal and synclinal structures.

Angular unconformity is refered between the units PCc and J1 and between the units K and Tc.

An elliptical complex intrusive, measuring about 70 km N-S by about 45 km E-W, is distributed somewhat east in the center of the survey area. Encircling the northern to northeastern part of the igneous body, a distinct collapse structure is recognized. According to the existing geological map, the body is formed by volcanic rocks in Cretaceous Period. There is a possibility that such a large-scaled magmatism may be related to mineralization. Therefore, this area is interesting as an object of detailed survey.

At the coastal part of the western margin of the survey area, well-continued fault parallel to the coast line is recognized and the unit lying west of the fault is inferred to have downthrown relatively.

Table II-2-1 List of Used LANDSAT Data

| | Satellite | Data Form | Sensor | Path | Row | Date | Cloud cover | Distributor |
|---|---|---|---|---|---|---|---|---|
| 1 | L5 | CCT | TM | 158 | 76 | Nov.25,1984 | 20% | EOSAT |
| 2 | L5 | CCT | TM | 158 | 77 | Nov.25,1984 | 20% | EOSAT |
| 3 | L5 | CCT | TM | 159 | 76 | Jan.19,1985 | 10% | EOSAT |
| 4 | L5 | CCT | TM | 159 | 77 | Jan.19,1985 | 10% | EOSAT |
| 5 | L5 | CCT | TM | 160 | 76 | Feb.11,1985 | 10% | EOSAT |
| 6 | L5 | CCT | TM | 160 | 77 | Feb.11,1985 | 10% | EOSAT |

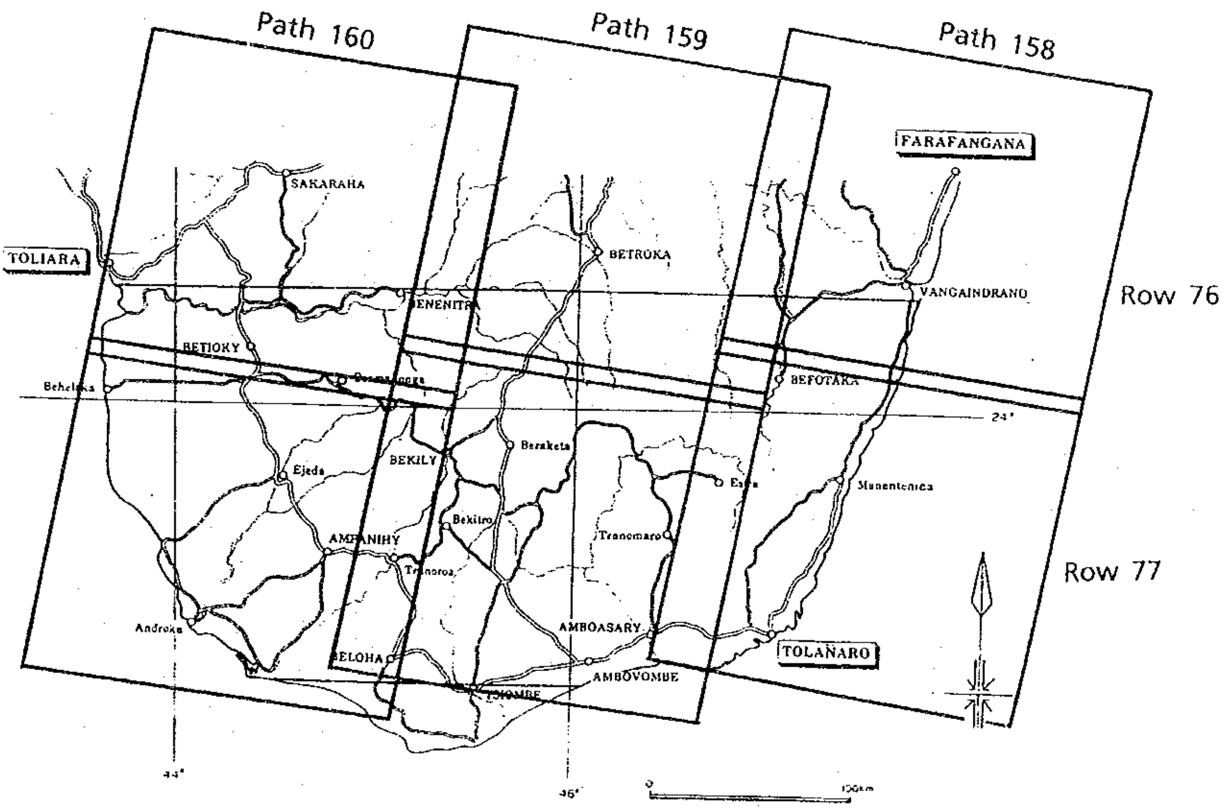



Fig. II-2-1 Index of LANDSAT Images

## Table II-2-2 List of Geological Units by Photointerpretation

| | Units of Interpretation | Color | Tone | Texture | Resistance | Landform | Bedding | Pattern | Correlation with geologic map and rock types |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Q5 | various | light | fine | low | plain, alluvial fan | none | granular | alluvium |
| 2 | Q4 | white | very light | medium to fine | low | plain, dune | none | wavy form | dune, alluvium |
| 3 | Q3 | dark grey, greyish green | dark | coarse | moderate to low | plain, dune | none | wavy form | Aepyornis old dune |
| 4 | Q2 | white | very light | very coarse | moderate to low | plain | none | speckled | eluviated white sand |
| 5 | Q1 | reddish brown, dark red | dark | coarse | low | plain | horizontal | speckled | Carapace sand |
| 6 | Ta | dark green, dark red | moderate to dark | fine | moderate | plain, mesa | horizontal | stratiform, sinkhole | Eocene marine facies |
| 7 | Tb | bluish green, white patch | dark | coarse | moderate to high | plain, mesa | horizontal to gentle | spotted, sinkhole | Eocene marine facies, Carapace sand |
| 8 | Tc | dark bluish green | very dark | rough | moderate | plain | gentle | stratiform | Eocene marine facies, Clavator Quaternary |
| 9 | Kvr | greysh white to yellowish brown | moderate to light | coarse | moderate to high | roundish ridge | none | ring structure | Cretaceous (rhyolite, dellenite, trachyte) |
| 10 | Kvl | bluish green | moderate to dark | fine | low | U-form valley | thin layered | ring structure | |
| 11 | Kvb | bluish green | moderate to dark | fine | low | U-form valley | thick layered | ring structure | Cretaceous (basalt, labradorite, sakalavite) |
| 12 | Kvt | deep green | dark | rough | moderate | hilly | massive | none | |
| 13 | K | bluish green, reddish brown | moderate | fine | moderate to high | cuesta | well-bedded | stratiform | Lower to Middle Cretaceous marine facies |
| 14 | J5 | reddish brown | dark | smooth | moderate to high | plain, cuesta | thick | none | Middle to Upper Jurassic marine facies |
| 15 | J4 | reddish brown | dark | fine | low | plain | poorly bedded | white spotted | |
| 16 | J3 | greysh green | moderate to light | fine | high | assymmetric ridge | well-bedded | banded | Lower Permian to Lower Triassic |
| 17 | J2 | deep green | moderate to dark | fine | low | hogback | well-bedded | banded | continental facies |
| 18 | J1 | deep geen | dark | medium to coarse | moderate | cuesta | well-bedded | banded | |
| 19 | PCa | pale brown | light | medium to coarse | high | V-form ridge | well-bedded | foliation | |
| 20 | PCb | yellowish brown | light | rough | moderate to high | mountainous | thick | foliation | Precambrian metamorphic rocks |
| 21 | PCc | bluish green, white | moderate to dark | coarse | moderate to high | hogback | well-bedded | foliation | |
| 22 | Gra | reddish brown | light | smooth | very high | steep mountainous | none | joint set | Anosyennes granite |
| 23 | Grb | white to pale pink | light | coarse | high | blocky and hilly | none | shistose structure | granite, migmatite |
| 24 | A | milky white, bluish white | very light | smooth | moderate to high | blocky and hilly | none | centripetal | anorthosite |
| 25 | L | bluish white | light | smooth to fine | moderate to high | ridge | thick | fine dendritic | marble |
| 26 | S | white | light | smooth | very high | ridge | thick | none | quartzite |
| 27 | TA1 | deep green | very dark | fine | moderate to high | ridge | thick layered | lineation | tone anomaly |
| 28 | TA2 | bluish green | dark | fine | moderate to low | elongated depression | thin layered | banded | tone anomaly |
| 29 | TA3 | pinkish white | light | coarse | moderate to low | hilly | none | lineation | tone anomaly |

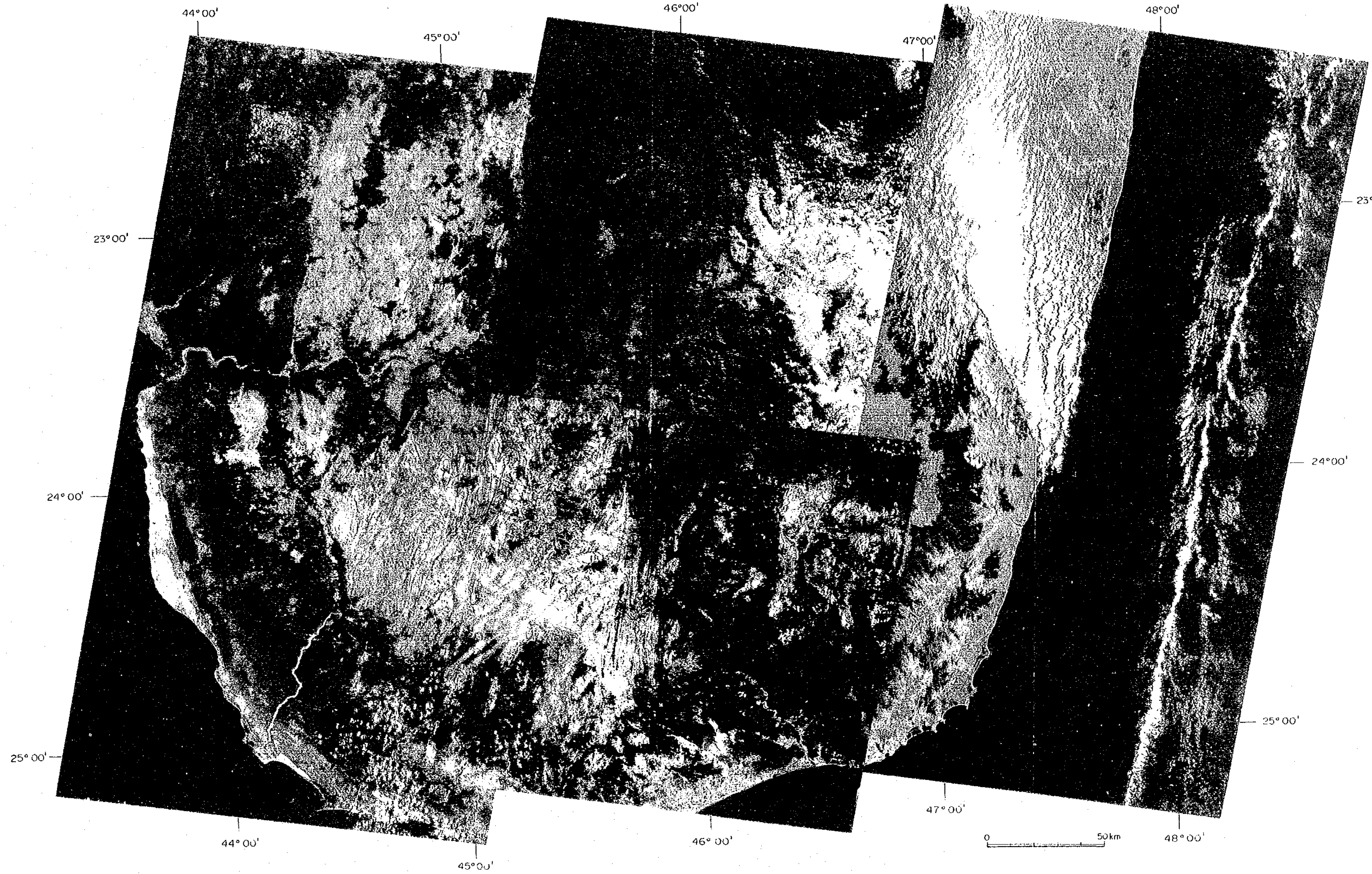
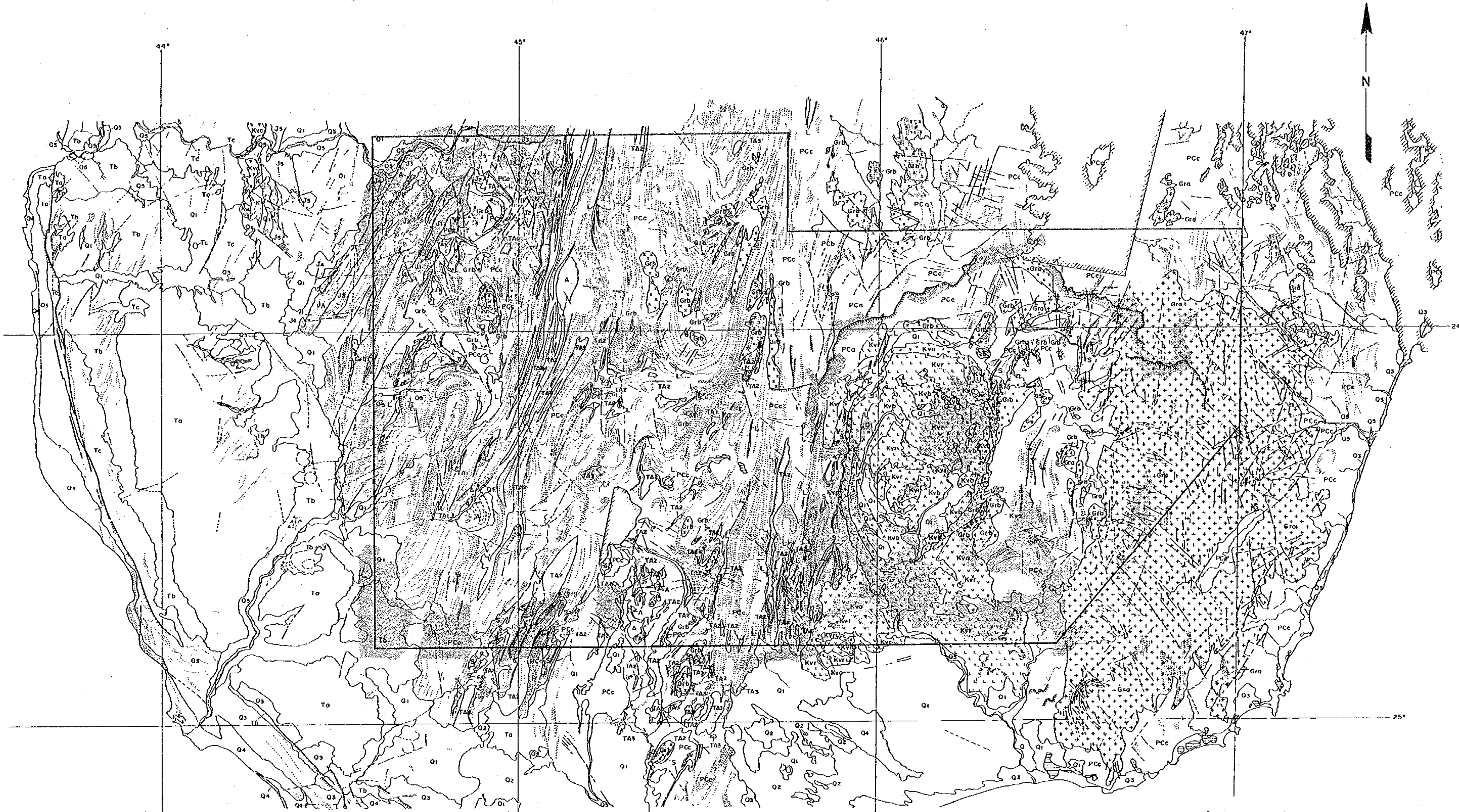



Fig. II-2-2 Mosaic of LANDSAT Images

Fig. II 2 2 Mosaic of LANDSAT Images




LEGEND

| Interpreted units | Correlation with geologic map and rock types |
|---|---|
| Q5 | alluvium |
| Q4 | dune, alluvium |
| Q3 | Aepyornis old dune |
| Q2 | aluviated white sand |
| Q1 | Carapace sand |
| Ta | Eocene marine facies |
| Tb | Eocene marine facies, Carapace sand |
| Tc | Eocene marine facies, Clavator Quaternary |
| Kvr | Cretaceous (rhyolite, dellenite, trachyte) |
| Kva | Cretaceous (basalt, labradorite, sakalavite) |
| Kvb | |
| Kvc | |
| K | Lower to Middle Cretaceous marine facies |
| J5 | Middle to Upper Jurassic marine facies |
| J4 | Lower Permian to Lower Triassic continental facies |
| J3 | |
| J2 | |
| J1 | |
| PCa | Precambrian metamorphic rocks |
| PCb | |
| PCc | |
| Gra | Anosyennes granite |

| Interpreted units | Correlation with geologic map and rock types |
|---|---|
| Grb | granite, migmatite |
| A | anorthosite |
| L | marble |
| S | quartzite |
| TA1 | tonal anomaly |
| TA2 | tonal anomaly |
| TA3 | tonal anomaly |
| | unit boundary |
| | uncertain unit boundary |
| | bedding trace or schistosity |
| | strike and dip direction |
| | anticline with direction of plunge |
| | syncline with direction of plunge |
| | fault (barbs on downthrown side) |
| | inferred fault |
| | lineament |
| | drainage |
| | lake |
| | cloud cover |

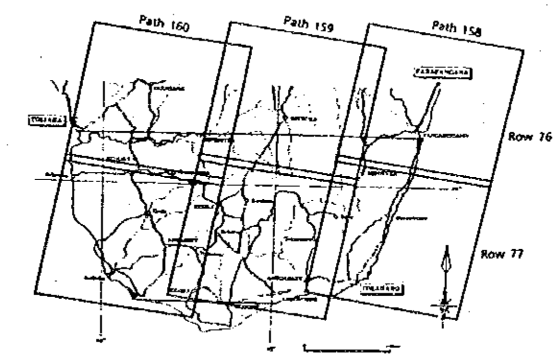



Fig. II-2-3 Photointerpretation of LANDSAT Image

## Chapter 3 SPECTRAL ANALYSIS OF LANDSAT DATA

### 3-1 Method of Spectral Analysis

In the Phase II survey, the spectral digital analysis of LANDSAT TM CCT data were carried out in order to perform more detailed investigation. At first, two model areas, Soamanonga area in which copper indications are distributed and Tranomaro area in which uranothorianite ore deposites are in occurrence were selected for training studies. Totalling 7 kinds of images were prepared, such as 3 kinds of false color images (Fig. II-3-3, Fig. II-3-8), combined of bands 1•4•5, 1•5•7, and 4•5•7, 3 kinds of ratioing pseudo color images (Fig. II-3-4, Fig. II-3-9) band ratio 3/2, 4/3, and 5/7, and DPCA (Direct Principal Component Analysis) pseudo color image (Fig. II-3-4, Fig. II-3-9).

Each subscene image of two model areas was studied and compared to the existing geological data. As the results, the false color image of bands 4•5•7 was judged to be the best for the interpretation of rock facies and geological structure, and ratioing pseudo color image of band ratio 5/7 was proper for the extraction of clay minerals and alteration zone.

Two types of full-scene images, the false color image combined of bands 4•5•7 and the ratioing image of band ratio 5/7, were prepared in scales of 1:200,000 and 1:500,000 covering the survey area and re-interpretation was carried out.

### 3-2 Analysis Results of Model Areas

(1) Soamanonga area

1) Outline

Soamanonga area is located in the middle reaches of the Onilahy river and vegetation is supposed to be rare excluded in the northern part where density of drainage is high. Precambrian and Permian rocks are distributed and indications of copper mineralization are reported. Relationship between geological setting and distribution of copper mineralization is not represented clearly in existing geologic map.

2) False color image (Fig. II-3-3 (1), (2), (3))

① Dense part of vegetation cover is displayed in green and contrast with sparse part of vegetation is very clear in bands 145 false color image. Lithologic boundaries in this image, however, are not clear except boundary between granite and surrounding units.

② In bands 1•5•7 false color image, lithologic units in Precambrian are easily differentiated but those in Permian to Triassic sedimentary rocks are not so.

③ In bands 4•5•7 false color image, lithologic units in Precambrian are clearly recognized and those in sedimentary rocks can also be delineated.

3) Ratioing pseudo color images (Fig. II-3-4 (1), (2), (3))

① Most of pixels with high 3/2 ratio are distributed in granite and Precambrian. Marble in Precambrian has low value of 3/2 ratio. Ratioing by TM bands 3/2 is available to detect iron oxides. In this case, rocks including iron minerals like magnetite are probably displayed as red with high 3/2 ratio because of oxidized iron minerals in surface.

② Bands 4/3 ratio is available to know density of vegetation. High density zones of vegetation are observed as reddish color with high 4/3 ratio in this image.

③ Since TM band 7 covers absorption peak of infra-red by many clay minerals, 5/7 ratio is effective to detect distribution of clay minerals. In this area, 5/7 ratio shows positive correlation well with 4/3 ratio. Anomaly of 5/7 ratio might indicates surface materials contain many clay minerals.

4) DPCA image

DPCA image by ratio 4/3 and 5/7 is shown Fig. II-3-4 (4). Second principal component is displayed in pseudo color in this image. DPCA method is expected to extract the distribution zones of minerals which have absorption peak of infrared in range of TM band 7 like clay minerals or carbonate minerals, reducing effects by vegetation cover. We can differentiate distribution zones of carbonate rocks in Precambrian and Permian by DPCA image of Soamanonga area but PC2 is generally low in Permian units which have originally much amount of clay minerals. DPCA image, therefore, is not available for extraction of zones where clay minerals are distributed in this case.

Geologic interpretation map of satellite images in Soamanonga area is shown in Fig. II-3-5. Boundaries among each geologic units are delineated accurately with respect to existing geologic map. Since many of copper deposits are located along faults or lineaments in this interpretation map, fissure controlling can be important role for mineralization. Relationship between distribution of copper deposit and possible alteration zone (positive anomaly of band ratio 3/2 and 5/7) is not clear but many deposits located inside or near by anomaly of bands 3/2 ratio.

(2) Tranomaro area

1) Outline

Tranomaro area is located in the upper reaches of the Mandrare river and eastern part shows mountainous topography with more than 1,000 m in elevation. Granitic complex is distributed in eastern mountainous part. Central to western part of the area mainly consists of metamorphic rocks in Precambrian age. Many uranothorianite deposits are located in topographically lower part in western front of eastern mountains made of granitic complex (Fig. II-3-7).

2) False color images (Fig. II-3-8 (1), (2), (3))

① Boundaries between Precambrian and granitic complex are not clear in bands 1•4•5 false color image.

② In bands 1•5•7 false color image, to delineate boundaries between Precambrian and granitic complex is possible but Precambrian subunits are not easily recognized.

③ In bands 4•5•7 false color image, we can easily recognize unit boundaries between Precambrian and granitic complex and subunits in Precambrian.

3) Ratioing pseudo color images (Fig. II-3-9 (1), (2), (3))

① Most of pixels with high 3/2 ratio are distributed in topographically lower part. That might mean oxidation is controlled by humidity or other climatic conditions.

② Since reddish pixels with high 4/3 ratio are concentrated in a area where the Mandrare river meanders down to north, this ratio probably indicates density of vegetation.

③ 5/7 ratio shows positive correlation with 4/3 ratio. Anomaly of 5/7 ratio might indicate surface materials contain many clay minerals.

4) DPCA image

DPCA image by ratio 4/3 and 5/7 is shown in Fig. II-3-9 (4). Second principal component is displayed in pseudo color in this image. Granitic complex and Antsakaominary formation in Precambrian show high value of PC-2 but the distribution zones of clay minerals cannot be extracted from this image.

Geologic interpretation map of satellite images in Tranomaro area is shown in Fig. II-3-10. Folded structures which are not indicated on existing geologic map are interpreted but distribution of lenticular granite cannot be interpreted clearly compared with existing geologic map. Uranothorianite deposits are located commonly inside of anomalous zones of bands 5/7 ratio.

Depending on the results of case study in Soamanonga area and Tranomaro area, we selected a combination of bands 4•5•7 for false color images as the best combination to make geologic interpretation and bands 5/7 ratio pseudo color images to delineate alteration zones.

## 3-3 Synthetic Interpretation

TM bands 457 false color image mosaic is shown in Fig. II-3-11 and bands 5/7 ratioing pseudo color image mosaic in Fig. II-3-12. Fig. II-3-13 is geologic interpretation map of those images. Color prints of the images in scales of 1 : 500,000 and 1 : 200,000 were prepared for interpretation.

Following 3 areas are extracted as the areas where positive anomalies of band 5/7 ratio possibly related to alteration are concentrated:

1) Northwest end of survey area

The lower Permian to lower Triassic sedimentary rocks originally contain more clay minerals than the Precambrian metamorphic rocks or granitic rocks surrounding those units, and also those rock types have comparatively low resistivity to weathering. On the surface of those sedimentary rocks, therefore, weathered materials which contain a great quantity of clay minerals might be exposed.

2) An area along circular collapse structure

Positive anomalies of 5/7 ratio may represent a distribution of this talus deposits along the circular structure and argillization zones caused by hydrothermal circulation may have been formed along the circular collapse structure.

Distribution of positive anomaly of 5/7 ratio located inside of the circular structure has no relation with geologic structure. This anomaly can represent alteration zone formed by unknown reason.

3) Southwest end of the area

Eocene marine facies and Quaternary beds which originally contain much clay minerals are mainly distributed in this area. Precambrian units showing high 5/7 ratio should be covered by thin layer of younger sediments like that, which is supposed from false color images.

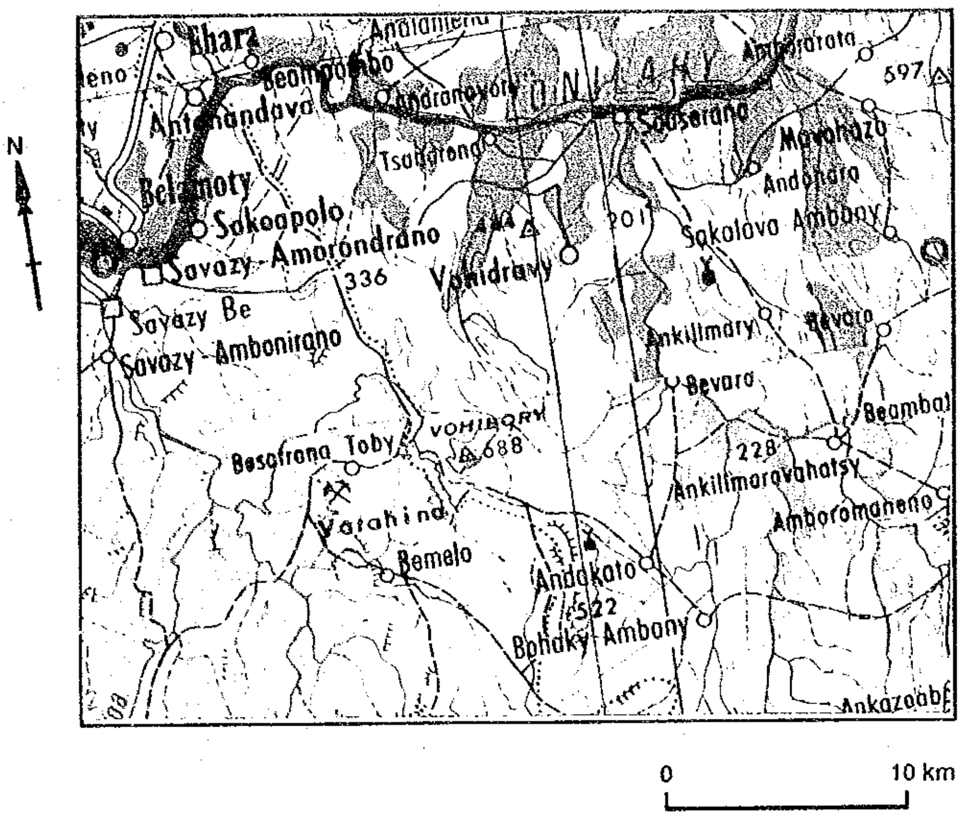



Fig. II-3-1　Topographic Map of Soamanonga Area


Fig. II-3-3　False Color Image of Soamanonga Area

(1) Band 1・4・5 = B・G・R

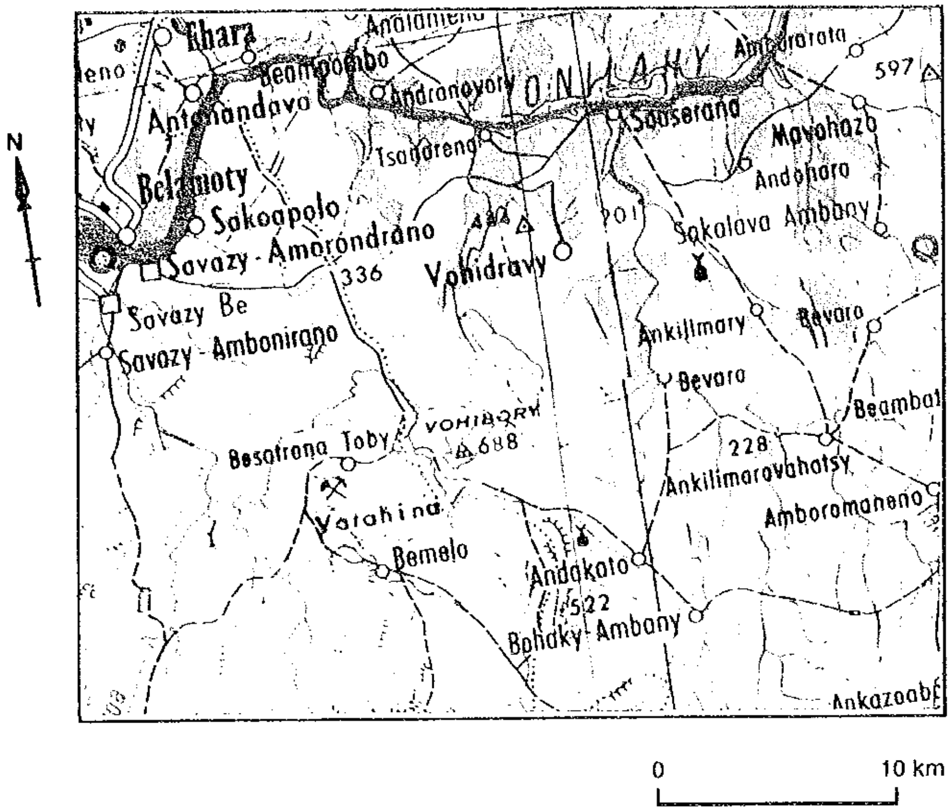



Fig. Ⅱ-3-1 Topographic Map of Soamanonga Area

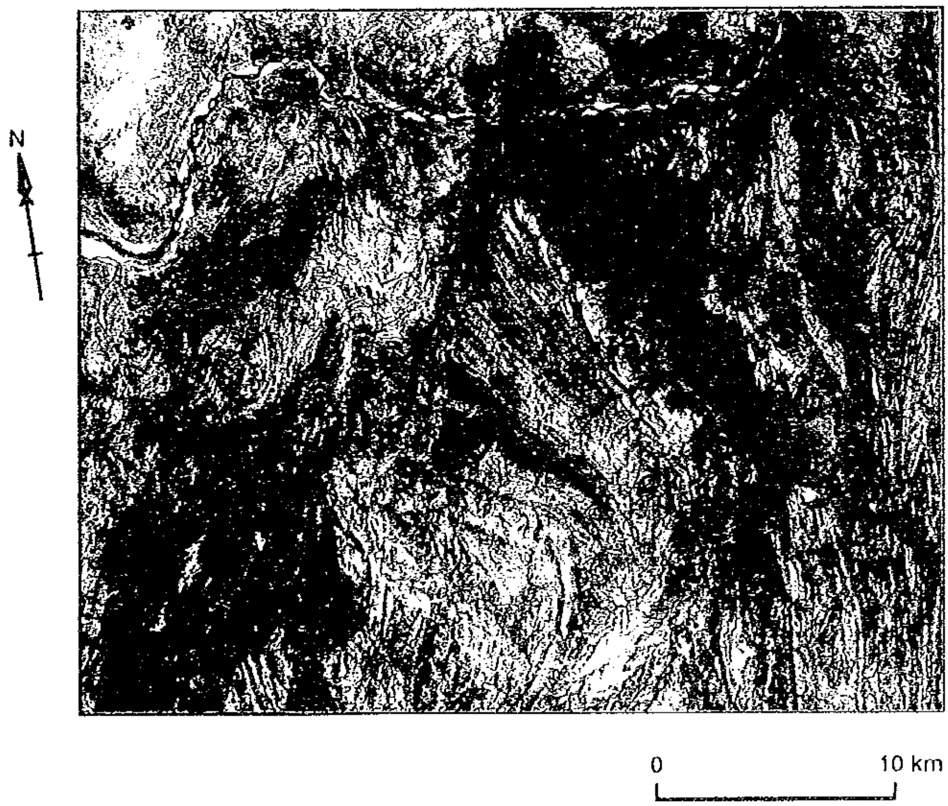
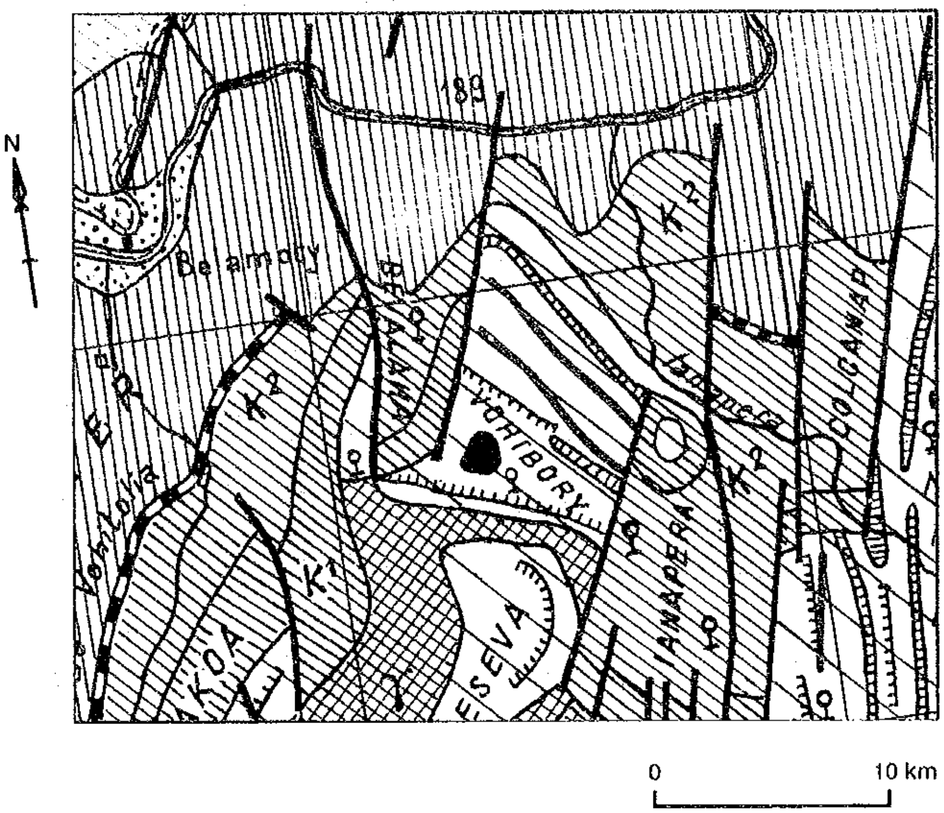



Fig. Ⅱ-3-3 False Color Image of Soamanonga Area

(1) Band 1・4・5 = B・G・R




## LEGEND

Alluvium

Permian - L. Triassic

K4 upper Sakamena group

K3 middle and lower Sakamena group

marine limestone

K2 upper Sakoa group

K1 lower Sakoa group

granite

stratiform granite

c marble

amphibolite

copper

Precambrian

5v Vohibory system
gneiss, leptinite, amphiboleite

Fig. II-3-2 Geological Map of Soamanonga Area

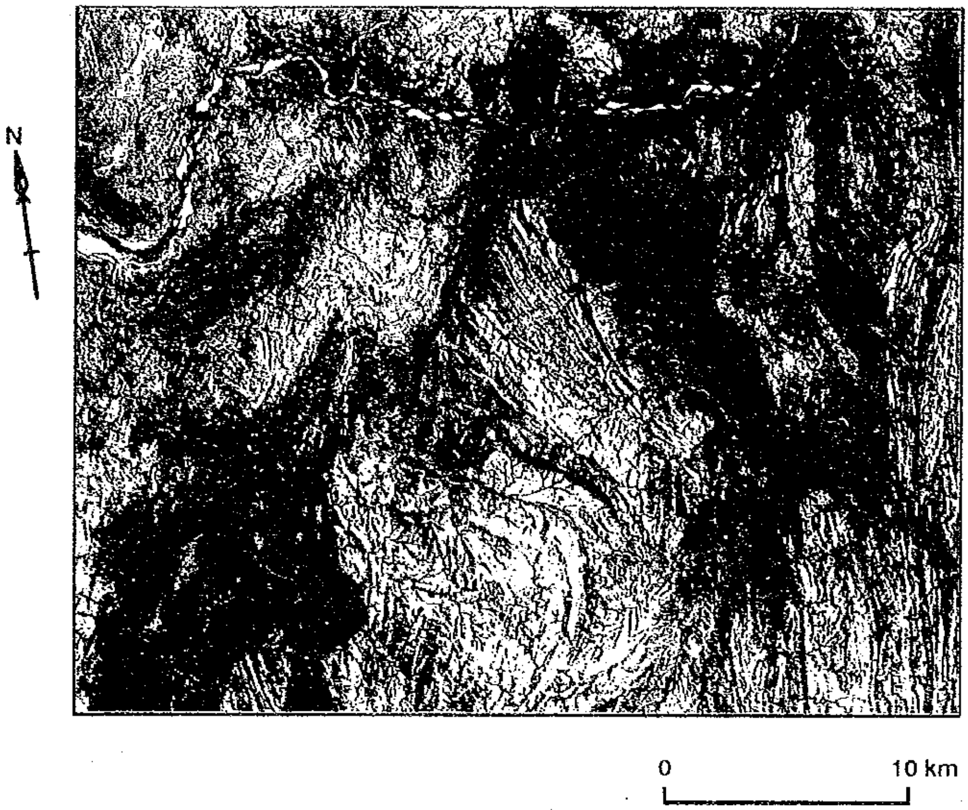



Fig. II-3-3 False Color Image of Soamanonga Area

(2) Band 1・5・7 = B・G・R

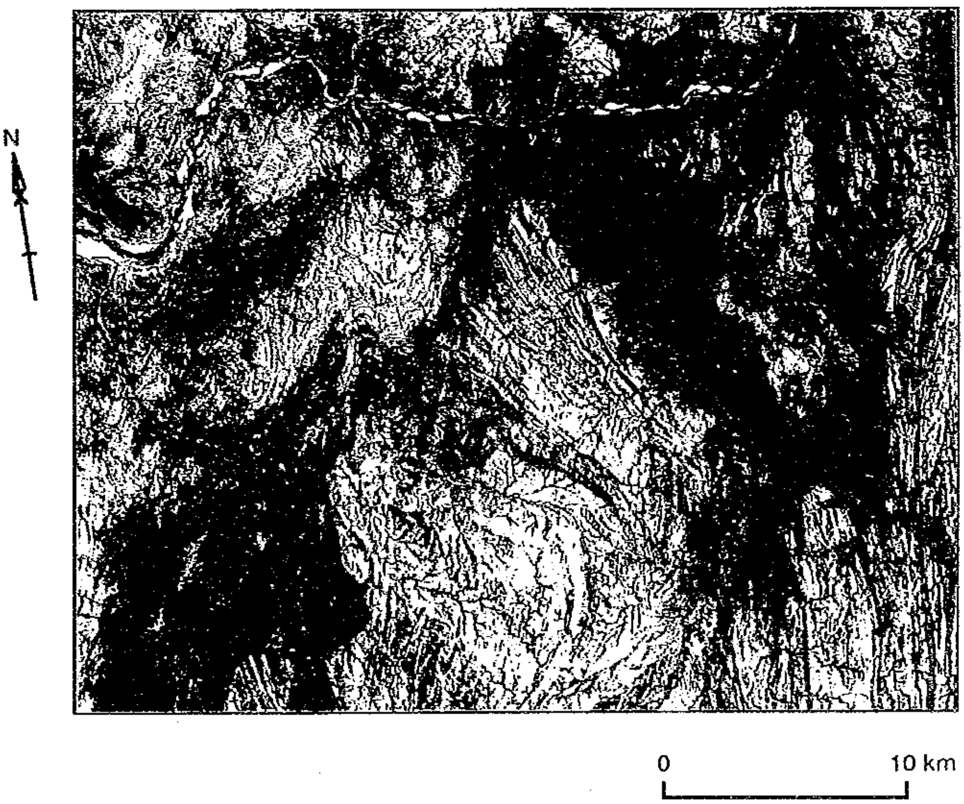



Fig. II-3-3 False Color Image of Soamanonga Aréa

(3) Band 4・5・7 = B・G・R