REPORT

ON

THE MINERAL EXPLORATION

IN

THE SOUTHERN AREA

[illegible] OF MADAGASCAR

(PHA[illegible])

[illegible]

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

(PHASE III)

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 JICA and MMAJ sent to the Republic of Madagascar a survey team headed by Mr. Jinichi Nakamura from September 26 to November 12, 1993.

The team exchanged views with the officials concerned of the Government of the Republic of Madagascar and conducted a field survey in the Southern Area of Madagascar. After the team returned to Japan, further studies were made and the present report has been prepared.

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

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

Kensuke Yanagiya
President
Japan International Cooperation Agency

Takashi Ishikawa

Takashi Ishikawa

President

Metal Mining Agency of Japan

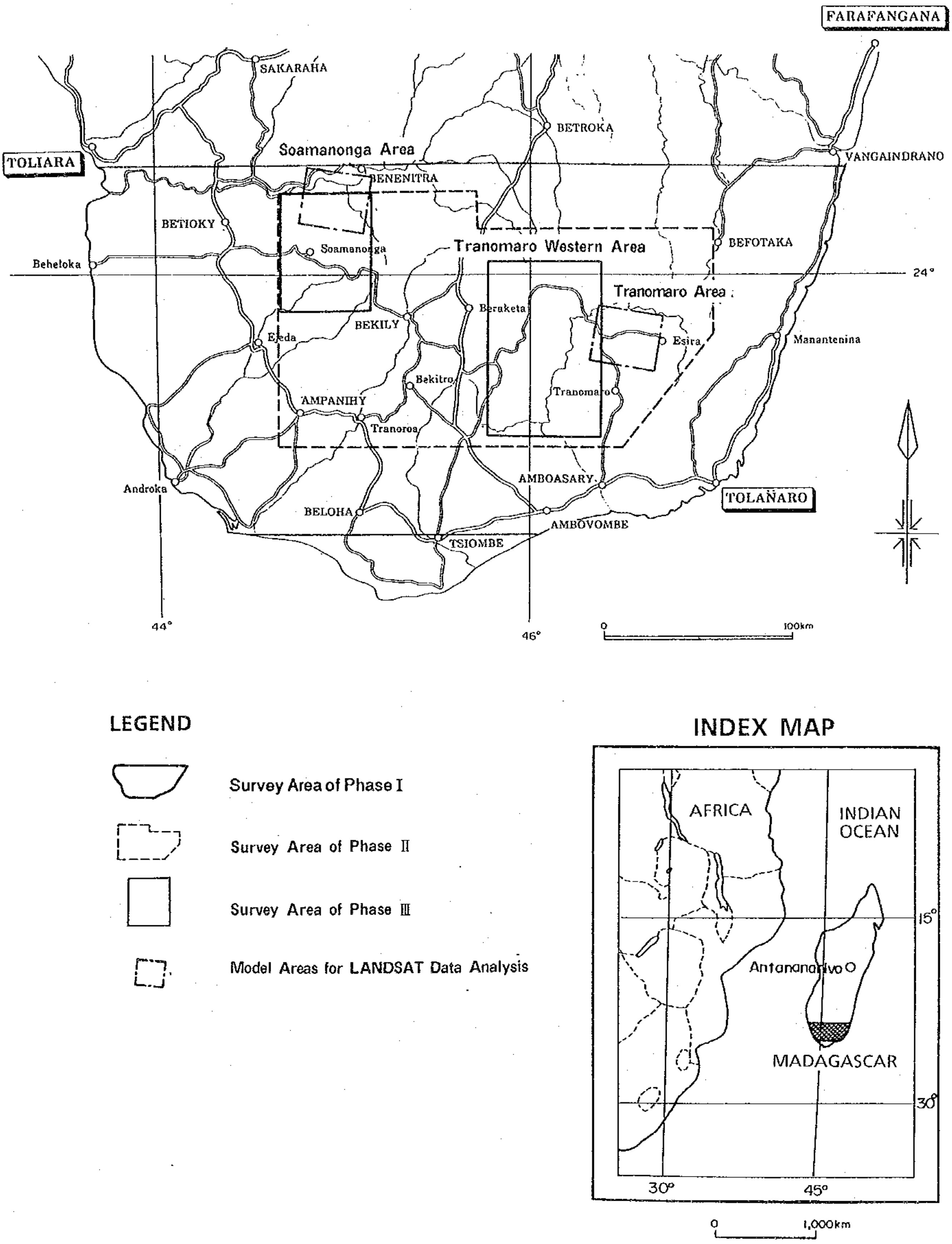

Fig. I-1 Location Map of Survey Area

Résumé

Ce rapport présente les résultats de la troisième phase annuelle d'une étude fondamentale réalisée dans la partie sud de la République de Madagascar dans le cadre de la coopération au développement de ressources naturelles. Les objectifs de cette troisième phase étaient les suivants : procéder à des sondages géologiques in situ pour contrôler les résultats obtenus par la compilation de documents, la lecture des images satellite et l'analyse spectrale des données satellite effectuées dans la première et deuxième phase, examiner la présence d'éventuelles ressources minières.

Des sondages géologiques in situ et une prospection sur un total de 280 km ont été effectués dans la zone de Soamanonga (2 000 km^2) et dans la zone occidentale de Tranomaro (5 000 km^2), zones jugées prometteuses sur la base des résultats des deux premières phases. Ci-suit la synthèse des résultats de cette troisième phase.

(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 suspectible 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 SOAMANONGA AREA

1-1 Outline of the Survey

The field geological check survey, a surveyed route of 120 km, was carried out in the Soamanonga area, an area of 2,000 km^2. Topographical maps on a scale of 1:100,000 were used for the survey and the survey results were compiled finally in the geological map on a scale of 1:250,000.

The Soamanonga area is an undeveloped area located on the dry highland. Main road is from Soamanonga to Fotadrevo and others are small ways for walking and for animals, but some parts of the small ways are possible to pass by 4WD vehicle. The road to the Varahina copper indication zone has been broken and it needs to walk from Sakoa.

1-2 Outline of Geology

The gneissic rocks of the Precambrian Vohibory System are distributed in the central to southern parts of the Soamanonga area. The Vohibory System is composed of leptinite, gneiss, amphibolite and marble (Besairie, 1963). The isotopic age using Pb isotopes in galena indicates 1,890 Ma (Furon, 1963). The gneissic rocks have been intruded by the Cambrian granite showing 485 Ma (Furon, 1963).

The continental sedimentary rocks of Permian to Jurassic covers unconformably the basement gneissic rocks in the north-eastern and north-western parts. They are correlated to the Karroo System of the south Africa. General stratigraphy is described below from lower to upper (Raron, 1963; Besairie, 1964).

(1) Sakoa Group (lower Permian)

1) The Lower Formation:
The formation is composed of black shale and conglomerate about 150 m in total thickness. The black shale contains plant fossils.

2) The Middle Formation:
The formation is an alternation of sandstone and shale containing several coal seams about 100 m in total thickness. Each coal seam is less than several meters. The alternation contains plant fossils such

1) Tolanaro (Fort-Dauphin) district:
Black sand deposits containing monazite, ilmenite, rutile and zircon along the coast line facing the Indian Ocean. Bauxite deposit at Manantenina.

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

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

4) Ampanihy district:
Ore showings such as precious stones (ruby, garnet, etc.), graphite, phlogopite, ilmenite, copper, manganese, etc. Although, only precious stones are mined now.

5) Northern Beraketa district:
Ore deposits and showings of phlogopite. Phlogopite was mined at the Marovala, Ampandramdava and Ambararata mines from the beginning of 1900's to about 1940. Ore showings of graphite, uranothorianite and beryl are found in this district.

6) Soamanonga district (Vohibory district):
Ore showings of gold, silver, copper, zinc and manganese are known. They were explored in the colonial time. The Sakoa Group of the Karroo System in the district contains coal seams.

(2) Satellite image photointerpretation

Six false color images were prepared using CCT data, alloting blue, green and red to bands 2, 3 and 4, respectively, after linear stretch and edge enhancement process. 29 geological units were divided as a result of photogeological interpretation. An elliptical igneous composite body was found measuring about 70 km in N-S and about 45 km in E-W, in the east-central part of the survey area. Along the northern to northeastern margin of the igneous body, a distinct collapse structure was recognized. Such a large-scale magmatism has a possibility to form some kind of mineralization.

1-2-2 Recommendation for the Phase II Survey

The data compilation of this year found that most of the ore deposits and showings have been scarcely explored, and unsatisfactorily developed, notwithstanding, the potentiality of mineral resources is not low. To clarify the ore-bearing conditions, the following surveys for the Phase II were recommended.

1) Satellite data analysis
   There is a lot of tonal anomalies in the TM images of this area, some of which seem to be alteration zones concerned with the igneous activity. There exist an elliptical complex intrusive and a distinct collapse structure which may be related to the occurrence of ore deposits. Therefore, LANDSAT data spectral analyses is recommended to carry out with an aim of extracting alteration anormalies.
2) Geological and geochemical survey
   To confirm the information acquired by the TM image interpretation and the compilation of available data actually in the field, a geological and geochemical field survey is recommended to carry out in some promising areas.

1-3 Conclusion and Recommendation of the Phase II Survey

1-3-1 Conclusion of the Phase II Survey

In the Phase II, the spectral-digital analysis on the LANDSAT TM CCT data was conducted. At first two model subareas, Soamanonga and Tranomaro areas, were selected for training to decide the best band combination and processing method. As the results, it became clear that the false color image combined of band 4•5•7 was the best for photointerpretation and the pseudo color image of band ratio 5/7 was the most effective to distinguish clay minerals and alteration zones.

By the photointerpretation using the renewed full scene images of false color and pseudo color, following two interesting areas were extracted:

1) Copper indications in the Soamanonga area are located around the boundary of Precambrian basement rocks and Post-carboniferous sediments, and also located near the lineaments in the image and inferred faults.
2) Anomalies of band ratio 5/7 are found inside of the ring structure composed of volcanic complex in the Tranomaro area.

1-3-2 Recommendation for the Phase III Survey

Geological field check survey in the Soamanonga area and the Tranomaro Western area was recommended to carry out for the Phase III survey.

1-4 Outline of the Phase III Survey

1-4-1 The Survey Area

Geological field check survey was carried out for the two areas, the Soamanonga area of 2,000 km^2 and the Tranomaro Western area of 5,000 km^2, both of which were extracted for interesting areas by the LANDSAT image photointerpretation and data spectral analysis.

The Soamanonga area is located at the inner plateau, about 130 km of east southern-east of Toliara city. The Tranomaro Western area is located at the middle part of the river Mandrare, about 130 km of northern-west of Tolanaro city. Both areas are undeveloped and general conditions such as road, sanitary and living levels are very wrong.

1-4-2 Objective of the Survey

The objectives of the field surveys are to confirm the relationship between the LANDSAT TM information and actual geologic condition and besides to evaluate the potentiality of mineral resources in these areas.

1-4-3 Method of the Survey

Geological field check survey, total surveyed route of 280 km, was carried out in the two areas. Topographical maps, a scale of 1/100,00 were used for mapping. According to the field measurement preceding to the field survey, the magnetic north shown about 22° diflection to the west from the real north, hence, this figures was used for the field survey. About 60 rock and ore samples were collected for the indoor test and chemical analysis.

The field survey was carried out by mobile camping method using a pair of 4WD cars. The basement was set up in Toliara city and all materials, such as drinking water, foods and fuels were prepared in Toliara city.
The details are as follows:

1) Field Survey

Area	Surveyed Route
Soamanonga Area	120 km
Tranomaro Western Area	160 km
Total	280 km

2) Laboratory Test

Item	Quantity
Thin Section	22 pcs.
Polished Section	3 pcs.
X-Ray Diffraction	10 pcs.
Ore Assay (Au, Ag, Cu, Pb, Zn, Fe)	10 pcs.
Whole Rock Chemical Analysis	20 pcs.
Total	65 pcs.

1-4-4 Organization of the Survey Team

(1) Planning and Negotiation

Japan side:	Nobuyuki MASUDA	MMAJ
Madagascal side:	J.R. RATSIMBAZAFY	DMG/MEM

(2) Field Survey Team

Japan side:	Jinichi NAKAMURA	Leader, MINDECO
	Haruo HARADA	Geology, MINDECO
Madagascar side:	J.R. RATSIMBAZAFY	Coordinate, DMG/MEM
	J. ANDRIANARIMANANA	Coordinate, DMG/MEM
	R. ANDUAMANANTENA	Geology, DMG/MEM

MMAJ: Metal Mining Agency of Japan
DMG: Department of Mines and Geology
MEM: Ministry of Energy and Mines
MINDECO: Mitsui Mineral Development Engineering Co., Ltd.

1-4-5 Period of the Survey

	1993				1994	
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
Preparation	10 — 25					
Field Survey	26 —	—	— 12			
Test & Analysis			13 —	— 31		
Report Making				1 —	—	— 25

Chapter 2 GEOGRAPHY OF THE SURVEY AREA

2-1 Location and 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 undeveloped area in the island. Main modernized cities are Toliara to the west and Tolanaro to the east.

Five flights a week are operated between Antananarivo, the metropolis and Toliara or Tolanaro cities. It takes about 7 hours by car to arrive at the Soamanonga area from Toliara city running about 220 km and about 17 hours to reach the Tranomaro western area running about 520 km. The road condition is very bad and 4WD car is necessary even in the dry season.

2-2 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.

2-3 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 3 GENERAL GEOLOGY

3-1 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-3. A geological map of the southern part of Madagascar compiled by H. Besairie (1963) is shown in Fig. I-2.

3-2 General Geology of the Survey Area

(1) Soamanonga area

The Soamanonga area is composed of the Precambrian basement and the late Paleozoic to Mesozoic sedimentary rocks covering the former. The basement belongs to the Proterozoic Vihibory System, the uppermost group of the Precambrian basement. The sedimentary rocks are of the Sakoa and Sakamena Groups distributed to the northwestern part of the area.

(2) Tranomaro western area

In the Tranomaro western area that is composed of the Androyen System, the lowest group of the basement belonging to the Archaean to Proterozoic, a remarkable ring structure formed by the Cretaceous volcanisms is found in the basement rocks.

Table I-3 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		B, 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, E=Eastern, S=Southern

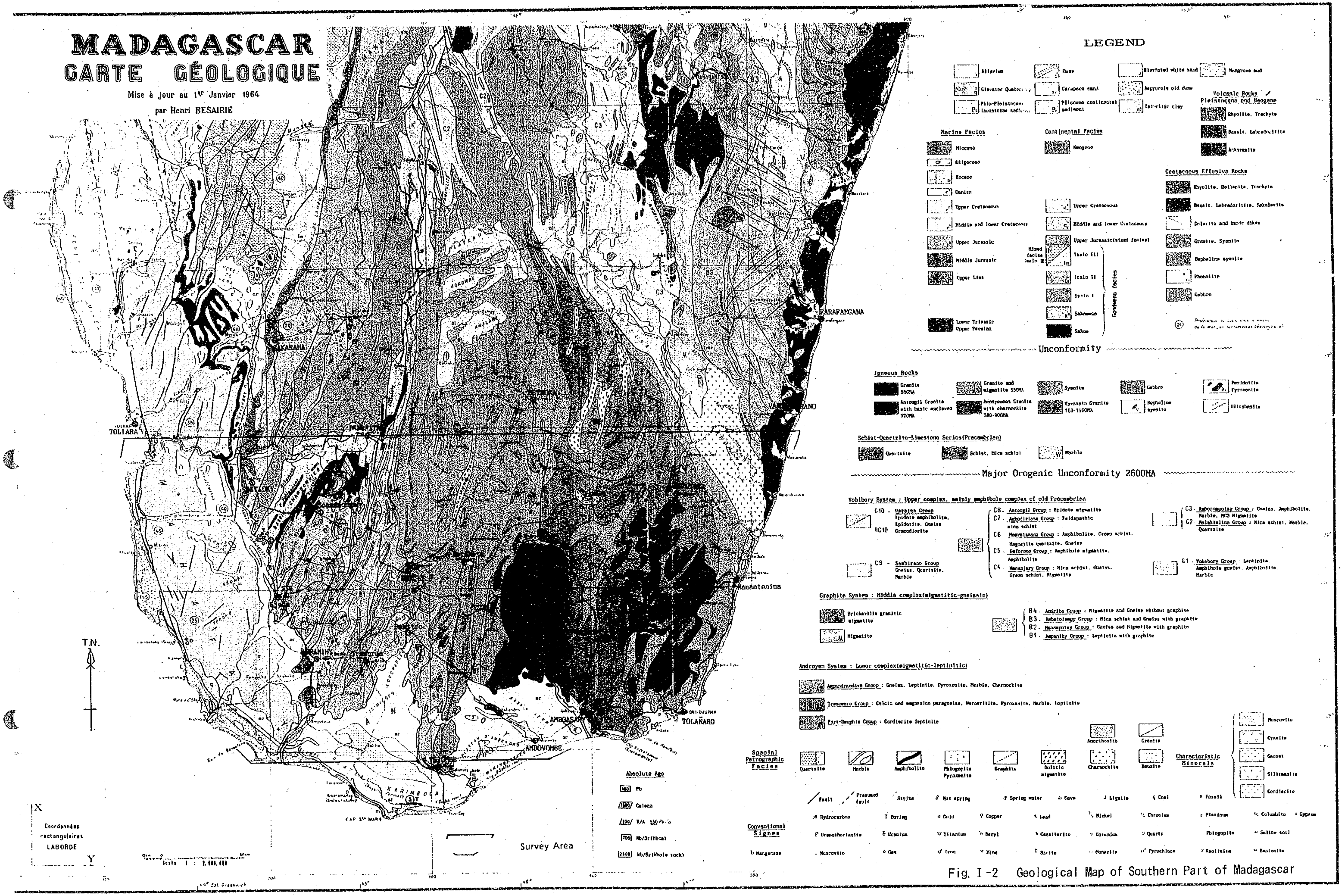

Fig. I-2 Geological Map of Southern Part of Madagascar

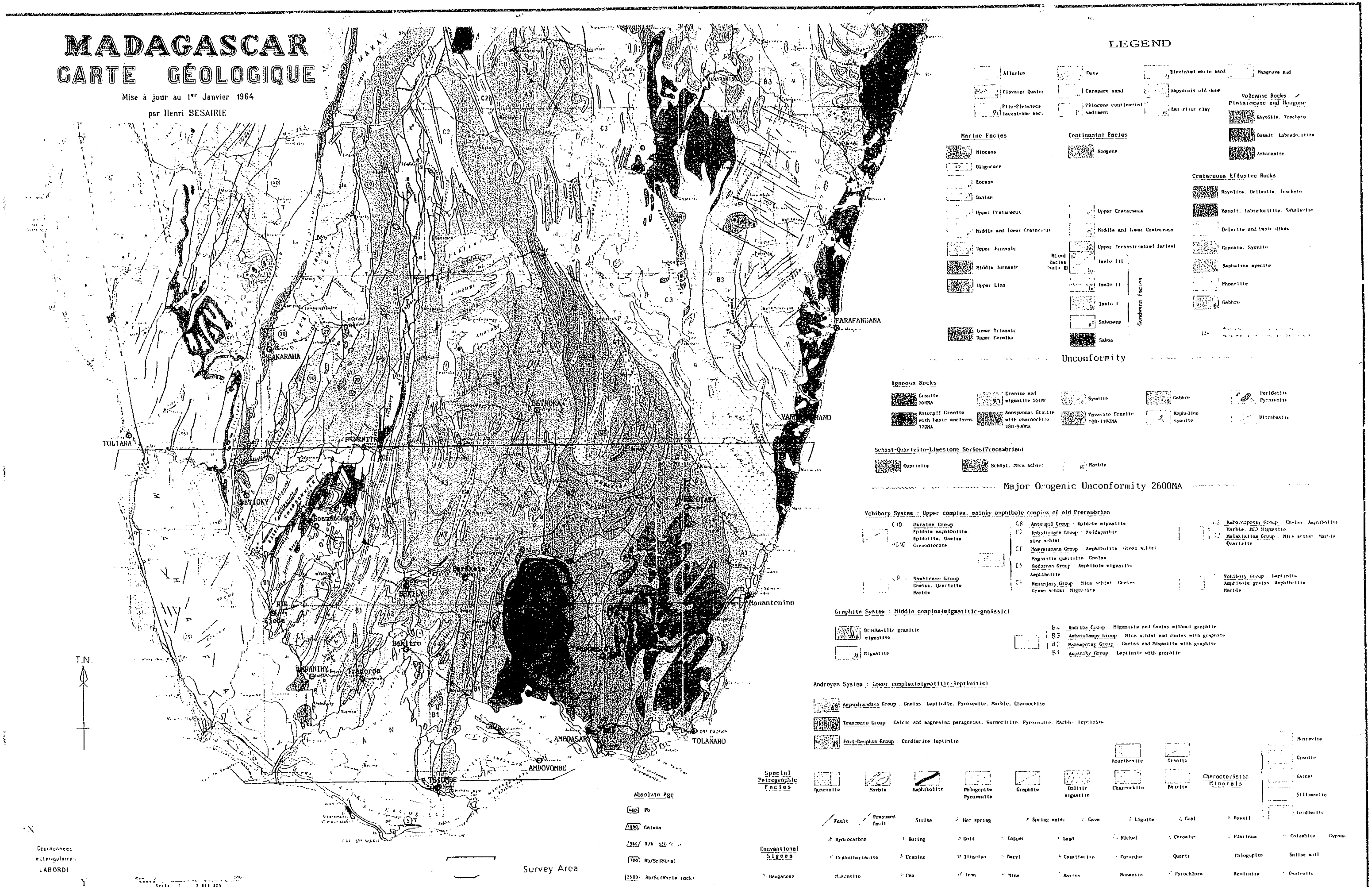

Fig. I-2 Geological Map of Southern Part of Madagascar

Chapter 4 CONCLUSION AND RECOMMENDATION

4-1 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, micrograninite 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.

4-2 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 SOAMANONGA AREA

1-1 Outline of the Survey

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(1) Sakoa Group (lower Permian)

1) The Lower Formation:

The formation is composed of black shale and conglomerate about 150 m in total thickness. The black shale contains plant fossils.

2) The Middle Formation:

The formation is an alternation of sandstone and shale containing several coal seams about 100 m in total thickness. Each coal seam is less than several meters. The alternation contains plant fossils such as pteridophytes and Calamites.

3) The Upper Formation:
The formation is composed mainly of feldspathic sandstone and red shale yielding silicified woods. The thickness is 500 m to 600 m. The uppermost part is made of limestone.

(2) Sakamena Group (upper Permian ~ lower Triassic)

1) The Lower Formation:
This formation is characterized by shale containing plant fossils such as pteridophytes. The lowest part is made of conglomerate. Thin limestone beds are intercalated in some places.

2) The Middle Formation:
The formation is mainly of sandstone containing animal fossils such as reptiles and amphibians. This formation indicates the end of Permian Period and the beginning of Triassic Period.

3) The Upper Formation:
The formation is composed of mudstone and marlstone containing animal fossils such as fishes, ammonites and amphibians. The uppermost part is laid by shale and sandstone.

(3) Isalo Group (upper Triassic ~ middle Jurassic)

The Isalo Group is composed mainly of sandstone and distributed to the north western part of the area. After Jurassic Period, the marine sediments composed of marlstone, limestone and calcareous sandstone are prominent and distributed to the west of the area covering the Permian to Jurassic continental sediments (Fig. II-1).

1-3 Survey Results

(1) Gneissic rocks

The gneissic rocks in the Soamanonga area are composed mainly of paragneiss, orthogneiss, amphibolite and marble.

Paragneiss was derived from alternations of the pelitic and psammitic sediments. The alternation pattern is changeable from several millimeters to more than 10 meters in thickness. Contained mafic minerals are mainly hornblende and biotite. The pelitic part is usually fine-grained and the psammitic part is fine to medium-grained.

Orthogneiss is pale-grey and usually medium to coarse-grained. Main mafic mineral is hornblende and accompanied by biotite and garnet, although main constituents are quartz and feldspar. This type of gneiss is exposed occasionally as oval hills.

Amphibolite is mainly of hornblende and medium to fine-grained showing black color. Small bodies of serpentinite are rarely found in the area.

Marble is usually well exposed showing light color and coarse-grained. Therefore, marble can be used as key bed.

The orthogneiss distributed in Betaly shows very regular oval shape accompanied by marble in its margin. These features suggest that such orthogneiss may have been originated from sedimentary rocks.

The gneissosity is predominant in the directions of NNE-SSW and NNW-SSE, dipping to the west. The gneissosity shows usually a steep inclination and occasionally a gentle inclination in the NNW-SSE direction.

Although general thend of gneissic rocks is of NNE-SSW direction dipping to the west, it is assumed that there exists a repetition of dome and basin structures with the direction of NNW-SSE or NW-SE in this area.

(2) Sedimentary rocks

The sedimentary rocks correlated to the Karroo System of Permian to Triassic age are distributed in the north-western and the north-eastern parts covering unconformably the Precambrian basement gneissic rocks. It seems that the boundaries of the both rocks are controlled by the fault of NNW-SSE direction.

Around the Vohimary in the north-eastern part, there distributed are an flat-lying alternation of shale and sandstone, which are correlated to the upper formation of the Sakoa Group.

In the north-western part, the sedimentary rocks are distributed mainly to the west of the line from Vohimary to Ankinany. They are an alternation of sandstone and shale in the northern part and coarse sandstone in the central part, both of which are correlated to the lower to middle formations of the Sakoa Group.

They show N-S and NNW-SSE strikes dipping 20° to 30° to the west. To the west side of the Sakoa river, shale beds correlated to the lower formation of the Sakamena Group are widely distributed striking NNW-SSE dipping gently about 10° to the west. Coal seams are intercalated in the alternation of sandstone and shale correlated to the middle formation of the Sakoa Group. Main coal beds are said to be five. There is an abandoned coal mine at Ankinany.

(2) Mineralization

The Soamanonga area is included in the Vohivory area in which copper indications are recognized (Bouteyak, 1970). Around Vorahina pitting for copper ore has been performed formerly and copper ores are remained as piles. This time, 3 pits were confirmed.

Copper indications are found as disseminations of green copper on a small scale in the quartz veins and the surrounding sheared and brecciated zone in amphibolite. Quartz veins strike usually in NNE-SSW and NW-SE directions. The width of quartz veins is usually several centimeters or less than 1 m. Copper ores are usually sporadic and lenticular on a scale of 10 cm to 30 cm (Fig. II-4).

According to Bousteyak (1970), copper indications are found not only in the basement rocks but in the upper sedimentary rocks of the Karroo System. Most of these copper indications are seemed to be distributed along the faults of NNW-SSW directions and, consequently, a close relationship is inferred between copper mineralization and faulting activity.

Gossan outcrops are found near to Ampisapio, about 4 km west of Betaly and 2 km of Soamanonga. Each gossan occurs in the sheared and brecciated zones of the NNW-SSE direction.

1-4 Assay Results of Ore Samples

(1) Copper ore of the Varahina area

The assay results of the green copper ores collected from 3 pits and 1 ore pile are shown below:

No.	Name	Location	Length* (m)	Au (g/t)	Ag (g/t)	Cu (%)	Pb (%)	Zn (%)	Fe (%)
511	Green Cu	V-No. 1	0.1	3.38	125	15.6	0.01	0.01	2.88
512	Green Cu	V-No. 1	0.1	<0.02	<0.3	0.14	<0.01	0.01	5.90
514	Green Cu	V-No. 1	0.1	0.30	110	21.6	<0.01	0.01	3.20
515	Green Cu	V-Pile		2.57	184	31.7	<0.01	<0.01	5.60
516	Green Cu	V-No. 2	0.1	0.03	1.6	0.49	<0.01	<0.01	1.38
518	Green Cu	V-No. 3	0.2	3.27	198	14.8	<0.01	<0.01	1.06
519	Green Cu	V-No. 4	0.2	3.56	8.4	9.7	<0.01	<0.01	2.04

* length of sampling channel

According to the assay results, the high grade parts show around 15% in Cu, 3 g/t in Au, and 120 g/t in Ag. According to the X-ray diffraction analysis and microscopic observations, the constituent copper minerals are malachite, azurite, brochantite, digenite, boothite, chalcocite, and covelline. Main gangue minerals are quartz, K-feldspar, and plagioclase.

These copper ores bear gold and silver. These copper ore bodies become very promising if larger scale and continuity of the high grade parts are confirmed, since the grade is high enough to exploit.

(2) Gossan

The assay results of the gossan samples are shown below, showing very low contents in Au, Ag, Cu, Pb, and Zn, and high content in Fe:

No.	Name	Location	Length (m)	Au (g/t)	Ag (g/t)	Cu (%)	Pb (%)	Zn (%)	Fe (%)
313	Gossan	Ampisapiso	0.5	<0.02	0.3	0.01	<0.01	0.01	31.6
358	Gossan	Betaly	0.5	<0.02	<0.3	0.01	<0.01	<0.01	1.9
359	Gossan	Soamanonga	1.0	0.03	0.6	0.01	<0.01	<0.01	19.8

According to the X-ray diffraction analysis, the constituent minerals of gossan consist of quartz, goethite, and hematite.

Chapter 2 TRANOMARO WESTERN AREA

2-1 Outline of the Survey

The geological check survey, a surveyed route of 160 km, was carried out in the Tranomaro western area, an area of 5,000 km². Topographical maps on a scale of 1:100,000 were used for the survey and the survey results were compiled in the geological map on a scale of 1:250,000.

The Tranomaro western area is an isolated undeveloped area located at the middle reaches of the Mandrare river. It is possible to pass the main road by 4WD vehicle from Bekily located to the west and Ambosary located to the south of the area to Tsivory, the northern part, Marotsiraka, the central part and Ebelo, the southern part.

2-2 Outline of Geology

A remarkable ring structure is recognized developing in the central part of the Tranomaro western area. The gneissic rocks of the Precambrian Androyen System, the oldest system formed in 3,000 Ma and composed of gneiss, leptinite, pyroxenite, and gneissose granite are distributed to the outside of the ring structure (Furon, 1963). And the Cretaceous volcanic rocks mainly of basalt and rhyolite are distributed filling inside of the ring structure. In addition, the Cretaceous microgranite is found intruding into the gneissic rocks along the outer side of the ring structure.

2-3 Survey Results

(1) Gneissic rocks

The gneissic rocks in the Tranomaro western area are composed of gneissose granite, orthogneiss, paragneiss and pyroxenite, and distributed outside of the ring structure.

The gneissose granite and orthogneiss are leucocratic, coarse-grained and comparatively homogeneous, and contain a small amount of pyroxene, garnet and biotite as mafic minerals. They are distributed in the eastern part of the area. Pyroxenite is dark green, medium to coarse-grained and comparatively homogeneous and distributed in the north-eastern part of the area.

Paragneiss is pale to dark grey, medium to coarse-grained and heterogeneous, containing hornblende, pyroxene and a small amount of garnet, and distributed widely outside of the ring structure. The paragneiss in the western part contains cordierite. Strike of the gneissosity is changeable from N-S to NNE-SSW.

(2) Microgranite

The microgranite is pale grey, fine-grained and granular containing biotite and hornblende, and distributed along the outer margin of the ring structure intruding in the Precambrian gneiss as a stock or dyke.

Judging from the texture and the occurrence, this microgranite is regarded as a intrusive rock related to the Cretaceous volcanism.

(3) Cretaceous volcanic rocks

The Cretaceous volcanic rocks are composed of basalt and rhyolite and distributed inside of the ring structure. The basalt is mainly lava and the rhyolite occurs as lava, dyke and stock.

1) Basalt

The basalt is dark grey to black and compact, and contains pyroxene and olivine as phenocrysts. The flow structure of the basalt lava is generally flat and distributed up to the elevation of 300 m in the northern and central part and about 100 m in the southern part. As a whole, it dips gently to the south or south-east.

To the south, it is distributed even to the outside of the ring structure. Radial dykes of basalt high-angle with the ring structure are recognized in the vicinity of Elonty, north-eastern part of the area. Around Ebelo, the surface of the basalt lava has been brecciated and shows greenish or brownish color.

2) Rhyolite

The rhyolite is usually pale grey and contains the phenocrysts of quartz and feldspar. Occasionally it is disseminated by limonite, showing brown color.

Three kinds of rock facies are generally observed in the rhyolite as follows:

① fluidal rhyolite

② massive rhyolite

③ rhyolite severely silicified and brecciated, and disseminated by pyrite

General speaking, above rock facies ①, ② and ③ will correspond to lava, dyke and stock, respectively. The rhyolite is usually intruded in the basalt lava and effused on the basalt lava plateau that filled the caved ring structure.

The rhyolite occurs as double to triple rings in or on the basalt lava plateau up to 900 m above sea level. Outside of the ring, rhyolite dykes are intruded in the gneissic rocks.

Judging from the structure of the rhyolite lava plateau, three or four cycles of activity are inferred.

(4) Mineralization

As for non-metallic mineral resources in this area, kaolin and silica stone are found in the gneissic rocks to the east of Elonty, though they are small scale. As for metallic resources, there are not found any noteworthy ore deposits excepting indications of the disseminated pyrite in the rhyolite stock and the disseminated magnetite and pyrite in the basaltic lava.

In the vicinity of Tranomaro village to the east of the area, uranothorianite ore deposits have been found in the gneiss. The ore bodies are of vein type and uranothorianite is disseminated in quartz-K-feldspar vein. The widths are up to several meters, but the high grade parts are usually sporadic. Large porphyroblasts of biotite up to 10 cm in diameter are observed characteristically in the gneiss around the ore bodies. Uranothoriamite was mined in several sites by CEA from 1954 to 1964, however, the operation has been now abandoned.

2-4 Geochemical Analysis of Whole Rock Samples

The results of geochemical analysis of whole rock samples are shown in Appendix 3. The rock samples are totaling 20, 15 samples collected in the Tranomaro western area and 5 samples in the Soamanonga area. According to the results of analysis, the following tendencies are clearly recognized:

- basalt: rich in MgO, FeO, Fe_2O_3, TiO_2 and CaO
- rhyolite: rich in K_2O and SiO_2
- microgranite: rich in SiO_2
- orthogneiss: rich in SiO_2 and Al_2O_3
- amphibolite: rich in MgO and CaO
- anorthosite: rich in Al_2O_3 and CaO

— brecciated and silicified rhyolite: poor in Al_2O_3, K_2O, and Na_2O

In order to study the geochemical character of volcanic and intrusive rocks, two diagrams, SiO_2 — (Na_2O+K_2O) diagram and ACF (Al_2O_3-(Na_2O+K_2O) — CaO — (FeO + MgO)) diagram are prepared as shown in Fig. II-7.

In the SiO_2 — (Na_2O+K_2O) diagram, the volcanic rocks in the Tranomaro western area are classified into rhyolite and alkaline basalt, missing the intermediate composition. This fact shows that the volcanism was a typical bimodal igneous activity.

In the ACF diagram, all of the intrusive rocks and orthogneiss are classified into I-type (White and Chappel, 1977), which is rich in CaO in comparison to Al_2O_3, and FeO+MgO.

Time (Ma)	Era	System (Igneous Activity)	Rock Facies
	Cenozoic	Holocen-Pleistocene(Volcanics)	Sand, Mud (Ba, Ry)
		Neogene-Paleogene	Ls, Marl
65	Mesozoic	Cretaceous (Volcanics)	Marl, Ss (Ba, Ry) (Micro Gr)
		Jurassic	Marl, Ls
250	Paleozoic	Karroo System	Ss, Sh, Tillite
		Unconformity	
		Cambrian (Intrusives)	(Granite, etc)
570	Proterozoic		
		Vohibory System (1900Ma)	Granite, etc
		Graphite System (2400Ma)	Granite, etc
2500	Archaean	Androyen System (3000Ma)	Granite, etc

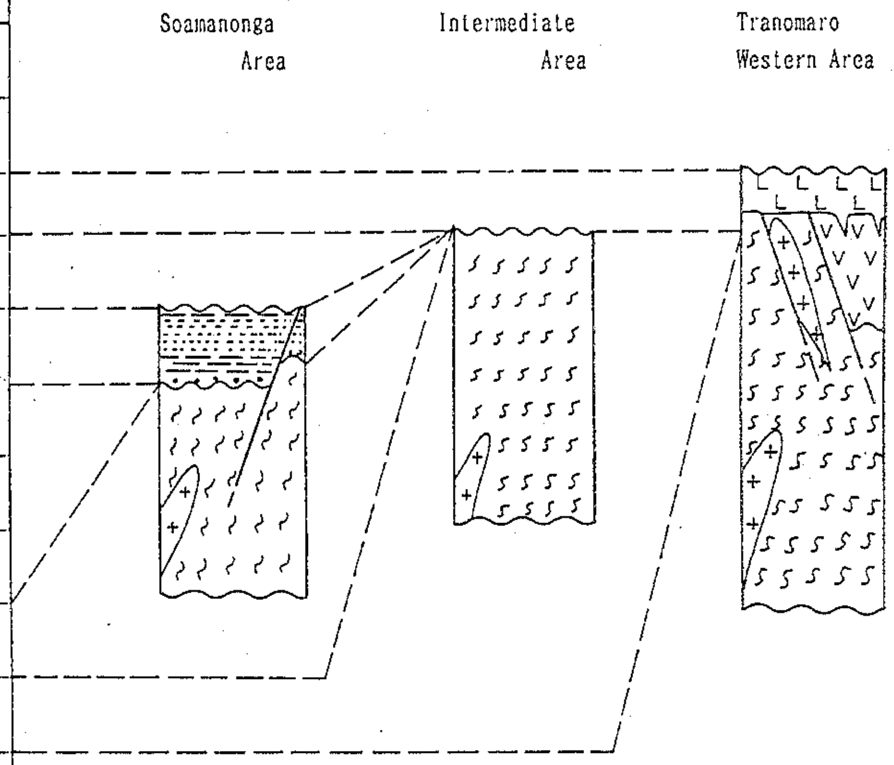


Fig. II-1 Geologic Column of Survey Area

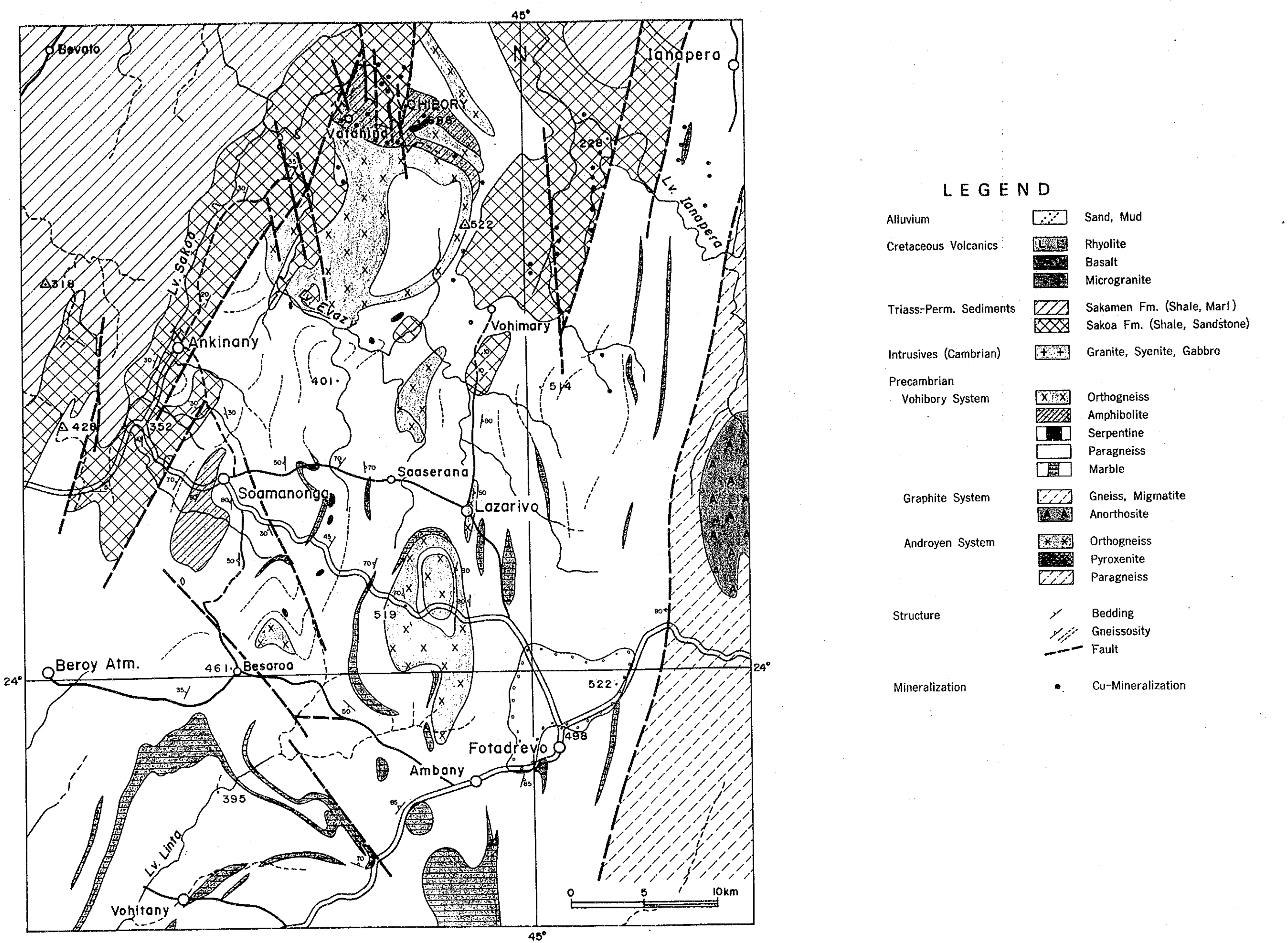
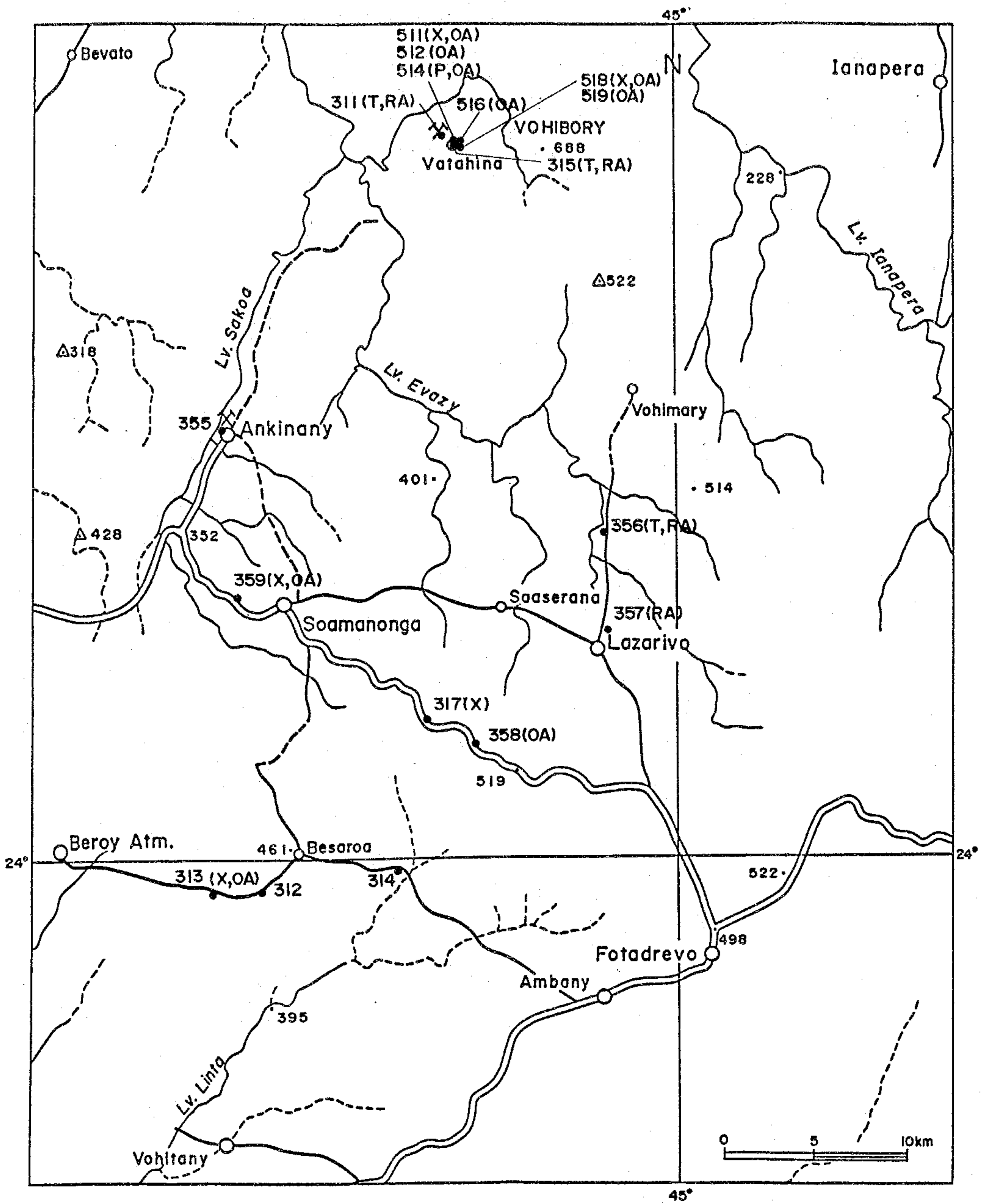


Fig. II-2 Geological Map of the Soamanonga Area, 1:250,000



LEGENDE

•311	Sampling Location and Sample No.
T	Thin Section
P	Polished Section
X	X-Ray Reflaction
RA	Whole Rock Analysis
OA	Ore Assay

Fig. II-3 Sampling Location Map of the Soamanonga Area, 1:250,000

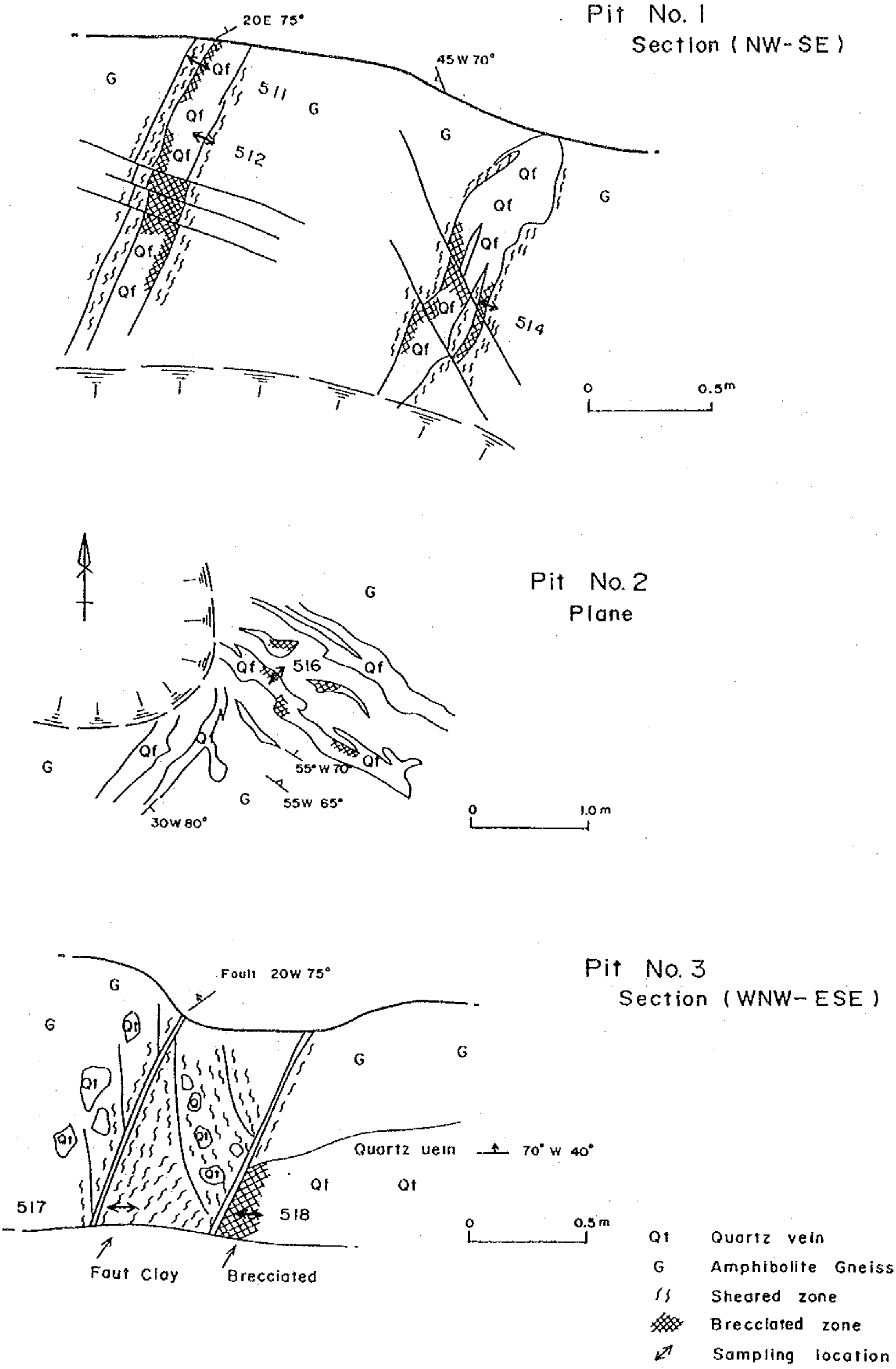


Fig. II-4 Geological Sketch of Copper Indication of Vohibory Area

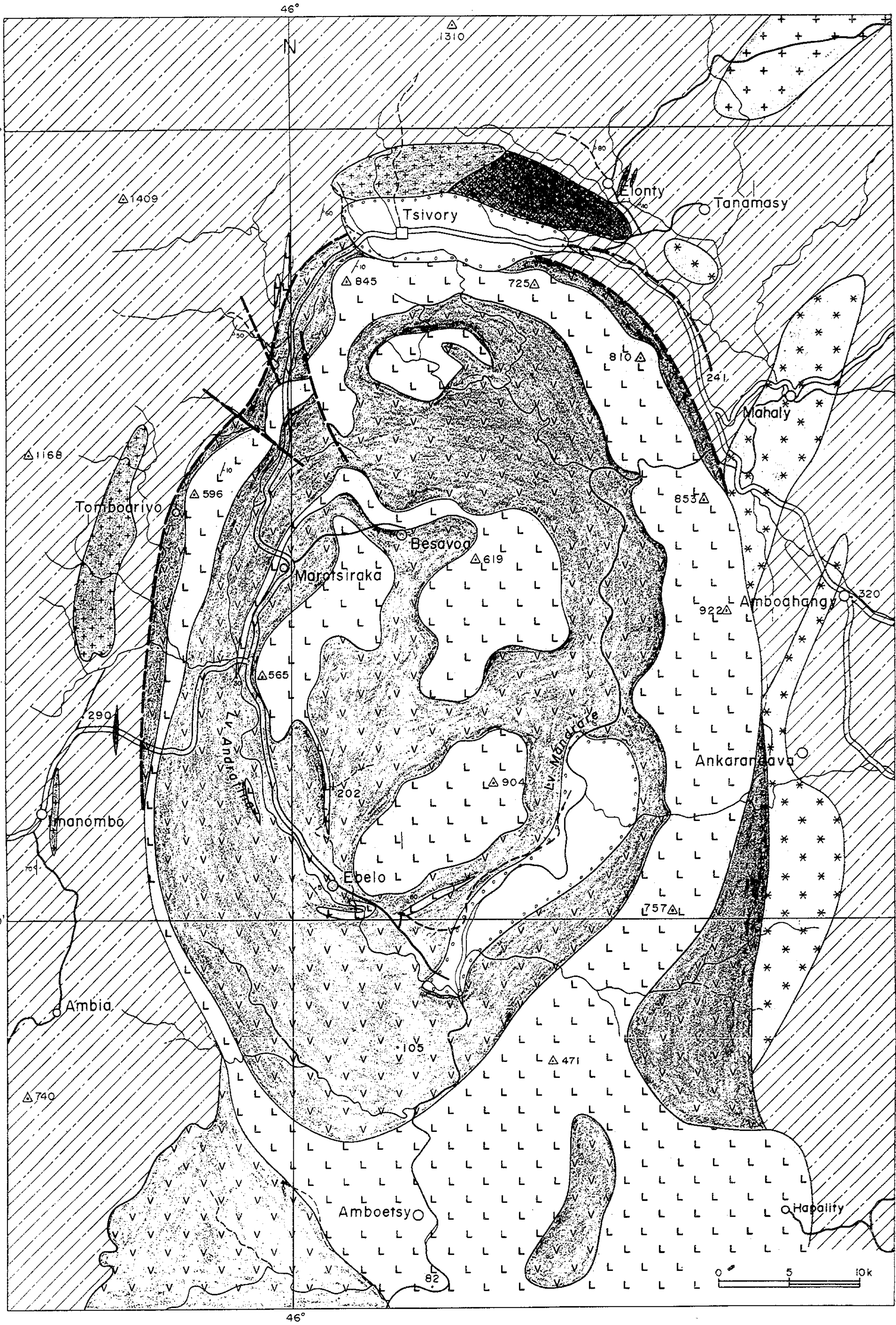
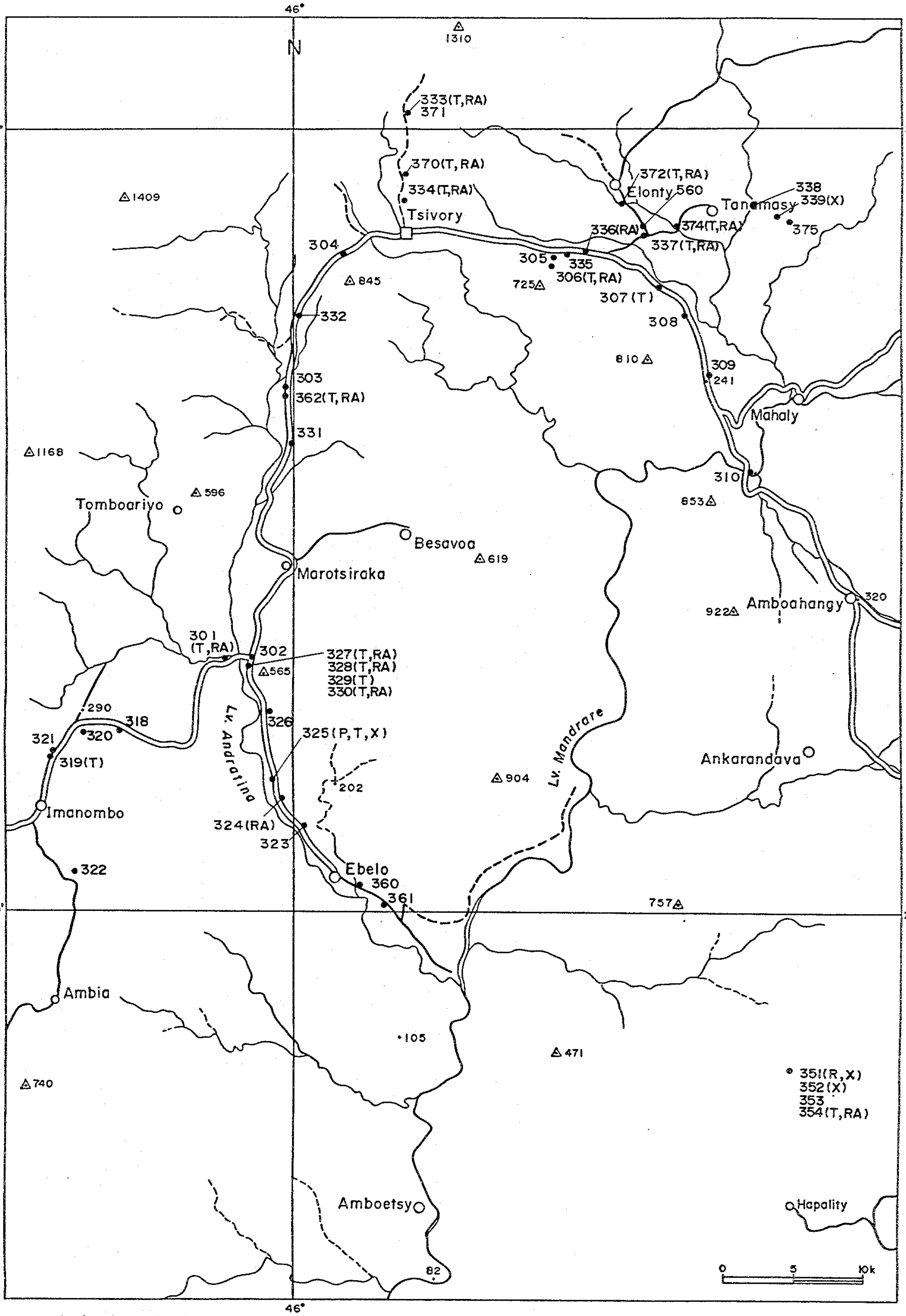
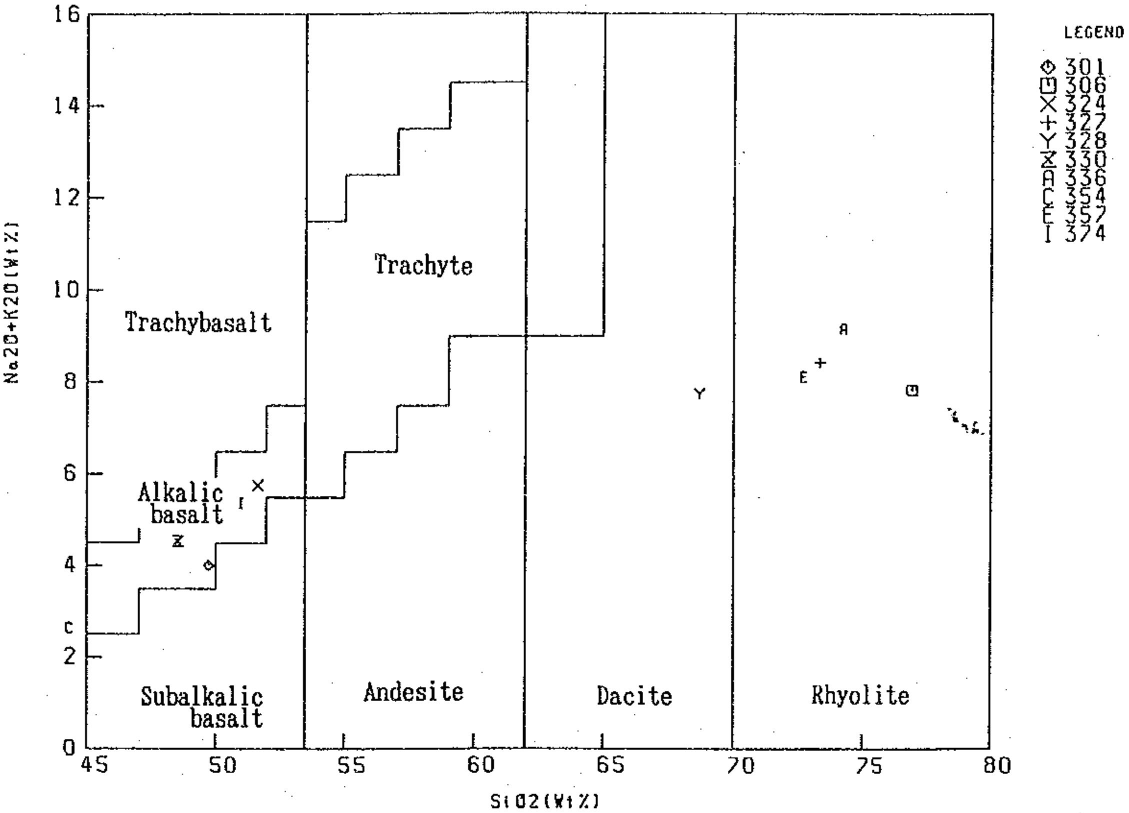


Fig. II-5 Geological Map of the Toranomaro Western Area, 1:250,000



Legend is shown in the Fig.Ⅱ-3

Fig. Ⅱ-6 Sampling Location Map of the Tranomaro Western Area, 1:250,000



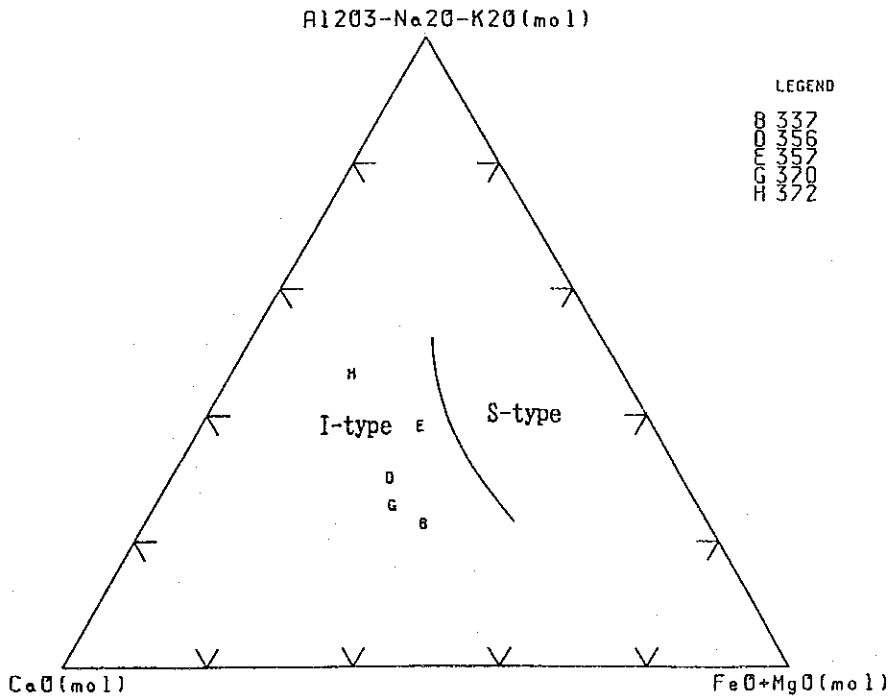


Fig. II-7 Geochemical Diagram of Rock Samples

Chapter 3 SYNTHETIC STUDY

3-1 Satellite Image and Surface Vegetation

The satellite images indicate clearly regional geological structures which are difficult to detect by the field survey. However, it is not always easy to distinguish the rock types and their distributions on the satellite images, because the spectral character of each rock is disturbed by the radiation from the vegetation on the surface.

The surface vegetational conditions in the area are various as follows:

- desert (with rock or sand)
- glassy plain
- shrub zone
- forest (evergreen, fallen leaves or thorny trees)
- cultivated land

These vegetational conditions depend basicaly on the regional meteorological and individual geographical and geological conditions.

The geographical and geological conditions are classified into the following factors:

- geological structure and lithological distribution
- topography
- soil
- drainage system (by running and ground waters)

The vegetational condition is directly influenced by the water drainage system and thickness of the soil, both of which are dependent on the topographical features and basically related to the geological structure and lithological distribution.

The following facts were recognized by the field surveys:

1) In the false color image of the band assenblege of 2•3•4, rhyolite shows various color of pale-blue, pale-brown, yellowish brown and black.
2) The vegetation shows red color by deep green trees, dark-brownish color by fallen leaves and thorny trees, and blue color by glassy plain.
3) The Sakoa System composed of sandstone and shale shows dark brown by the forest caused by the unpermeable gneiss in the lower part.
   The Sakamena System composed of sandstone shows pale-blue by the desert or glassy surface caused by the permeable Sakoa System in the lower part.
4) Limestone is ditinguished by light-grey color in the false color image

of bands 2•3•4.

5) The spectral anomalies in the ratioing image using bands 3/2 are seemed to indicate the limonite concentration on the surface.
The spectral anomalies by the band ratio 5/7 are seemed to indicate the accumulation of clay minerals and soil on the surface.

3-2 Relation between the Basement and the Upper Sediments

The continental sedimentary rocks belonging to the Karroo System are distributed on the Precambrian basement rocks unconformably showing occasionally straight boundaries in NNE-SSW direction in the Soamanonga area.

The boundaries are thought to have been influenced by the fault system that is related to the large graben structure formed in the late Mesozioic age to the west of this area.

3-3 Rock Facies of the Basement Gneiss

In the area from Soamanonga to Beraketa, the Precambrian basement rocks are mainly composed of paragneiss belonging to amphibole facies, high pressure and medium temperature. They are usually fine to medium-grained developing remarkable banding structure composed of leucocratic and melanocratic parts from several centimeters to more than 10 m intervals. Mafic minerals are usually hornblende and biotite. Leucocratic part is mostly seemed to be originated in sandstone and melanocratic part is in mudstone.

On the other hand, in the area to the east of Tsivory, the basement rocks are of granulitic gneiss belonging to granulite facies, high temperature and medium pressure. They are usually coarse-grained showing mineral assemblage of pyroxene and garnet accompanied by gneissose granitic masses.

3-4 Caved Ring Structure in the Tranomaro Western Area

A remarkable caved ring structure is developed in the Precambrian basement rocks in the central part of the Tranomaro western area. The structure, measured about 45 km × 70 km, has been filled up by the Cretaceous basaltic lava forming a lava plain or basin which has been intruded and effused by the

Cretaceous rhyolite in the mode of double or tripple rings.

Moreover, the intrusions of micrograni te which is seemed to be an intrusive facies of the Cretaceous volcanism are found in the Precambrian basement along the outer side of the ring structure.

Besides, the ring structure is encircled by a collapsed topographical structure on a scale of about 100 km in diameter.

This type of volcanic activity will be a hot-spot type originated in the stable continental crust. A possibility of mineralization accompanied by this type of igneous activity is a very interesting subject in the future.

3-5 Regional Geological Structure of Madagascar Island

According to the existing topographical maps and geological maps of whole Madagascar island, basic geological tectonics are recognized as follows:

1) NNE-SSW tectonic falt system accompanied by NW-SE fault
2) NNW-SSE tectonic falt system accompanied by NE-SW fault

The NNE-SSW fault system is generally accompanied by the Cretaceous volcanic rocks and supposed to connect with the formation of large scale Graven-Horst structure developed in the Precambrian basement. The shape of Madagascar island and the distribution of the Precambrian basement are seemed to be controlled by this fault system.

The NNW-SSE fault system is developed more or less in parallel with the distribution of the Mesozoic formation and accompanied by the Tertiary volcanic rocks. Recent river or drainage system on the surface is remarkably influenced by this fault system.

It is supposed that the former fault system was active in the older time from late Paleozoic to Mesozoic and the later was active in the younger time from Mesozoic to Tertiary.

3-6 Mineral Resources

The following mineral resources are expected to be occurring in the southern area of Madagascar:

- precious stones in gneiss (emerald, ruby, sapphire, garnet, etc.)
- nonmetallic deposits in gneiss (silica stone, graphite, uranothorianite, etc.)

- residual deposits in gneiss (kaolinite, bauxite, etc.)
- metallic deposits in gneiss (banded iron ore, etc.)
- placer deposits (black sand)
- Au-Ag-Cu mineralization in the Varahina area

These mineral resources shall be classified based on the genesis of ore:

- ore deposits formed in the Precambrian age: precious stones, banded iron ore, etc.
- ore deposits formed by the Cambrian orogeny: uranothorianite, Cr, Ni, etc.
- ore deposits formed by the Cretaceous volcanism and tectonics
- ore deposits formed by the Tertiary volcanism and tectonics
- residual and placer deposits formed in the Tertiary to Quaternary age: kaolin, bauxite, black sand, etc.

The gold-silver-copper mineralization in the Virahina area may be classified as the ore deposits formed by the Cretaceous volcanism and tectonics, by reason that the deposits are occurring not only in the quartz veins of NNE-SSW and NW-SE directions in the basement rocks but also in the sedimentary rocks belonging to the Karroo System.

Various mineral resources expected to be existing in the area bring about different problems when exploration and development are taken into consideration;

- resources which are suitabe for the private exploitation: precious stone
- resources which require severe qualities: silica stone, kaolinite, bauxite, etc.
- resources which require low cost operation: iron ore, coal, etc.
- resources which require stable operation: black sand, etc.
- resources which require intentional exploration and exploitation: non iron metallic ore and precious metals
- resources which are dealt with at international open market: non iron metallic ore and precious metals

Judging from the above mentioned viewpoint, non iron metallic ores such as copper and precious metals such as gold and silver are thought to be favorable resources for the future exploration.

It will be desirable to collect various data of the gold-silver-copper ore bodies and indications in the Varahina area, although they are not objects for exploitation at present because of the small scale of ore bodies.

Part Ⅲ　CONCLUSION AND RECOMMENDATION

Chapter 1　CONCLUSION

In this year, geological check field surveys were carried out in the Soamanonga area and the Tranomaro western area, 7,000 km² in total, both of which were extracted by the existing data compilation, the satellite image photointerpretation and the satellite data spectral analysis. As the results, the following facts were clarified.

1) The satellite images are reflecting regional geological structure clearly and various surface information objectively. Consequently, the images 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 supplementary means for the interpretation of rock facies, because the spectral data are disturbed by the radiation of vegetation on the surface.
2) The gneissic rocks forming the basement of the area are different in rock facies and metamorphic facies between in the eastern part and the western part. The gneissic rocks in the Tranomaro western area and eastward belong to the Androyen System, the lowest member of the Precambrian basement. They show comparatively homogeneous, corse-graind granular texture containing usually pyroxene and garnet and belong to the granulite facies of high temperature. The gneissic rocks in the soamanonga area and westward belong to the Vohibory System, the uppermost member of the Precambrian basement. They show heterogeneous, fine to corse-grained, rich in hornblende and belong to the amphibolite facies of medium temperature.
3) The boundary lines between the basement gneiss and the upper sedimentary rocks covering unconformably the basement rocks have been influenced by the fault system of NNE-SSW direction. The NNE-SSW fault zone in the Soamanonga area is supposed to be at the east end of the large graben zone that divides Madagascar island from the African continent.
4) Dimensions of the caved ring structure in the Tranomaro western area are about 45 km in N-S direction and about 70 km in E-W direction. The caved ring structure has been filled up by the Cretaceous basalt lava forming a lava plain or basin which has been intruded and effused by the Cretaceous rhyolite in the mode of double or tripple rings. Moreover, the caved ring structure is encircled by a topographically collapsed land on a scale of about 100 km in diameter.

   This type of volcanic activity will be a hot-spot type igneous activity originated in the stable continental crust. The microgranite intruded in the outer margin of the caved ring structure is seemed to be an intrusive facies of the Cretaceous volcanism. Probably another intrusive bodies are supposed to intrude underground in the deep part. A possibility of mineralization related to this type of igneous activity is a very interesting subject in the future.

5) Following two types of geological tectonics are important to the basic geological structure of Madagascar island.

   - NNE-SSW tectonic fault system accompanied by NW-SE fault
   - NNW-SSE tectonic fault system accompanied by NE-SW fault

   The NNE-SSW tectonic fault system is supposed to connect with the formation of large scale Graben-Horst structure developed in the Precambrian basement and accompanied by the Cretaceous volcanism.

   The shape of Madagascar island and the distribution of the Precambrian basement are seemed to be controlled by this fault system.

   The NNW-SSE fault system is developed more or less in parallel with the distribution of the Mesozoic formation and accompanied by the Tertiary volcanism. Recent river or drainage system on the surface is remarkably influenced by this fault system.

6) Various types of mineral resources such as precious stones, non-metallic minerals and metallic minerals are expected to be occurring in the southern area of Madagascar. Considering each quality, quantity, conditions of occurrence, development and market, the gold-silver-copper mineralization in the Varahina area is most interesting for future exploration.

   The ore deposit is of vein-type or dissemination type in the gneiss. It is difficult to proceed to the exploitation under the present conditions, because the orebodies are of small scale and sporadic. However, assay results of this survey indicate that the high grade ores show about 15% Cu, 3 g/t Au, and 120 g/t Ag. Moreover, it is reported that copper indications are found widely in the surrounding areas.

7) The gold-silver-copper ore deposits in the Varahina area, up to this time, have been regarded to be a mineralization related to the granite of Cambrian age. However, the possibility of the mineralization being related to the Cretaceous fault moving of NNE-SSW is inferred by this survey. This fault system is accompanied by a remarkable volcanic activity in other areas, and then, the mineralization is supposed to be originated in the Cretaceous igneous activity of deep underground.

Chapter 2 RECOMMENDATION FOR THE FUTURE

1) The gold-silver-copper orebodies in the Varahina area are of small scale, fragmentary and unstable continuity. However, some parts show very high grade in gold, silver and copper. It is advisable in the future to enforce basic survey such as detailed geological survey, geochemical prospecting, geophysical prospecting and so on in the areas where copper indications are reported.

   The principal obiect of the basic survey will be to confirm the relation of the mireralization to faulting and igneous activities, and to clarity the zonal distribution of ore minerals and the circumstauces of mineralization at the lower part. The target area for the further survey will be selected as an area including Varahina, Vohibory, Ianapera, and Vohimary.

2) Almost all the mineral resources of various kinds in the southern area of Madagascar are in existence in the Precambrian gneiss. However, the genetic ages may be extended over a long time and the genesis may be various, that are Preambrian sedimentation, Precambrian orogeny and metamorphism, Cambrian igneous activity, from Cretaceous to Tertiary volcanism and tectonics, and Quaternary weathering and drifting.

   In order to select a preferential target of mineral development for the future, it is advisable to compile the data concerned of mineralization and to study each deposit with regard to the geneisis and genetic age.