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REPORT
ON
THE MINERAL EXPLORATION
IN
THE SOUTHERN AREA OF
DEMOCRATIC REPUBLIC, MADAGASCAR

(PHASE I)

FEBRUARY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

PREFACE

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

We have summarized the existing information about mineral resources, and have done satellite image interpretation in Japan in the first year (1991) of the Project. This report which is based on these results should form a part of the final report.

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

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

February, 1992

Kensuke YANAGIYA
President
Japan International Cooperation Agency

Gen-ichi FUKUHARA
President
Metal Mining Agency of Japan

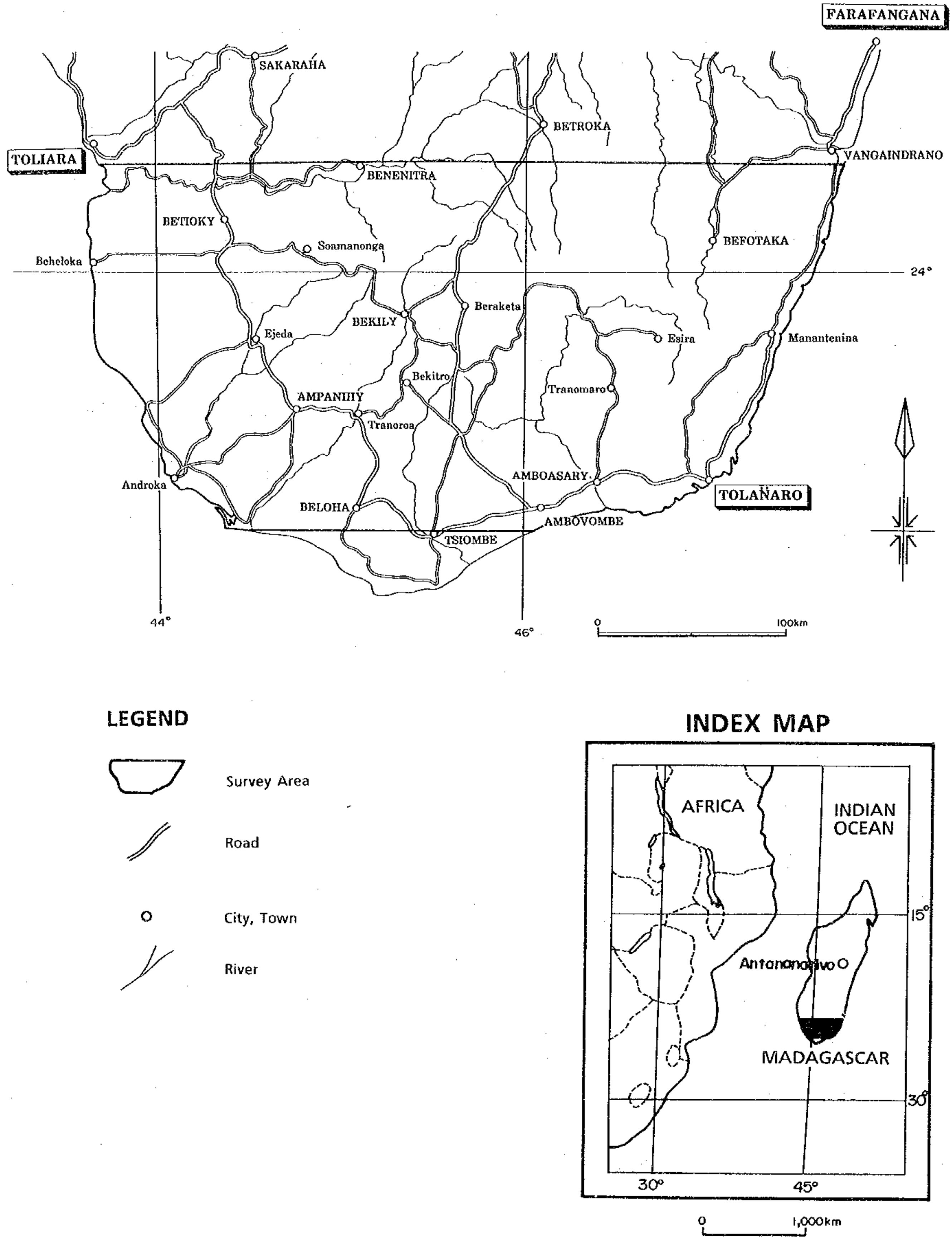
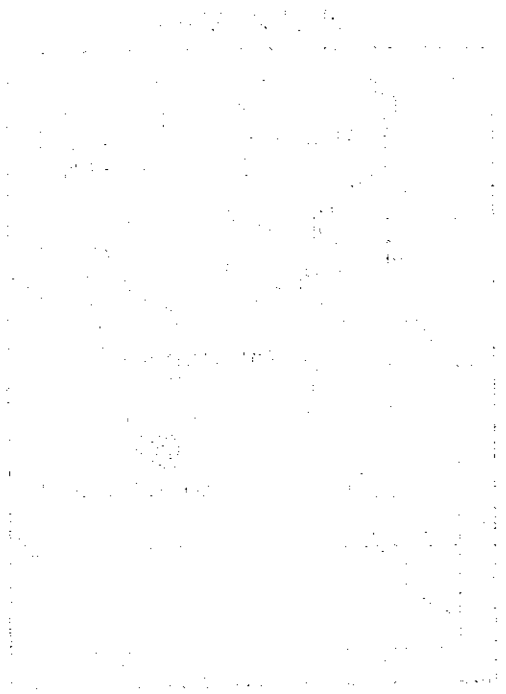


Fig. 1 Location map of survey area



RESUME

Cette exploration des ressources minérales, effectuée par le Gouvernement Japonais en réponse à la demande du Gouvernement de la République Démocratique de Madagascar, a été effectuée sur la base de l'Etendue des travaux approuvée le 19 juin 1991.

L'objectif de cette étude est la compréhension des conditions métallifères par la mise au clair des conditions géologiques. Ainsi, cette année, nous avons collecté et analysé les données concernant les ressources minérales disponibles au Japon. Sur la base de ces résultats, nous avons analysé les images prises par satellite, qui nous ont permis de comprendre la structure géologique régionale et la minéralisation dans la zone d'étude.

Avant l'étude sur le terrain prévue pour la seconde année et au delà, nous avons compilé les données existantes et les analyses des images LANDSAT TM d'une zone d'environ 66.300 km^2 entre 23°27'S et 25°22'S à Madagascar. Le contenu de cette étude a été le suivante:

Contenu de l'étude	Cartes présentées	
Compilation des données existantes	Carte géologique (1:2.000.000)	1
	Cartes géologiques (1:100.000)	12
	Carte de localisation des gisements et affleurements de minerai (1:500.000)	4
Analyse des images LANDSAT TM	6 scènes entières (1:500.000)	

Les résultats de l'analyse sont les suivants.

(1) Compilation des données disponibles

Sur le plan géologique, la zone Sud de l'Ile de Madagascar se compose d'une substructure et de formations Précambriennes d'époques géologiques variées allant du Permien au Holocène. Ces formations sont presque perpendiculaires à l'allongement (N-S) de l'île. Les formations plus jeunes, couvrant l'Erathen Précambrien, ont une structure non-symétrique, elles sont larges dans la partie Ouest, et étroites dans la partie Est. L'Erathen Précambrien forme les hautes terres centrales de l'île, où se trouvent la plupart des gisements.

La zone d'étude renferme des gisements et des affleurements de sable noir (monazite, ilumenite, rutile, zircon), du graphite, du phlogopite, des pierres précieuses (grenat, corindon, béryl, etc.), de l'uranothorianite, de l'or, de l'argent, du cuivre, du zinc, du fer, du chrome, du kaolin, de la bauxite et ainsi de suite. Certains de ces gisements d'uranothorianite, de phlogopite, d'or, d'argent, de cuivre et de zinc ont été exploités dans le passé. Mais la plupart des gisements et affleurements de minerai ont été peu exploités, ce qui s'est traduit par un faible développement. On exploite seulement à petite échelle le phlogopite et les pierres précieuses actuellement.

Ces travaux effectués sont décrits ci-dessous selon les districts:

District de Tolañaro (Fort-Dauphin) : Un certain nombre de gisements de sable noir contenant de la monazite, de l'ilumenite, du rutile et du zircon sont formés dans les sédiments des dunes de sable et les sédiments littoraux le long de la ligne côtière face à l'Océan Indien. Il y a un gisement de bauxite à Manantenina.

District de Tranomaro : Des gisements et affleurements de pierres précieuses (corindon), phlogopite, uranothorianite, cassitérite, etc. sont connus.

District de Bekitro : Des affleurements de minérais, tels que phlogopite, manganèse, pierres précieuses (béryl et grenat), ilumenite, etc. sont connus. Les gisements de phlogopite en forme de couches ou lenticulaires se composent de pegmatite logée dans la pyroxénite du Système Androyen composé de gneiss et de leptynite.

District d'Ampanihy : Bien que des affleurements de minérais, tels que pierres précieuses (rubis, grenat etc.), graphite, phlogopite, ilumenite, cuivre, manganèse, etc. soient connus, seules les pierres précieuses sont exploitées actuellement.

District du Nord Beraketa : Des gisements et affleurements de phlogopite sont connus. Des gisements de phlogopite sont exploités à Marovala, Ampandramdava, Ambararata, et d'autres mines ont existé dans les années 1900 a 1940. En plus des gisements de phlogopite, des affleurements de graphite, d'uranothorianite et de béryl existent dans ce district.

District de Soamanonga (district de Vohibory) : Des gisements d'or, d'argent, de cuivre, de zinc et de manganèse sont connus. Ils ont été exploités dans les mines de Besakoa etc. à l'époque coloniale. Le Groupe Sakoa du Système Karroo contient des veines de charbon.

(2) Interprétation des images LANDSAT TM

Six fausses images couleur ont été réalisées à partir des données CCT par traitement d'extension linéaire et de renforcement des extrémités, et les bandes 2, 3 et 4 apparaissent respectivement bleue, verte et rouge. Nous avons divisé cette zone en 29 unités géologiques sur la base des résultats de l'interprétation géologique des photos. Il existe un complexe linéaire intrusif, mesurant environ 70 km N-S sur 45 km E-O, un peu à l'est du centre de la zone d'étude. On reconnaît une structure affaissée distincte encerclant la partie nord à nord-est de cet élément intrusif. Une magmatique d'une telle envergure doit être liée à la minéralisation.

(3) Propositions pour la seconde année d'étude

Les analyses de données de cette année ont montré que la plupart des gisements et affleurements de minerais étaient insuffisamment exploités, bien que les minéralisations variées aient été découvertes dans cette zone et que le potentiel des ressources minérales soit élevé. Nous proposons les études suivantes comme projet pour la seconde année afin de saisir les conditions métallifères par la mise au clair des conditions géologiques.

1) Analyse des images de satellites

Il y a un grand nombre d'anomalies tonales sur les images de satellite de cette zone, dont certaines semblent être des secteurs d'altération sur le plan de l'activité ignée. Il existe un complexe elliptique intrusif et une structure affaissée distincte qui pourraient être liés aux gisements de minerais commandés par la structure. Les données du détecteur optique et du radar à ouverture synthétique du satellite japonais étudiant les ressources mondiales (FUYOU-1) lancé le 11 février de cette année sont utiles pour analyser et interpréter les conditions de ce type de cadre géologique. Nous pouvons espérer une analyse efficace en combinant les données de FUYOU-1 avec celles de TM et SPOT.

2) Analyses des données existantes

Nous avons analysé les données disponibles au Japon cette année. Il devrait y avoir beaucoup de données à la Direction des Mines et de la Géologie de Madagascar, que nous pourrions obtenir. Nous pourrions compiler ces nouvelles données et les combiner à nos résultats de cette année en utilisant l'interprétation des images de satellite et l'étude sur le terrain du projet de la seconde année.

3) Etude géologique et géochimique

En confirmant sur le terrain les informations obtenues par l'interprétation et la compilation des images TM, nous mettrons au clair la relation entre le cadre géologique et la minéralisation pour en déduire les districts prometteurs en ressources minérales. Les districts concernés sont ceux de Tolañaro (Fort-Dauphin), Tranomaro, Bekitro, Ampanihy, Nord Beraketa et Soamanonga

(Vohibory). Dans le district de Tranomaro, nous ferons une étude pour vérifier l'existence d'une minéralisation accompagnant un élément intrusif complexe elliptique du Crétacé et une structure affaissée, en plus de la confirmation de l'existence de gisements et d'affleurements de minerais.

CONTENTS

List of Figures

List of Tables

List of Plates

CHAPTER 1 OUTLINE OF SURVEY

1-1 Background and purpose of the survey

The Democratic Republic of Madagascar is a country, having an area of about 590,000km². Geologically, two third of the land consist of the Precambrian igneous and metamorphic rocks, and one third is the post-Carboniferous sedimentary and igneous rocks, respectively. Although Madagascar is rich in mineral resources of various kinds, they have been poorly developed due to poorly maintained infrastructure and to lack of capital. The mineral resources which are worked now are chromite, phlogopite, graphite and precious stones (ruby, garnet, beryl, etc.). In addition, ore showings of iron, coal, uranothorianite, nickel, bauxite, ilmenite, niobium, tantalum, gold, copper, lead, zinc, etc. are known. During and after the period when the country was governed by France, geological survey and exploration have been done. The Andriamena chromite deposit, Soalala iron deposit, Manantenina bauxite deposit, etc. have been discovered through the exploration done by the Direction of Mines and Geology (DMG).

This exploration for the mineral resources, being put into effect by the Japanese Government in response to the request of the Government of the Democratic Republic of Madagascar, has been practiced based on the Scope of Work concluded dated June 19, 1991.

The purpose of the survey is to clarify the ore-forming conditions through making clear the geological environment. Therefore, in this year, we have collected and analyzed the resources-related data obtainable in Japan. Using the results, we have analyzed the satellite images, resulting in the understanding of the regional geologic structure and mineralization throughout the survey area.

1-2 Survey area and outline of works of the first year

1-2-1 Survey area

The survey area, as shown in Fig. 1, is situated between 23° 27′ S Lat. and 25° 22′ S Lat., the southern area of the Madagascar Island, covering about 66,300km².

1-2-2 Existing data compilation

Collecting the data related to the geology and ore deposits in this area, we have compiled the geological maps and location maps of mineral deposits and showings available. Also, we have summarized the geological units, ore deposits and showings found in the survey area.

1-2-3 Satellite image analyses

Taking into consideration of clouds, we have obtained the six scenes, the best suitable for analysis, of the LANDSAT images which cover the survey area, in the form of CCT. Processing the CCT with SUN SYSTEM, we have made the false color images. The photogeological interpretation of the images has led to the interpretation maps.

1-3 Term of the survey and organization of the survey team

1-3-1 Term of the survey

Item	1991						1992		
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Making survey plan	26	2							
Satellite image analyses		3				31			
Compilation of existing data		3				31			
Making report					6			20	

1-3-2 Survey team

The survey team participated in the planning, negotiation and survey of the first year of this project is as follows:

Survey planning and negotiation

Member Japanese delegation

Yoichi YAMAGUCHI,	Executive Director, MMAJ
Kyoichi KOYAMA,	MMAJ
Hiroshi ASAHI,	Ministry of International Trade and Industry
Norio NAKANO,	Ministry of Foreign Affairs
Haruhisa MOROZUMI,	MMAJ
Nobuyuki OKAMOTO,	JICA
Takahisa YAMAMOTO,	MMAJ Nairobi

Member Malagasy delegation

Dauphin ANDRIAMBOLOLONA,	Directeur des Mines et de la Géologie, MIEM
Jeannot RASOANAIVO,	Chef du Service de la Géologie, DMG/MIEM
Arvilson FITAHINTSOA,	Chef du Service des Projets Miniers, DMG/MIEM
Ranaivoarivelo ANDRIAMANANANTENA,	Ingénieur Géologue, DMG/MIEM
Vololona RAKOTONOMENJANAHARY,	Ingénieur Géologue, DMG/MIEM

Survey team

Katsuji FUKUMOTO,	Chief engineer, summarization of survey, analyses of existing data	MINDECO
Itoshi KOHNO,	Satellite image analyses, analyses of existing data	MINDECO
Kiyohisa SHIBATA,	Analyses of existing data	MINDECO
Koji YASHIRO,	Satellite image analyses	MINDECO
Kazuhiro ADACHI,	Satellite image analyses	MINDECO
Haruo HARADA,	Analyses of existing data	MINDECO

CHAPTER 2 GEOGRAPHY OF THE SURVEY AREA

2-1 Location and transportation

The Democratic Republic of Madagascar is an island country on the Indian Ocean, which is located 350km east of the eastern coast of Africa through the Mozambique Strait. It measures 1,580km in N-S length, 560km in maximum width and about 590,000km² in area, corresponding to about 1.6 times that of Japan. The country is located between 12° S Lat. and 26° S Lat. and belongs to the tropical zone extending over the Tropic of Capricorn. The survey area, occupying its southern part, lies between 23° 27′ S Lat. and 25° 22′ S Lat.

Except Fridays, they have seven flights per week from Toliara northwest of the survey area to the capital, Anatananarivo. They have four flights per week from Tolañaro southeast of the area to the capital except Mondays, Wednesdays and Saturdays. They have one or two flights per week from Toliara to Tolañaro and among Toliara, Ampanihy and Bekily. In the eastern mountainous district, the road is badly developed, while in other areas, they have roads connecting the main cities. From Toliara to Andranovory 80km northeast and from Tolañaro to Sakaraha 110km west roads are paved, while paved roads are not available in other areas.

2-2 Topography and drainage system

In the Madagascar Island, an elevation decreases from the eastern coast area forming a mountainous district, through the central highland, toward the western lowland. The southern part of the island is also similar in topography with the mountain range of about 2,000m above sea level in the eastern coast. The mountainous district, about 100km wide, ranges north and south along the eastern coast. Except the district, the survey area has generally a gentle topography with less undulation.

Rivers run to the east in the eastern side of the mountainous district, while they flow to the west or south in the gentle hilly district of its western side.

2-3 Climate and vegetation

According to the geographical location, topography, effects of ocean and wind direction, climatic seasons of the island are divided into two. April to October correspond to winter season. During the season, due to the southeast trade wind, wet and cold wind blows to the eastern coast, while it is dry in the western part beyond the central highland. December to March correspond to hot summer season and rainy one. Throughout the eastern coast, annual rainfall amounts to 2,000 to 3,600mm, because rain originated from the trade wind or monsoon is shut out by the mountainous district. In the central highland and the northern half of the western coast, and in the southwestern and the southernmost parts, it amounts to 500 to 2,000mm and less than 400mm, respectively, showing the variation from the tropical rainy climate to the tropical semi-arid climate. In the eastern mountainous district, annual precipitation is abundant, resulting in the wide tropical rain forest zone. However, it is small in amount in the hilly district covered by thickly growing thorny shrubs and grassland. Along the river trees grow thick.

CHAPTER 3 AVAILABLE GEOLOGIC INFORMATION ABOUT THE SURVEY AREA

3-1 Outline of existing data

A list of literatures referred to the survey of this year is shown at the end of this report. Their main contents are outlined below.

Geologic structure: The geologic structure is relatively well studied in the Madagascar Island. In particular, studies by H. BESAIRIE and others for many years are important. Their results are compiled in `Geology of Africa' by R. FURON (1963) and in `Géologie de Madagascar' by H. BESAIRIE and M. COLLIGNON (1972).

Geological mapping in this area had been carried out by H. BESAIRIE, J. AUROUZE, J. BOULANGER, G. NOIZET and others from 1920's to 1960's as maps at a scale of 1:100,000 and their explanations. Compiling these results, H. BESAIRIE published the geological maps at a scale of 1:1,000,000 in 1964 and the geological maps at a scale of 1:500,000 in 1970.

Ore deposits: As to the ore deposits throughout Madagascar, there have been the reports on each mineral by J. BEHIER (1960) and H. BESAIRIE (1966). The ore deposits and showings in the survey area are described in the geological maps at a scale of 1:100,000 and their explanations. In 1956, H. BESAIRIE compiled the Carte Miniere et des Indices (1:500,000) in which these ore deposits and showings are shown. The mines in this area were all closed in 1960's. Recently, graphite, phlogopite and garnet have been mined on a small scale by private owners. Therefore, summary report for the ore deposits is unavailable. The Overseas Technical Cooperation Agency of Japan sent a survey team in 1964 in order to carry out a survey of mineral resources throughout the Madagascar Island. In 1974, Metal Mining Agency of Japan made a geological structure survey for chromite resources in the Andriamea area located in the north of the capital, Antananarivo being out of the survey area.

3-2 Outline of geology and ore deposits in the southern Madagascar

The southern part of the Madagascar Island consists of the Precambrian basement and the Permian to Quaternary formations (cf. Fig. 2, PL.3-1-1～PL.3-1-12). These formations are distributed almost parallel to the elongation (N-S) of the island, and show an unsymmetrical structure, with their wide distribution in the western part, while with their narrow distribution along the eastern coast.

The Precambrian rocks crop out on the inland central highland, where most of various ore deposits occur. The Precambrian rocks are divided into the followings from young to old, among which the Marbles System and the Schists-Quartzites Series do not crop out on the survey area:

Pegmatite
Granite, charnockite, syenite
Schists-Quartzites Series
Marbles System
.... unconformity ....
Vohibory System
Graphite System
Androyen System

The Permian to Quaternary formations are distributed mainly in the western part of the island, becoming young from east to west. They consists of the following systems in a descending order:

Quaternary	System	
Tertiary	System	
Cretaceous	System	
Jurassic	System	
Karroo (Permian to Jurassic)	System	Isalo Group Sakamena Group Sakoa Group

In the survey area, distributed are the ore deposits and showings of black sand (monazite, ilmenite, rutile, zircon), graphite, phlogopite, precious stones (garnet, corundum, beryl, etc.), uranothorianite, gold, silver, copper, zinc, iron, chromium, kaolin, bauxite and so on (cf. PL. 3-2-1~PL. 3-2-4). Of these, uranothorianite, phlogopite, gold, silver, copper and zinc deposits were previously mined. However, most of the ore deposits and showings have been poorly explored, resulting in their poor development. Now only phlogopite and precious stones are worked on a small scale. Relationship between the formations and the ore deposits in the survey area is shown in Tab. 3-1.

3-3 Geology of the survey area

(1) Precambrian rocks

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

1) Androyen System

This system is distributed from the eastern coast to the most part of the central highland, and is composed of gneiss, leptinite and pyroxenite with some marble, quartzite and charnockite. The system is divided into the three groups in

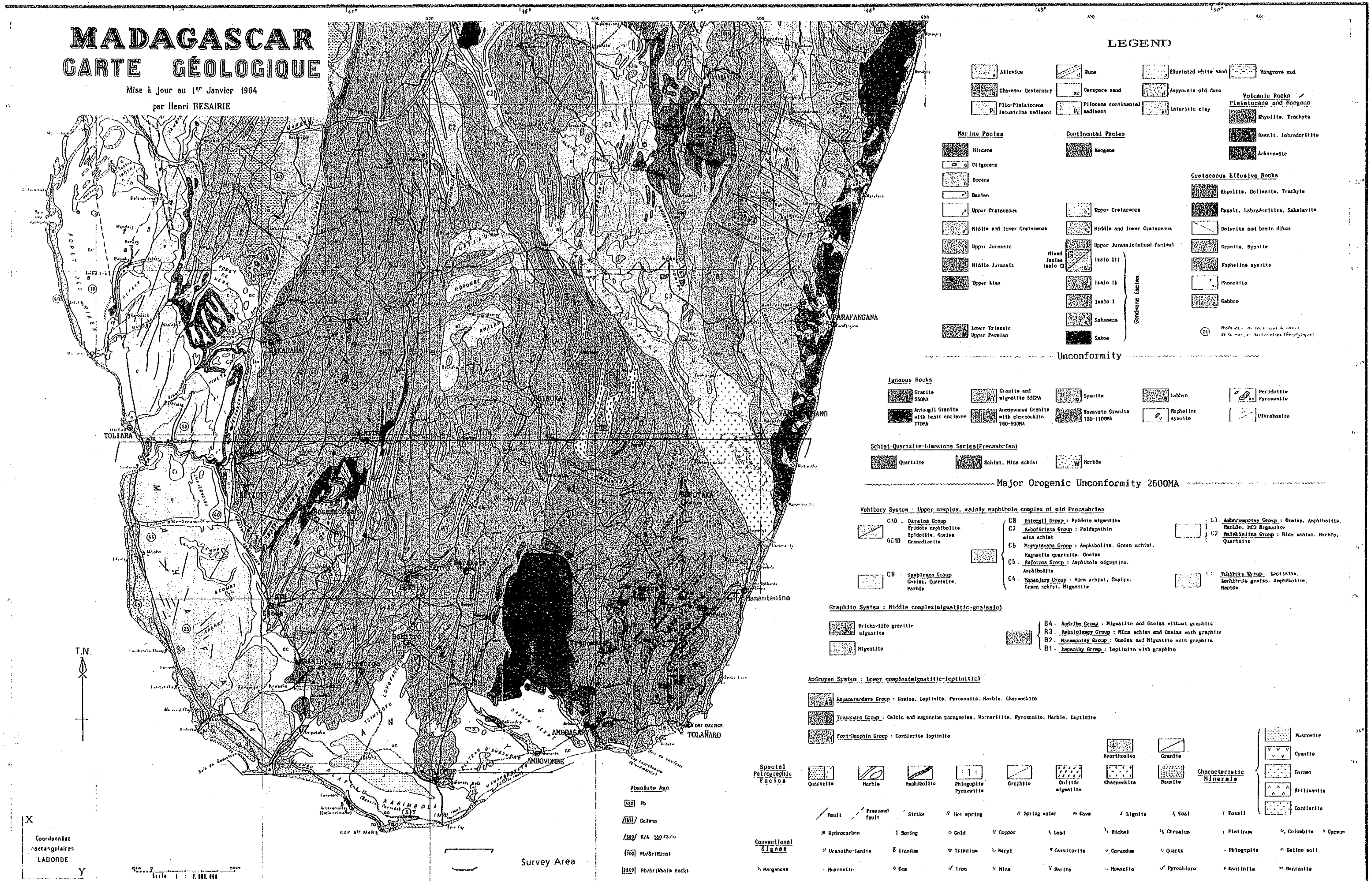


Fig. 2 Geological Map of the southern area of Democratic Republic of Madagascar

Tab. 3-1 Relations between formations and ore deposits

Formation		Important rocks	Ore deposits
Neogene-Holocene		Muddy sand, Mudstone, Sandstone	Placer (Monazite, Ilmenite, Zircon) Kaoline, Lignite, Bituminous shale
Paleogene		Limestone, Marl	Limestone
Cretaceous	Igneous Rocks	Sandstone, Marl / Basalt, Rhyolite	
Jurassic		Limestone, Marl	Limestone
Karroo System (Permian-Jurassic)	Isalo Group	Shale, Sandstone	Bituminous sand
	Sakamena Group	Shale, Marl	
	Sakoa Group	Limestone, Sandstone, Shale, Tillite	Coal
Precambrian	Granite, Pegmatite	Granite, Charnockite, Syenite, Pegmatite	Quartz, Beryl, Garnet, Columbite-Tantalite
Precambrian	Vohibory System	Gneiss, Leptinite, Amphibolite	Ni, Chromite, Fe, Barite, Asbestos, Chrysotile, Cu, Zn, Au
	Graphite System	Leptinite, Mica schist, Migmatite	Graphite, Fe, Bauxite, Garnet
	Androyen System	Gneiss, Leptinite, Pyroxenite	Uranothorianite, Uraninite, Phlogopite, Bauxite, Cassiterite

an ascending order; the Fort-Dauphin Group, the Tranomaro Group and the Ampandrandava Group, being arranged from east to west. Ore deposits of uranothorianite, uraninite, phlogopite and cassiterite occur in this system.

2) Graphite System

This system, though most widely distributed on the Madagascar Island, shows only a limited distribution in the area. In the central-southern part of the area, the Ampanihy Group made of graphite-bearing leptinite occur, while migmatite and the Ambatolampy Group made of mica schist occur in the northeastern part of the area. Where graphite- or granet-bearing beds have been lateritized, they are worked as graphite mine or as garnet mine. In part, banded iron formations (magnetite-bearing quartzite) occur. In addition, there are bauxite deposits in some places.

3) Vohibory System

This system is distributed from Ejeda to Soamanonga in the Vohibory area. In the area, the Vohibory Group composed mainly of leptinite, gneiss and amphibolite with marble is exposed and is characterized by amphibolite originated from basic igneous rocks and intrusives. Chromite and nickel deposits occur in association with basic igneous rocks. In spite of the presence of copper and zinc deposits, minable deposits have not been discovered. In places, quartz veins occur, sometimes containing gold and silver. In part, banded iron formations occur, but they are not minable because of low grade or small size. In addition, iron-oxide crust is formed on the exposed surface of basic rocks.

4) Granite and pegmatite

Intruding the Precambrian rocks described above, granite, charnockite, syenite and pegmatite occur as sheets in the Precambrian schist and gneiss. The radiometric ages of these intrusives from different parts of the island range from 550 Ma to 485 Ma, indicating intrusions of Cambrian to early Ordovician age.

These ages are consistent with that of thorianite mineralization (485Ma: R.FURON, 1963). Quartz, beryl, garnet, columbite-tantalite etc. occur in these rocks.

(1) Karroo System

The Permian to Jurassic sediments on the Madagascar Island are called the Karroo System (The Madagascar Karroo) based upon their similarities to those of the Karroo System in South Africa. This System, though mainly composed of continental formations, is divided into the three groups by unconformity and intercalation of marine beds and becomes young westward. In the northern part, the continental facies shows a gradual change to marine facies which corresponds to the stratigraphically upper part.

1) Sakoa Group (Lower Permian)

This group crops out over a distance of 100km in the Soamanonga district and its surroundings (Vohibory district). The following horizons are distinguished, from bottom to top:

① Tillite

This consists of black shale and conglomerate with thickness of 150m. The black shale contains plant fossils such as calamites (Schizoneura).

② Coal Beds

They consist of sandstone, shale and coal seam, yielding plant fossils of pteridophytes and calamites. The coal measure is about 100m thick. Although its total reserves are estimated to be more than 1,000mil.tons, the minable reserves are reported to be 50～60mil.tons.

③ Lower Red Series

This series, 500 to 600m thick, consists of feldspathic sandstone, silicified wood-bearing red shale and the uppermost conglomerate.

④ Vohitolia Marine Beds

They are made of brachiopods-bearing limestone and overlie the red sandstone at Vohitolia located about 10km northwest of Soamanonga.

2) Sakamena Group (Upper Permian～Lower Triassic)

This group, overlying unconformably the Sakoa Group, is distributed in the Vohibory district. It is mainly of continental facies, changing to marine facies northward. Three horizons are distinguished from bottom to top as follows:

① Glossopteris Shales

This strata consist of the lower conglomerate and upper shale with thin intercalations of bivalves-bearing marine bed. The shale yields plant fossils such as pteridophytes (Glossopteris, Pecopteris), cycadales and conifers (Voltzia).

② Reptile Beds

This strata yield fauna of reptiles and amphibians, indicating the end of Permian Period and the beginning of Triassic Period.

③ The Lower Triassic Series (Middle～Upper Sakamena Group)

The Middle Sakamena Group consists of mudstone and marl and yields fauna of fishes, ammonites, and amphibians (frogs, etc.) with the uppermost part composed of shale and sandstone.

3) Isalo Group (Upper Triassic~Middle Jurassic Bajocian Stage)

Unconformable on the underlying formations, this group begins with the basal conglomerate and is distributed from Betioky to Sakaraha. It is divided into the following three units from bottom to top:

① Isalo I (Upper Triassic)
This series, locally up to 500m thick, consists of soft unfossiliferous sandstone and conglomerate with well-developed cross bedding.

② Isalo II (Lower Jurassic Lias Series)
This series consists of continental red sandstone and red to variously colored shale, several hundreds to 1,000m thick, with well-developed cross bedding. This formation yields silicified woods, fishes and reptiles. Toward north, it gradually changes into marine limestone and marl, yielding brachiopods, ammonites and bivalves.

③ Isalo III (Middle Jurassic Bajocian Stage~Bathonian Stage)
This series, though not exposed in the survey area, consists of dinosaurs-yielding alternation of sandstone and shale and marine sandstone and shale.

(3) Middle Jurassic Bathonian Stage

This stage is distributed in the northwest of Betioky. The Lower and Middle Bathonian Stage consists of calcareous algae-yielding reef limestone and bivalves-yielding limestone. In part, it yields crocodile fossils, indicating a sedimentary facies of brackish water environment. The Upper Bathonian Stage consists of marine marl and limestone which are characterized by the abundant fauna such as ammonites, brachiopods and echinoids.

(4) Upper Jurassic Series

This series is distributed in the northwest of Betioky, overlying the Bathonian Stage. The Upper Jurassic Series exposed in the area is divided into the following three stages, from bottom to top:

① Callovian Stage
This stage consists of marl and marly limestone which yield ammonites and belemnites.

② Oxfordian Stage
This stage consists of ammonites-yielding calcareous marl and marl.

③ Argovian Stage

This stage consists of belemnites-yielding limestone and marl with some intercalation of sandstone with cross bedding.

(5) Cretaceous System

The Cretaceous System is distributed in the northwest of Betioky, unconformably overlying the Middle Jurassic or Upper Jurassic Series.

1) Lower Cretaceous Series

① Valanginian Stage

This stage consists of ammonites-and belemnites-yielding glauconite marl. These fossils belong to the Mediterranean fauna.

② Hauterivian Stage

This stage consists of belemnites-yielding marl and glauconite sandstone.

③ Barremian Stage

This stage consists of beds which yield belemnites, etc.

2) Middle Cretaceous System

① Aptian Stage

This stage consists of an alternation of red shale and sandstone, and of ammonites-yielding limestone.

② Albian Stage

This stage consists of ammonites-yielding red sandstones.

③ Cenomanian Stage

This stage consists of ammonites-yielding marl and red muddy sandstone.

④ Turonian Stage

This stage consists of ammonites-yielding yellow sandstones accompanying basalt lava.

3) Upper Cretaceous System

① Coniacian Stage

This stage consists of green sandstone which yields ammonites and bivalves (Inoceramus, etc.) and basalt lava.

② Santonian Stage

This stage consists of continental sandstone with well-developed cross bedding and basalt lava. This stage is generally of regressive time.

③ Campanian to Maestrichtian Stage

The Lower Campanian is also regressive like the Santonian. This is mainly of several basalt lava flows which are black, compact, and contain augite phenocryst with rare olivine. They are distributed from Betioky to Sakaraha in the west, and accompanied with rhyolites in western Tranomaro in the southeastern part of this area and along eastern coast. In western Tranomaro, the basalts and rhyolites form an elliptical composite intrusive mass, measuring about 70 km in N-S and about 45 km in E-W.

Overlying the basalts, occur limestone, marl and calcareous sandstone, corresponding to the Upper Campanian to Maestrichtian Stage. They yield fauna such as ammonites, bivalves, echinoids, etc.

(6) Tertiary System

Marine and non-marine formations of Eocene to Pliocene are distributed along the western coast, forming a belt 30 to 60km wide.

1) Eocene Series

The Eocene Series is the most wide-spread among the Tertiary System. It is composed of limestone and marl which yield echinoids, bivalves (oyster, etc.) and calcareous algae (Lithothamnium).

2) Miocene Series

It is distributed locally in the south of Toliara of the western coast and yields echinoids and bivalves (oyster, etc.).

3) Pliocene Series

It is distributed locally in the eastern Sakaraha, northwestern Ejeda, western Ampanihy and around Amboasary, and consists of continental mudstone and sandstone. Besides, dikes of basalt and rhyolite, possibly of Pliocene to Pleistocene age are found in the survey area.

(7) Quaternary System

It consists of sand-dune sediments, red sand, carapace sand, white sand, mangrove sediments, alluvium, etc. Numerous placer of black sand in which monazite, ilmenite, rutile and zircon are included, occur in the sand-dune sediments and in the present littoral sediments along the eastern coast.

3-4 Ore deposits of the survey area and brief history of mining

Although ore deposits and showings of various kinds have been discovered in Madagascar, only a few of them have been exploited as a mine. This is because they are of a small-scale possibly due to poor exploration and also sufficient ore reserves are not confirmed.

Mineral resources mined at present are mainly chromite, phlogopite, graphite and precious stones. In addition, ore showings 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, USSR, UK, etc.

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

Tolañaro (Port-Dauphin) district: A number of deposits of black sand 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 from a peneplain composed of gneiss and leptinite of the Precambrian Androyen System down to their mouth and deposited there and furthermore concentrated by the coastal current. The Antete deposit and the Vohibarika deposit are located 25km southwest and 100km north of Tolañaro, respectively. Other small-scale deposits are ubiquitous. In the district, 1,750t of monazite was produced from 1959 to 1963 by the SOTRASSUM, French Pechiney-CEA (Commissariat á l'Energie Atomique) joint venture. After 1965, however, no production has been made. Proved reserves of black sand at 1970 in the district amount to 2.7 mil. tons. Grade of crude ores from 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 sand around Tolañaro is scheduled to be started at 1992 by the OMNIS-Canadian QIT (Quebec Iron & Titanium) joint venture. Bauxite deposit (120 mil. tons with average grade of 30% Al2O3) occurs at Manantenina located about 120km north of Tolañaro.

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, etc. by CEA from 1954 to 1964. Uranothorianite is distributed within a district measuring about 60km in N-S and about 20km in E-W along the Manamboro river. The ore deposits occur as lenticular or pipe-like bodies within pyroxenite of the Androyen System consisting of pyroxenite, charnockite and marble. It is said that uranothorianite ores with U grade higher than 12% were mined and the main deposits were almost mined out.

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 composed of gneiss and leptinite.

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

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 consisting mainly of gneiss and leptinite. 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.

Soamanonga district (Vohibory district): Ore showings of gold, silver, copper, zinc and manganese have been known. They were mined at the Besakoa mine, etc. in the colonial time. Copper mineralization in this district is recognized as disseminated bornite 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 Permian to Jurassic Karroo System (Bevalaha deposit). The Sakoa Group of the Karroo System in the district contains coal seams, which are now explored by the British BB-C Coal Co. in Ankinany along the Sakoa river. There occur iron-bearing sandstones with average thickness of 30cm in southern Betioky situated to the west of this district. They are limonite- and hematite-bearing sandstones for cement. According to BRGM (Bureau de Recherches Géologiques et Miniéres, 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 H. BESAIRIE (1966), possible reserves are estimated to be: 130 mil.tons (10~14% Fe) or 30 mil.tons (24% Fe).

CHAPTER 4 INTERPRETATION OF SATELLITE IMAGES

4-1 Data and interpretation method

Image data used for this interpretation are listed in Tab. 4-1. Position of each data is shown in Fig. 4-2 and PL. 4-1 along with interpretation maps.

We have obtained the TM data of six scenes in the form of CCT. Throughout the scenes, cloud cover under the full scene is less than 20 %, but in the Path 158/Row 76, about 80 % of the land area is covered with clouds.

From the data obtained, the bands 2, 3 and 4 are displayed as blue, green and red, respectively. Then, with a linear stretch and edge enhancement process, false color images at a scale of 1:200,000, being suitable for the TM resolution (30m), are made and interpreted. In Fig. 4-1, mosaic image of the survey area is shown.

Aiming at tone and texture on the images, we have made a photogeological interpretation. During the interpretation, we have used mainly the H.BESAIRIE (1970) `Carte géologique, Feuille Ampanihy No.8 au 1/500,000' as a reference data. The interpreted result on each scene compiled at a scale of 1:500,000 are shown in PL. 4-1. Also, the interpreted results at a scale of 1:1,000,000 are shown in Fig. 4-2 and the units of interpretation are listed in Tab. 4-2.

4-2 Interpretation of photogeological units

In the following, we describe the characteristics of each photogeological unit and correlations with the geological map at a scale of 1:1,000,000 by H.BESAIRIE (1964).

(1) Unit PCa

This unit, being pale brownish on the false color images, is distributed in the northeastern part of the survey area, forming mountain ranges with steep peaks. Its erosion resistance is high. On the geological map, this unit is correlated with the cordierite zone of the Precambrian metamorphic rocks.

(2) Unit PCb

This unit, being yellow ocher on the images and hard, is distributed near the Unit PCa in the northeastern 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 and shows bluish green or white tone on the images. Since mountain range and valley appear alternately, this area is inferred to be mainly of rhythmic alternation of soft and hard rocks. Recognition of complicated fold structure shown by schistosity and stratification leads to an interpretation that they have been subjected to an in tense deformation. 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 mainly 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 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 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 stratification is obscure, it is considered to be 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 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 structure, forming a well-continued U-shaped valley. On the geological map, this unit is correlated with the Cretaceous basalts.

(11) Unit Kv6

This unit, being bluish green on the images and soft, forms a ring 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 stratification. 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 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 is carbonate rock-dominant formation, 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. Its erosion resistance is somewhat high. The presence of a stratification and hollows considered to be sinkholes leads to an interpretation that this unit consists of carbonate rock-dominant formations, 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 up-and-down, 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 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 mainly of soft sedimentary rocks. On the geological map, this unit is correlated with the Carapace sand bed.

(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 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 is mainly 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 an isolated hilly landform. 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 eye-shaped mass in the folded belt in the center of the area. It is somewhat hard, forming an isolated 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.

4-3 Structure

The major geologic structures interpreted on the satellite images are mentioned below.

The interpretation units PCa to J5 have the general strike of N-S to NNE-SSW and younger formations are distributed from east to west. Complicated fold 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 recognized between the units PCc and J1 and between the units K and Tc.

An elliptical composite intrusive body, measuring about 70 km in N-S and about 45 km in E-W, is distributed in the east-central part of the survey area. Encircling the northern to northeastern margin of the intrusive body, a distinct collapse structure is recognized. According to the existing geological map, the intrusive body was formed by a successive intrusion of basic and acidic magmas 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, a well-continued fault parallel to the coast line is recognized and the units lying west of the fault are inferred to have downthrown relatively.

Tab. 4-1 LANDSAT data for geological interpretation

	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

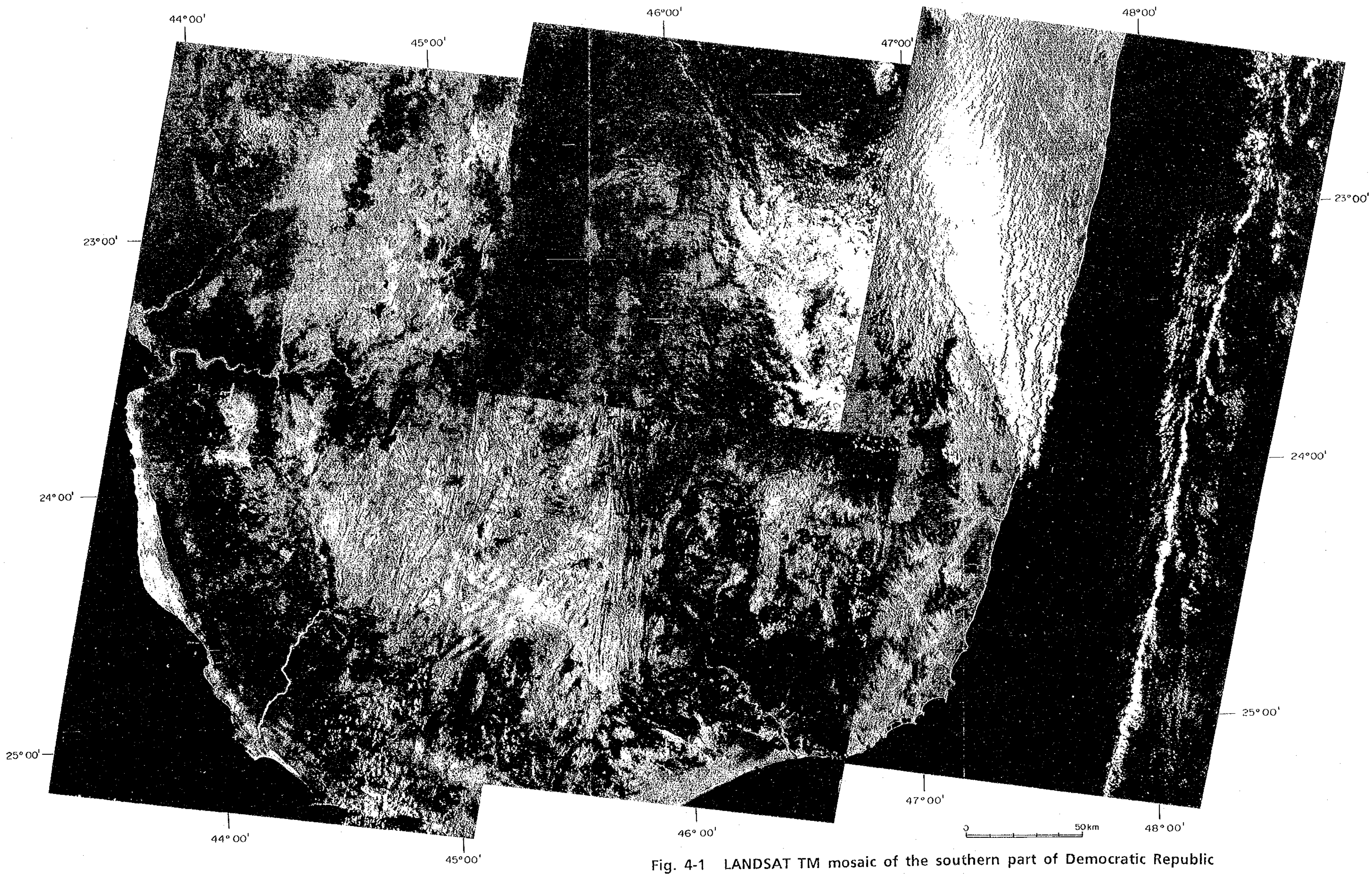


Fig. 4-1 LANDSAT TM mosaic of the southern part of Democratic Republic of Madagascar

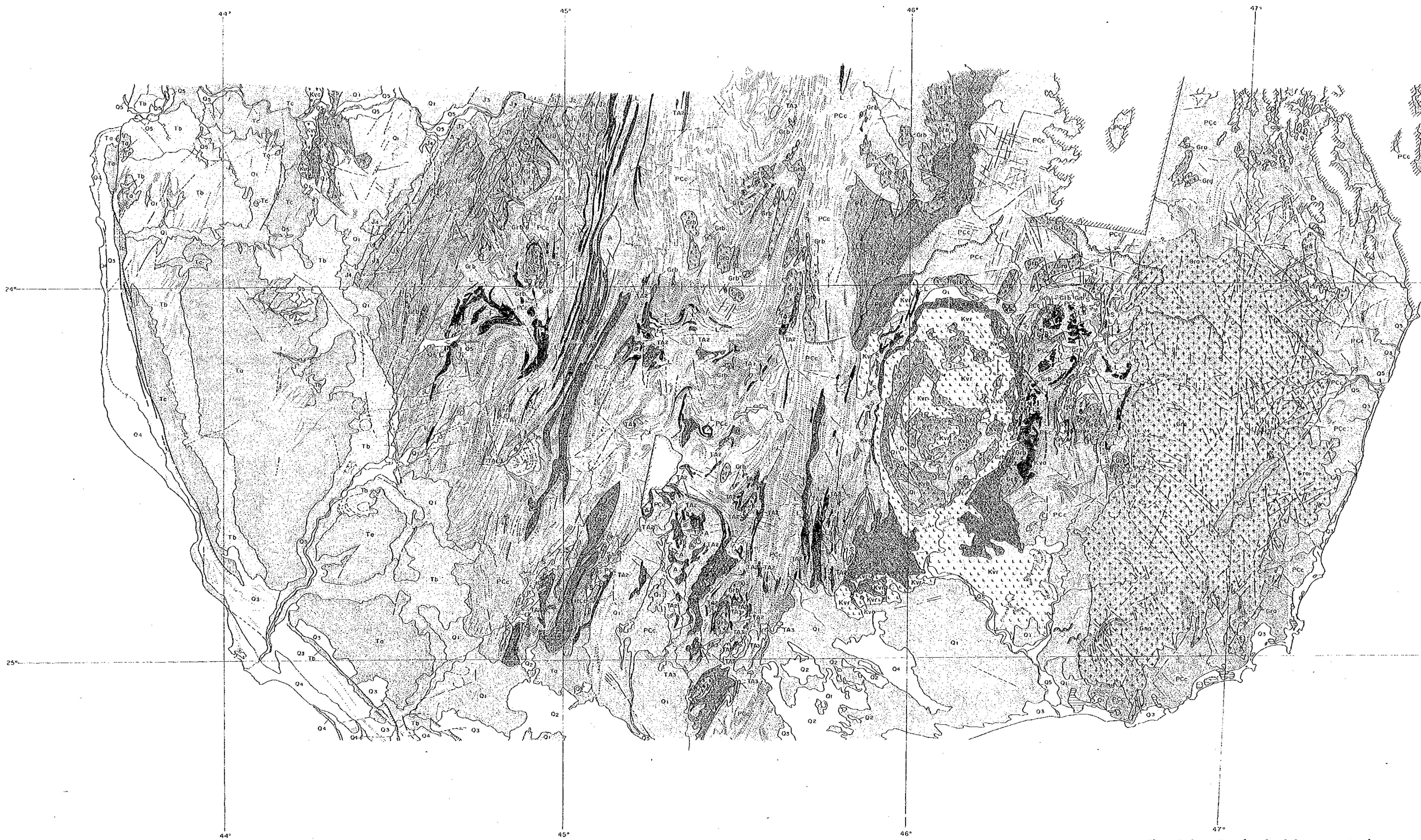
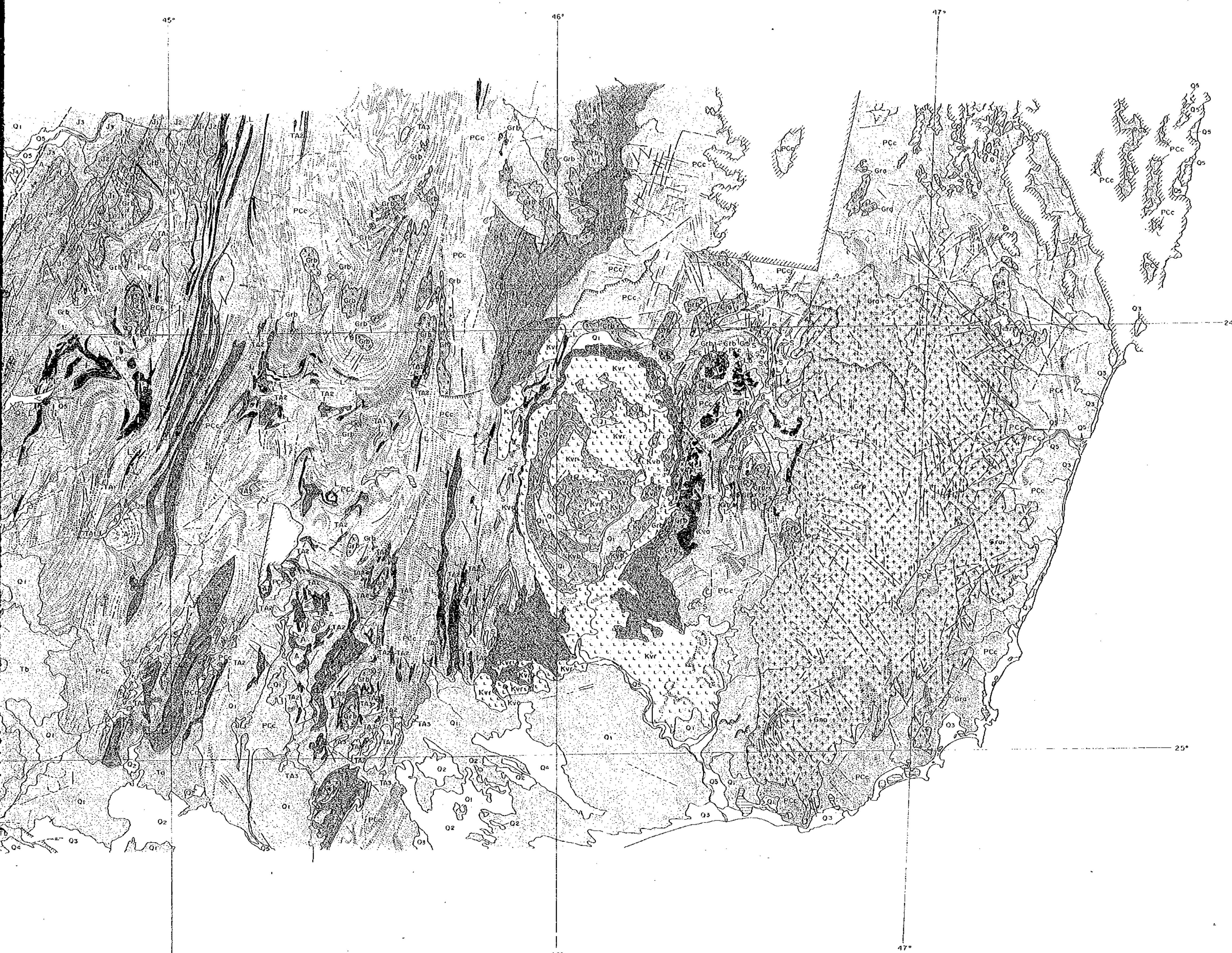
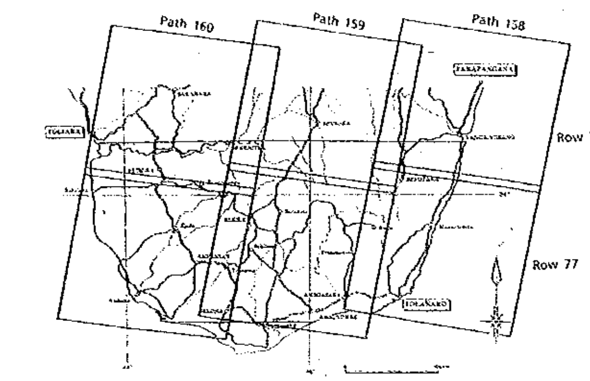


Fig. 4-2 Geological interpretation map



PL. 4-1

THE MINERAL EXPLORATION
IN
THE SOUTHERN AREA,
DEMOCRATIC REPUBLIC OF MADAGASCAR
(PHASE I)
GEOLOGICAL INTERPRETATION MAP OF
LANDSAT TM FALSE COLOR IMAGERY



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1992

Scale 1:1,000,000

LEGEND

Interpreted units	Correlation with geologic map and rock types
Q5	alluvium
Q4	dune, alluvium
Q3	Aepyornis old dune
Q2	eluviated white sand
Q1	Carapace sand
Ta	Eocene marine facies
Tb	Eocene marine facies, Carapace sand
Tc	Eocene marine facies, Clavator Quaternary
Kr	Cretaceous (rhyolite, dellenite, trachyte)
Kb	Cretaceous (basalt, labradorite, sakalavite)
Kl	
Kv	
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
Grb	granite, migmatite
A	anorthosite
[illegible]	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. 4-2 Geological interpretation map of LANDSAT TM false color imagery

Tab. 4-2 Geological units of interpretation map

	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	blueish green, white patch	dark	coarse	moderate to high	plain, mesa	horizontal to gentle	spotted, sinkhole	Eocene marine facies, Carapace sand
8	Tc	dark blueish 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	Kva	blueish green	moderate to dark	fine	low	U-shaped valley	thin layered	ring structure	Cretaceous (basalt, labradoritite, sakalavite)
11	Kvb	blueish green	moderate to dark	fine	low	U-shaped valley	thick layered	ring structure	
12	Kvc	deep green	dark	rough	moderate	hilly	massive	none	
13	K	blueish 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	Lower Permian to Lower Triassic continental facies
16	J3	greysh green	moderate to light	fine	high	assymmetric ridge	well-bedded	banded	
17	J2	deep green	moderate to dark	fine	low	hogback	well-bedded	banded	
18	J1	deep geen	dark	medium to coarse	moderate	cuesta	well-bedded	banded	
19	PCa	pale brown	light	medium to coarse	high	V-shaped ridge	well-bedded	foliation	Precambrian metamorphic rocks
20	PCb	yellowish brown	light	rough	moderate to high	mountainous	thick	foliation	
21	PCc	blueish 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, blueish white	very light	smooth	moderate to high	blocky and hilly	none	centripetal	anorthosite
25	L	blueish 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	tonal anomaly
28	TA2	blueish green	dark	fine	moderate to low	elongated depression	thin layered	banded	tonal anomaly
29	TA3	pinkish white	light	coarse	moderate to low	hilly	none	lineation	tonal anomaly

CHAPTER 5 CONCLUSIONS AND PROPOSALS

5-1 Conclusions

The purpose of the survey is to clarify the ore-forming conditions through making clear the geological environment. Prior to the field survey scheduled on the second year, we have carried out compilation of the existing data available in Japan and LANDSAT TM image analyses of the area covering about 66,300km² between 23° 25′ S and 25° 17′ S in the Madagascar Island.

The analyzed results are as follows:

(1) Compilation of available data

Geology of the southern area of the Madagascar Island consists of the Precambrian basement and the Permian to Quaternary formations covering the former. These formations are distributed almost parallel to the elongation (N-S) of the island, and show an unsymmetrical structure, with their wide distribution in the western part, while with their narrow distribution along the eastern coast. The Precambrian rocks forms the inland central highland, where most of various ore deposits occur.

In the survey area, distributed are the ore deposits and showings of black sand (monazite, ilmenite, rutile, zircon), graphite, phlogopite, precious stones (garnet, corundum, beryl, etc.), uranothorianite, gold, silver, copper, zinc, iron, chromium, kaolin, bauxite and so on. Of these, uranothorianite, phlogopite, gold, silver, copper and zinc deposits were mined previously. However, most of the ore deposits and showings have been poorly explored, resulting in their poor development. Only phlogopite and precious stones are worked on a small scale.

The ore deposits and showings of each district are summarized as follows:

Tolanaro (Fort-Dauphin) district: A number of deposits of black sand 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. Bauxite deposit occurs at Manantenina.

Tranomaro district: Ore deposits and showings of precious stones (corundum), phlogopite, uranothorianite, cassiterite, etc. are known.

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 composed of gneiss and leptinite.

Ampanihy district: Although ore showings such as precious stones (ruby, garnet, etc.), graphite, phlogopite, ilmenite, copper, manganese, etc. have been known. Only the precious stones are mined now.

Northern Beraketa district: Ore deposits and showings of phlogopite have been known. Phlogopite deposits were mined at the Marovala, Ampandramdava, Ambararata and other mines from the beginning of 1900's to about 1940. In addition to the phlogopite deposits, ore showings of graphite, uranothorianite and beryl are distributed in this district.

Soamanonga district (Vohibory district): Ore showings of gold, silver, copper, zinc and manganese were known. They were mined at the Besakoa mine, etc. in the colonial times. The Sakoa Group of the Karroo System in the district contains coal seams.

(2) LANDSAT TM image interpretation

Six false color images are made from CCT data, with a linear stretch and edge enhancement process, and the bands 2, 3 and 4 are displayed as blue, green and red, respectively. We divide the area into 29 geological units as a result of photo geological interpretation. There exists an elliptical composite intrusive body, measuring about 70 km in N-S and about 45 Km in E-W, in the east-central part of the survey area. Encircling the northern to northeastern margin of the intrusive body, a distinct collapse structure is recognized. Such a large-scale magmatism may be related to mineralization.

5-2 Proposals to the second year survey

The data analyses of this year found that most of the ore deposits and showings have been poorly explored, resulting in their poor development, though mineralizations of various kinds have been discovered in the area and the potentiality of mineral resources is high. To clarify the ore-forming conditions through making clear the geological environment, we propose the following surveys as the second year project:

(1) Satellite image analyses

There is a lot of tonal anomalies in the TM images of this area, a part of which seems to be alteration zones related to the igneous activity. There exist an elliptical composite intrusive body and a distinct collapse structure which suggests an existence of the structure-controlled ore deposits. The optical sensor data and synthetic aperture radar data of the Japanese Earth Resources Satellite (FUYOU-1) launched on February 11th of this year is useful to analyze and interpret such geological settings. We can expect the effective analyses through combining FUYOU-1 data with TM and SPOT data.

(2) Existing data analyses

We analyzed the data available in Japan this year. There should be a lot of data in the Direction of Mines and Geology of Madagascar which we could not obtain. We can compile such new data and combine them with the result of this year to make them use to satellite image interpretation and the field survey of the second year project.

(3) Geological and geochemical survey

Confirming the information in the field acquired by the TM image interpretation and compilation of available data in Japan, we clarify the relation between geological settings and mineralizations and to extract the promising districts for mineral resources. Interesting districts for field survey are Tolañaro (Fort-Dauphin), Tranomaro, Bekitro, Ampanihy, northern Beraketa and Soamanonga (Vohibory). In the Tranomaro district, we make an investigation for the presence of mineralization accompanied with an elliptical composite intrusive body of Cretaceous age and a collapse structure in addition to confirm the existing of ore deposits and showings.

REFERENCES

ALLARD, M., AUBERT, J. -M. et LACOSTE, Ph. (1970) Géologie de Madagascar. l'Ecole, Paris, 89P.

AUROUZE, J. (1953) Etude géologique des feuilles Fotadrevo-Bekily, au 1/100.000. Travaux du Bureau Géologique, numéro 42, Service Géologique, Tananarive, 44P.

BAZOT G., RAZAFIMANANTSOA et RAMANITRIRAISANA C. (1978) Carte géologique de feuille Sainte Luce. La coordination a ete effectuee par G. BAZOT. Service Géologique de Madagasikara, Tananarive.

BEHIER, J. (1960) Contribution a la minéralogie de Madagascar. Ann. Géol. Madag., XXIX, 78P.

BESAIRIE, H. (1964) Madagascar, feuille du Sud, carte géologique, au 1/1.000.000. Service Géologique de Madagascar, Tananarive.

BESAIRIE, H. (1966) Gites minéraux de Madagascar. Ann. Géol. Madag., XXXIV, premier vol., 437P.

BESAIRIE, H. (1970) Carte géologique, feuille Fianarantsoa numéro 7, au 1/500.000. Service Géologique de Madagasikara, Tananarive.

BESAIRIE, H. (1970) Carte géologique, feuille Ampanihy numéro 8, au 1/500.000. Service Géologique de Madagasikara, Tananarive.

BESAIRIE, H. et COLLIGNON, M. (1972) Géologie de Madagascar. I. Les Terrains Sédimentaires. Ann. Géol. Madag., XXXV, 463P.

BESSON, M. (1953) Carte géologique de feuille Ampandrandava, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

BOULANGER, J. (1953) Etude géologique des feuilles Ejeda-Gogogogo, au 1/100.000, campagne 1952. Travaux du Bureau Géologique, numéro 45, Service Géologique, Tananarive, 70P.

BRENON, P. (1953) Etude géologique des feuilles Isakoa(J.58), Betroka(K.58) et d'une partie de la feuille Ianakafy(I.58), au 1/100.000, campagne 1952. Travaux du Bureau Géologique, numéro 48, Service Géologique, Tananarive, 105P.

DELBOS, L. et NOIZET, G. (1955) Carte géologique de feuille Tsivory, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

FURON, R. (1963) Madagascal. Geology of Africa, English edition translated by A. Hallam and L.A. Stevens, Oliver and Boyd Ltd., Edinburgh and London, P.354-370.

Japan Society of Newer Metals(1970) Madagascal. Report on the investigation for the promotion of buying new metal resources in Africa and Nepal (in Japanese). P.30-104

MMAJ(1970) Metal deposits in Madagascar(in Japanese). Inside data no.3, 15p.

MMAJ(1974) Report on the overseas geological structure survey in the central area of Madagascal(summarization in Japanese).

MMAJ(1975) Madagascar. Report on the investigation of overseas mining circumstances[Madagascar • Swaziland] (in Japanese), inside data, P.2-13.

MMAJ(1981) Mining circumstances of the Democratic Republic of Madagascar (in Japanese). Report on the investigation of overseas mining circumstances [Zimbabwe, Mmadagascar, New Zealand, New Caledonia, Venezuela, Panama], inside data P.26-29.

MMAJ (1984) Mining circumstances of Madagascar (in Japanese). Report on the investigation of overseas mining circumstances [Finland, Sweden, Thailand, Indonesia, Botswana, Madagascar], inside data, P. 102-122.

MOUFLARD, R. (1953) Etude géologique des feuilles Bevary, Isoanala, Ianakafy Sud, au 1/100.000, campagne 1952. Travaux du Bureau Géologique Service Géologique, Tananarive, 64P.

NOIZET, G. (1953) Etude géologique des feuilles Ankazotaha-Ampanihy-Tranoroa, au 1/100.000. Travaux du Bureau Géologique, numéro 46, Service Géologique, Tananarive, 65P.

NOIZET, G. et LAUTEL, R. (1953) Carte géologique des feuilles Tranoroa-Bekitro, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

NOIZET, G. (1954) Carte géologique des feuilles Imanombo-Ranomainty, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

NOIZET, G. (1955) Carte géologique des feuilles Tranomaro-Marohotro, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

NOIZET, G. de la, ROCHE, H., ORLOFF, O. et DELBOS L. (1955) Carte géologique des feuilles MAHALY-ESIRA, au 1/100.000. Travaux du Bureau Géologique, Service Géologique, Tananarive.

Overseas Technical Cooperation Agency (1964) Report on the investigation of the mineral resources development plan in Madagascar (in Japanese). 153P.

RAZAFIMANANTSOA, RAKOTOMANGA A. et RANDRIANARISOA J.D. (1978) Carte géologique de feuille Ranomafana du Sud. La coordination a ete effectuee par G. BAZOT. Service Géologique de Madagasikara, Tananarive.

VERSTRAETE, BAZOT G., RAZAFIMANANTSOA, RAMANITRIRAISANA et RAKOTOARIVONY (1978)
Carte géologique de feuille Fort-Dauphin. La coordination a ete effectuee par G. BAZOT. Service Géologique de Madagasikara, Tananarive.