GEOLOGICAL CHARACTERISATION AND REALISATION OF THE NEW LITHOSTRUCTURAL CATOGRAPHY OF THE GABBROIC MASSIF OF ANKERANA, MADAGASCAR

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ABSTRACT

A geological study for the renewal of the geological map was conducted on the gabbroic massif of Ankerana. The objective was to identify all the geological formations constituting this massif, called gabbroic according to H Baiserie in the "Geology of Madagascar", in order to establish a detailed outcrop map of this area. The determination of the rocks was made from the macroscopic and microscopic petrographic description of the geological formations outcropped and sampled by grid of 500 meters. At each station, a detailed petrographic study, structural measurements crossed with the map of the lineaments realized on GIS, a geomorphological analysis were made. These are the essential elements for the establishment of the lithostructural mapping. The results allowed the identification of ten different rock types including Peridotite, Pyroxenolite, Amphibolite, Gabbros, Dolerite, Milky Quartz Vein, Leptynite, Ferruginous Cuirasses, Iron Oxide grains, Bauxitic Carapaces and red and yellow soils The new lithostructural map verifies the presence of ultrabasic formations that are alternated with basic rocks and/or residual rocks. This set has been intersected by quartz veins that are obtained after circulation of the last magmatic liquids inside the weaknesses zones where they crystallize.

Keywords: substratum, structural, mineralogy, petrography, amphibolites, pyroxenolites, residual rocks, magmatic rocks, metamorphic rocks, basic rocks, ultrabasic rocks, seams, phenocrysts, phaneritic and aphanitic structure, texture, lineament.

1. INTRODUCTION

The geological substratum plays a very important role as the main habitat for plant biodiversity [7]. The knowledge of the geological bedrock is very important in order to understand the physiognomic relationship of the substrate with the vegetation. Indeed, geological studies have been conducted on the gabbroic massif of Ankerana to better understand the relationship between the substrate and the habitat. The objective of this research is to characterize the geology of the gabbroic massif of Ankerana, in the central east of Madagascar. More specifically, it involves: detailed mineralogical and petrographic studies of the different lithologies, structural studies, a new fine and detailed lithostructural cartography of the study site, inventory of the hydrographic characteristics of the watersheds, characterization of the different types of soil, and finally, study of the relationship between geomorphology and soil degradation. For these geological studies, three main steps were followed, including literature review, field data collection, and analysis and processing of the data collected in the laboratory. The data used and the technical details for each methodology are detailed in the second, third and fourth paragraphs. The following paragraphs gather the respective results related to the respective methodologies. These results are interpreted and discussed in the last paragraphs. The section ends with a partial conclusion.

2. METHODOLOGY

The different methods used for the geological characterization of the Ankerana massif are summarized in the following flow chart, synthesized and proposed by the author. To achieve the objectives mentioned above, studies and works have been carried out. They are subdivided in four complementary parts such as: the bibliographical review; the treatments of the satellite pictures, the application of the remote sensing and the GIS;

the field works for the petrographic, mineralogical and structural studies of the various geological formations; the laboratory works (mineralogical study and the calculation of the modal composition.

2.1. bibliographic review

This is one of the crucial steps in determining the future success of the study. It mainly consisted in gathering primary and secondary data; compiling maps and numerous information of various natures, such as topographic, geological, pedological, geomorphological maps and possibly satellite and/or aerial photos as well as pre-existing geophysical and geochemical maps completed sometimes by plans of previous geological works. This sectorial compilation of existing information and data consists of an analysis of the data in order to produce a state of knowledge and to specify, by zone, the complementary information required for the studies.

2.2. Petrographic and structural study

Two expeditions were carried out, the first in 2012 in the northeastern part of the gabbroic massif, and the other in 2014 in the northeastern part of the Ankerana gabbroic massif. We divided the study area into several 500 m grids. Observations and sampling were conducted at each observation point. Rock samples were taken from natural outcrops in place (slope, ravine, river etc.). At each outcrop, a detailed petrographic description was made (Boulevain, 1976). It is divided in two: the macroscopic petrography and the microscopic petrography. The macroscopic petrographic description of each type of geological formation was carried out in the field according to a collection sheet that we established for this research. It consists of inventorying the mineralogical and petrographic characteristics of the rocks including structure, texture, color in fracture, without forgetting the location of position by GPS, recording the number of each station, labeling the outcrop, and taking samples of healthy and / or altered rocks for analysis and verification in the laboratory [1]. Structural measurements were also taken in the field. This involved taking the directions and/or dips of the planes of all structures observed at the outcrop scale. On the one hand, the tectonic study allows to have information on the geomorphology as well as on the evolution of the alteration. On the other hand, the data measured in the field allow to verify the types of lineaments on the lineament map produced on GIS and teledetection before the descent on the field. These are the directions and dips of the fracture planes and/or foliations as well as the general direction of the major faults and veins.

2.3. Petrographic analysis in the laboratory

Detailed petrography requires the preparation of thin sections of rock. The fabrication and observation of thin sections are very important for microscopic studies in Earth Science [3]. It consists in making a few thin sections of rocks and/or soil on samples taken in the field. This is done in order to determine the exact nature of the minerals, their abundance, and their mutual relationships (structure). This study is used to determine the constituent minerals and to characterize their granulometry under the optical microscope by natural light and polarized light. The preparation of the thin slide sugars for the fourteen representative samples was carried out at the laboratory of the Department of Earth Sciences, University of Antananarivo

Fig- 1 : Rock sample (left) and Pyroxenolite sugar in sample bags (right)

The modal composition is determined by macroscopic and microscopic analysis of rocks. This analysis of data according to the proportions of cardinal minerals was done to determine the nature of the rock. It is necessary to identify the different minerals of the rock and express the percentage of the volume occupied by each mineral. For basic rock we use the diagram of streckeisen (QAP). For gabbroic rock we used the ternary diagram Olivine, Pyroxene and Plagioclase. For ultrabasic rocks we used the diagram of classification of ultrabasic rocks based on mafic minerals such as Olivine, Clinopyroxene and Orthopyroxene.

2.4. Lineament Analysis on GIS and Remote Sensing

In this analysis, ArcMap, ENVI and PCI Geomatica are the main software used for the automatic extraction of lineaments from remote sensing data. Indeed, the extraction of lineaments in the Ankerana area was done with the 'Line module' associated with the PCI Geomatica software. This tool reduces subjectivity, saves time and helps in comparison and validation for lineament extraction [6].The principle of this method is simple, the total number and total length of the obtained lineaments depend on the values of the input parameters, represented by the optional values of line module in the software. the 'line module' algorithm is composed of three steps: contour detection, thresholding and curve extraction. Indeed, the algorithm consists in extracting the lineaments from the image and converting the linear objects into vector form using the six optional parameters (Sarp, 2005). For this study, we chose to work with the MNT image (alos palsar) of the region. This image has a good spatial resolution of 12.5m which could give the maximum detail on the topography. These images are freely available via the Alaska Facility website. Automatic lineament extraction begins with image enhancement by applying NS, EO, NESO, and NWSE directional filters on ENVI. Then, we switch to PCI Geomatica, with the 'LINE module' tool, the six parameters are adjusted. The parameters used for this lineament map are given in table 1.

Table 1 : Les Parameters used in the LINE module of PCI Geomatica for the automatic extraction of lineaments

RADI - Radius of filter in pixels	12
GTHR - Threshold for edge gradient	80
LTHR - Threshold for curve length	30
FTHR - Threshold for line fitting error	10
ATHR - Threshold for angular difference	30
DTHR - Threshold for linking distance	15

The next step is to statistically analyze the lineaments obtained to eliminate duplicates and those that do not match the geology, and to determine the lengths, density and finally to generate a rose diagram, a density map of the lineaments. The lineaments obtained were plotted with the "Polarplot" extension of ArcMap software as a rose diagram to show the direction and orientation of the lineaments.

2.5. Realization of the geostructural map

The geological map was established by delimiting each formation of the same nature (mineralogical composition) taking into account reasoning and logical hypothesis from field observations taking into account topographic, geomorphological, mineralogical and structural data. The lineament maps are classified from the punctual measurements verified in the field, then extracting the fracturations. The lithological delimitation predefined in the radiometric map is to be verified on the field. Finally, the lithostructural or geostructural map is obtained after the superposition of these two types of data.

3. RESULTS AND DISCUSSIONS

3.1. Results of the geological studies

3.1.1. the different lithologies of the massif

From the petrographic studies carried out in 2012 and 2014, the general result of all outcrops shows us that the massif is formed by basic and ultrabasic rocks in the presence of acidic rocks on the outer part. Seven types of rocks have been observed:

- Gabbros : basic rocks
- Microgabbros (dolerites) : basic rocks
- Amphibolites : ultrabasic rocks
- Pyroxenolites : ultrabasic rocks
- Peridotite: ultrabasic rocks
- Ferruginous breastworks: product of the alteration of ultrabasic rocks (in the form of breastworks and/or iron oxide grains).
- Milky quartz vein : acidic rocks

The results as a percentage of the total number of samples in the study area are shown in the diagram below:

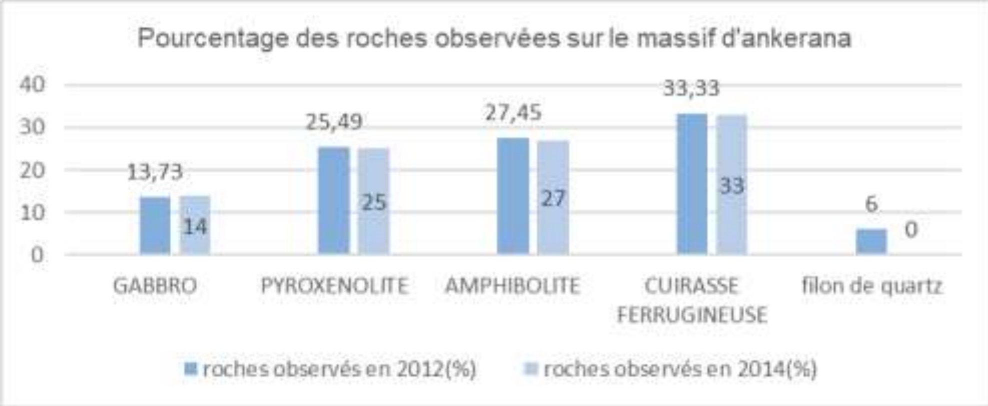

Chart 1 : percentage of rocks on the massif

This diagram shows the whole of collection even if the total number of the collected samples are not proportional, by transposition the massif of Ankerana is formed by 33% of residual rocks (ferruginous breastworks), 52% of ultrabasic rocks of which 27% of amphibolites and 25% of pyroxenolites; the gabbros are not very remarkable in this observation with a rate of 13, 87% compared to the total number of observations carried out. Acidic rocks are present but insignificant in this sector with a rate of 6%. They are observed only in the south-eastern part.

3.1.2. General petrography of the massif and mineralogical assembly

3.1.2.1. The basic rocks

These rocks belong to the family of plutonic magmatic rocks. They are characterized by the dark color of the type mesocrate to melanocrate [4]. These rocks are formed by Gabbros having a massive texture, of gritty structure, composed of medium and fine grain. The mineralogical composition of these gabbros is formed by pyroxenes, amphiboles and basic plagioclase feldspars (labrador) and olivine minerals sometimes accompanied by sulfide minerals (pyrite). According to the macroscopic characteristics, we have three varieties of basic rocks: the medium-grained gabbros, the fine-grained gabbros, the olivine gabbros and the orthoamphibolites. According to the microscopic characteristics after having made the calculation of percentage of the two slides of the basic rocks, the modal values found are the following:

Table 2 : Modal composition of Gabbros samples

Mineralogical composition	Percentages % (Quantitative)	
	Medium-grained Gabbros	Olivine Gabbros (troctolite)
Plagioclase	95,17	53,84
Quartz	4,83	None
Pyroxènes (les deux pyroxènes)		7,69
Olivine	None	38,46
Amphibole	None	Not determinated
Minéraux opaques		Not determinated
TOTAL	100	Not determinated

By analyzing the values and percentages of each mineral, it results that the comparison of the two gabbros presents some differences: The medium-grained gabbro shows a relatively high percentage of pyroxene (34.28%) against (7.69%) for the Olivine gabbros; on the other hand, the latter has a higher value of Olivine (38% against 0% for the medium-grained gabbro). Carried on the diagram (Q.A.P) [10] our sample falls in the field of gabbros (Fig- 2).

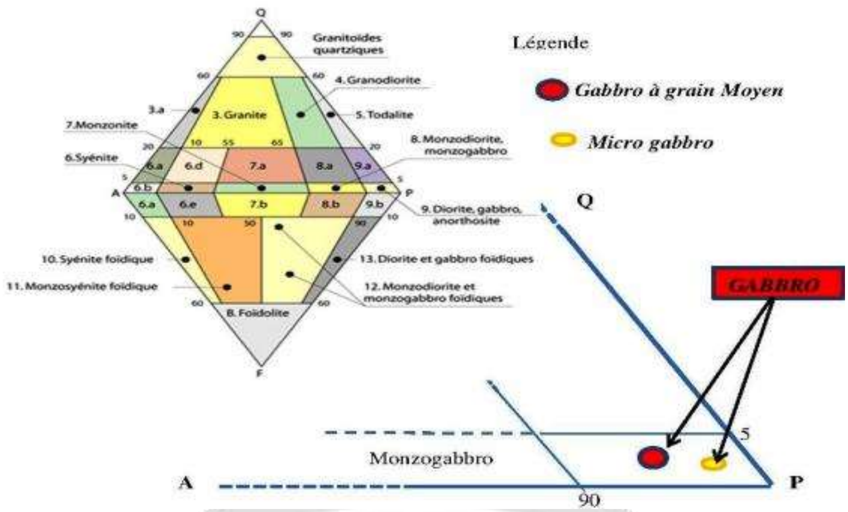

Fig- 2 : Diagram (QAP) of STRECKEISEN showing the transfer of the representative samples of the basic rocks of the NW part of the massif of Ankerana

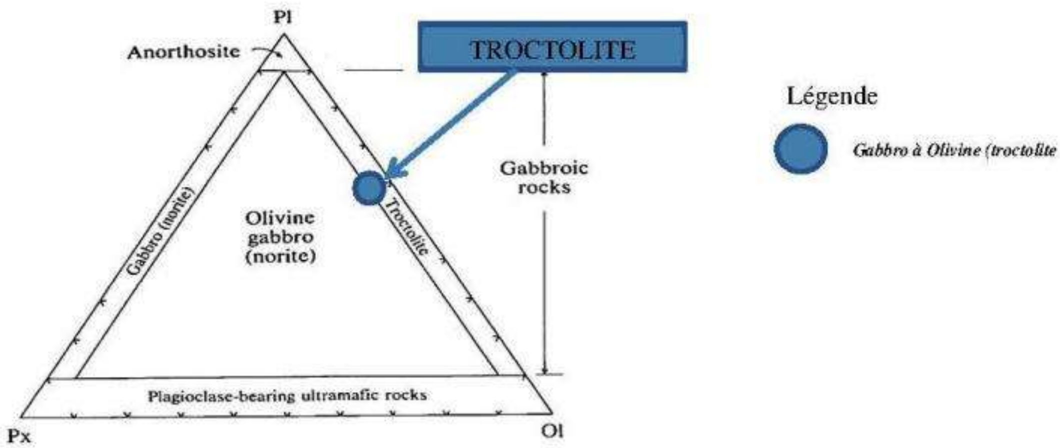

Fig- 3 : Diagram (Pl.Px.Ol) showing the transfer of Olivine gabbro (troctolite)

a. The medium-grained gabbros

These gabbros are characterized by their dark melanocratic color with a massive texture, of gritty structure with medium grain (Fig- 4). They are composed by blackish green pyroxenes (dark minerals), plagioclases (light minerals). The presence of pyrites is sometimes noted in these gabbros. Amphibole minerals are difficult to identify because of their similarity with pyroxenes. Thanks to the mineralogical percentage, we can affirm the presence of gabbro and gabbro-norite. The mineralogical characteristics of the representative samples (X: 266 508, Y: 7 964 252, Z: 925 m) analyzed under a polarized microscope are summarized as follows: the whole rock observed in thin slide shows a predominance of well developed plagioclases and colored ferromagnesian minerals (pyroxenes). These minerals are dispersed and are attached to each other without following any privileged plan. Quartz is probably unnoticed. Plagioclase feldspars (labradors) occupy most of the section of the thin blade.

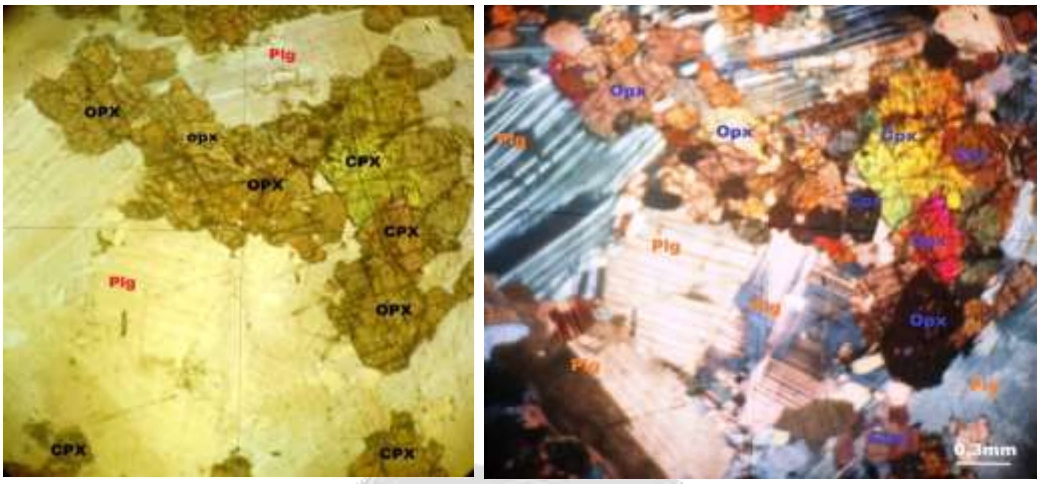

Fig- 4 : Microphotograph of medium-grained melanocratic gabbro (right) and gabbro-Norite (left) from left to right in LPNA, then in LPA. Note the development of plagioclase laths (X10 enlargement)

b. Fine-grained gabbros

The micro-gabbros or dolerites encountered in our sectors are generally fine-grained, i.e. fine-grained and less darkly colored than the melanocrate gabbros (Fig. 5). The rock presents a massive texture and the minerals are equant. The accompanying mafic minerals are difficult to identify with the naked eye without using a magnifying glass, but the color remains a better recognition of the rock.

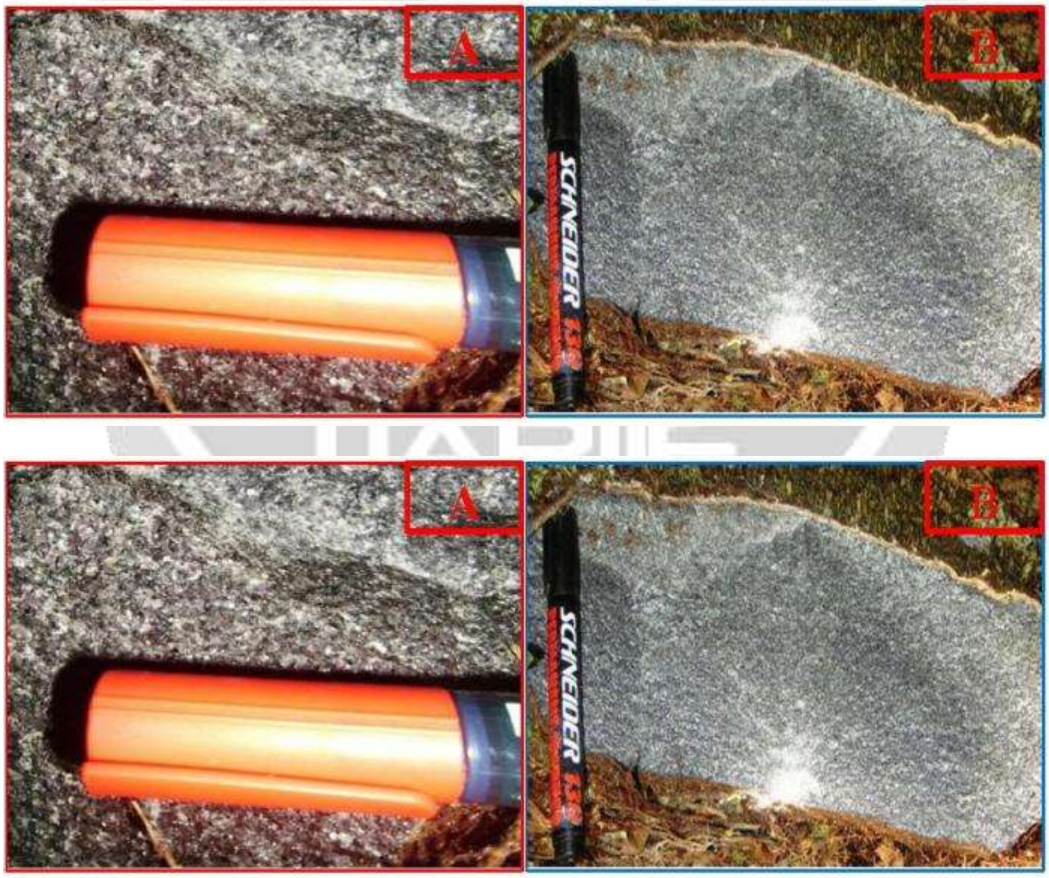

Fig- 5 : A) Melanocratic gabbro sample (X : 266 508, Y : 7 964 252, Z : 925 m); B) Gabbro with fine-grained structure, (X : 263 540, Y : 7 964 800, Z : 950 m)D'une manière générale, ces roches présentent une texture micro grenue accompagnée de gros minéraux ferromagnésiens de grande taille dispersés dans la matrice de la lame.

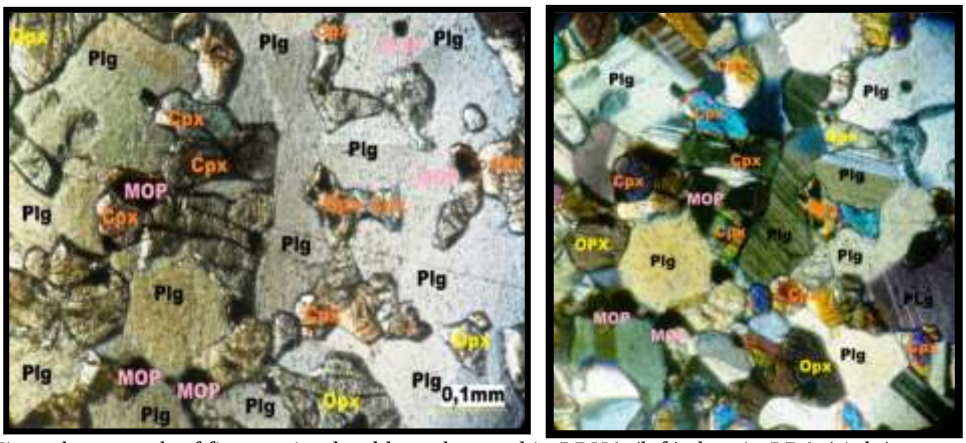

Fig- 6 : *Microphotograph of fine-grained gabbro observed in LPNA (left) then in LPA (right)*

c. **Gabbros with olivine or Troctolites**

In the field, olivine gabbros are different from other basic rocks by their more or less coarse grading (Fig. 7). The rock is of purplish gray color. The presence of green colored minerals is generally remarkable. The grains are medium sized, formed by mafic minerals which are greenish peridots, black pyroxenes and purplish plagioclase. These rocks were encountered on some outcrops in the form of mass.

Fig- 7 : Sample of gabbro with olivine ; (X : 264 853, Y : 7 964 915)

Generally, they present a gritty texture with medium grain. The mineralogical compositions are marked by the presence of pyroxenes and the predominance of olivines and plagioclases. The representative sample was taken at the coordinate (X: 264 853, Y: 7 964, Z: 915 m). Thin section observations of our sample revealed two types of mineral paragenesis: primary minerals formed by the assemblage of olivine plagioclases and pyroxenes and secondary minerals constituted by coronites with opaque minerals. The secondary minerals are the minerals neoformed from the reactions between the different crystals of primary minerals. They are presented by: olivine relics, opaque minerals, coronites which are reaction minerals.

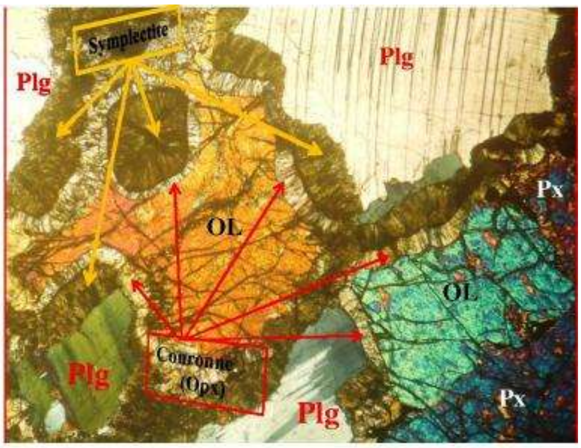

Fig- 8 : Microphotograph of coronitic olivine gabbro in LP showing the reaction aureas between olivine and plagioclases

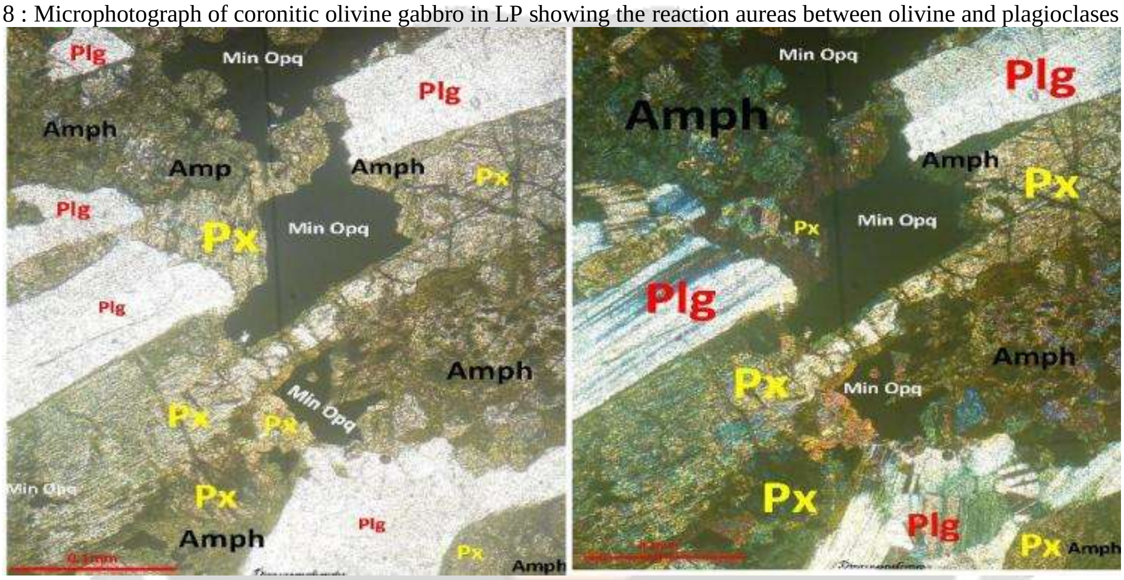

Fig- 9 : Microphotographs of orthoamphibolite in LN, then in LPNA showing the formation of secondary minerals such as amphiboles and opaque minerals

3.1.2.2. The ultrabasic rocks

They are composed of peridotites, amphibolites and pyroxenolites. The peridotites belong to the family of ultramafic rocks. They are characterized mineralogically by the abundance of mafic minerals (olivine more than 70%), which implies a consideration of very dark color ranging from melanocratic to holomelanocratic. Macroscopic observation in the field has identified dark holomelanocratic minerals (olivine>pyroxene) of unequal proportion. In case of dominance of pyroxenes, we have pyroxenolites. Some rocks have minerals of blackish green color with a gritty texture, formed mainly by olivines and porphyry pyroxenes. The representative sample on the picture is taken in the western part of our study area, as enclaves within gabbros.

Orthoamphibolites are difficult to differentiate from gabbros in the field (Fig- 10). They are related to gabbros but their study under the microscope allows us to classify them in the family of metamorphic rocks resulting from the transformation of magmatic rocks, hence their nomenclature.

Fig- 10: Sample of an orthoamphibolite (X: 264 860, Y: 7 964 915)

Under the microscope, it is composed mainly of basic plagioclase feldspar (labrador), opaque minerals and amphibole and pyroxene minerals (Fig- 11). These minerals are localized and lined in the cleavages or in the interstices of pyroxenes. In LPNA they are green-brown. In LPA they are bottle green. These amphibole minerals are probably formed by the reaction between pyroxenes and plagioclases.

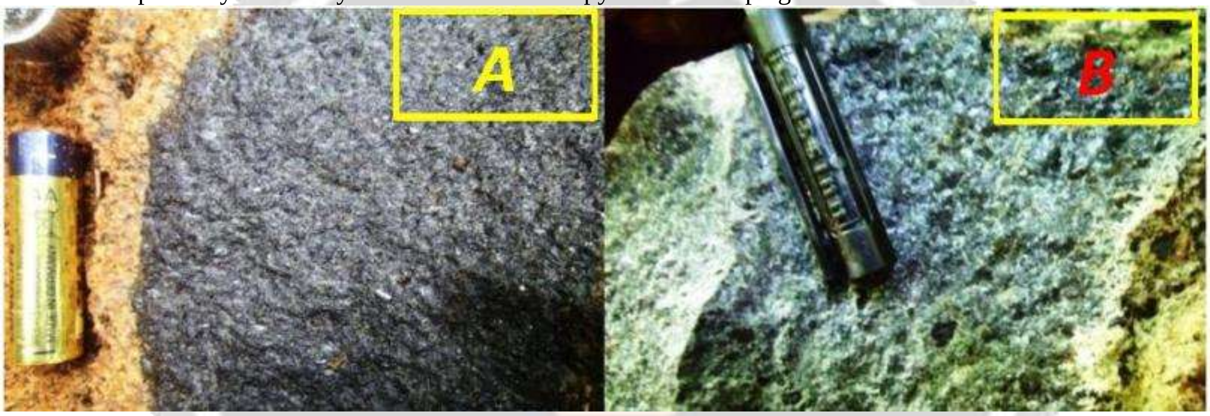

Fig- 11 : A) Sample of holomelanocrate peridotite (X : 266 529, Y : 7 962 200, Z : 1001m ; B) Blackish green peridotite with pyroxene porphyries (X : 264 014, Y7964 282 : Z : 968 m)

The peridotites are composed of ferromagnesian minerals with the dominance of olivines. For the samples analyzed in the laboratory, the proportion of minerals presented in Table 3 has been plotted (OL CPX OPX). The projection of these values gives peridotites of the Lherzolite type (Fig. 12)

Table 3: Modal composition of ultrabasic rocks

Minerals constituting of the rock		**Percentages % (Quantitative)**
Plagioclase		None
Quartz		None
Pyroxenes	OPX	13,4
	CPX	20
Olivine		66,6
TOTAL		100

Fig- 12 : Plot on Ternary diagram OL-CPX-OPX of the representative sample of ultrabasic rocks.

This dominance of olivine minerals is verified in the analysis and observation of rock thin sections (Fig- 13)

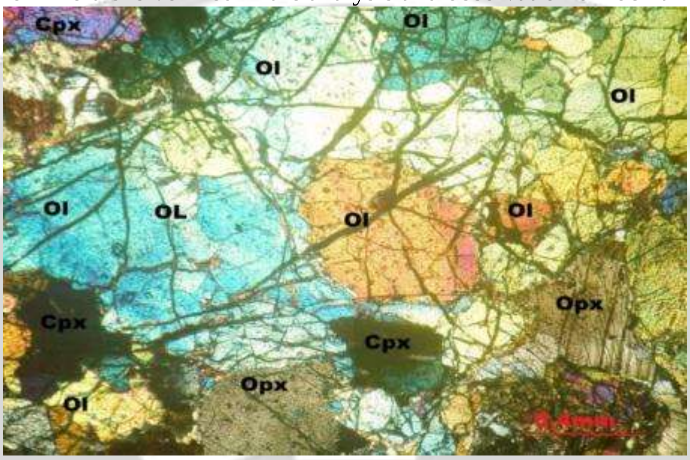

Fig- 13 : Microphotograph of peridotite in LPA, composed of globular and multicolored mafic minerals of 2nd and 3rd orders

3.1.2.3 The ferruginous armor

These rocks are generally dark red to rusty red in color and of varying thickness. They are formed by a skeleton hardened by the precipitation of iron hydroxides. Their type of alteration are specific either vacuolar or in iron oxide grains or concretions. The grains of iron oxide, products of alteration of the cuirasses, are dominant and are focused especially in the central part of the massif. Intact and indurated iron armour (Fig. 14) also dominate this area.

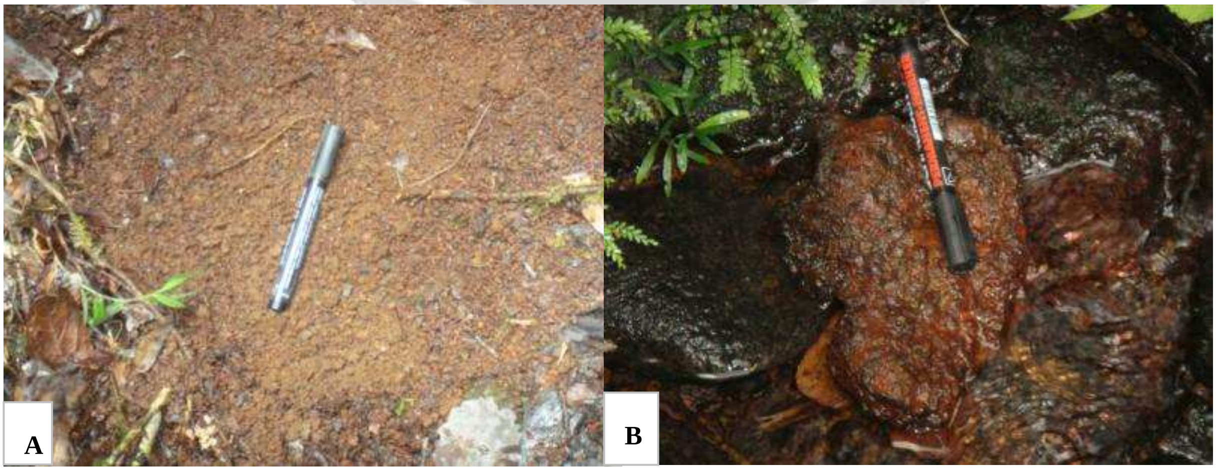

Fig- 14 : Iron oxide grains (figure7A), indurated ferruginous clays (figure7B) observed in a stream.

Macroscopically, they are formed essentially by goethites and matrix of ultrabasic rocks (Figure 37). The knowledge of their mineralogical assemblage is still an interesting research and requires a better knowledge in this matter, but we tried to interpret them from the works explored by Trescases, in New Caledonia. The mineral paragenesis defined for this type of rock are the following (Fig- 15): Goethite is a hydroxide formed by hydration of hematite; these minerals are classified in the Oxides groups and present a black color that is always opaque in polarized light and in natural light. The matrix of mafic minerals is composed of alteration residues of ultrabasic and basic rocks. During this process in humid areas with a warm tropical climate, the silicates release all the iron they contain [9].

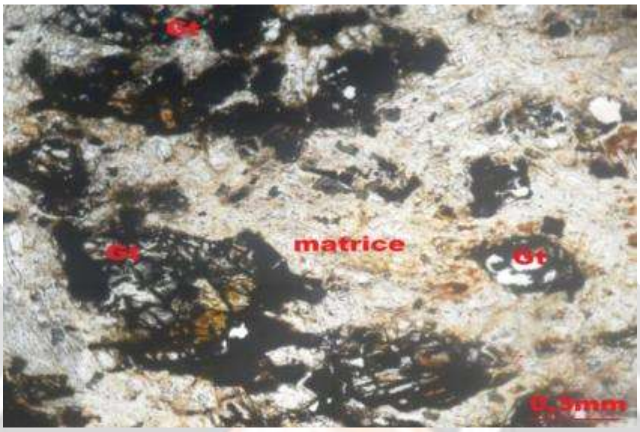

Fig- 15 : Microphotographs of iron armour in LPNA showing black crystals of goethite (Gt) in a matrix of mafic ***mi****nerals*

3.1.2.4. Acid rocks

The quartz veins belong to the group of acid rocks and are formed essentially by silicas. This milky coloration is characteristic of this zone, and, is due to the very high temperature of crystallization of the formation of these rocks. These quartz are arranged in veins anastomosing in microfractures inside the rocks and in annular vein at the scale of the study area. These veins form a thin sheet a few meters thick forming a kind of ring more or less continuous observed on the edge of the eastern part of the massif where they occur in discontinuous clusters with a characteristic ball alteration (Fig-16A). These rocks are dominant in the south-eastern part, along the road to the base camp and in the vicinity to the east of it.

Leptynites are metamorphic rocks derived from an acidic magmatic rock. They have a foliated structure, oriented texture of the gneissic type, of light color and fine grains, compact, constituted by deformed Quartz (more or less stretched) (Fig-16B) and alkaline feldspars dominant, very poor in amphiboles. They are found in the southern part of Transect C, showing the beginning of yellow alteration due to the action of water on the feldspars on the surface of the rock.

Fig- 16 : A Milky quartz vein in place showing ball alteration, B Leptynites at the beginning of alteration, the light minerals are represented by quartz, feldspars and the dark minerals by ferromagnesian minerals.

I.6.1.3. Structural geology and lineament mapping

The study area had been subjected to several types of brittle deformation. Several types of deformation were observed in different locations. At the scale of the massif, this area was affected by a large fault of general NE-SW direction. At the outcrop scale, faults, fractures materialized by fracture planes and quartz vein intrusion in microfractures forming stockwerk. Forces are permanently exerted on the rocks and eventually cause their rupture. The deformations following a rupture of the rocks at great depths are manifested at the surface by faults and/or fracture planes. In general, the deformation in this area is typical and marked by the existence of parallel fracture planes (Fig-17), of the same direction and dip N 005°- 70°W, in pyroxenolites.

Fig- 17: Fractured pyroxenoliths showing parallel fracture planes N 005°- 70°W

In other parts of the study area, the presence of fractures and microfractures in rocks facilitate fluid flow after tectonic deformation. Within some rocks these weak zones are filled by quartz veins of N 110° direction (Fig. 18) of varying thickness arranged irregularly or anastomosed according to the shapes of the fractures. According to the crosscutting principle, these quartz veins are therefore post-tectonic because they crosscut the pre-existing ultrabasic formations, hence the name quartz vein dykes.

The faults are also evidence of deformations that affected the study area and the entire region. Normal faults are observed in amphibolite formations showing three parallel fault mirrors (Fig. 19), mirror 1: N148°-84°SW and mirror 2: N150°-85°SW, as they have the same directions and dips. These faults show oblique downward discharges on their mirrors indicating the direction of displacement of the overthrusted part. The latter was not observed because the fault is located within a stream.

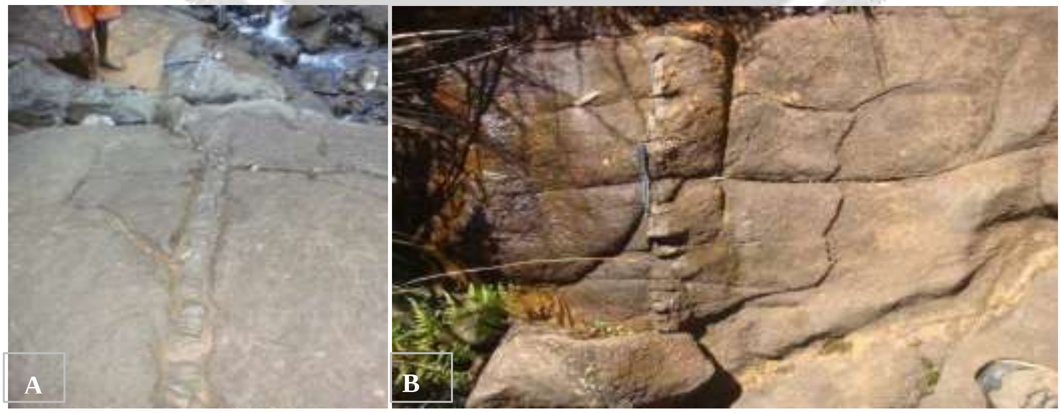

Fig- 18: 7A Amphibolites recut by quartz veins (acid rocks). The quartz veins show an anastomosing arrangement with various sizes. 7B The quartz veins are parallel with a direction of N 100°.

Fig- 19 : normal faults with three parallel mirrors from left to right

In this same area, we observed mirrors or parallel fault planes that are not visible on this figure. Pyroxenolites and amphibolites present a typical type of alteration that is related to the regular arrangement of weak zones or network of diaclases more or less rectangular, it is the networks of diaclase. This type of typical alteration affecting the interior of the rocks is at the origin of their fracturing in the North-East part of the ultrabasic zone: At the time of the crystallization of the rocks, there was reorganization of the molecules of the silicates which are going to associate for their constitutions. The detachment or separation, without modifying the form, of these microstructures is provoked only after a succession of deformation which had affected the region in general. It had therefore appearance of the microfractures inside the rock. Thanks to the action of the meteoric waters having an erosive power the microfractures widen while keeping the more or less rectangular form well organized of the mineral associations. The mechanical effect of the roots of the higher plants, which creep inside these fractures, will develop with time and facilitate the erosive action of the waters thus leading to the bursting of the rock. As the fracture is not followed by a displacement then the rock was not affected by a fault but just a simple regular break called networks of diaclases. These diaclases evolve into rockfalls of various weights that can reach several tons.

Fig- 20 : genesis and evolution of rockfalls from diaclases

3.2. Results on the modeling of lineaments on GIS

The automatic extraction of the lineaments validated by the measurements taken in the field led to the establishment of the lineaments map. We used remote sensing since the area is heavily covered with vegetation. The validation of the final result presented on the lineament map is done visually by comparison with the different scientific documents available (geological map and geophysical data) and in the field. These lineaments correspond either to faults or fractures that could be materialized by watercourses of different types and directions or by seams.

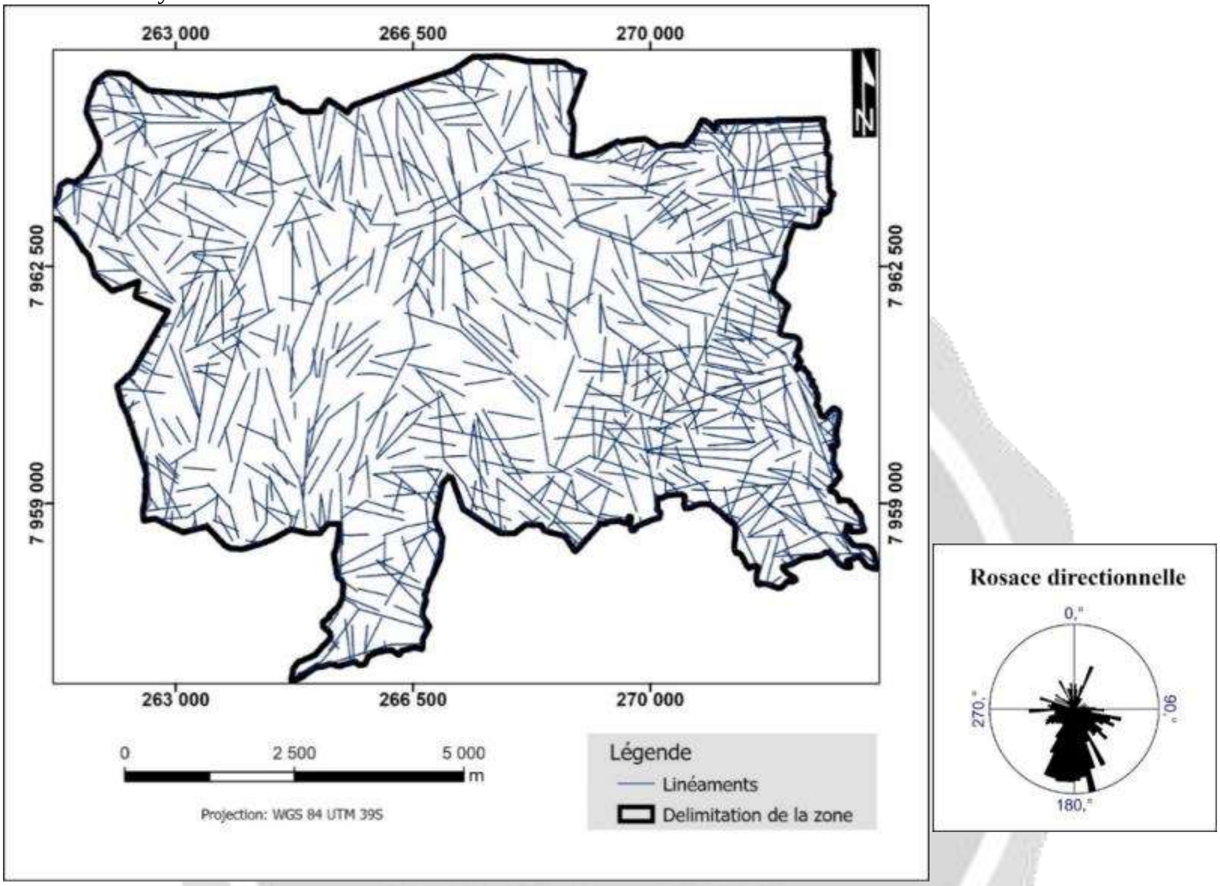

Fig- 21 : Map of the lineaments of the gabbroic massif of Ankerana

The directional rose shows the different directions of the lineaments. Several types of lineaments have been found, the statistics are given in the table below. The general orientation of these lineaments is North-South, NE-SW and NW-SE. They correspond to the directions of the rivers seen in the massif. The large NE-SW lineament represents the large listric fault cited in BRGM geological reports.

Table 4: Basic statistics of the lineament map from the automatic extraction

Number of lineaments	1337
Maximum length (m)	2188
Minimum length (m)	0,3
Total length (m)	629650
Average (m)	471
Standard deviation (m)	359,2

In relation to the density of the lineaments, the densest areas are colored in red. In the density map, we have three sectors: the eastern part, the southern part and some areas in the west. The high density of the eastern part corresponds in the field to the steep slope area, to the different types of escarpment. This proves the existence of a large irregular fault of NE-SW direction. In the field this area was inaccessible because of the steep slope almost close to 75°.3.3. New geo-structural mapping of the Ankerana massif at 1:10,000 scal After the superposition of all the petrographic data as well as the data on geological structures collected during the two expeditions of 2012 and 2014, the new lithostructural map of the Ankerana massif is given by Figure 48

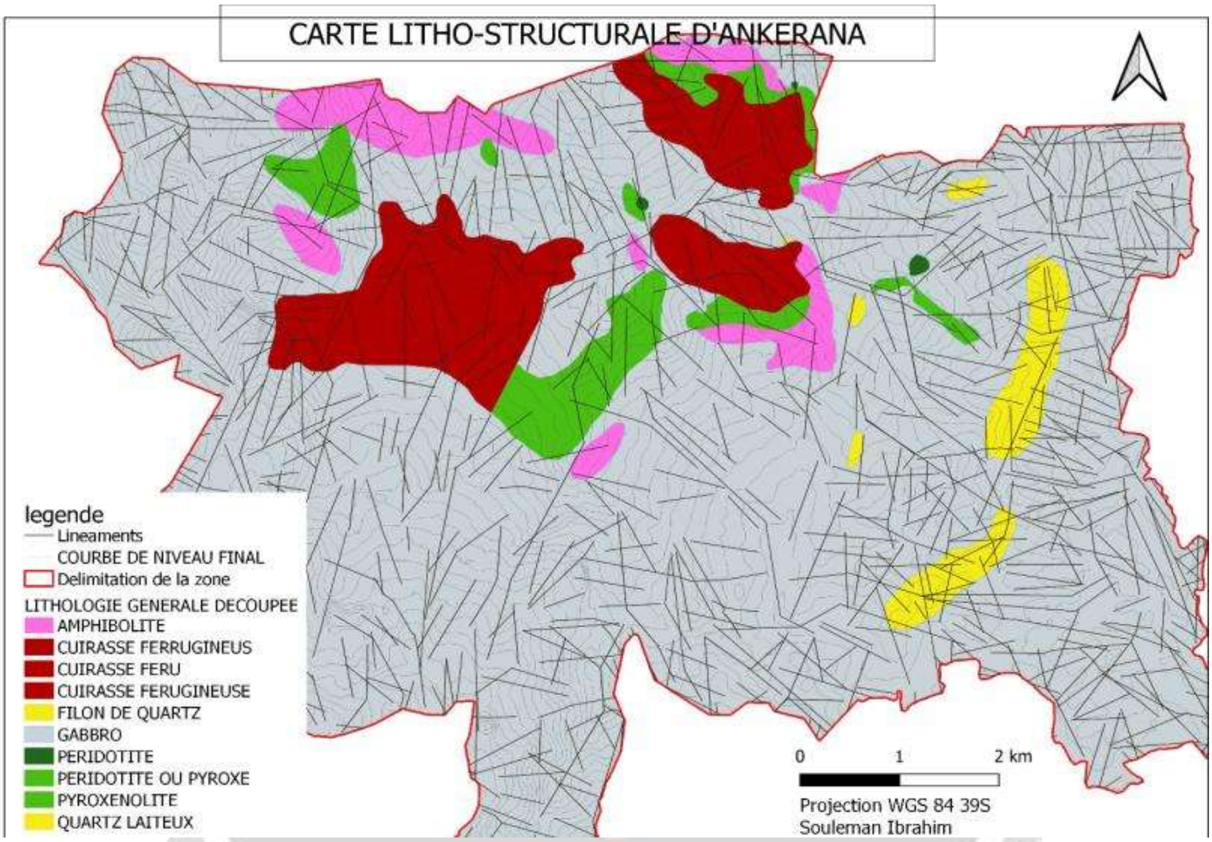

Figure 48: New lithostructural map at 1:10,000 scale of the Ankerana massif

This new detailed geological map of the sector shows the dominance of gabbros. Lenses of ultrabasic rocks exist in the northern part. Some lenses of milky quartz veins appear in the eastern part. These veins are indicators of deformations following the opening of the surrounding rock, they come from the cooling of the last magmatic liquids which had filled these openings. The summit plateau in the center of the sector is occupied by residual rocks, notably the ferruginous cuirasses. From the lithological point of view, the combination of microscopic and macroscopic petrographic observations has highlighted three types of geological formations: basic, ultrabasic and acidic formations. The sector is dominated by gabbros with veins of acidic rocks in the eastern part of the massif, which confirmed the studies of Besairie [5] and the studies of BRGM. The difference with their studies, the geological mapping object of this part of the thesis was fine and very detailed since all observations were made every 50 m. Indeed, we produced a new map of the area at a scale of 1/10.000e. The basic and ultrabasic formations are essentially amphibolite pyroxenolites and lherzolites, according to the studies of modal compositions under polarizing microscope. They are lens-shaped and scattered in the north-northwest and northeast parts of the gabbroic massif. On the stratigraphic plan, if we retrace the history of the geological events which had set up this massif, from these lithological arrangements and mineral paragenesis, we can say that this massif is stemming from a fractional crystallization from a basic magma which is in intrusion in the metamorphic formations of the Tsaratanana series. The magmatic differentiation had been slow and complete until the cooling of the last magmatic liquids at the origin of the acid rocks. These parameters verify its similarity to the Analamay Ambatovy formation in Moramanga. All these formations had undergone brittle deformations. These are verified by the presence of several fault planes and fracture planes. The acidic magmatic liquids trapped in chambers had found openings to migrate and then cool. Hence the formation of quartz veins in dyke arrangement with respect to the surrounding formation. This opening is materialized by a large escarpment in the eastern part. This zone is occupied by milky quartz veins with micropyrites and/or pyrites. In other areas, fractured basic and ultrabasic rocks also show centimetric to metric size microfilons with anastomosing directions forming a stockwork. The contacts between the microfilons and the host rock are clear. These indications prove that all fractures are post formation. These deformations are responsible for the formation of dendritic streams in all directions as well as the very rugged topography. These fractured rocks also favor the increase of the permeability of the rocks, the water tables have become free since they are in direct contact with the atmosphere. In this sector, even in period of low water, some rivers are fed with water from the upstream and/or the top of the mountains. The Ankerana massif is a free mountain-sourced acquifere.

4. CONCLUSIONS

The complete data collections of the studies allow to obtain the following results: 350 stations, more than 240 samples collected among which 40 samples of typical formations and some soil samples. The geological studies from field observations and laboratory analysis have allowed us to have new knowledge on the gabbroic massif of Ankerana to better understand the relationship between the substrate and the habitat. The objectives have been achieved in this part of the research. We characterized the geology of the gabbroic massif of Ankerana. More specifically, this includes detailed mineralogical and petrographic studies of the different lithologies, structural studies, the production of a new fine and detailed lithostructural cartography of the study site; the inventory of the hydrographic characteristics of the watersheds. We encountered some logistical and technical problems during the two expeditions, but this did not prevent the continuity and progress of the hammer prospecting work. The topographic, climatic and vegetation thickening or density factors of the area are very extreme. The data that we have collected are sufficient to answer the hypotheses of this research.

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