BUREAU DE RECHERCHES GÉOLOGIQUES ET MINIÈRES

SERVICE GÉOLOGIQUE NATIONAL

GEOLOGICAL STUDY USING ERTS ORBITAL IMAGES OF THE SOUTHERN PART OF THE MALAGASY REPUBLIC

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Département carte géologique et géologie générale

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GEOLOGICAL STUDY USING ERTS ORBITAL IMAGES OF THE SOUTHERN PART OF THE MALAGASY REPUBLIC

by

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Principal investigator :	Guy WEECKSTEEN
Name and address of principal investigator's organization :	B.R.G.M. Boîte postale 6009 - 45018 - Orléans cedex.
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15. Abstract

The Malagasy stratigraphy and tectonic are very complex, but the results obtained using ERTS 1 images interpretation make credible some hypothesis recently proposed by geologists. Most of known fractures are identified and numerous new observations are made on these images in the field of linear fractures. Some of them extend or relay known fractures and many others are totally new even if scattered field observations make it possible to assume that they correspond to reality. In the domain of lithology different types of rocks are distinguished, but the results are better in sedimentary formations than in the basement.

Our attempt to establish a chronostratigraphy was not realistic because ERTS images are not stereoscopic, but it appears a convergency of the results obtained with some new general ideas.

SUMMARY OF CONTENTS

I - HISTORY OF THE RESEARCH PROJECT

In 1971, we proposed to N.A.S.A., using ERTS 1 imagery, a survey of the southern part of the Malagasy republic. The aim of this investigation was to prove the ability of spacecraft images in the tectonic domain under tropical climate in an area where outcropping is fairly good.

1.1 - Reasons for this choice

We have chosen this country to investigate the potential application of ERTS imagery in geology for several reasons :

- The Malagasy republic government agrees with this experiment, conscious of its potential interest in the domain of earth resources : resident geologists have cooperated with the B.R.G.M..

- Compared with other African countries, the geological mapping in the Malagasy republic is quite good and a comprehensive map exists at a 1/500 000 scale. According to BESAIRIE (1957) the main geological units are :

.In the basement

- The Androyan system, located in the southern part of the island, is considered as the oldest unit. The rocks forming this unit are leptynites and aluminious gneiss.

- The Graphite system outcrops all over the island. It is laying on the Androyen system. It is characterised by graphite layer which exists everywhere except in the upper series. Migmatites, gneiss and micashistes are found in this unit.

- The Vohibory system : It is the upper series of the Precambrian in the Malagasy republic. Near "The Sakoa", the Vohibory is clearly superposed to the graphite system but some geologists (BOULANGER 1956) do not agree with this stratigraphy. Mainly outcropping in the South-western part, this system is characterized by amphibolitic minerals.

- The Cipolin series : this unit is overlaying the basement but is ante-Karroo. A. LACROIX (1921) and A. LENOBLE (1940) have described in this unit cristallin limestones and dolomites at the bottom and micaschists and quartzites at the top. The roof beds are constituted by schists, 300 m thick.

- The quartzitic series : is located in the centre part of the island. According to EMBERGER (1955) this unit is disconformable on the Cipolin series but the stratigraphic gap is less important than previously admitted by BESAIRIE. The main rock type in this series is a quartzite, but some schists are found in its lower part. The Cipolin series and the quartzitic series form, according to EMBERGER, the Itremo group.

At last, various types of granites outcrop everywhere in the basement, and specially stratiform granites.

. In the Karroo

BESAIRIE gives the following stratigraphy :

- the Sakoa group with tillites, coal beds, red beds and limestones.

- The Sakamena group, with a basal conglomerate and fossiliferous layers described by BESAIRIE (1936).

- The Isalo group begins during the Trias and ends at the middle Bathonian. Above a basal conglomerate, cross-bedded sandstones, claystones and limestones exist in the different horizons of the Isalo group.

. Post-Karroo

Sedimentary formations are known in the island, from upper Jurassic to Miocene.

From the time BESAIRIE established this stratigraphy and before he had published the 1/50 000 scale geological map of the Malagasy republic (1970), several ages, ranging from ± 3 200 to ± 500 m.y. are available for the rocks of the basement (BESAIRIE 1963) : if considered

alone, these results are insufficient to set up a stratigraphic tectonic sequence. One examination of these data, obtained by H. BESAIRIE and his team during 40 years of field and laboratory studies, enabled L. RADELLI and CHANTRAINE to give a new idea of this basement, based upon the notion of orogenic and tectonic zones. In this manner, the following main tectonic units were recognized : (see tectonic map of the basement of Madagascar)

- old cratons or nuclei
- the Andringitra orogen
- the Ikalamavony orogen
- the Vohimena orogen.

At last this sequence is different from the BESAIRIE one, but during the years separating these two opposite interpretations, geologists have carefully surveyed the island and some results obtained make it possible to understand the evolution of the ideas.

1957 - A. EMBERGER thinks the Itremo group is entirely Precambrian.

1957 - J. BOULANGER, G. NOIZET, H. de la ROCHE assume that the Vohibory is a less metamorphic equivalent of the Androyan system.

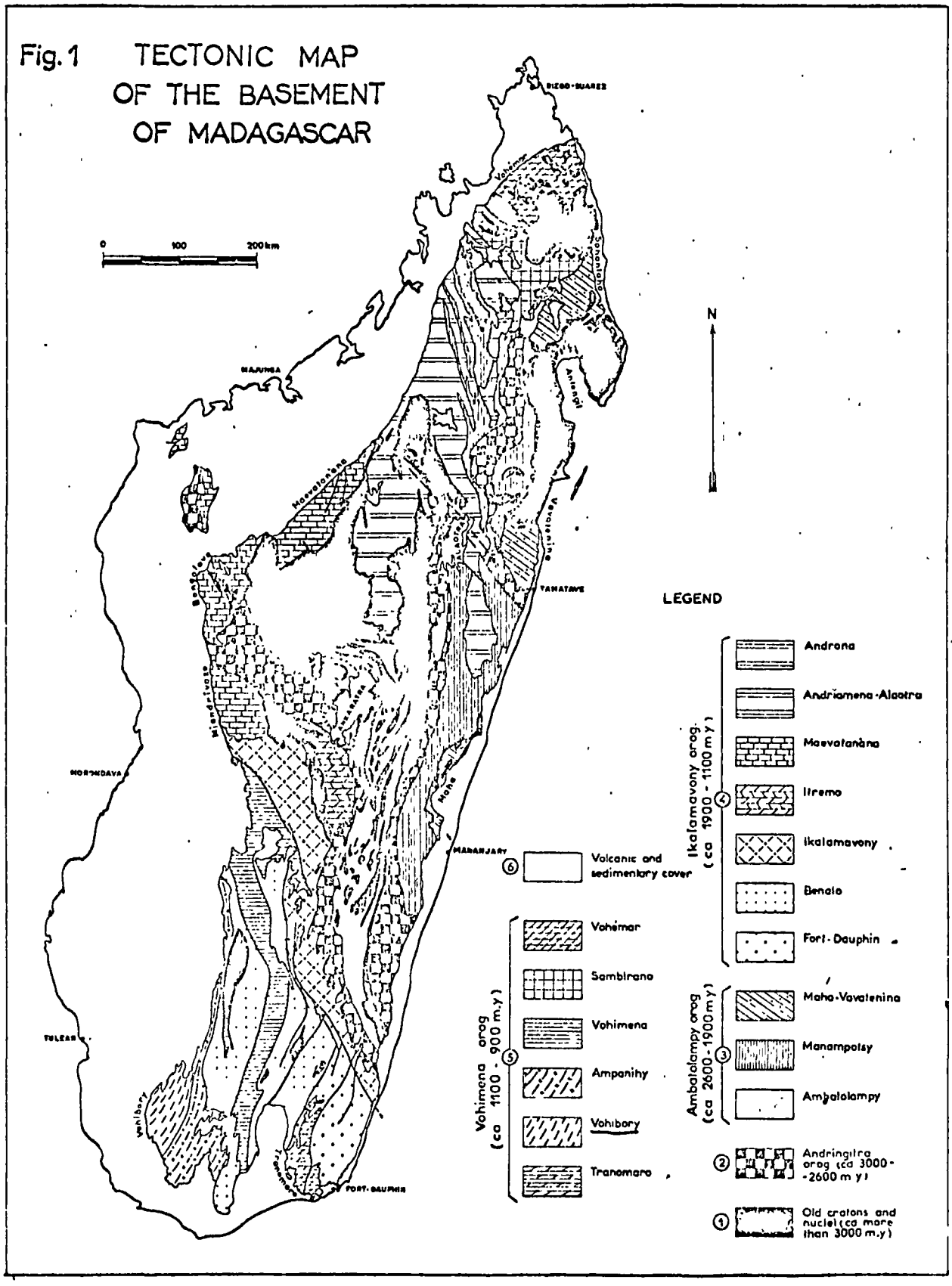
1960 - In the International stratigraphic lexic BESAIRIE considers that the quartzitic series is Precambrian (paleozoic in the former interpretation) but disconformable on the old basement.

1963 - L. FOURNIE, G. HEURTEBIZE observe in the Ikalamovony region the migmatites and the quartzites (Solila series) are under the Androyan system. This point is important because the authors think these units belong to the Graphite system.

1964 - M. BERTUCAT, L. FOURNIE and G. HEURTEBIZE demonstrate that the quartzites (centre part of the island) form only one series on which the Cipolin series is laying, where it exists. Interstratified into the basement, the quartzite series is conformable above a granite migmatitic formation correlated with the Graphite system and lying under an

TECTONO-MINEROGENETIC UNITS OF MADAGASCAR

J Chantraine and L Wadeff



upper horizon having a Vohibory facies.

In 1966 BERTUCAT and JOURDE give a comprehensive stratigraphy of the Malagasy republic basement, taking into account all the recent observations.

In 1970 J. CHANTRAINE agrees with the Androyan-Vohibory equivalent showing the importance of the Ranotsara fault. He outlines the existence of an old craton in the Benato group and - but this is only a possibility - in the Trenomaro series into the Kalambatitra massif.

1.2 - Other reasons for the choice of this test site

The above mentioned hypothesis outline the complexity of the geology in the basement. The tectonic is apparently not very simple and unsolved problems are numerous.

The B.R.G.M. is preparing a 1/2 000 000 scale tectonic map of the whole island of Malagasy. The today's hypothesis are summarized in "the Schema general" prepared by G. HOTTIN and to be published with an explanatory paper, in 1974 (see map).

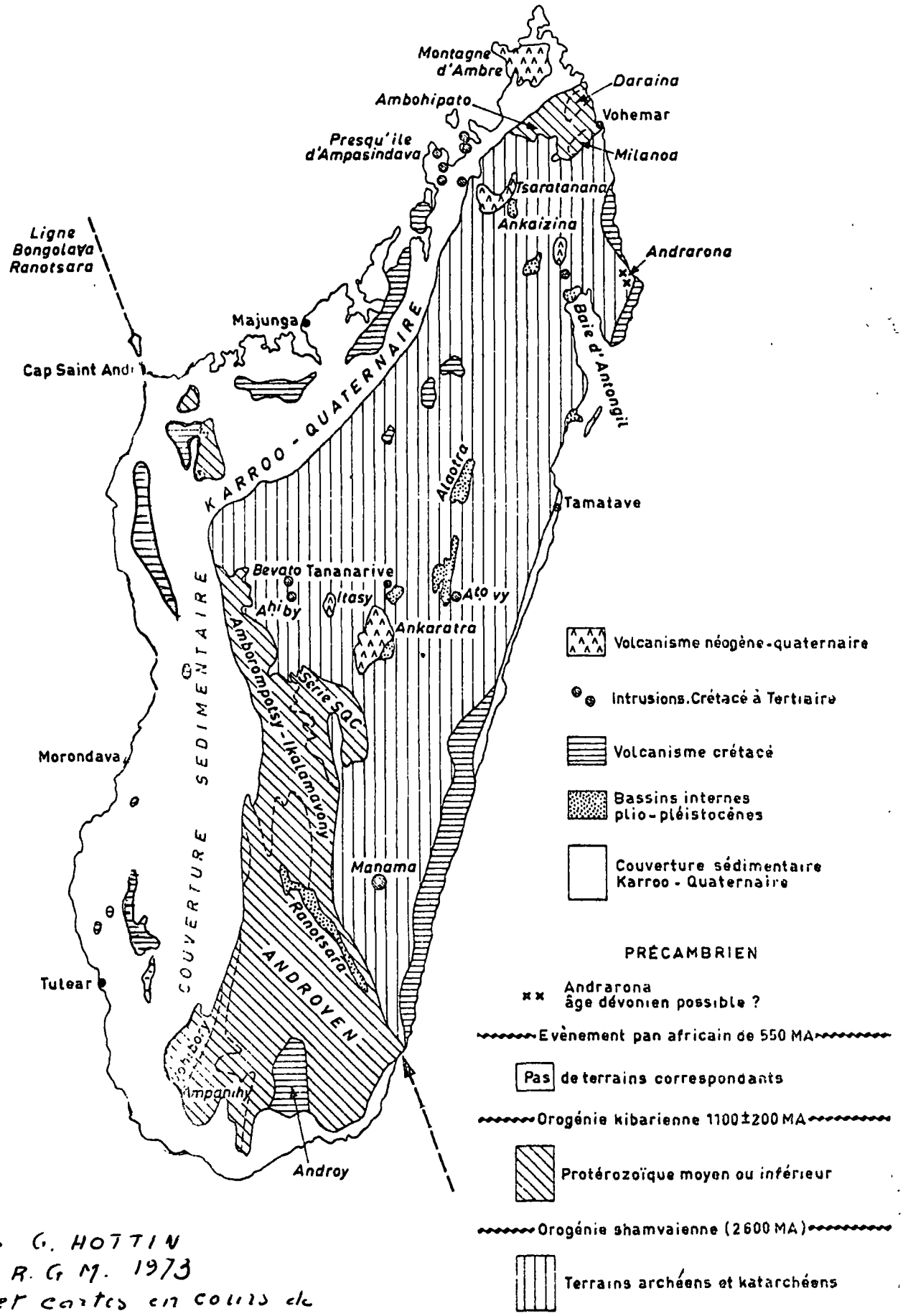
From the time ERTS was launched, several B.R.G.M. geologists have accomplished geological surveys on the basement of the proposed test site.

Finally, numerous geologists working at the moment for the B.R.G.M. have surveyed some years ago the area concerned with the investigation i.e., CHANTRAINE, EMBERGER, FOURNIE, JOURDE, LAMBOLEZ, DELFOUR, DONNOT, BLANCHOT, BELBOS, BOULAGER, BOULADON, BERTUCAT... and a group seminar have discussed the results obtained with ERTS interpretation.

1.3 - Objectives

At the time we wrote our proposals, it was known, demonstrated by Apollo and Gemini photographs, that spacecraft imagery makes possible the detection of lineameater structures into well exposed rocks in Africa.

MADAGASCAR
Schéma général



d'après G. HOTTIN
B. R. G. M. 1973
Texte et cartes en cours de Publication (1974)

The principal aim of our investigations was to look on the possible application of the method to the basement area of the southern part of the Malagasy republic, i.e. in an area where vegetation is not important, rocks well differenciated and geological problems very interesting on a mining point of view.

The most specific objectives were :

- To detect ability of spacecraft photographs in structural geology and prove the existence of a main fracture running SE-NW, through the southern part of the island, disturbing or not geological units. This point, not proved on the field, is important on a mining point of view.

- To map carefully the main structural units of Precambrian rocks defined by Dr. M. BESAIRIE in 1964, but partly discussed by geologists surveying the country from that time : new hypothesis are proposed by private mining geologists and B.R.G.M. geologists, which are not in complete agreement with the BESAIRIE chronology. At last the investigation includes : recognition of the already known units, understanding of their relationship and setting up a good chronology.

- To look for an eventual spectral response of the bauxite deposit already known. Superficial deposits exist in this part of the Malagasy republic which are hardly differenciated on panchromatic photographs, using tone, texture and morphology. Therefore, some local experiments above bauxite deposits in France were promising with infra red colour photographs : probably due to granulometry and chemical compositions which influe on spectral response colour infra red enhanced the area where bauxites were known. The aim of the experiment was also to define the best spectral band or the more appropriate colour composite making possible the differenciation of bauxitic areas.

1.4 - Data requirements

1.4.1 - Periods

Only one set of images was required for the test site during the June-August period because it is the best season in the southern part of the Malagasy republic.

1.4.2 - Products

All bands of the multi-spectral scanner were required in positive print and bulk 70 mm.

1.4.3 - Cloud cover

In our proposals we required the best possible coverage during the mentioned period but, as Nasa thought this was not precise enough we have asked for images showing less than 20-30 % of clouds cover.

1.4.4 - Comments on data requirements

After this first experiment it seems very difficult to choose the good period of coverage : the eastern part of the island is very cloudy on the ERTS images we have received, and interpretation is not possible there. Nevertheless, on the same image, the western part is fairly good.

2. SCOPE OF ACTIVITIES

Because the launch of ERTS A was delayed, the coverage of the test site was realized in Octobre 1972, i.e. during a period less convenient on a meteorological point of view than the one scheduled in our proposal.

Delays of mailing being important, we received the first images in January 1973, and a second set in March 1973 ; this point is very important to mention because it explains why all the reports and mainly the type III report were not issued in the time scheduled by the convention.

2.1 - Images received

(see fig. 1)

ID Number	Date	Received	Product
1073.06201	Oct. 04.72	Jan. 01.73.	70 mn. MSS. 4,5,6,7
1073-06203	" " "	" "	" "
1075-06305	Oct. 06.72	" "	" "
1074-06250	Oct. 05.72	March. 02.73	" MSS 4,5,6
1074-06253	" " "	" "	"
1074-06255	" " "	" "	"
1074-06262	" " "	" "	"
1074-06264	" " "	" "	"

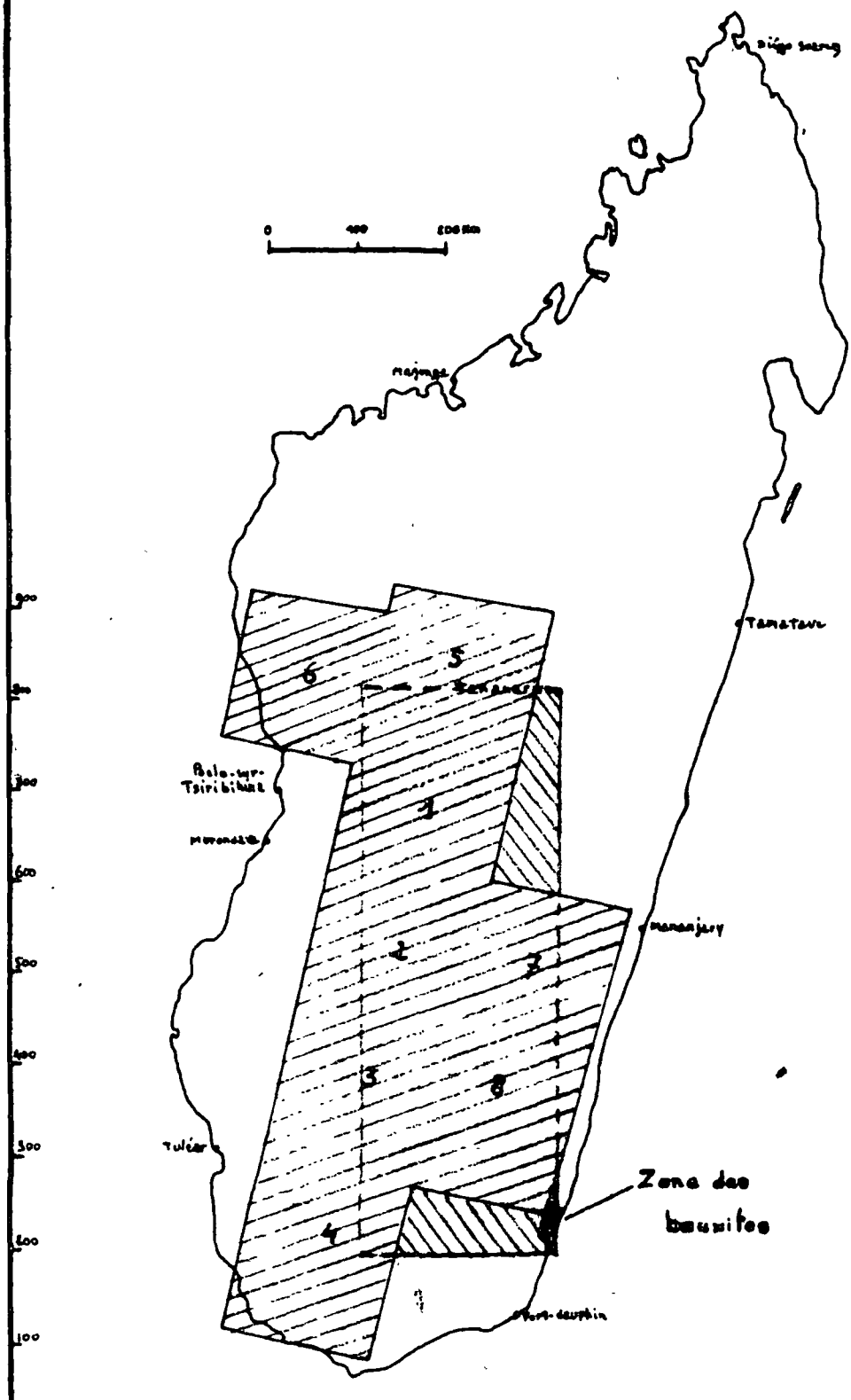
2.2 - Quality of the images

Quality	ID Number	Band 4	Band 5	Band 6	Band 7
XXXXXexcellent	1073-06201	XXX	XXXXX	XXXXX	XXXXX
XXXX good	1073-06203	XXX	XXXXX	XXXXX	XXXXX
XXXpretty good	1075-06305	XXX	XXXXX	XXXX	XXXXX
XX adequate	1074-06250	XXX	XXXXX	XXXX	not owned
X bad	1074-06253	XXX	XXXXX	XXXXX	-
	1074-06255	XXX	XXXXX	XXXXX	-
	1074-06262	XX	XXXXX	XXXX	-
	1074-06264	XX	XXXX	XXX	-

2.3 - Position of the images (see location map)

ID Number	Map references (see location map)	Cloud cover	Geographical description
1073-06201	7	20 % concentrated	the Ambalavao region (Andringitra area)
1073-06203	8	20 %	the southern part of the island between Betroka (South) and Ivohibe (North)
1074-06250	5	25 %	Area of Bevato (West of Tananarive)
1074-06253	1	5 %	the Itremo mountains (on the parallel of Morondava)

LOCATION MAP



LEGEND

not yet receipted area

covered area

numbering of images :

1 = 1074 - 06253 Erts
2 = 1074 - 06255 "
3 = 1074 - 06262 "
4 = 1074 - 06264 "
5 = 1074 - 06250 "
6 = 1075 - 06305 "
7 = 1073 - 06201 "
8 = 1073 - 06203 "

1074-06255	2	25 %	the Beroroha region (Mangoki river area)
1074-06262	3	10 %	western zone of Betroka, Onilahy river area
1074-06264	4	20 % scattered	Ampanihy region (South-western part of the island)
1075-06305	6	30 % scattered	the Bemaraha plateau, Maintiriano area (western coast)

2.4 - Comments on data receiption

The images are generally cloudy but make possible, excepting on the coastal area, interpretation.

Our experience above the Massif Central test site, in a basement area, clearly shows that the spectral band 7 is the most useful for surveying the tectonic in a such type of rock : we therefore regret the absence of band 7 for five of the eight images received.

The bauxitic area (see fig. 2), located at the North East of Fort Dauphin was not scanned by ERTS 1, making impossible the realization of the investigation concerning the eventual differenciation of such deposit by spectral approach.

2.5 - Activities during the investigation period

From the launch of ERTS to January 1973, (reception of the first images)

- Survey of the existing literature.

- Gathering of the necessary maps : geological, geophysical, pedological.

From January to May 1973

- Surveying the images received.

- Reporting : "Geological study in the southern part of Madagascar".

- Group seminar with J. CHANTRAINE and G. HOTTIN, two B.R.G.M. geologists recently back from the Malagasy republic.

From June to October 1973

- Surveying the images received.

- Enlargement of the images received at a 1/500 000 scale.

- Preparation of a mosaic of the whole area at a 1/500 000 scale.

M. FOURNIE, resident geologist in Tananarive, consults Malagasy geologists on our results. Group seminar with L. DELBOS and A. EMBERGER.

From November to January 1974

- Preparation of a tectonic map of the test site.

- Comparison of this map with all data available.

- Reporting.

- Attending a meeting (G. WEECKSTEEN) in Frascati - Italy, organized by the ESRO for the ERTS users. A document has been published during the meeting - partly concerning the Malagasy test site.

2.6 - Technics

All bands of the multi-spectral scanner were required in positive print and bulk 70 mm, black and white.

The survey of each image was made only by direct ocular vision because there was no overlapping of these images. Nevertheless, it has been found practical to observe two bands of the same image with a stereoscope in spite of the lack of relief, because of the magnifiance due to the lenses.

The survey has been made with prints at a scale of 1/1 000 000 and with prints at a scale of 1/500 000 which allowed to observe more details. These two scales had the advantage of being the same as the geological maps' ones and therefore allowed the superposition.

Concerning the enlargments, it may be said that they are excellent (see p. 7).

A photo mosaic of the test site has been made at the scale of 1/500 000. The plotting was easy because the geometric accuracy was good enough.

Concerning the ground truth approach, the writers not having acquaintance of the country, had some "échanges de vue" about structural and lithological aspects of the test site with Mr. CHANTRAINE, EMBERGER, HOTTIN and KUTINA, each of them giving a part of their field experience.

3 - SIGNIFICANT RESULTS

The enclosed map of linear structures clearly demonstrates the ability of spacecraft images in the tectonic domain.

The results obtained in geological mapping are good, and the enlargement of the 1/1 000 000 images to 1/500 000 make possible a good survey of the lithology even in the basement area.

3.1 - Analyse of images

In this section we intend to describe briefly each image received from Nasa. The Location map (see fig.) shows the respective extent of the sedimentary layers and the basement.

Image ID 1073-06201

A well marked linear feature is recorded on this image approximately North-South in direction along the western border of the Andringitra area. A second one, trending NE-SW is visible along the margin of the Tafia basement : both represent faults.

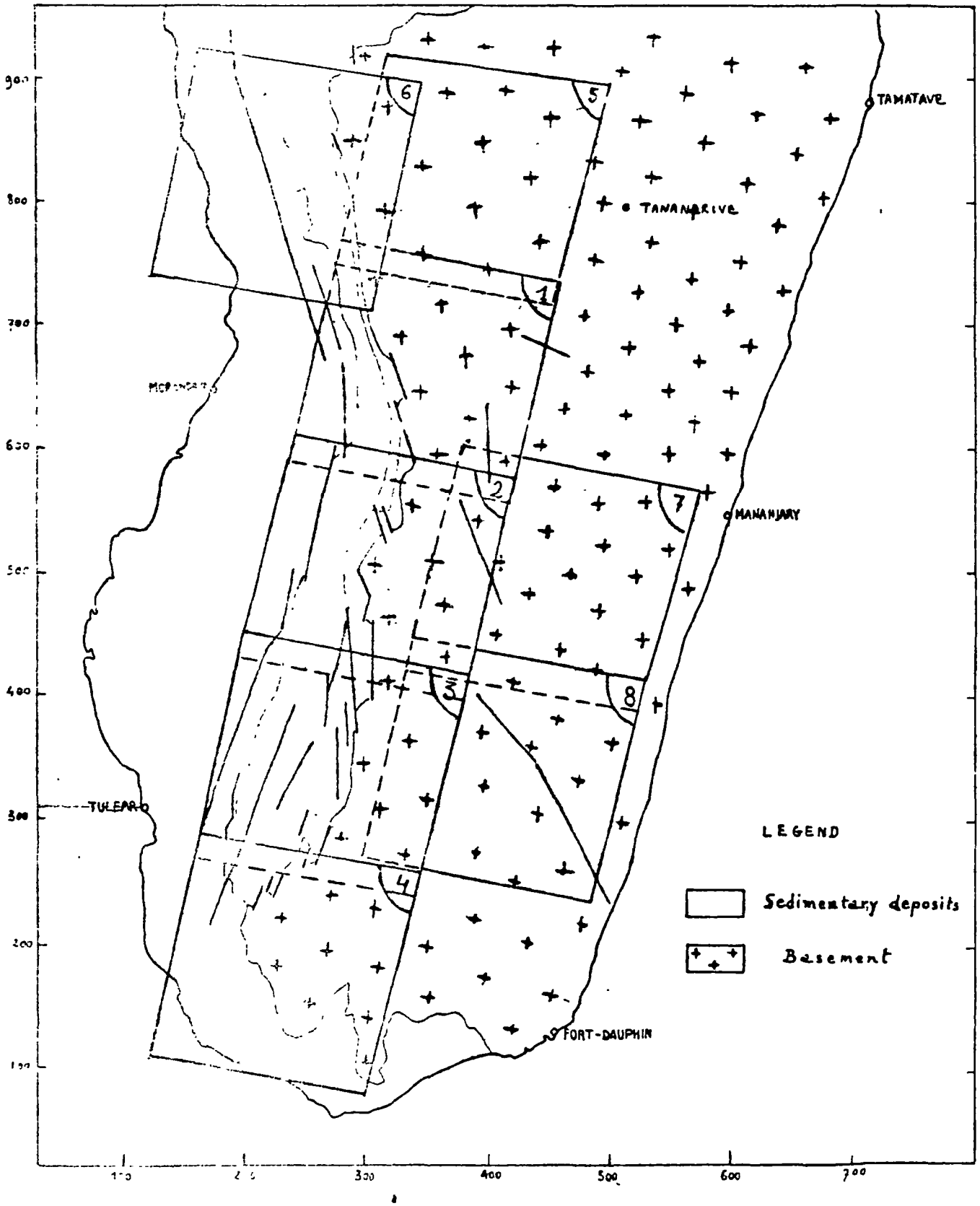
The quartzitic outcrops are clearly registered on the four spectral bands. A fringe of thick vegetation appears in the eastern part of the image on spectral bands 4 and 5.

Image ID 1073-06203

A complex faulting, NW-SE in direction, is the major feature represented on the image : it is the Ranotsara fault, of which continuity towards the South East is hidden by clouds cover.

LOCATION MAP

scale : 1/4.500.000



Therefore, where the fault is observed, we have carefully surveyed the granitic stratus and we have reached the conclusion that it is continuous from one side to another of the fault, an important point to understand the relationship of the units.

We then studied a core of granite and migmatic which is very fractured, transversal fractures being the most important. These lithological and tectonical details appear on bands 6 and 7, whereas they are hidden on bands 4 and 7.

Finally, a folded area is visible in the North of the image in the Ivohibe area.

Image ID 1074-06250

The north-western quarter of the image is not usable because the cloud cover is very important.

Elsewhere the outcrops of the Ambohiby granite and the Bevato gabbro are quite distinct and in the north-eastern part of the image the migmatic granite is clearly recorded and makes possible an accurate mapping.

An important linear feature, East-West in direction, runs close to the South of the Ambohiby outcrop : this data, quite obvious on the image, corresponds certainly with a fracture.

Image ID 1074-06253

On this image the limit between the sedimentary formations and the basement complex is enhanced by differences in the vegetation cover. The main units mapped on the 1/500 000 geological map are easily differenciated. A white band recorded in the western part of this image corresponds particularly with the Isalo II formation constituted by red claystones.

The basement area is tightly folded and the folding is enhanced by a quartzite bed. We have enlarged this scene at a 1/500 000 scale

to see how the mapping in such formation is accurate. The interpretation resulting from this enlargement is registered on fig. 1.

An important linear feature, directed approximately North-South, limits the quartzitic area to the East.

Image ID 1074-06255

On this image, the limit between a white tone formation to the West and a grey tone tightly folded unit to the East, corresponds with the unconformity existing between the basement and the sedimentary formations. Locally, along the main river crossing the scene, quaternary sediments, being registered in a very white tone, are distinct on bands 4 and 6. This tone is probably due to a change in the composition of the alluvial fan which comes from the basement area.

In the basement area the strates of oriented granite, cipolins and quartzites are very clearly recorded and make possible an accurate mapping. Figure 2 represents the interpretation of the scene enlarged at a 1/500 000 scale : this enlargement makes possible the comparison with the 1/500 000 geological map of the Malagasy republic.

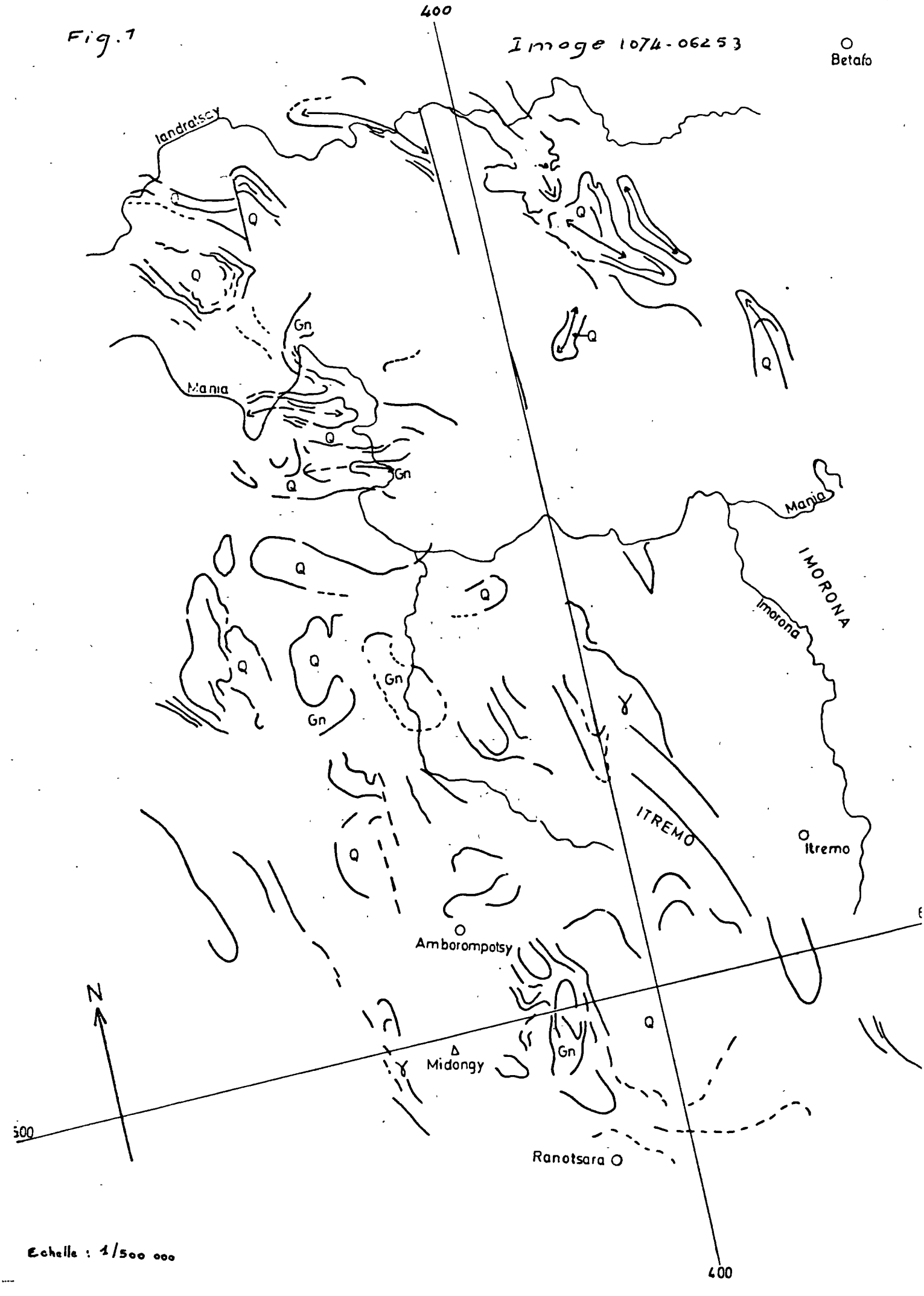
Image ID 1074-06262

On this image the boundary between the basement complex and the sedimentary formations is quite clear and is interpreted as a faulted contact nearly North-South in direction.

The basement is tightly folded as it appears on the interpretation realized from an enlargement at a 1/500 000 scale. (fig. 3). In the north-eastern part of the scene, outcrops of lateritic claystone are distinct from the basement, the hydrographic pattern and the tone being characteristic.

In the South of the image the Vohibory basin is recognizable. The western part of the scene covers the sedimentary formations and the differences in tone, even if they are very slight, make possible the mapping of the known levels (Jurassic and Cretaceous in age).

Fig. 1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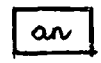
LEGEND OF FIGURES 1-2-3-4

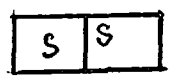


Anorthosite

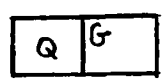
Granite

Stratoid granite

Migmatite and granitoid migmatite



Syenite



Quartzite

Cipolin

Charnockite

Undefined

Gneiss

Image ID 1074-06264

In spite of the cloud cover and the haze effect, the granites and the surrounding well beded migmatites are easily observed in the basement area. Fig. 4 is the interpretation of the enlarged image (1/500 000).

In the sedimentary basin the differenciation between Eocene and Cretaceous is possible, the Eocene being registered in a black tone.

Image ID 1075-6305

Clouds cover the whole image but make possible observation in a few places.

A fractured limit - between Jurassic and Cretaceous formations, is the main feature of the scene - outlined on spectral band 5 by a strong change in the grey tone.

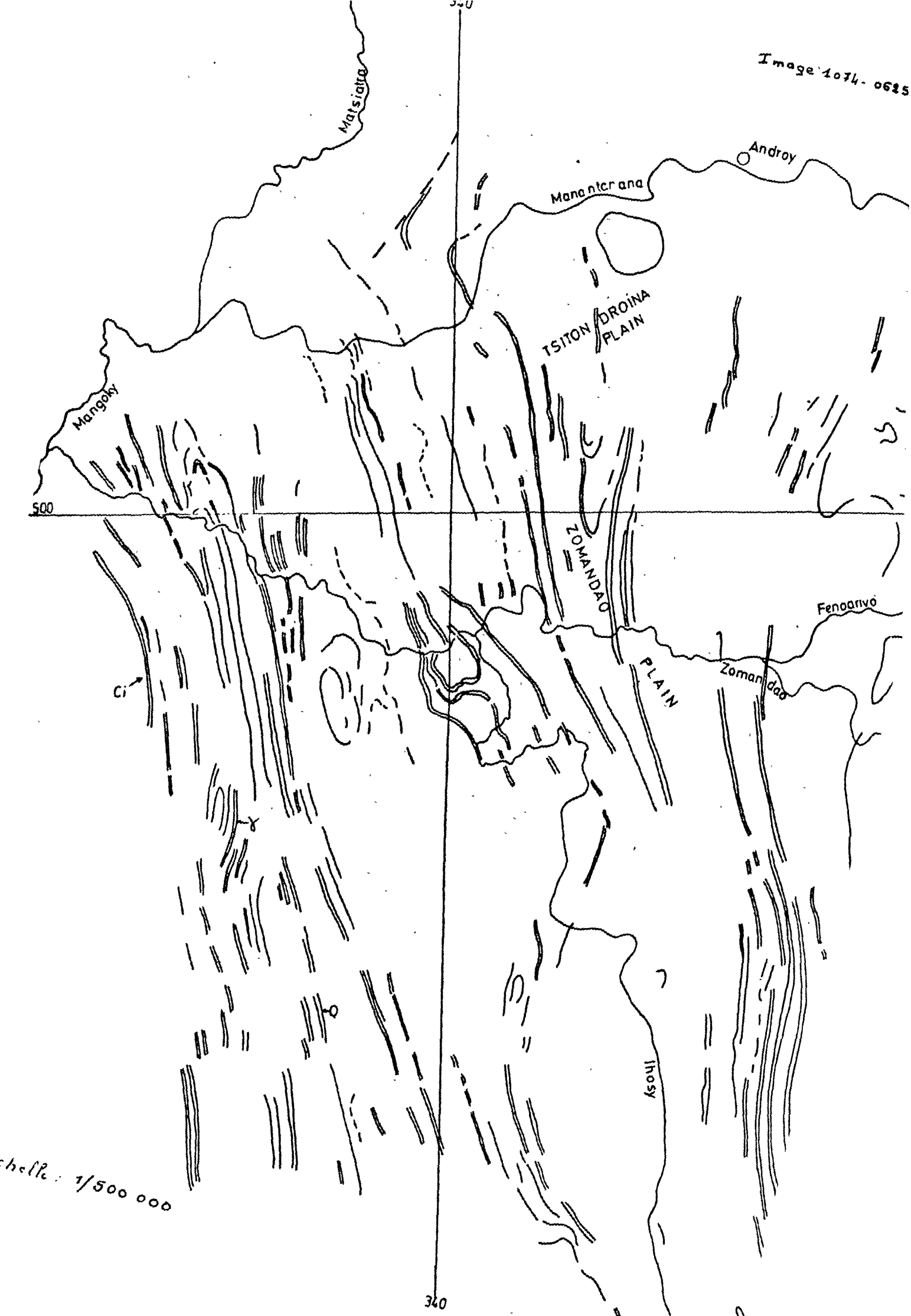
3.2 - Synthesis of the results

Results obtained during this investigation concern structural features and lithology.

3.2.1 - Linear features

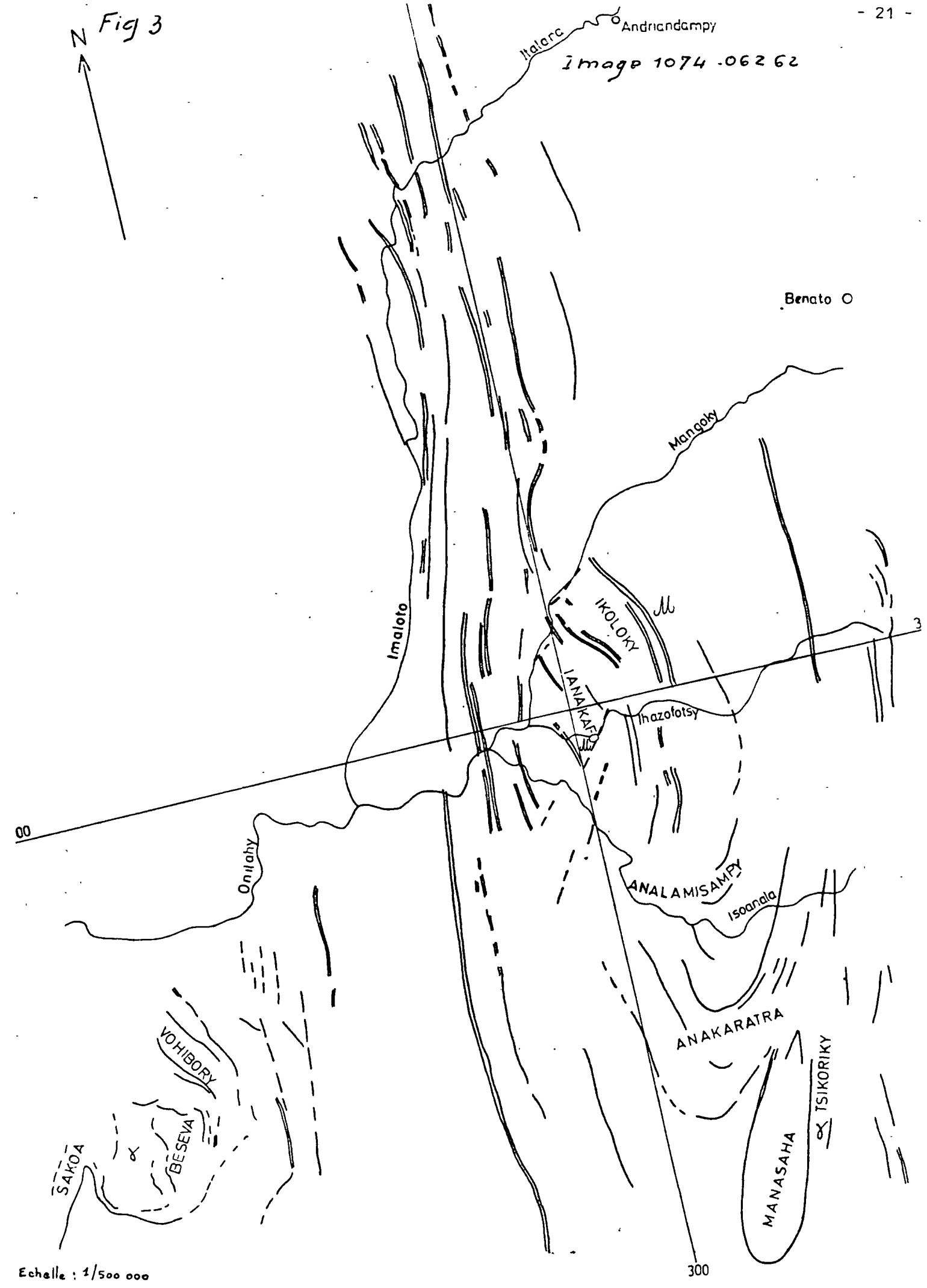
The experience we have in other investigations using ERTS imagery (Massif Central - France) indicates that the main part of the linear features recorded on the orbital views correspond with tectonic data. We also assume that nearly all the linear features visible on the Malagasy republic images have a structural origin. The main data observed are :

a) A main faulting zone, running along the western border of the Andringitra and the Vohibe area, is recorded on ERTS imagery and extends to the North between the Itremo and the Imorona (images 1073-06201 and 1074-06253, fig. 1). The part of this lineament observed



Echelle : 1/500 000

Fig 3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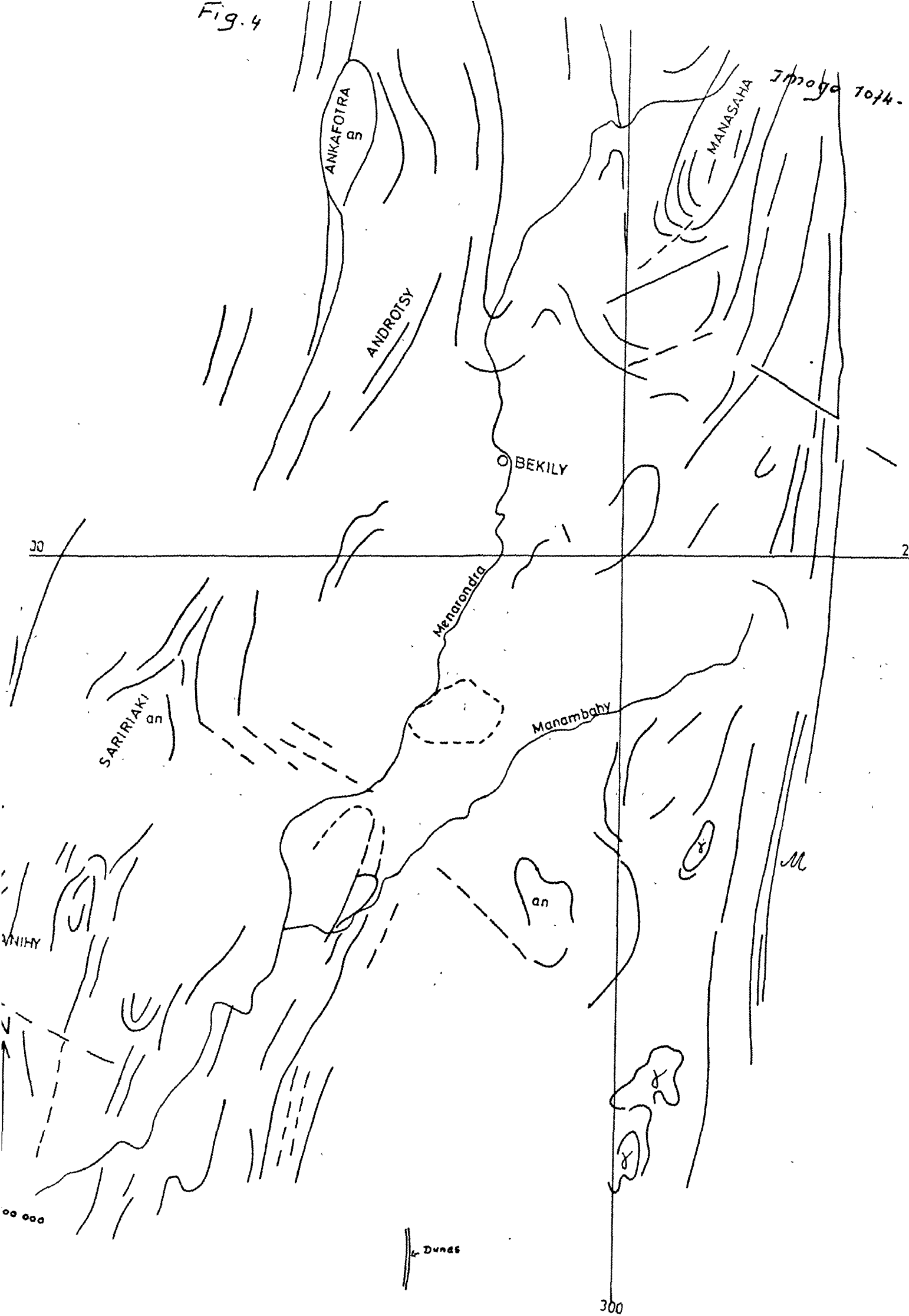
Fig. 4
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Dunes
300

between the Itremo and the Imorona, would be according to J. CHANTRAINE and G. HOTTIN (oral communication), the trace of an overthrust towards the East. On the BESAIRIE 1/500 000 geological map, this lineament does not exist and its trace runs through different formations i.e. from South to North from Maropaika (on the road from Vondrozo to Ivohibe). But it follows the limit between the Antambohobe migmatites (Graphite system) to the West and the Ikalamavony gneiss (Vohibory system) to the East. It then corresponds with the syenite (with pyroxene) forming the Ivohibe and Andringitra massives. Note that EMBERGER (1953) mapped numerous faults along this linear feature (geological maps 1/200 000, of Tsitondroina-Solila.

Towards North, it runs through the granites named "andringitreen" by H. BESAIRIE. In the area where this lineament separates the Itremo and the Imorona, it bounds the migmatitic granites to the East and the micashistes to the West : according to EMBERGER (p. 14, 1955) the Imorona depression is a low weathered surface in the granitic complex where numerous traces of faulting are observed. A gravimetric investigation (R.P. CATTALA) confirms this fracture zone, (EMBERGER 121.1) and the presumed overthrust could represent a more recent tectonic, the youngest Itremo quartzite being overthrusted on the basement graben.

North of the Mania river - where the Imorona migmatic granites end - this linear feature cuts the micaschists (Itremo area).

Finally, the today geological knowledge of the area (CHANTRAINE-RADELLI) makes it possible to think that such a lineament, 300 kilometers long, exists along the Andringitra craton, but new field works are necessary on this topic. Future mapping programs must take this into account as geologists having achieved the survey of this region assume that there are some local evidences of a tectonic event existing along this recorded ERTS linear feature.

b) The Ambalavao - Tafia area is a linear feature visible on ERTS images, East of the Itremo-Imorona fracture. It runs North East-South West, about 110 kilometers from the Ambalavo village (to the South) to the granitic Tafia massif (to the North). This lineament

affects the gneiss and migmatites (Ambatolampy group) which belong to the graphite system according to the BESAIRIE geological map, but its trace passes in the South between the Andringitreen granites (to the West) and the Lakera migmatitic granites. To the North of Fianantsora it bounds the Tafia massif, constructed in the same migmatitic granites.

Finally, the only field evidence of such a tectonic feature is a 10 kilometers fault located to the North East of the Tafia massif and discovered by geophysical investigation, (geological map 1/500 000 No. 7) : this fault follows the trace of the ERTS recorded lineament.

c) The Ikalamavony (North) Amboangy (South - along the Ionaivo river) lineament is a complex system of faults roughly parallel to the Andringitra one and ending in the South on the Ranotsara fracture. The southern branch of this fracturing is recorded on ERTS image from Amboangy, a village located 240 kilometers North of Midongy-West (sheet N). 7), to Lamosina, North West of Ambalavao. It runs North-South with a change towards the North-East in the North. It affects the gneiss and migmatic of the Vohibory system in the South and follows a quartzitic bed and some scattered stratoid granites in the northern part. The Mananantanana river locally gives a morphological evidence that a fault could exist along this linear feature because of a change in direction following the ERTS trace on about 10 kilometers.

The western branch of this system, from the Ikalamavony plain to the North of the Fenoarivo river at the South, follows the contact between the gneiss and migmatite (Vohibory system) and the Tranomaro group (migmatites - gneiss - Androyan system). This contact is considered faulted on sheet 5 and unfaulted on sheet 7 of the 1/500 000 geological map. The linear feature registered on ERTS image makes possible a choice between these two possibilities.

Finally, a third branch exists in the North between the eastern and western ones. It runs into the Vohibory system gneiss and migmatites and we have no field evidence of its existence. This North-South fault ends near Ikalamavony.

d) A complex faulting system called the Ranotsara-Ranomena trends across the island following a SE-NW direction which changes to

a N-S one near Ihosy.

According to the BESAIRIE map, this fault could be a major fracture separating the Androy and Vohibory systems. Nevertheless, recent works outline that this fracture is not very important from a paleogeographical point of view, the formation of both sides having the same age. This hypothesis is interesting on a mining point of view and geologists are looking for data to confirm recent detailed magnetic investigations at a scale of 1/100 000. It is therefore impossible to conclude the topic and minor its paleogeographical importance. The interpretation of ERTS imagery seems of some interest, but does not formally prove anything : on both sides of the fracture are recorded several beds which look alike. These beds correspond with stratoid granites and their continuity is favourable to the last above mentionned idea. On the other side, the fracture is clearly registered on ERTS, which at last indicates that it is a major tectonic fracture, mainly composed of two parallel faults running along 150 kilometers before disappearing under the cloud cover.

e) The North-South Betroka-Ihosy lineament separates a fractured zone to the East from a different type of zone (facies, morphology, structure) to the West.

The fractured zone, named Kalambatitra, is located in the South of the Ranotsara-Ranomena system. It is characterized by a North East fault in the North and East-West one in the South. These two types of fractures are already known, at least partly, on the field (geological map, sheet No. 7). The main Betroka-Ihosy fracture affects the gneiss of the Androyan system, partly following a contact between cordieritic gneiss and leptynites (A^2-A^4)*. In the North of Soasirano, this lineament is a double one and the Ihosy river is running between the two branches which are in the cordieritic gneiss A^{2*}. Along this part of the linear feature, scattered faulting traces are known on the field (sheet No. 7).

Let us mention, West of this alignement, that the basement, mainly represented by the $A5^*$ leptynites of the Androyan system, is affected by a faulting NE-SW in direction, conspicuously outlined by the river's course. (Imaloto and Mangoky rivers).

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* Notations of the 1/1 000 000 geological map.

f) The lineament trending North-South to the West of the Horombe (leptynites - Androyan system) bounds this unit to the leptynites forming the graphite system (Ampanihy). On the field, geologists have locally found evidences of this important faulting. Towards the North it separates the basement from the Sakamena series.

Let us point out a possible closure of the Androyan series towards the North in the area NW of Mangoky-Matsiatra confluent, under sedimentary cover (image 1074-06255). This fact allows to hope (if proved) from ERTS imagery, to translate deep structural elements, under rocks cover, on the surface.

In the West of the Bemaraha plateau (sheet No. 6) the North-South Ilovo fracture, which separates the Jurassic from Cretaceous, is clearly visible on ERTS images. Towards the South, on the Mangoky river, (West of Beroroha), on the Fiherenana river, and near Tulear, on the Onilahy river, the linear features observed on ERTS images correspond to the trace of this important lineament which runs between the Isalo II and III series.

g) In the West and South-West of Tananarive, in the northern part of the test site, an important East-West faulting has been recorded on ERTS images which is not pointed out on the geological map : the first one is going from the Ambohiby massif -to the West- to the Itasy mountains ; the second follows the Mahajilo river. Further South, two other East-West lineaments are visible, one along the Mania river, and the other South of Amborompotsy, paralell to the road Malaimbandy-Ambositra. This later lineament is most interesting to discuss upon, as it corresponds with a gravimetric anomaly outlined by R.P. CATTALA (see EMBERGER 1955). This fracture, which is not truly visible in the field, according to EMBERGER, could have an importance in the mineral history of the area : in the northern part, stratoid granites, without berylium, are croping out, and in the southern part numerous berylium bearing pegmatites are found in the migmatites. In the same area, faults indicated on RADELLI's map have some extention.

3.2.2 - Lithology

The comparison of MSS images interpretation with the

geological map (BESAIRIE 1969) shows :

- a good correlation with the sedimentary formations,
- an irregular conformity with the basement units.

These are two conclusions reached in a previous investigation.

The border of the sedimentary basins is well recorded on ERTS imagery and also the subdivisions inside these units because of grey tones and other criteria related to the vegetation.

Distinctions in the basement are possible when the lithology is quite different - it is not very frequent in Madagascar, rock types being mainly leptynites, gneiss and migmatites - or when contacts are faulted.

Finally, superficial deposits are sometimes distinct and some areas covered by lateritic shales are recognized on ERTS images : this allows us to think that there is a possibility of surveying the problem of bauxite differenciations from the surrounding, using colour composites or ratio technics, used by ROWAN to enhance tones in weathered formations above a gold mining area.

A - Criteria which make possible the geological mapping in the Karroo and post-Karroo formations are the following :

a - Sakoa (K1)

Briefly constituted by red claystones and black shales, it appears in a pretty dark grey (images 1074-06255 and 06262). Locally, on image 06255, the tone is darker on the top of the formation, but this phenomenon is not explained by a known geological change.

b - Sakamena (K2)

Red coloured formations are dominant in this serie which appears in a light grey (images 1074-06253, 06265 and 06262). It is obviously lighter than the basement when they are both in contact.

c - Isalo (I_1)

Diaclased, light coloured sandstones and siliceous veins or

pseudo veins of quartz are found in this series. The grey tone is the same as that of the Sakamena (images 1074-06253 and 06255 k spectral band 5) in the areas where the two formations are covered with a similar vegetation i.e. Savannah of trees and bushes, with locally a thick forest on arenaceous acid soil. Nevertheless, on image 1974-06262 it appears in a grey darker than the one of the Sakamena - on spectral bands 4, 5 and 6 - as in this area, it grows on the Isalo a low sclerophylle forest of a damp type.

d - Isalo I_{11}

Red claystones, and sometimes green and light coloured sandstones, form this series which is recorded on ERTS images in a grey tone, lighter than the one in Isalo I_1. The explanation of this is that the dominant red coloured one is reflected on spectral band 5 where it becomes white. The same phenomenon is observed on band 6 but not as clearly. On band 4 it is also very light. Images 1074-06255 and 1074-06253 illustrate that.

e - Isalo I_{111}

The facies are similar to those of the Isalo I_{11} in the continental series, and are calcareous in the marine series.

The Isalo I_{111} appears in a darker grey than that of the Isalo I_{11} and I_1. (Images 1074-06253, 06255, and 06262, bands 5 and 6).

f - Jurassic (J)

Is essentially constituted of limestones which are recorded in a light grey tone on the ERTS image 1073-06203.

g - Cretaceous (c)

Limestones and sandstones which form this system are registered in a pretty high grade of grey on image 1073-06203, but it appears nearly in the same tone as J and I_{111} on image 1074-06253.

h - Eocene (e)

This unit, essentially calcareous, mainly outcrops in the Mahafaly district (SW of the island) and is recorded on ERTS images in an unsignificant tone because of clouds and a vegetation cover.

To resume, it is difficult to assign a definite grade tone to each formation, but differences in grey tones make possible a geological mapping at a reconnaissance scale in sedimentary formations.

B - In the basement the ability of ERTS images in the geological mapping domain is very irregular. Partly because rock types are not very different : migmatites and granites for instance, but also because the colour of the rocks morphology, hardness, weathering and vegetation are not contrasted enough as they quite often are in the sedimentary formations. As far as some of these characteristics are different between adjoining formations - and this is not a rule in the basement rock types - the boundaries appear accuratly. Some examples are pictured on the map presented with this report and on the enlargement (1/500 000) interpretations. They concern :

- Some kinds of rocks which appear much more fractured than others : migmatites and granites of the Kalambatitra area and of the Vohibe region.

- Some bodies are well delineated, colour and morphology being distinctive : the Bevato gabbro, the Ambohiby and Tafia granite. This suggestion may make it possible to distinguish different kinds of granites.

- Quartzitic beds and stratoid granites are generally outlined from the surrounding rocks as they are folded and regularly stratified. Folded areas are distinct from the other regions of the basement.

- Large bands of cipolins are recorded on ERTS images and a careful mapping on the enlargements (1/500 000) make it possible to outline unknown extensions of this unit which are interesting on a mining point of view. For instance, it seems that the cipolin band is running in continuity between Betroka and the Mangoky river and does not close in a gulf in the Zomandao river area as indicated on the 1/1 000 000 geological map, In the North this series is known for its Niobium, Tantal,

Beryllium bearing pegmatites ; in the South the ONU prospection found interesting shows of rare earths. The continuity, suggested by the ERTS images interpretation, if proved, is therefore favourable to a prospecting all along this band.

Finally, if different kinds of rocks may be locally distinguished, the accuracy of these lithological boundaries is unsteady and a certain carefulness is necessary in their drawing.

3.2.3 - Chronostratigraphy

After having reviewed the ability of ERTS images in the domain of tectonic and lithology, we may pose the question to know if the results obtained in these two domains make it possible to give advice on the chronostratigraphic problem as stated in our proposals.

The ERTS images make possible :

- To delineate, locally, different "facies" into the basement in using grey tones. Unfortunately correlations between two similar facies not adjoining are hazardous.

- To outline the main lineaments sometimes bounding different units.

- To point out the existence of different tectonic styles in some areas (Vohibe - Kalambatitra, etc.).

The non overlapping of images, which does not allow the stereoscopic effect, is a very limiting factor because it is impossible without the perception of the relief to observe eventually the relationship between formations.

For this reason, the interpretation deduced from the ERTS images, if it reaches to important but local conclusions, cannot give a whole idea of the chronostratigraphy of a country.

3.2.4 - The bauxitic problem

In our proposals, we have offered to investigate the ability

of ERTS images and to differenciate bauxite from the surrounding. The Manatenina bauxite deposit is a 120 000 000 tons occurrence with 38 % Al_2O_3. We thought that the spectral differences might have made it possible to outline the area of bauxite from non bauxitic laterite, this possibility being important all over Africa. Unfortunately, the eastern coast, where the deposits are located, is not covered by ERTS images.

3.3 - ACCOMPLISHMENTS

Details pertaining to the usefulness of ERTS data and analysis relative to the test site are particularly valid in the structural problems. We have noticed that they complete and improve acquaintances and even corroborate some theories ; that is the case for East-West lineaments put in light :

- the big lineament West of Tananarive is in a western extension of a fault seen on the field by L. RADELLI,

- this lineament is conform with the G. HOTTIN's opinion as, according to him, it is separating two very different areas,

- this lineament is a confirmation of the Dr. J. KUTINA's theory of East-West fracturation of Madagascar, and is situated where this author expected to find it. According to that theory, such discoveries are promising on a mining point of view.

Another example which completes previous data is a lineament South of Amborompotsy corresponding to a gravimetric anomaly outlined by R.P. CATTALA, but not pointed out by a fracture truly visible on the field (see p. 17).

If comparing results obtained with existing geological map (scale 1/500 000 - 1970) :

- it is obvious that fracturation is much more important than indicated (see sheet 5),

- the river courses as seen on ERTS imagery avoid the drawing blunt and frequent right angles allow a better vision to detect fracturation,

- concerning lithology, it is difficult to give an opinion. According to the photographical aspect, some zones are easily distinguished : old granites of Tafia area, old craton of Kalambatitra, quartzitic zones etc.. The probably most effective result lithologically is the possibility to extend or interpolate strata, (e.g. stratoid granites, quartzites and cipolin beds). This must be checked on the ground, and from this mapping new mineral researches could be forecast (see p. 20).

The bauxitic area was not covered by the test site, but on the other hand, lateritic shales seem to be well delineated in some areas and this is a favourable point.

4 - CONCLUSIONS

This attempt to evaluate the geological interest of the ERTS images taken above in the southern part of the Malagasy republic, confirms its anticipated value for geoscientific study. Most of known fractures are identified and numerous new observations are made on these images. Some of them extend or relay known fractures. Many others are totally new ones, but scattered field observations make it possible to assume that they correspond to reality.

In the domain of lithology, different types of rocks are distinguished, but the results are generally better in the sedimentary formations than in the basement, because the characteristics which allow the separation of units on ERTS images are more contrasted in the sediments.

Our attemps to establish a chronostratigraphy was not realistic as ERTS images are not stereoscopic and a grey tone does not give a signature of the units. From such a survey appears a convergency of the results obtained with some new general ideas. This makes it possible to draw up the conclusion that ERTS imagery allows to help enormously the conventional methods and gives a complete understanding of the major structural elements and tectonical events. At last, the impact of ERTS usefulness economically, socially and technically, as it relates to the test site and our organization is really important.:

- seminar groups with geologists who worked in the Malagasy

republic demonstrate that people prefer discussing upon ERTS observations rather than upon classical results of aerial photographs. They find something new and hope discoveries from it. From such seminars facts become certainly clearer.

- excepting the fact that it was not possible to observe the test site in relief, the excellent quality of images permitted sufficient approach of details and mainly a large view of synthesis which does not exist in classical methods. This may help enormously the understanding of geological features of countries and gain a lot of time chiefly in new countries,

- at present, no conclusion may be drawn on the test site study from an economical point of view. The primary objective expected to investigate, the "Bauxite prospect", was not covered by ERTS imagery.

Concerning other mineral prospects, the appearance of the North-South continuity of the cipolin zone between Betroka (South) and the Mangoky river (North), might deserve a new prospection of this area (see p. 20).

5 - FUTURE ACTIVITIES

The B.R.G.M. activities in the Malagasy republic not being important at the moment, nothing has been forecast. We therefore expect the Malagasy geological survey to make a profit of this survey.

6 - APPENDIX

Only one paper has been prepared :

"Contribution des images ERTS à la connaissance géologique sous différents types de climats (France, Togo, Dahomey, Madagascar"). B. KOCH, J.Y. SCANVIC, G. WEECKSTEEN - FRASCATI (Italy) January 1974.

This paper is to be published in the proceedings to be printed by the ESRO in the next coming months.

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GEOLOGICAL STUDY
IN THE SOUTHERN PART OF MADAGASCAR

LITHOLOGIC AND TECTONIC SCHEMA FROM ERTS IMAGERY

Approximate scale : 1/1 000 000

B. KOCH OCT. 1973