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Petrographic Study and Geological Structure of the Bekitro Area, Precambrian of Southern Madagascar

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A B S T R A C T

Bekitro is located in the south of the Androyan domain, at about 55 km south-west of the Bekily district. The update need of the old geological map carried out by Noizet in 1958 allows us to make the study of the structural geology of this region. The purpose of the study is to obtain petrographic, structural and geodynamic information. 03 groups characterize petrography: groups of the basic gneisses (biotite gneiss, amphibole, garnet, graphite, phlogopite and +/- sillimanite and kyanite); Group leucogneiss, compound gneisses, quartzites and pegmatites and group slickenside rocks (dykes basaltic and veins of the quartz). Structurally, this zone is very disturbed, folded, often fractured and sheared. It has three major orientations of foliation of which S1, directed by WNW-ESE towards the northern part with a granulite faces with amphibolite. This part has undergone a D1 deformation. In the zone center, this orientation of the foliation becomes S2, N-S, marked by the amphibolite faces and D2 deformation. The last part is testified by foliation S3, directed ENE-WSW; It has a granulite faces with a catazone metamorphism and shows a D3 deformation. The kinematics indicators present in this zone are the folds of type the sinistral and laid down, the normal layer and opposite, the fissures and haulage.

Keywords: *Bekitro*, cartography, *petrography, structure, lithology, deformation*.

Introduction

Previously, Madagascar was a supercontinent that was formed in the Neoproterozoic (-600 million years). It was located in the southwestern Indian Ocean, between 12° and 24° south latitude and between 42° and 50° east longitude in the central part of Gondwana [Fröhlich F. 1996]. The Upper Carboniferous (-257 million years ago) fractured after three movements (rifting, spreading and insularization) which led to the separation of the Big Island from Gondwana [Regnoult J.A et *al*., 1996]. This separation causes the resemblance between the geology of Madagascar and the evolutionary history of Gondwana which was marked by the presence of this double metamorphic intures [Katz M.B, 1974]. At the end of this resemblance, the geology of Madagascar is divided into two parts: the first is the Phanerozoic due to the sedimentary formation and the magmatic (or plutonic) formation that covers the western third of the island and the second is the Precambrian also called the crystalline basement composed of metamorphic, granitic and magmatic crystalline rocks occupying the eastern two-thirds [Caen V. M, 1979; Besairie H, 1946].

The separation and geochronology of the crystalline terrain of Madagascar is an unsolved problem for the geologist because of the insufficient updating of the geological map, the improvement of studies of the Precambrian terrains due to the advancement of current technology and advanced structural models. This is why the World Bank and the Malagasy State have supported the mapping project aims to update the geological map of Madagascar and their data [Roig.J.Y et *al*., 2012].

At the end of this project clarified that the Precambrian of southern Madagascar is divided into three domains: Vohibory, Androyen and Anosyen [Razakamanana, 1999; Windley et *al*., 1994] and noted that the Androyan domain is bounded to the west of the Ampanihy shear zone and to the east of the Beraketa shear zone. The Androyan domain is composed of an intercalation of felsic volcanic rocks, psammitic to pelitic paragneiss, graphitic gneiss and siliceous limestones. The age of protolithe varies between 1200 Ma and more than 2000 Ma [Vachette and Hottin, 1979; Cahen et *al*., 1984; and Windley et *al*., 1994] and in addition the Bekily composite block is included in the formation of the Androyan domain [Roig.J.Y et *al*., 2012]. This block has complex structures that may originate from the compression of the Tranoroa Formation to the south and the Menarandra Formation to the north [GAF/BRG, 2008].

In our time, Madagascar has become a center of mining projects and non-renewable natural resources underground by high potential investors. Faced with this exploitation, investors are drawing up new maps of the geological, metallogenic and industrial mineral syntheses of Madagascar. The indicators in these maps explain that the basement of Madagascar is strongly tectonized and metamorphosed during the Gondwanian oregenesis.

Inadequacies of the data in the geological maps concerning the Bekitro zone in the Bekily district include in the formation of the Androyen domain, the complexity of the structure, the kinematics of the terrestrial materials and the degree of metamorphism decreasing from east-west, ranging from granulite facies to amphibolite facies which prompted me to make the petrographic and geological structure study of the Bekitro zone, Precambrian of southern Madagascar aims to determine the petrographic, structural and geodynamic characteristics of this area in order to complete the missing data on the geological map of Madagascar.

Materials and methods

Presentation of the study area Localization

Our study was carried out in the Rural Commune of Bekitro, bounded by the rural communes of Tsikolaky and Manakompy to the north, Belindo Mahasoa to the northeast, Bevitsika southeast, Tranoroa to the southwest, and Beteza to the northwest, located 55km southwest of Bekily district, Androy region in the southern part of Madagascar. In the UTM projection system in Madagascar, it is located between latitudes 7,289,960 to 7,273,760 South and longitudes 519,065 to 530,429 East (figure.1).

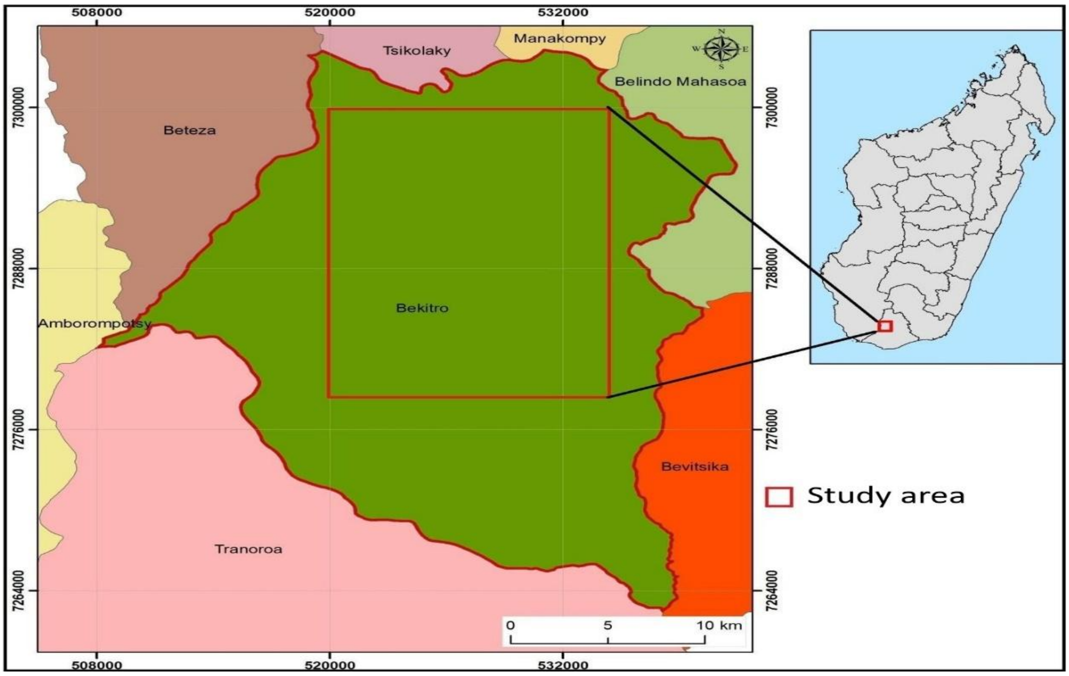


Figure 1: Study area location Map

Climate of the study area

This area is characterized by a tropical semi-arid climate with the average annual temperature around 23°C and 24°C. It undergoes strong wind almost permanent, drying from the south "Tiokatimo" and the presence of periodic drought every eight to ten years. The climate of this area is divided into two seasons: rainy from November to March with an irregular rainfall rate, poorly distributed and decreased from the northern zone to the extreme south and the dry season from April to October. ». The Bekitro area is dominated by a very uniform peneplain relief.

Geological presentation of the Bekitro area

Information on the geology of the Bekitro area is very insufficient. However, the Bekitro area is located in the Bekily Formation included in the Androyen domain. This domain is composed of an intercalation of felsic volcanic rocks, psammitic to pelitic paragneiss, graphitic gneiss, siliceous limestone [Vachette and Hottin 1977; Cahen et *al*., 1984; Windley et *al*., 1994] and the Bekily composite block [Roig et *al*., 2012]. The Bekily Formation is an amalgamation derivative of terranes displaced during the two phases of the Pan-African orogeny [Ashwal, L.D. et *al*., 1999]. The Bekitro terrane is known from the outcrop of the Manambahy anorthosite massif [Noizet, 1952; Nicollet, 1988; GAF/BGR., 2008; Roig et *al*., 2012]. This anorthosite massif of Manambahy has a subcircular shape (figure2), crossed by the MANAMBAHY river, consisting of homogeneous petrographs and surrounded by: graphite, quartzite, grenatifere and gneiss banks. There is also the existence of amphibolites on the western part of this terrane. Basaltic protrude on the edge of this river [Noizet et *al*., 1958; Roig et *al*., 2012]. The set of gneiss-anorthosites-granites of Bekily justify the tectonic movement giving deformations in scales of the lower crust.

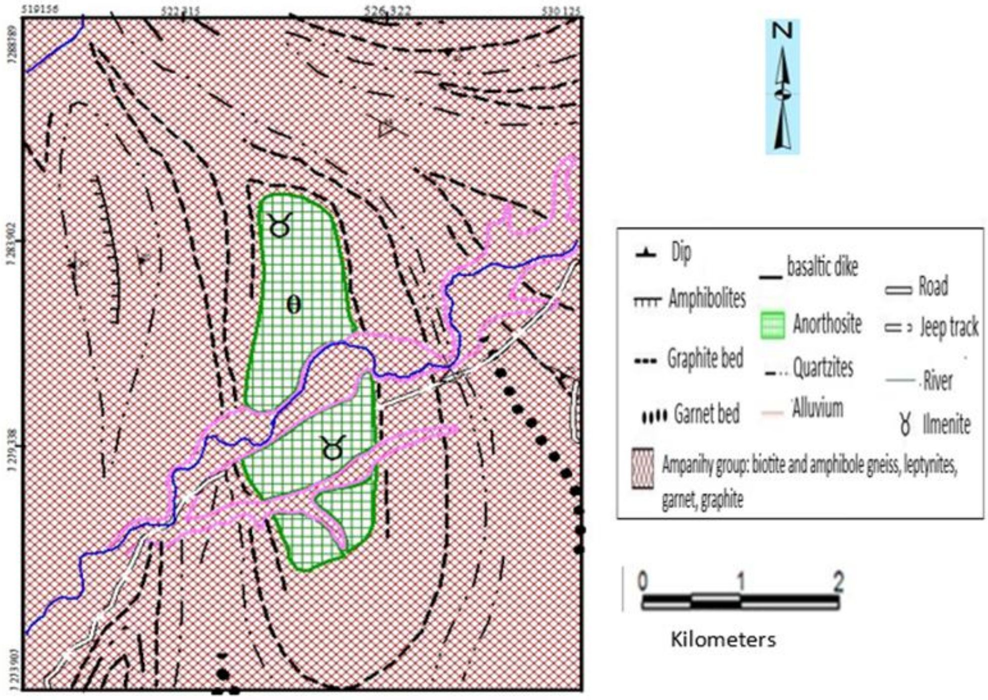


Figure 2: Geological map of the Bekitro area, extract from the Bekily sheet HI 60-61 (605) (Noizet et *al.* in 1958 cutting and digitizing by Ramanampison, 2015 (in press).

Methodology

To carry out this work, our method is divided into three stages:

Literature searches

The purpose of this technique is to collect information and data on previous studies carried out in the study area. It is divided into three stages:

Consultation of existing geological maps

The maps consulted are the geological maps at a scale of 1:100,000 of the sheet FG-HI (60-61) of Noizet et *al*. in 1958, that of Razakamanana Théodore in 1999 and GAF/BGR in 2008. There are also maps at the scale of 1:1,000,000 that of Windley et *al*. in 1994 and the geological map of Madagascar at the scale of 1:1,000,000 (PGRM, 2012). These maps provide more information about the geology of the study area.

Acquisition of satellite images

We use the image of Landsat 7, ETM (Enchanced Thematic Mapper) has 06 bands and the Google Earth image, whose plath/row is 158/073 that were downloaded from the internet. After the treatments, these images make it possible to know the information on the petrographs and the structural of the study area.

Map Processing

This processing is based on the uses of different types of software such as: Stretching, Envi 4.7, filter, MapInfo 8.5, Stereonet, Pink Diagram and Spot. This software makes it possible to make a map by including the necessary information to be able to process the data obtained.

Stretching

It is a linear spreading of the raw images obtained to improve their quality, their readability in order to facilitate reading.

Envi 4.7 (Environment For Visualizing Images)

This software is used to visualize and analyze remote sensing images. It is based on dynamic equalization and spreading, principal component analysis, banding ratio and filtering. The application of this software allows you to make geometric corrections, classification and map layout.

The filter

The image obtained after processing with the ENVI is further processed using a filter of the composition of bands 1 to 6, which is used for the localization and extraction of lineaments.

The MapInfo 8.5

MapInfo is used to calibrate, create databases for all desired map processing. Calibration is a method of using previous geological maps and satellite images to compare old data with fieldwork.

The Stereonet

It is used to project planar and linear information collected in the field and also to identify the folding shapes encountered.

The Spot

It is used for the counting of lineaments (watershed lines, faults, rivers and linear geological structures), to calculate lengths to determine directions and orientations.

Field work

The purpose of this method is to: verify the bibliographic data collected and the acquisition of new geological data concerning the study area. It allows us to put ourselves in direct contact with the outcrops, and to see the realities closely, in order to reinterpret the geology of this area. This method is based on the geological section crossing the target area (figure.3). The length of each cut is on average 4.5 km. To make a section, we carry out the studies of the state of place, starting from a global overview, identifying the petrographic and structural

features using the geological map and the identified outcrops are studied in detail. Ten cuts are made.

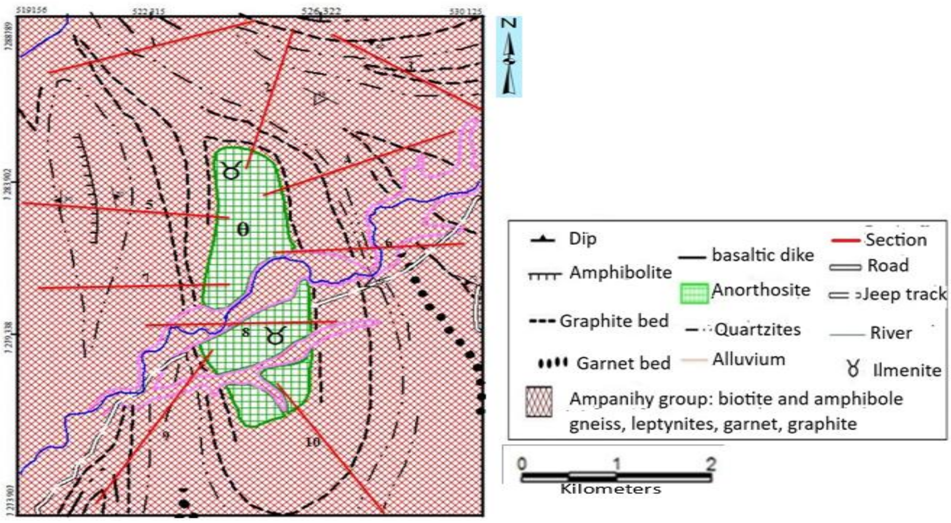


Figure 3: Sketch showing the cuts made in the field.

Sampling

The sampling is done in a very precise way and follows the orientation of the minerals and in the representative part. Two objectives were carried out by taking the samples: in case of the determination of the names of the rocks and the preparation of the thin blades. Then, the identified outcrops are dissected in detail: foliation measurements, petrographic descriptions, photographs, geographical coordinates and determination of kinematic indicators. Petrographic studies are undertaken after examining the outcrops to determine the nature of the formations, the states of alteration, the colors of the rocks present in the study area and the structures present (foliations and fractures) are measured, followed by sample collection. To carry out this work, the sampling form (Table-I) is used. During this descent, 55 samples were taken and brought to the laboratory for analysis.

Table I : Sample form template

Sample No.	Color	Seed size	Texture	Modal mineral composition per sample										Photo	Rock
				Qz	Fk	Px	Gt	Grp	Plg	Bt	Hyp	Opx	AMP		

Sample analysis

The samples collected in the field, were subjected to microscopic and macroscopic analyses. The purpose of these analyses is to identify the structure, texture, state of alteration, color of each sample and their mineralogical composition which constitutes it.

Results and discussion

Descriptions of structural element

The structural elements (lineaments: line of watersheds, hydrographic networks, faults and folds) are identified from the analysis of satellite images and data taken from the field.

Results from satellite images

From the processing and resolution of a Landsat 7 UTM satellite image of meta band 532 allowed us to identify that the structural alignments have various dimensions, and the accident of the Earth's crust of the Bekitro zone due to the influence of the different successive tectonic phases (figure 4). Then, it makes it possible to distinguish the watersheds, ridges and faults (figure 5). This means that the superposition of two images carried out justifies the presence of change of the bed of Menarandra and Manambahy. The values of the foliations are often varied and the dips are low between 25/20°NW and 300/60°NW for the majority (Table-II). This diversification of the direction of the foliations proves the variation in the direction of movement that touches the Bekitro zone.

Figure 4: Map showing Landsat 7 UTM meta-band 532 image showing the successive tectonic phases of the Bekitro area

Ta**ble-II:** Values of foliations collected during fieldwork in Bekitro

Areas	Foliations		
	Directions	Dip	%
North	310	41	45
Central	77	45	33
South	25	55	22

Figure 5: Representative map of lineaments obtained from filter images of the Bekitro area

Lineaments

Lineaments are observed from CP1 filtering during ETM+ image processing. Several filters were applied but among them, it is the directional filter, at α=30 ° with a 3×3 matrix, allowed to have a good visualization of the structural lines within the study area. The orientation of these structures is shown on the directional rose window (figure 6). Three important orientation families are identified: WNW–ESE, N–S and ENE–WSW. The WNW–ESE family is predominant, accounting for 51.43% of lineaments. The lineaments belonging to the N–S family are 15.86% frequency and that of the ENE–WSW to 32.57%. As for the other directorates, they are poorly represented either 0.14%. The N-S direction lineaments are probably related to the collision of the eastern and western parts of Gondwana, and the young NE and NW lineaments located in the central plateau, are due to the results of an active tectonic event in the study area. Brittle deformations are one of the factors controlling the mineralization around Bekitro. These mineralizations correlate with faults and fractures.

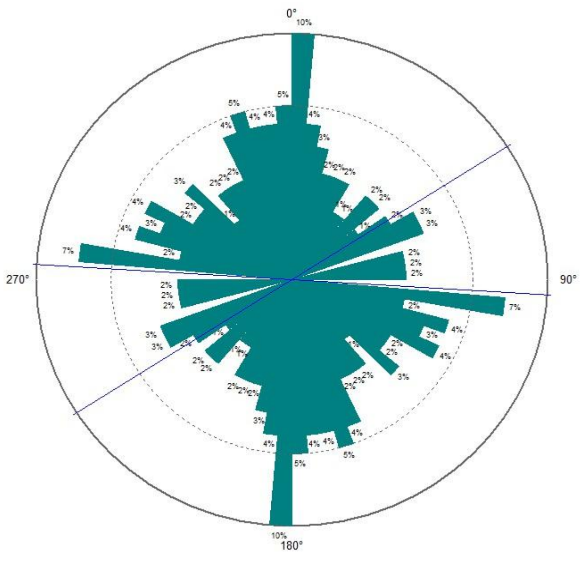


Figure 6: Lineament diagram

Sampling data

The river systems in the Bekitro area (figure 7) show that the different structures of this zone are controlled by tectonics and terrain morphology. The identification of the type of network that was hierarchical in the structures of this area made it possible to explain the hierarchical (dendritic) networks corresponding to the geological formation that is homogeneous.

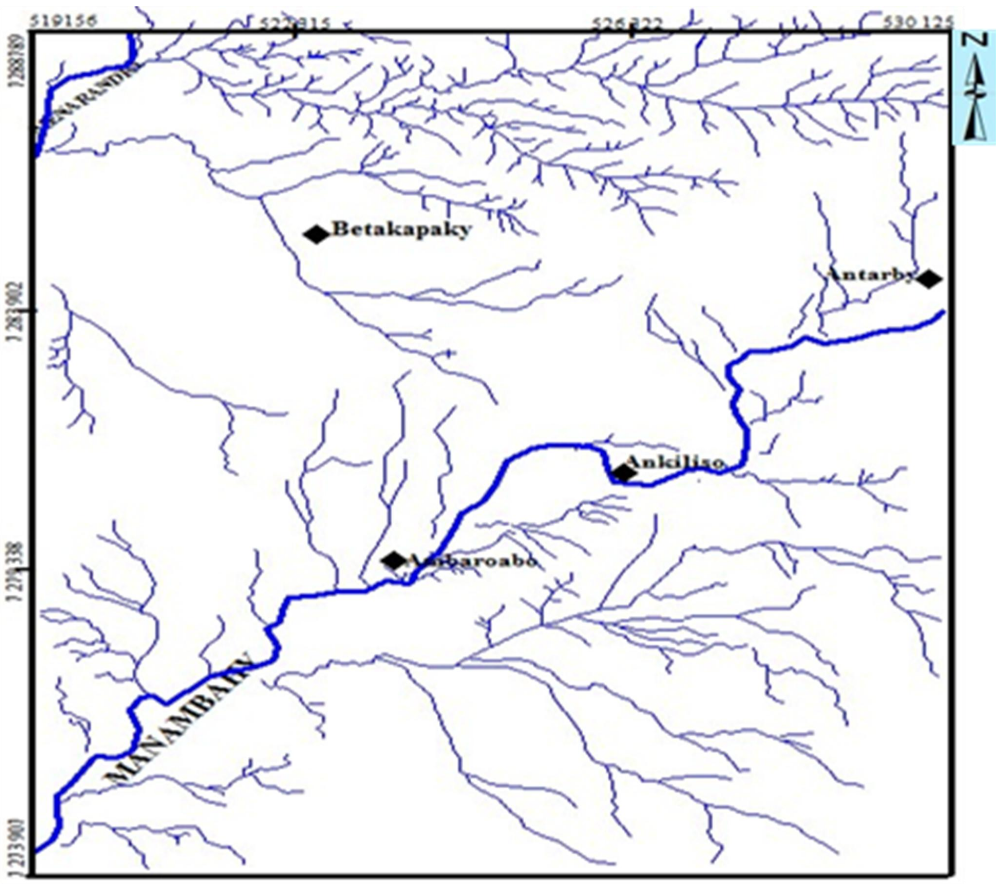


Figure 7: Map of river systems in the Bekitro area

The flow of the Menarandra River can flow into the sea. This means that the region constitutes exoheic basins while that of Manambahy is endorheic. These networks contain radial anomalies, watersheds that signify respectively the existence of dome or basin, and the antiform or synform (figure 8).

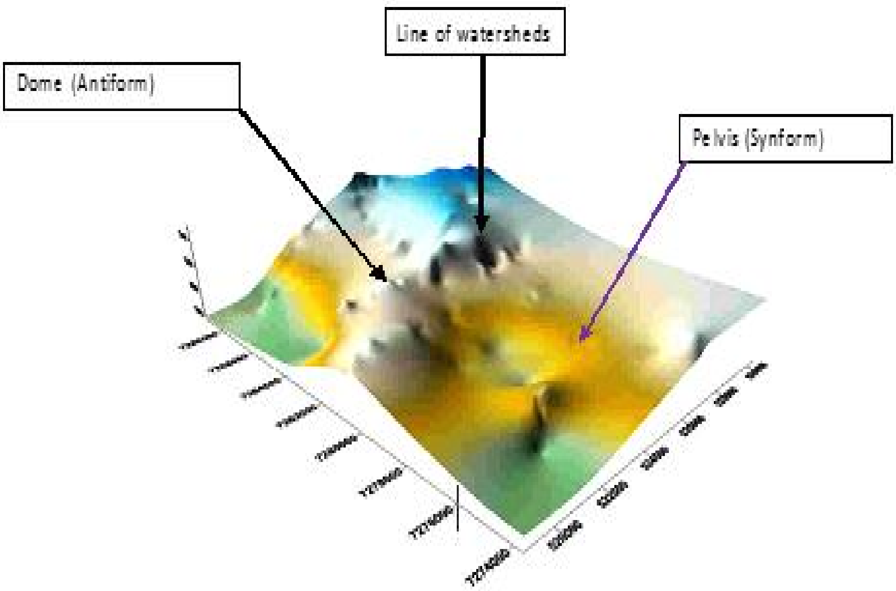


Figure 8: Block diagram showing the morphotectonics of the region studied, image 754 RGB represented in 3D on the Envi 4 software.

The Bekitro area is divided into three (03) parts according to the structural interpretation sections: the north; the central part and the south (Figure 9)

Figure 9: Representative map of variations in petrographic facies and river systems in the Bekitro area.

The North

The WSW-ENE oriented geological section n°1 allows us to study the deformations supported at different scales by the rocks, as well as to classify and discuss the constraints that are the cause of the structures of the northern part of the study area (figure 10). The internal granular structures and arrangements of the microstructures in this part are complex. However, the shape of the structures is very marked and clear in the outcrops observed on the ground. In order to do so, the two main families of structures of interest to geologists are observed in photo12, namely faults (figure 11a), and senestre-type folds (figure 11b). The northern part has undergone great D1 compression from the heavy weight of the Miary dome migrating south, therefore, it shows a lying fold (figure 11c) towards the NNW. However, it is important to note that these different morphologies are also due to the rheological properties of these rocks.

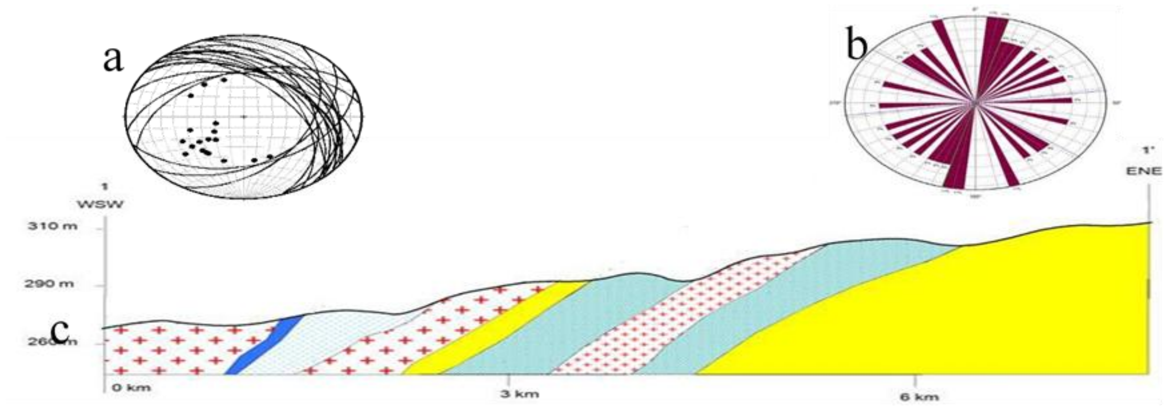
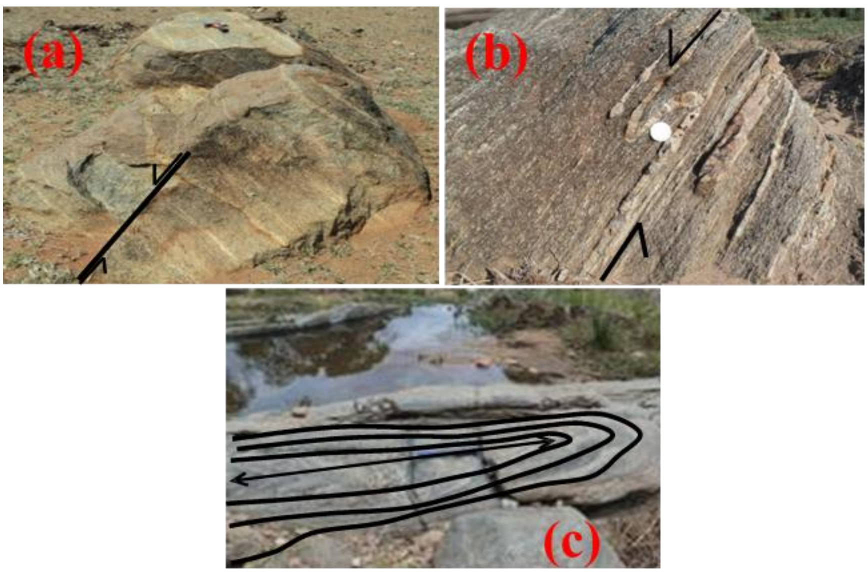


Figure 10: Geological profile according to section 1: a) identification of structural elements whose poles are concentrated in the SW and a small part in the NW and S. (b) foliation distribution diagram, the most representative is that of NW direction; (c) interpretative cut of recumbent fold, S-shaped, inclined to the west.

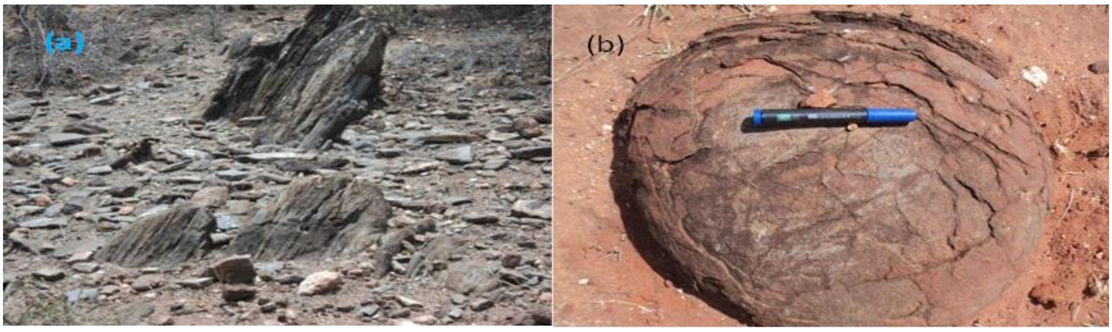


UTM.38S(WS84) geographic coordinates:
X = 45°12'21.9"E Y = 24°31'08.4"S Z = 279M
Localization : 5km North-West of BETAKAPAKY

Figure 11: Microstructures observed in the northern part: a) microfaults, b) microfolds and c) lying folds

The central part

The two sections that have the same SW-NE orientations, numbers 2 (Fig.13) and 3 (Fig.14) help us to determine the limit and tectonic movement carried out by the anorthosite block of MANAMBAHY. This part shows a foliation of general direction N015°, becoming more and more wrinkled with very variable directions to the east. The dip varies from medium (65°W) to low (43°W). The displacement of the Manambahy anorthosite to the south causes F2 foliation on the central western part. This movement causes a coaxial direction almost E-W, which may be the origin of the extension testified by the presence of basaltic of NE-SW direction, between this block and the gneiss with biotite, garnet and +/- sillimanite and disthene and amphibolite pudding (Fig.12b). This deformation leads to the formation of the graphite bench (Fig.12a). The synforms are thinned and sometimes pinched by the effect of compression accompanied by shear in which garnet migmatites and graphite-garnet-biotite migmatitic paragneisses resulting from partial fusion are present. This shear compression favored the establishment of numerous NNE steering fractures at SSW, attesting to the senestre direction of the movement of the D3 deformation.



UTM.38S (WS84) geographic coordinates: X = 45°13'44.3"E ; Y = 24°37'02"S; Z = 292M Localization: 3.5km South-West of Ambaroabo

Figure 12: (a- graphite white and amphibolite b- flange) shows the microstructure of the central part

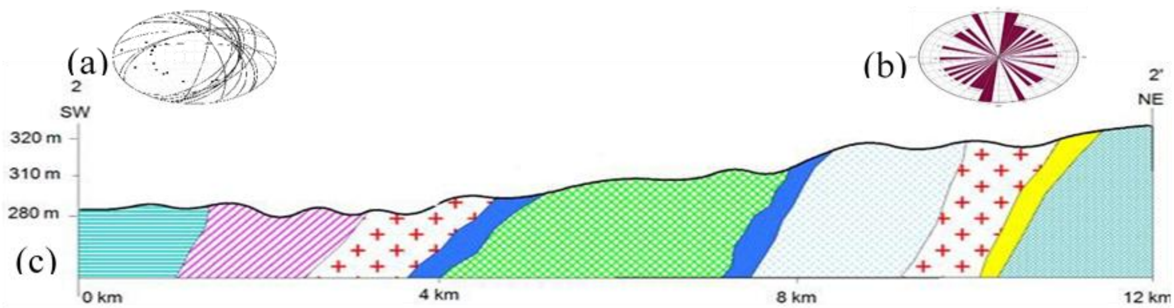


Figure 13: Geological profile according to section 2: a) demonstration of structural elements whose poles are concentrated at the NW and a small distribution at SW and SSE .b) distribution diagram of foliation, the most representative is that of NNE direction; c) interpretative section of the movement of the anorthosite of MANAMBAHY.

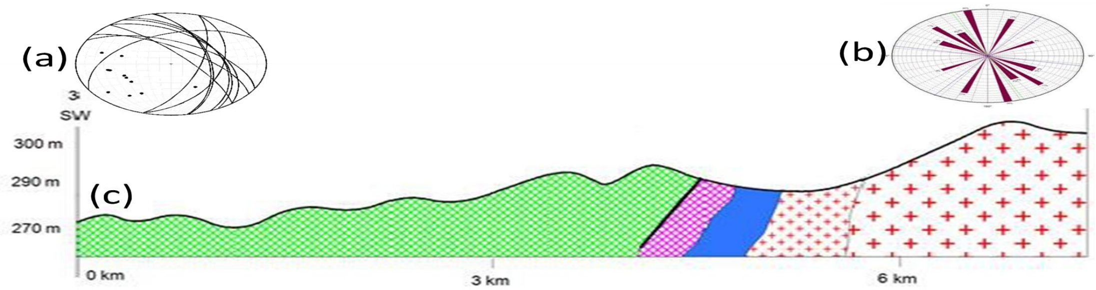


Figure 14 : Geological profile according to section 3: a) demonstration of structural elements whose poles are concentrated at SW and a small distribution at NW and SE; b) foliation distribution diagram, the most representative is that of NNW direction; (c) interpretative section of the micropleats in the shape of S and M, inclined subvertically to the west.

The South

Considering the 4th section (figure 16), the repetition of the antiforms is very visible which indicates a monoclinal structure connected to an accretion zone resulting from a compressive deformation repetition that amplifies more and more, from one deformation to another. Their foliations tighten and become subparallel to each other, where their dip is between 30°W and 65°W. The antiforms are formed by a series of horizontal S. On the other hand, a series of Z characterizes the synforms. This is manifested by the very frequent appearance of granitic to garnet leucogneiss; Garnet leucogneiss are poorly represented (figure15a). Kinematic indicators constantly preserve the normal direction of southward movement. The sub-vertical axial plane becomes straightened at the top, suggesting a ductile shift of the allochthonous formations to the south. Granitic pegmatites (Figure 15b) tend to orient parallel to the NE-SW direction of basal contact shear.

In most gneissic rocks, intrusive veins are consequent to partial melting and are parallel to the axial plane of the folds.

Basic are interpreted as igneous because apart from being strongly folded and sheared sometimes they have desquamated structures, structures specific to altered basic intrusive rocks. Those that do not show an apparent structure are considered to have a volcano-sedimentary origin. Many fragmented, folded and sulky amphibolites (Figure 15c) are frequent, and undergo transtensional shear deformation where granitic pegmatites invade open areas late. This indicates compressive and extensive tectonics, it's intense compression caused detachment at the rock level. During the deformation the veins have been shortened and folded, but still keep its direction because in an extensive area there is not enough stress

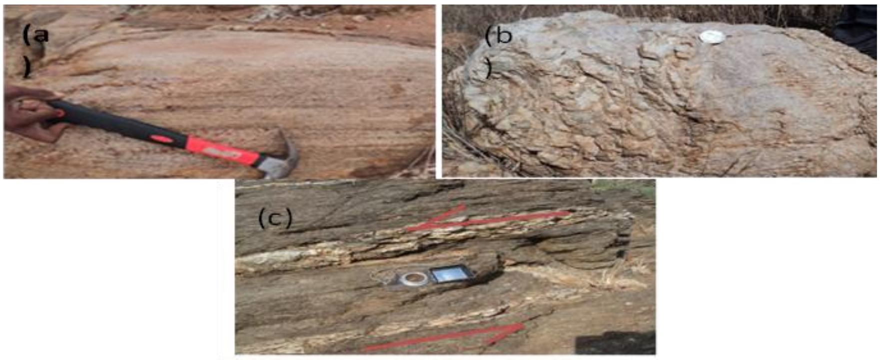


Figure 15: a-) leucogneiss with garnet; b-) granitic pegmatite; c-) orthogneiss of senestre type) shows microstructure of the southern part.

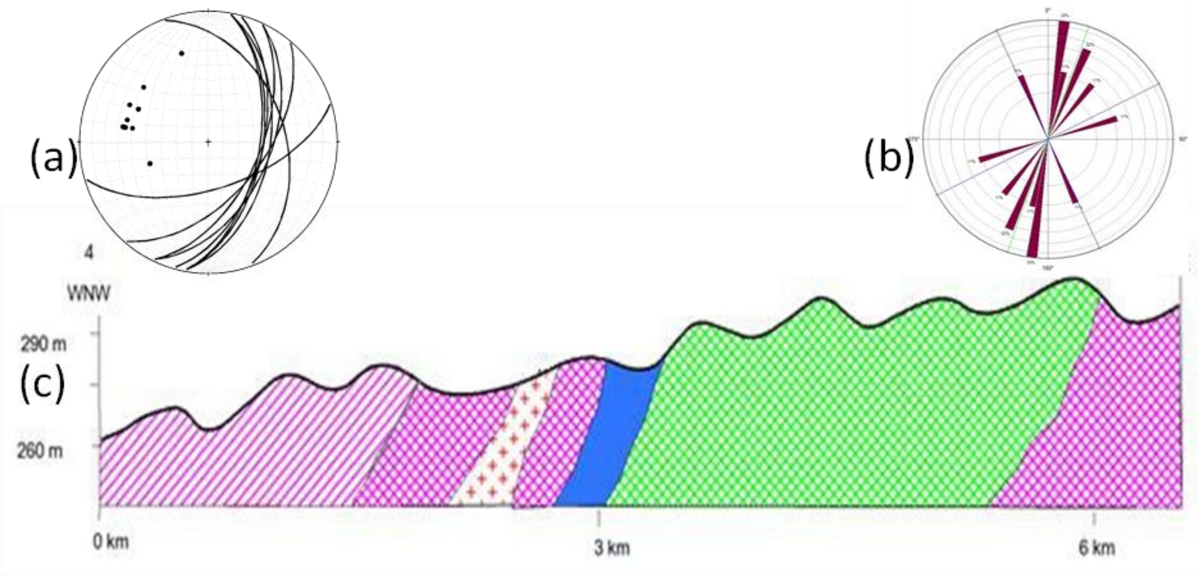


Figure 16: Geological profile according to section 4: a) demonstration of structural elements whose poles are concentrated at NW .b) foliation distribution diagram, the most representative is that of NNE direction; c) interpretative section of the succession of domes and plains, almost subvertical.

Results of petrographic studies

The Bekitro area is in the Mangoky Group. The Bekily Formation belongs to the Androyan domain formerly named Ampandrandava group. In general, it is dominated by varieties of gneiss.

The gneiss with biotite, garnet and +/- sillimanite and disthene are dominant, they are found almost in the different sides of the anorthosite massif of MANAMBAHY. The latter is the nucleus of the formations of our study area. It is an intrusive and igneous rock that takes its name from an orthosis (without orthosis). It is actually a rock composed mainly of plagioclase of 75 to 95% so it is leucocrat and some mafic rock components such as pyroxene, ilmenite, magnetite, and olivine.

The concentration of garnet in gneiss increases towards the south. Biotite and garnet leucogneiss elongate on the western part and stand side by side with hypersthene amphibolites. They are faded, sulked and appear on the outskirts of the road linking the rural commune of Bekitro and the Fokontany de Vohitrosa. Quartzites and pegmatites are abundant and cover almost the entire surface of Bekitro, but some parts are unmapped. The mineralogical compositions of these pegmatites vary from east to west by the presence of hypersthene, phlogopite and garnet. In the eastern part, they are at the frequency of coarse garnet and in the western part, at the dominance of phlogopite. Bekitro is also characterized by the presence of amorphous rocks namely jasper, basalt, agates and chalcedony often intercalated by mylonites. Orthogneiss are pyrope garnet biotite and graphite migmatites. Garnet and biotite are found on the eastern margin of the study area. They are intensely sulked and become porphyroblast troughs in the form of sygma.

The graphite and garnet shales are found in the northern part inserted by gneiss with biotite, garnet and +/- disthene and sillimanite. Garnet-rich leucosomes show partial fusion, giving a migmatitic character to leucogneiss. Basic formations are abundant but are often in the form of enclaves 5 to 9m long and 2 to 3m wide. Indeed, they are not mappable on the scale of our map. Intrusive horneblendites and are interspersed in granitic leucogneiss. They meet on the banks of the MANAMBAHY River.

The direction of foliation of the layers of the Bekitro zone varies from NE, NNE to NNW (almost submeridian) and NW. This change in the direction of foliation shows the direction of movement of the deformations that affected this area. The majority of the dips of the layers have a slope to the west and some dip from the eastern part to a slope to the east. This bimodal distribution of the plunging layers shows the flowering structure that is dominant and characteristic of the great Malagasy south. This makes it possible to revise the map of the Bekitro area (figure 17). Whereas, it is from the (figure 17) and the varieties of metamorphic rocks allowed us to classify the petrographic composition of the Bekitro terrane into three groups:

- Groups of basic gneiss are constituted by gneiss with: biotite, amphiboles, garnet, graphite, phlogopite and +/-Sillimanite and disthene; ultrabasic formations whose constituents are not indistinguishable because the rocks are friable and soft;
- Groups of leucogneiss, migmatites and quartzites and pegmatites.
- Groups of vein rocks are basaltic and quartz veins.

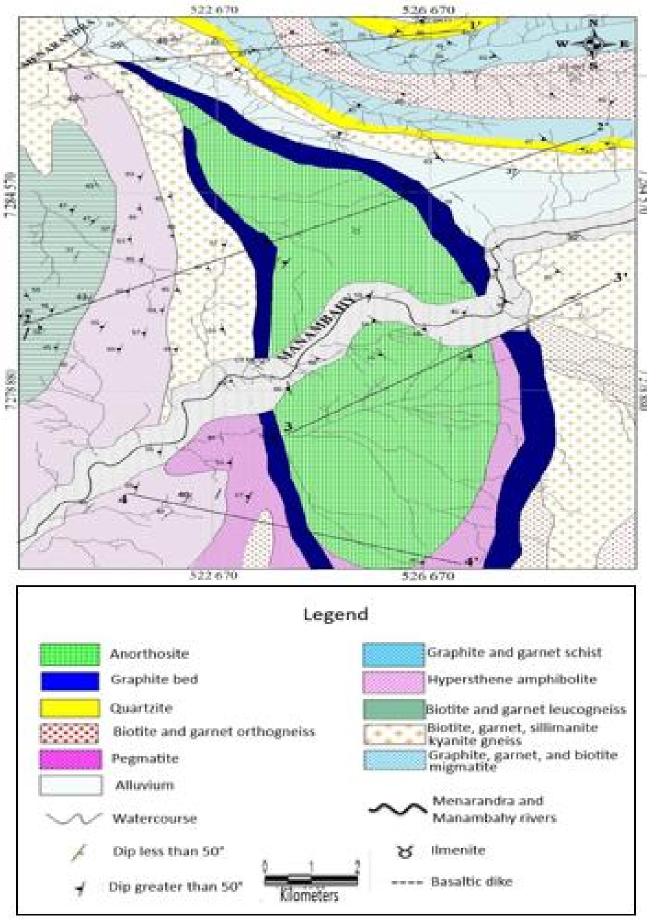


Figure 17: Revised geological map of the Bekitro area

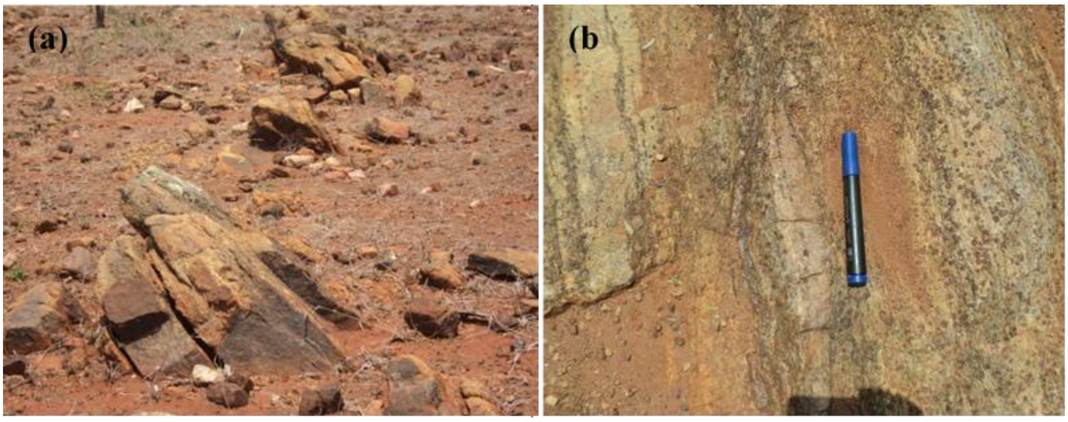
Groups of basic gneiss

The Paragneiss Group

Paragneiss are of great interest for understanding the dynamic evolution of a metamorphic terrain of the basement. They contain a very wide variety of tectonic and microtectonic structures that shed light on the interpretation of the deformation suffered. On the surface of dark beds, they wear stretching lineations indicating the direction of movement during deformation. In addition, they contain shear lenses and similar structures that give the direction (dextrous or senestre) of these movements. Paragneiss are also pleated; In places they can be affected by more than three generations of wrinkling. This fact is of great importance to establish the deformation phases of the rock concerned. All these structures appear during ductile dynamic metamorphism in the middle of the continental crust. When paragneiss are lifted after burial, they return to brittle and undergo compressive accidents (reverse faults, carries) or extensive accidents (normal faults, detachments). Arrived near the surface, they form networks of joints. An analysis of their metamorphic minerals gives important information about the ambient physical conditions and the course of metamorphism as a function of P and T. Paragneiss can produce granitoids when crossing the threshold of anatexia. In general, we can compare paragneiss and other crystalline schists associated with the matrix of the basement terrain, granitoids on the other hand are secondary and react in porphyroblasts.

The facies makes it easy to characterize a metamorphic rock and thus determine its conditions of formation. They do not necessarily imply the presence of the mineral referred to in this classification.

The Bekitro terrane is dominated by basic paragneiss ranging from superior amphibolite facies to granulite facies (Figure 18). These metamorphic rocks illustrate in (Table III) below are very abundant in the northern part of the Bekitro terrane, in contact with the Miary dome and at the edge of the Menarandra bed. The area is highly affected by high intensity of metamorphism because the majority of outcrops have a mylonitic tendency (Figure 18b). Next, the photo on the left (Figure 18a) states that the area is highly compressed. Generations of pegmatitic and granitic bodies have also appeared during the formation processes of gneissic complexes. Paragneiss differ according to their modal proportions and mineralogical components (Table III).



UTM38S (WS84) geographical coordinates:
X= 045° 13' 24.6''E ; Y= 24° 37' 33.8''S Z= 308M
Localization : 5km south west of Ambaroabo

Figure 18: a) Paragneiss with amphibole and garnet; b) Garnet and amphibole paragneiss.

Table III: Showing the different types of petrographic facies

Facies	Characteristic minerals
Green shale	Chlorite, epidote, albite
Amphibolites	Albite, epidote, Homblend
Granulite	Pyroxene, Garnet
Blue shale	Glaucophane, lawsonite
Eclogite	Sodium pyroxene, garnet

The Orthogneiss Group

Metamorphic rocks often undergo deformation. These stresses lead to the appearance of particular structures in the rock. During metamorphism, the same rock undergoes mineralogical and structural changes. Some minerals appear, others disappear. However, minerals only appear under certain conditions of temperature and pressure, called their stability domain. In fact we observe not a mineral, but an association of minerals, or paragenesis. At the level of regional metamorphism it is often possible to see the different stages of transformation of rocks.

These stages are characterized by the formation of certain minerals whose nature depends on the source (or pre-existing) rock. Thus some rocks are characteristic of a metamorphic series. The zones of metamorphism make it possible to establish a classification according to the intensity of the metamorphism brought to depth:

-Anchizone: This is the intermediate zone between diagenesis and metamorphism.

-The epizone: It corresponds to the metamorphism of low pressure and low temperature (300 to 500 ° C). There are many hydroxylated minerals.

-Mesozone: It characterizes an average metamorphism, with the appearance of biotite, muscovite, staurotide, amphibole and disthene.

-The catazone: It corresponds to an intense metamorphism. The temperature and pressure are high at a high stress. The minerals found there are sillimanite, andalousite, garnets and pyroxenes as well as plagioclases.

Orthogneiss is a metamorphic rock of magmatic origin. This source rock can be granite, gabbro or serpentinite and has undergone metamorphism and had orthogneiss (Fig.19). The latter, in the Bekitro zone is graphite and biotite with medium to fine grain size. If the temperature rises, these orthogneiss are amphibole and garnet. This means that metamorphism has a granulite amphibolite facies (Table III).

UTM38S (WS84) : geographical coordinates

X = 045 ° 11’ 58,2’’E, Y= 24° 31’ 18,6’’ ; **Z** = 281M

Localization: 5km north west of Betakapaky .

Figure-19: (a) Graphite and biotite orthogneiss, (b) Amphibole and garnet orthogneiss

Table IV : Different varieties of melanocratic gneiss

Samples number	**COLOR**	**Grain size**	**TEXTURE**	**Modal compositions of minerals by samples•:0%; 0≤10%; 00]10-30%[; 000 [30-70%[; 0000 ≥70%**										**Pictures**	**Rocks**
				Qz	**Fk**	**Px**	**Gt**	**Grp**	**Plg**	**Bt**	**Hyp**	**Opx**	**Amp**		
C1 BKT4	Dark	Fine	Massive	00	00	-	000	- -	- -	-	- -	- -	- -		Paragneiss to pyrope garnet.
C1 BKT1	Dark	Fine	Grenue	0	0	-	-	000	-	00	-	-	-		Paragneiss to graphite, biotite and quartz vein.
C1 BKT’2	Dark	Fine	Micrograin	0	0	-	00	-	-	-	-	-	000		Orthogneiss to amphibole and garnet.
C1 BKT’3	Dark	Very fine	Shale	0	0	0	-	-	-	-	-	0	000		Orthogneiss to amphibole and pyroxene.

The majority of gneisses are dark in color, dominated by fine grains and sometimes schistose. Amphibole and biotite are always present in the outcrops which have varying proportions from 20 to 70%. In general, the paragneisses in the Bekitro region are provided with quartzo-feldspathic veins and associated with garnet, sometimes with graphite.

Groups of leucogneiss, migmatites and quartzites and pegmatites.

The migmatites group

Migmatite comes from the Greek word "migma" that's to say mixture, sometimes called granitized gneiss, a metamorphic rock resulting from partial crustal anatexia. It is found in areas of medium metamorphic gradient to elevate. It is formed by two compositional ribbons that are identified by a different petrography:

Light-colored beaches, assimilated to the part of the rock that has melted, and which constitutes the mobilization; dark beaches, constituting the part of the rock that has remained solid and constitutes the restite.

Migmatites are rocks that, in a pressure-temperature diagram, lie between the solidus and the liquidus. They may belong to the domain of metamorphism or magmatism depending on the intensity of the partial fusion (either the intensity of the metamorphism) they have undergone. The physical barrier given to this limit is the Arzi threshold, which is reached experimentally for a proportion of liquid and solid of 12 to 20%. The boundary between metamorphism and magmatism is not obvious, since by definition, metamorphism includes all the physical and chemical transformations occurring in solid state rocks.

That is, from the solid state to the liquid, while magmatism is interested in the latter from the liquid state to the solid state. We therefore identify here a problem related to the stricosensus definition of these scientific fields. In the case of Bekitro migmatites (figure 20a), the source rocks that have undergone partial melting are leukocratic orthogneiss, it is ancient granites and rather dark paragneisses strongly metamorphosed that are the beginning of partial melting. These migmatites are obtained by regional metamorphism which corresponds to metamorphosed zones of more than 10 km. We can observe a succession of increasingly metamorphosed terrains as well as an increasingly advanced schistosity. This can lead to the beginning of fusion (Migmatite) or even a complete melting of the rock (Anatectite). The main cause of this type of metamorphism is tectonic in origin.

This is why the minerals in these metamorphic rocks are often flattened and oriented along the foliation planes (figure 20b).

The age of metamorphism and partial fusion is estimated in the Precambrian. Therefore, the molten fraction gathered after a very small migration into intercalated lenses in the pre-existing foliation and gave the lenses of granitic composition or leukosome. The majority of leucosomes are fractured and often wrinkled. Sometimes xenoliths in amphibole gneisses reveal themselves in different forms, folded, fractured, sulky and disoriented in migmatites.

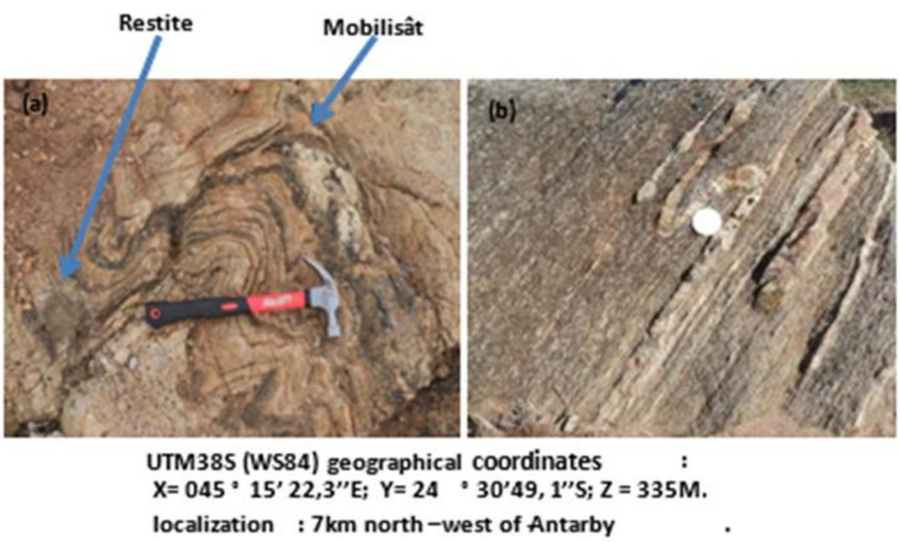


Figure 20:(a) Graphite and garnet migmatite, (b) Biotite and garnet migmatite..

To describe the changes in appearance of the ribbon structure of migmatites we define:

The neosome, as the part of migmatite that has been newly formed. It often consists of two parts:

-The leucosome, that is to say the clear part that corresponds to the mobilization: this area having undergone a fusion followed by recrystallization intersects the foliation.

-The melanosome, as the darker colored part of the neosome. This ribbon is usually thinner and is located at the edge of the neosome.

It corresponds to the residual solid fraction of partial melting. This ribbon is rich in "black" minerals, such as biotites, garnets, amphiboles, which explains its more pronounced colour than the last two. The paleosome (or mesosome), like the part of migmatite that has not melted. That is, the dark part of the rock. This corresponds to the restite where the foliation remains.

Table V : Different varieties of migmatite

Number samples	**COLOR**	**Grain size**	**TEXTURE**	**Modal compositions of minerals by samples•:0%; 0≤10%; 00]10-30%[; 000 [30-70%[; 0000 ≥70%**										**Pictures**	**Rocks**
				Qz	**Fk**	**Am**	**Px**	**Gt**	**Grp**	**Plg**	**Bt**	**Hyp**	**Opx**		
C1 BKT2	Darkish light	M to f	Migmatitic	0	00	-	-	0	0	-	00	-	-		Migmatite to biotite, graphite and garnet
C1 BKT6	Darkish light	M to f	Migmatitic	000	00	00	-	-	-	-	-	-	-		Migmatite to amphibole
C1 BKT'3	Darkish light	M to f	Migmatitic	000	0	-	-	-	0	-	00	-	-		Migmatite to biotite and graphite
C1 BKT'1	Darkish light	M to f	Migmatitic	000	0	-	-	0	-	-	00	-	-		Migmatite to biotite and garnet

The migmatites are light to blackish in color, medium to fine grained, with a migmatitic texture. They consist essentially of biotite with a proportion greater than 60%. Biotites are often associated with graphite and garnet, rarely with pyroxenes.

The Quartzite and Pegmatite Group

Quartz fleets that are rocks composed entirely of quartz appear in almost the entire area occupied by the Manambahy anorthosite block. They are drawn in the old map of Noizet and al.1958 which indicate extensive tectonics.

The particularity of Bekitro quartzites lies in the diversity of colours (milky white, pink and smoky) (table n°5) and draws our attention to study the origin of Bekitro quartzite which can be either magmatic or metamorphic and understand the presence of geological constraints marking the geodynamics of the region. Quartz is the most abundant mineral in the eastern and central part of this area. It is sometimes in vein form (Figure 21b). It is found in most rocks and sometimes consists only of quartzite blocks (Figure 21a). The presence of locally exploited pegmatitic formations proves that this area is in a zone of low stress and still it was either a desert zone or a littoral zone.

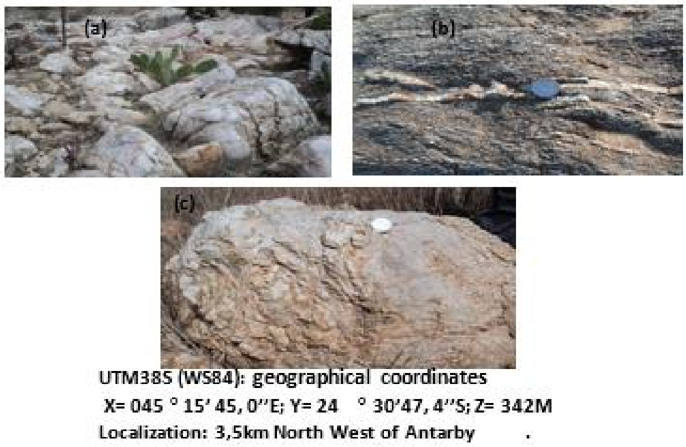


Figure 21: a) floats blocks of pure, white quartzite; (b) quartz vein and (c) pegmatite

Groups of vein rocks are basaltic and quartz veins

Locally, quartzite (at the edge of the Menarandra bed, 3.67km northwest of Fokontany Betakapaky) and basaltic are sulky and indicate a flattening deformation that is observed in the biotite-garnet mylonitic gneiss (Fig.22a). During the Pangondwanian orogeny, the Bekily block is moved southward by the presence of a transtensional movement passing through the western part of the Bekitro area. This movement favors the establishment of the basaltic (Fig. 22b) and the dominance of granulite and amphibolite facies. Then, in the bed of the Menarandra, well-lited and heterogeneous quartzo-feldspathic gneiss strongly deformed with concordant granitic and basaltic are isoclinally folded, sulky, and partially fragmented.

All these deformations of materials that are either brittle or ductile, and the formations of mylonites and testify that this Bekitro zone was tectonically very eventful.

All these rocks are encased by amphibole gneiss. During progressive deformation, angular fragments of folded amphibolites were rotated in the tonalitic and pegmatitic matrix.

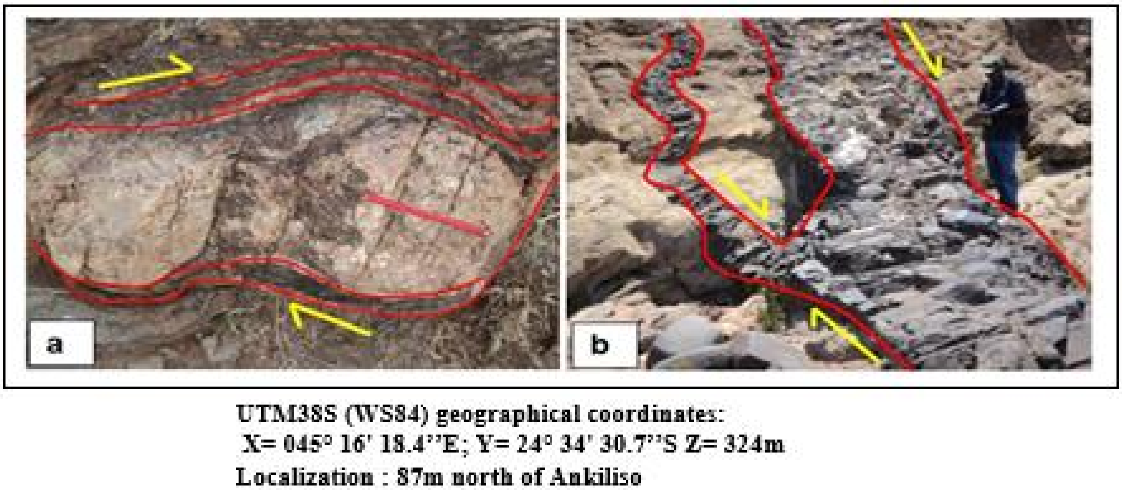
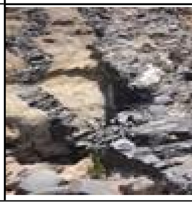


Figure 22: Typical examples of vein rocks in the Bekitro zone: (a) quartzo-feldspathic vein and (b) basaltic.

Table -VI: The different type of vein rock in Bekitro area

Number samples	COLOR	Grain size	TEXTURE	Modal compositions of minerals by samples•:0%; 0≤10%; 00]10-30%[; 000 [30-70%[; 0000 ≥70%										Pictures	Rocks
				Qz	Fk	Amp	Px	Gt	Grp	Plg	Bt	Hyp	Opx		
C1 BKT’3	dark	M to f	granoblastic	00	00	-	-	00	000						Quartzo-feldspathic vein in Graphite

C1 BKT'4	Clear blackish	M to f	grainy	000	00	0	-	-	-						**Pegmatitic vein in gneiss to amphibole**
C2 BKT'1	Clear blackish	M to f	granoblastic	00		00	0	-	0	-	-				**Granitic vein to amphibole and gneiss to biotite**
C6 BKT4	Clear blackish	M to f	microlitic	0	0	-	00	-	-	-	-				**Dykes basaltique**

The vein rocks are dominated by coarse-grained white quartz, there are also granites with their light color with medium grain and basaltic dykes of black color with fine grain. The Bekitro area is strongly deformed. The various intrusive rocks presented in table 6 are issued by brittle shears. They are folded and sheared which show us the second phases of the deformations (D2).

Conclusion

Thanks to the application of the satellite image processing and resolution technique and the application of the cutting method on the Bekitro area have made it possible to determine their petrographic characteristics and geological structure.

From processing and resolution of the image obtained by satellite Landsat 7 UTM of meta band 532 allowed us to identify the structural alignments of the Bekitro zone and their dimensions which were varied and it allows to distinguish, the watersheds, the ridges and faults. The superposition of two observer images justifies the presence of bed change. The values of the foliations are often varied and the dips are low between 25/20°NW to 300/60°NW for the majority. This diversification of the direction of the foliations justifies the different types of the direction of movements that affects the Bekitro area. The lineaments are also observed during processing of the ETM+ image using the directional filter, at α=30° coupled to a 3×3 matrix and allows structural lines within the study area. The orientation of these structures is presented on the directional rosette. Three important orientation families are identified: WNW–ESE, N–S and ENE–WSW. The WNW–ESE family is predominant, it represents 51.43% of the lineaments, the ENE–WSW family is 32.57%, that N–S at 15.86% frequency and so, the other directions are very weak and they represent the 0.14%. The lineaments of the N-S direction are probably related to the collision of the eastern and western parts of Gondwana, and the young NE and NW lineaments located in the central plateau, are due to the results of an active tectonic event in the study area. Brittle deformations are one of the factors controlling the mineralization around Bekitro. These mineralizations correlate with faults and fractures.

The river systems in the Bekitro area show that the different structures of this area are controlled by tectonics and terrain morphology. The identification of the type of network that was hierarchical in the structures of this area made it possible to explain the hierarchical (dendrical) networks corresponding to the geological formation that is homogeneous.

The application of the cutting method on the Bekitro area made it possible to determine the characteristics of the rocks in this area. Their petrographic is characterized by three groups including: the groups of basic gneiss characterized by gneiss with: biotite, amphiboles, garnet, graphite, phlogopite, +/- Sillimanite, disthene and ultrabasic formations whose constituents are indistinguishable because the rocks are friable and soft; The groups of Leucogneiss, migmatites, quartzites and pegmatites and in order the groups of vein rocks constitute by the basaltic and veins quartzes. Secondly, the structure of the Bekitro zone is very disturbed, folded, often fractured and sheared.

This zone has a particular specific character because of the three major orientations of foliation including: S1, oriented WNW-ESE on the northern part with a granulite to amphibolite facies and it undergoes a D1 deformation; the S2 which is in the center of the zone, the foliation orients from N-S, and it is characterized by the amphibolite facies whose deformation is D2, the last part is testified by the foliation S3, oriented ENE-WSW; It has a granulite facies with catazone metamorphism and shows a D3 deformation. The kinematic indicators present in this area are senestra and lying folds, normal and inverse faults, diaclase and carriage.

All of the above results were used to produce a new geological map and a structural map outline for the study area.

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