GOLD MINERALIZATION OF BETSIAKA IN THE NORTHERN PART OF MADAGASCAR.

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ABSTRACT

The Andavakoera area is located in the far north of Madagascar and falls within the Bemarivo geological domain. Our research included various structural, petrographic and geochemical studies on the gold deposits located in this region. The contact zone of the crystalline basement and the sedimentary formation is where it is located geologically. The marine Permian, the marine Triassic, the Isalo group, the Jurassic and recent sedimentary formations are the main components of the sedimentary formation. Eruptive rocks can be classified as either post-Liassic intrusive rocks or recent volcanic rocks. The mineralization is ephemeral in nature and involves low temperature hydrothermal MINERALIZATION.

Keywords: *Gold, Chemical analysis, Permian, mineralization, deposit***.**

1. INTRODUCTION

In the earth's crust, gold is a rare and abundant metal found in different forms. It may occur naturally when combined with silver, mercury, or mixed with other substances such as gold or silver tellurium, and may contain traces in pyrite, arsenopyrite, galena, etc. [1]. Madagascar is a country with considerable potential for gold. The mining potential is still significant and largely unknown. The far north of Madagascar is home to Andavakoera, a highly productive gold deposit among other regions [2]. The challenge is to examine the petrographic, mineralogical and geochemical characteristics of rocks to determine their lithological characteristics, precise composition, texture, structural relationships, etc. which compose them. The objective of this study is to provide an explanation of the mineralization process and how chemical elements are transferred through petrographic analysis of gold and sulfide paragenesis and geochemical analysis.

2. MATERIALS AND METHODS

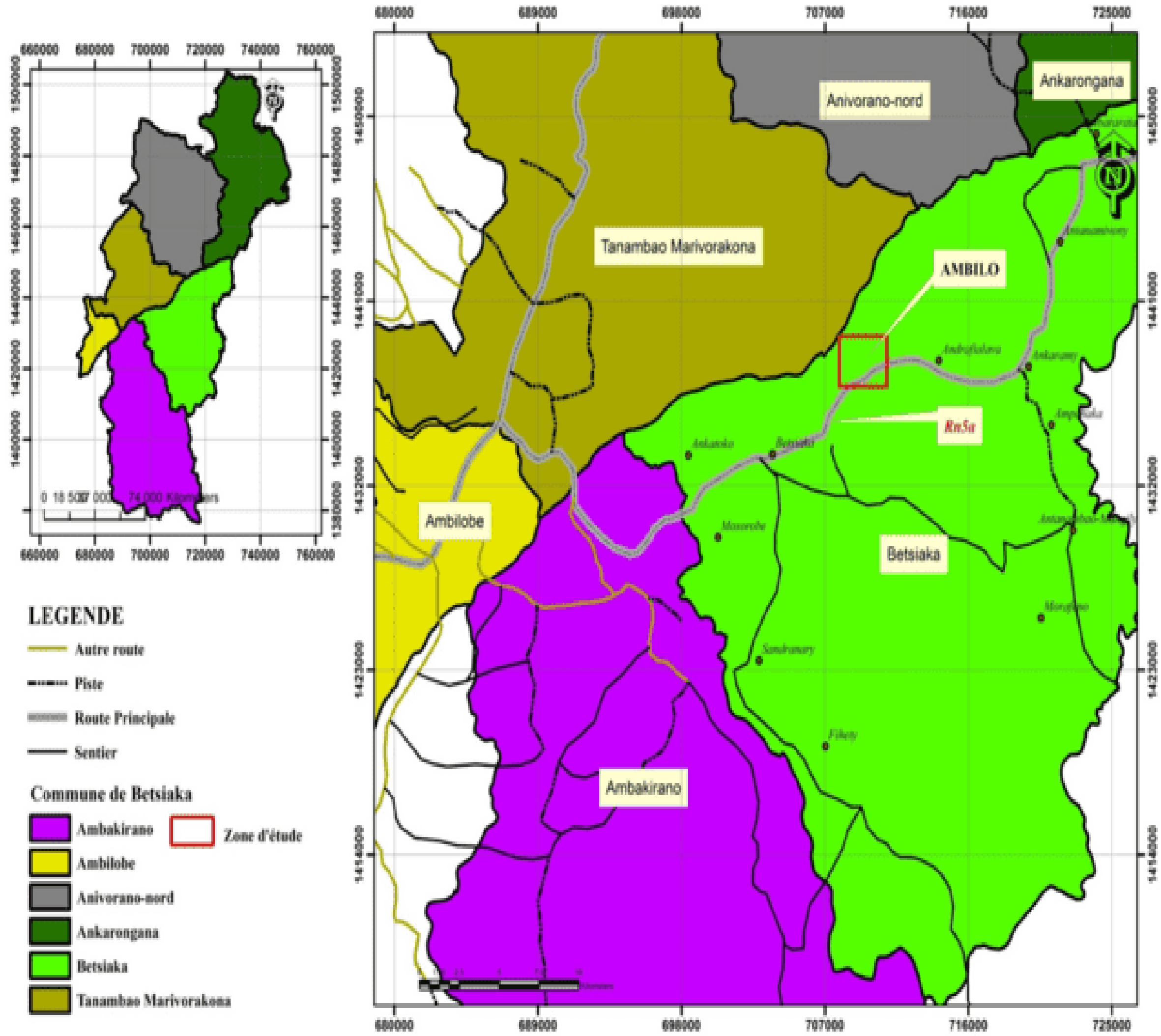
2.1. Materials

2.1.1. Presentation of the study area

The commune of Betsiaka is located 35 km from the district of Ambilobe and is one of the 15 communes of Ambilobe. Administratively, the study area belongs to the DIANA region, the district of Ambilobe, the commune of Betsiaka in the district of Ambilobe and the Fokontany of Betsiaka. Geographic coordinates (Table 1) also delimit it.

TABLE 1: Table showing the geographic coordinates of the study area

POINT	X (m)	Y (m)
A	708000	1436000
B	708000	1438000
C	711000	1438000
D	711000	1436000

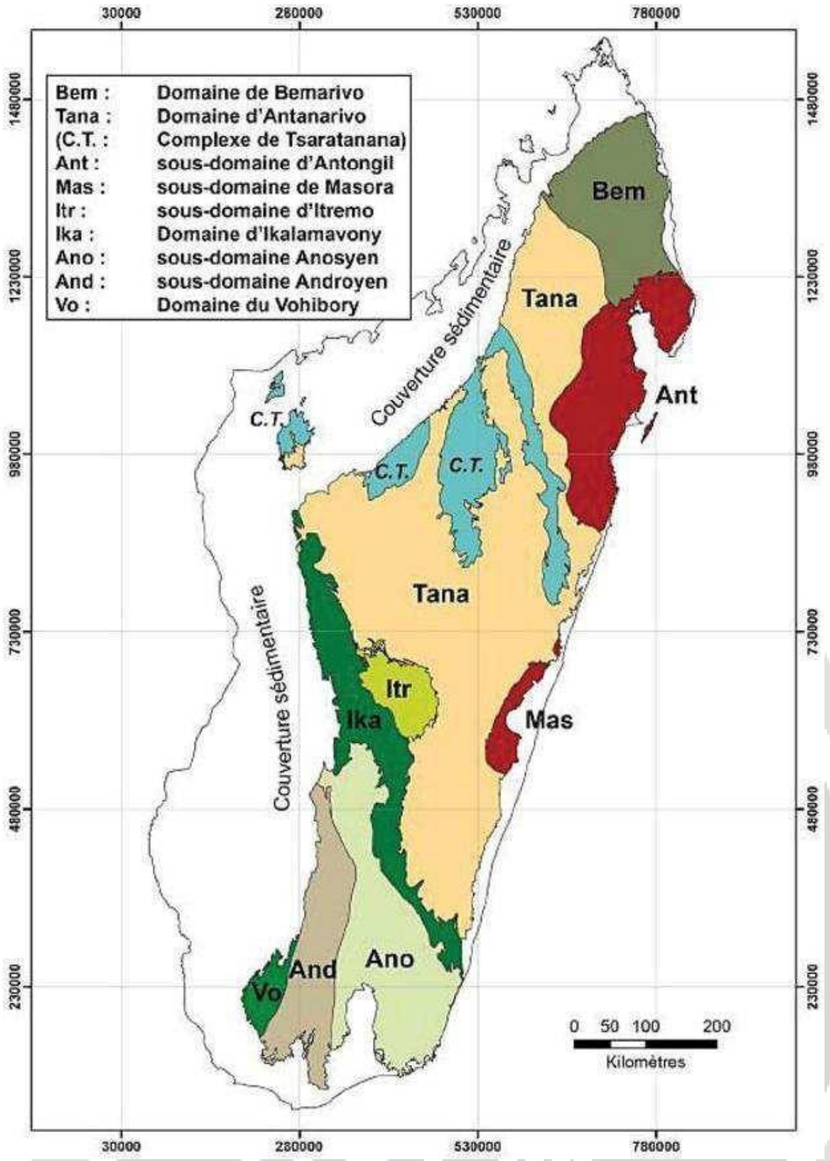


Map 1: Location map of the study area; Source: BD 500 FTM

2.1.2. GEOLOGICAL FRAMEWORK

- **Geology of Madagascar**

Map 2 shows the different tectono-metamorphic domains according to Jean Yves Roig [3].



Map 2: Tectono-metamorphic subdivision map of Madagascar (J.Y.Roig., 2012)

- **Crystalline base of Madagascar**

The crystalline base is Precambrian in age and constitutes the parent rock. It is made up of metamorphic and eruptive rocks. Repeated metamorphism associated with various orogenic activities resulted in a highly folded and complex formation.

These older formations cover the entire central area and almost the entire eastern area, an area of 400,000 km2 (approximately two-thirds of the island). These crystalline layers do not contain fossils, with the exception of stromatolites (mineral form formed by the biological activity of algae) which are found in siporins. [3]

- **Recent studies on the geology of Madagascar** have classified the Precambrian basement of Madagascar into six tectonic and metamorphic domains [3].
  - **The domain of Antongil and Masora**
  - **The Bemarivo estate**
  - **The Antananarivo area**
  - **The Ikalamavony estate**
  - **The Anosyen-Androyen domain**
  - **The Vohibory domain**

- **Sedimentary cover of Madagascar**

The fossils they contain reveal their age, ranging from the coal period to the Quaternary. These sedimentary layers are distributed along the western coast over a width of 250 km, or 1/3 of the island. The sedimentary layers consist of a non-sedimentary layer which slopes slightly at an angle of approximately 10° towards the Mozambique Channel. This sedimentary layer is also found along the east coast in the form of small, very narrow margins. These sedimentary layers include [3]:

The Gondwanan formations: the Karroo system

- Recent training: the Post-Karroo system
- Finally, volcanic and subvolcanic formations ranging from the Upper Cretaceous to the Quaternary, occur on the base and on the sedimentary cover.

2.1.3. THE GEOLOGICAL CONTEXTS OF THE BETSIAKA REGION

- **Regional geology**

The crystalline base: ortho gneiss with muscovite, orthogneiss with amphibole and garnet. Rare outcrops show the presence of a few horizons of quartzite to magnetite. The whole is intersected by fairly frequent pegmatite dykes.

It is noted that the dykes and veins generally align along the basement-sedimentary contact.

The Permian (Neo-Permian): arkosic sandstones with oblique stratification, medium to coarse, with lenticular episodes of black, pyritic clay-silts rich in carbonaceous materials. This formation begins at the base either with a polygenic conglomerate of very variable thickness, or with coarse arkoses. The association of these lithofacies reflects agitated detrital sedimentation in a reducing environment. We observe the coexistence of marine brachiopod fauna and marsh flora (Equisetum).

The variations in thickness of the whole are considerable: exceeding 80 m in certain places, the Permian can completely disappear due to a stratigraphic gap, with the Triassic shales then resting directly on the base (west of BETSIAKA).

- **The marine Lower Eo-Triassic**: greenish gray shales with fossiliferous nodules (fish and ammonites).
- **The Upper Eo-Triassic (Iraro layers)**: yellowish azoic clay-schists.
- **The continental sandstones of Isalo (Triassic)**: main ridge formation of ANDAVAKOERA. [4]

- **Structural context**

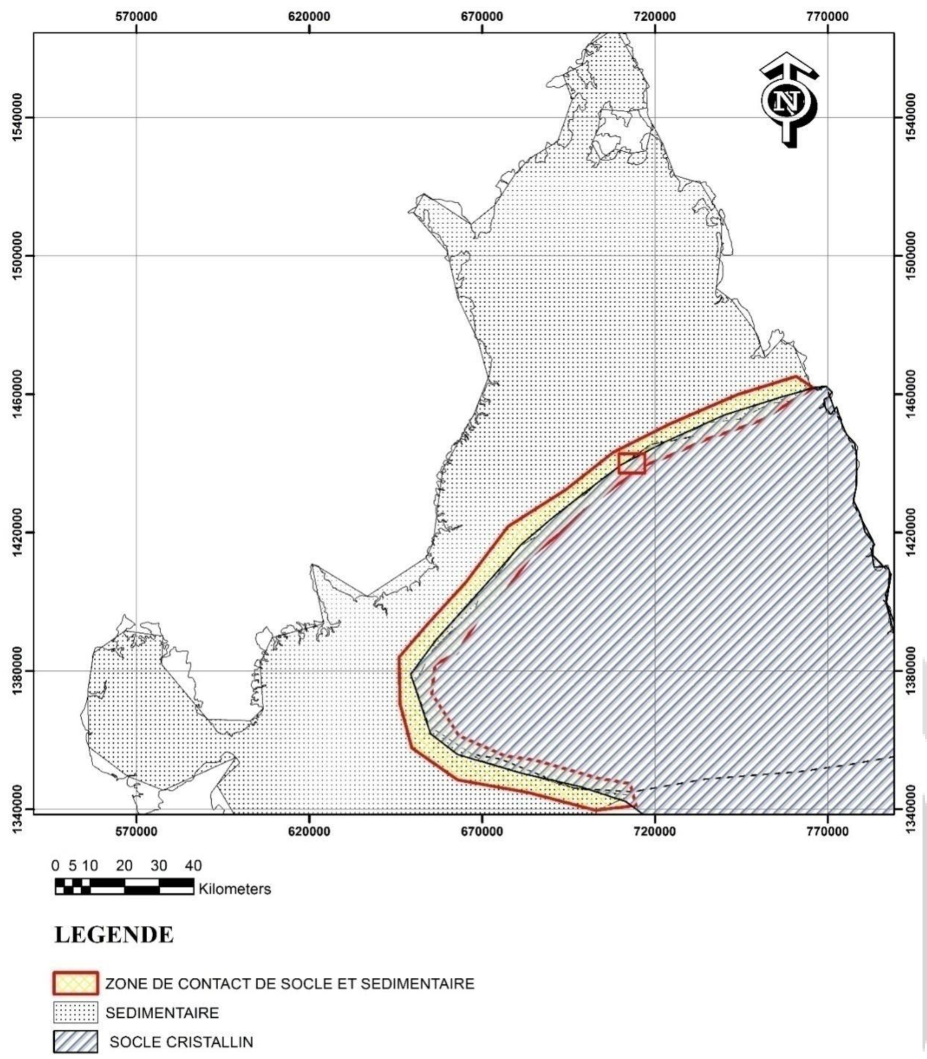
The sedimentary layers as a whole have a regional northwest dip of about 30°, while the basement layers also have a northwest dip, but more steeply (50°-75°).

The contact zone with the basement corresponds to a major accident associated with the collapse of the Mozambique Channel rift. This area extends from the Sambirano valley in the southwest to the east coast (LOKY valley) over a total length of 170 km.

The Andavacoela region is formed by a bundle of large post-Triassic faults oriented N20° to N50°, which separate the Permian and the basement, sometimes towards the northwest, sometimes towards the southeast.

The basement itself appears to be influenced by older faults with approximately the same orientation, forming shear zones where thick, angular silicified conglomerates develop.

Post-Triassic transverse faults (oriented N120°) have in places broken the N20°-N50° alignment, affecting all strata in the region until the Upper Triassic [4].



Map 3: Contact zone of crystalline basement and sedimentary; (Source: BD 500 FTM), digitized by Namana D V. 2018) [5]

2.2. Methods

Above all, we carried out bibliographic research to better understand our objective, target the most promising area in terms of gold and identify the mineralized veins.

During the field trip, we carried out surveys with gold miners regarding the content around the ore veins, the depth they reach, and the direction of their fatana (quarry). The quantity is of the order of grams per tonne. Each Fatana has its own GPS coordinate. We collected samples; we carry out structural measurements and observation of outcrops, relying on:

- Verification of data already acquired in order to understand the regional geology of the sector
- Carrying out geological surveys and making mineralogical inventories of the samples collected
- Collect information and validate information already had within the community of Betsiaka.
- The structural study consists of measuring the directions and dips of the foliations, and lineations as well as the general direction of the joints and veins. It is important to specify the directions of shear.
- To describe the structural occurrence of mineralizations, we processed satellite images of the region.
- We then carried out mineralogical observations and tectonic measurements on the ground.
- Samples of surrounding rocks and gold-bearing quartz veins were analyzed to determine the paragenesis of the veins on the one hand and petrographic studies on the other hand. A sample taken at the coordinate point was the subject of geochemical analyses: observation under an optical microscope in transmitted light, observation under an optical microscope in reflected light.

These observations relate to the petrographic and structural description of the outcrop.

The goal is to:

- Know the general structure of the outcrop: size, shape and orientation.
- Identify the rock based on size, color, texture, structure and the nature of the constituent minerals.
- Study the spatial and temporal relationships between each petrographic entity present in the field
- Regarding data processing and analysis. The objective was to compare studies carried out by the settlers, the BRGM, the former gold miners and ourselves, using the Arcgis 10.8 software.

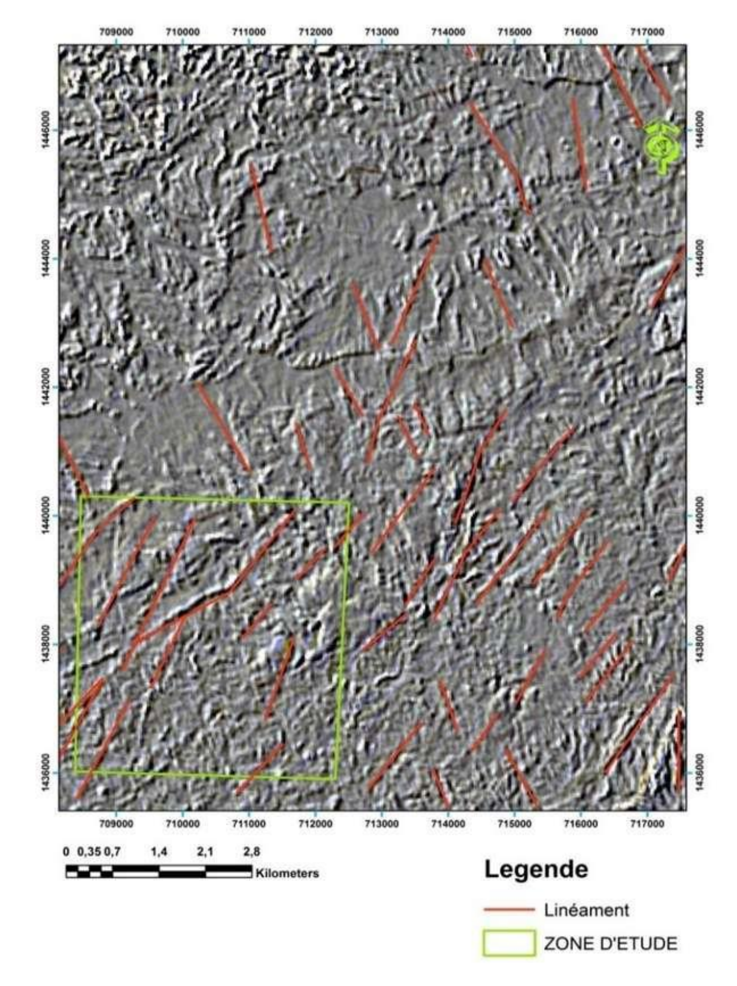
3. RESULTS

3.1. LITHO-STRUCTURAL MAPS OF THE STUDY AREA

➢ **Lineament map**

The lineaments are highlighted by filtering the CP1 during processing of the ETM+ image. Many filters have been applied, such as the directional filter and the Sobel filter. However, only the directional filter, at α=30° with a 3×3 matrix, allowed good visualization of structural lines within the study area. The brittle structures are therefore traced on the background obtained by directional filtering and are synthesized to give the lineament map of the Ambilo sector.

- Most of the faults are oriented NE-SW (the gold zone coincides with the contact between the gneissic to migmatitic basement of the Bemarivo field and the Permo-Triassic cover).
- There is also a fault oriented NW-SE (a later fault which serves as hot spring drainage intersects and offsets the quartz vein)



Map 4: Structural map of the Study area Source: Band Landsat 7, digitized by Namana D.

3.2. PETROGRAPHIC STUDY

3.2.1. SEDIMENTARY LANDS

Shale Slate

Photo 1: Shale; Source: Namana D.V. 2018

(a) Ambilo Ardoisier Slate Outcrop (x: 708858.533 m; y: 1438480.317m)

(b) Sample of Mantalimaro Slate Shale

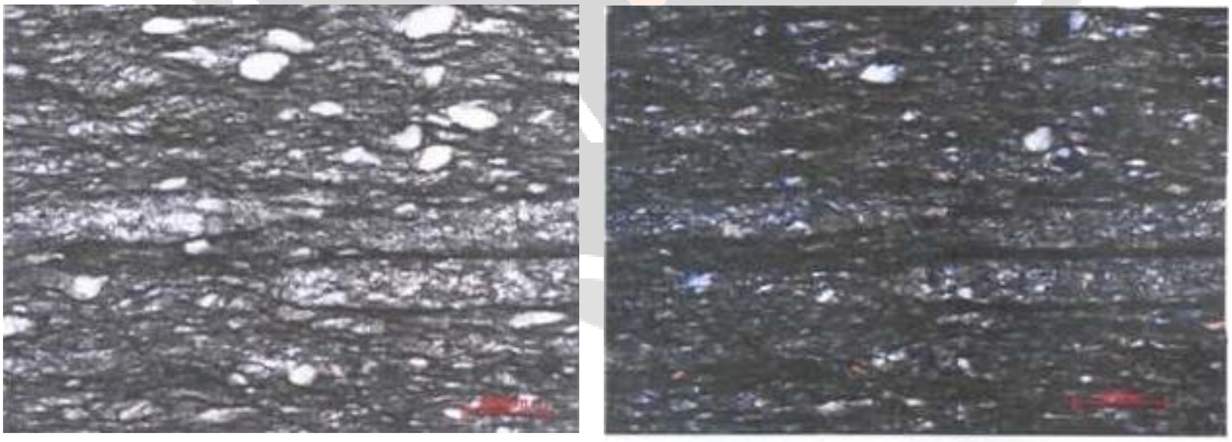


Photo 2: Microscopic analysis in non-polarized and polarized natural light

Slate is a metamorphic rock formed under high temperatures and pressures. It belongs to the shale family and is characterized by very fine particles and a tendency to break easily. These properties allow it to be used as a roofing material.

Slates are durable and come in different shades, including gray, dark red and green. Roofing slates are available in straight (rectangular) and scale shapes. Thicknesses vary from 3 to 9 mm; between 20 and 40 mm are available in pink, which is a stronger, less wrinkled shale.

3.2.2. BETSIAKA SERIES

- **Quartzo-Barite vein of Ambatomanindry – Ambilo**

quartzo-barite, taken at Ambatomanindry, it is an outcrop of quartzo-barite.

Photo 3: Ambatomanindry quartzo-barite vein – Ambilo X: 709273.891 m, Y: 1438492.621m; Namana D.V. 2018

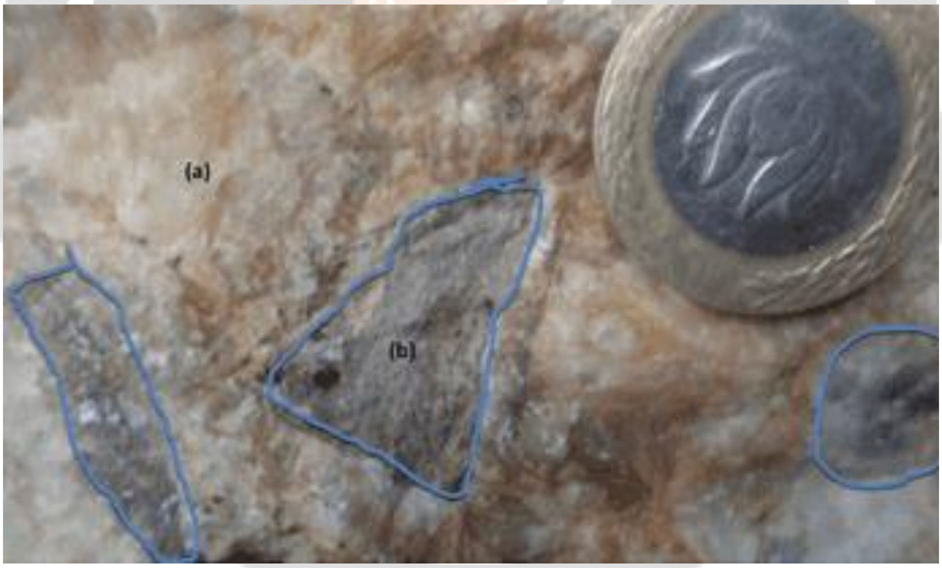


Photo 4: Photo showing quartzo-barite vein with microgranite enclave

(x: 709332.573m; y: 1438586.975m); Source: Namana D.V. 2018

(a): Quartzo-barite vein

(b): Microgranite enclave

These rocks are massive leucocratic rocks with well-developed quartz crystals. In these rocks, quartz usually forms small crystals. They are colorless to grayish transparent and have the appearance of coarse salt. The sheen is greasy and glassy.

Spotted quartz veins are intersected by microgranite outcrops. Microgranite is a leucogranite. Its structure is micro-gravelly and massive. The quartz-speckled veins penetrated the host rock at a soft stage.

In polarized light without an analyzer, quartz appears as very distinct spots, without any trace of mottling, cleavage or alteration. The relief of the quartz is weak and these spots are barely visible in thin layers.

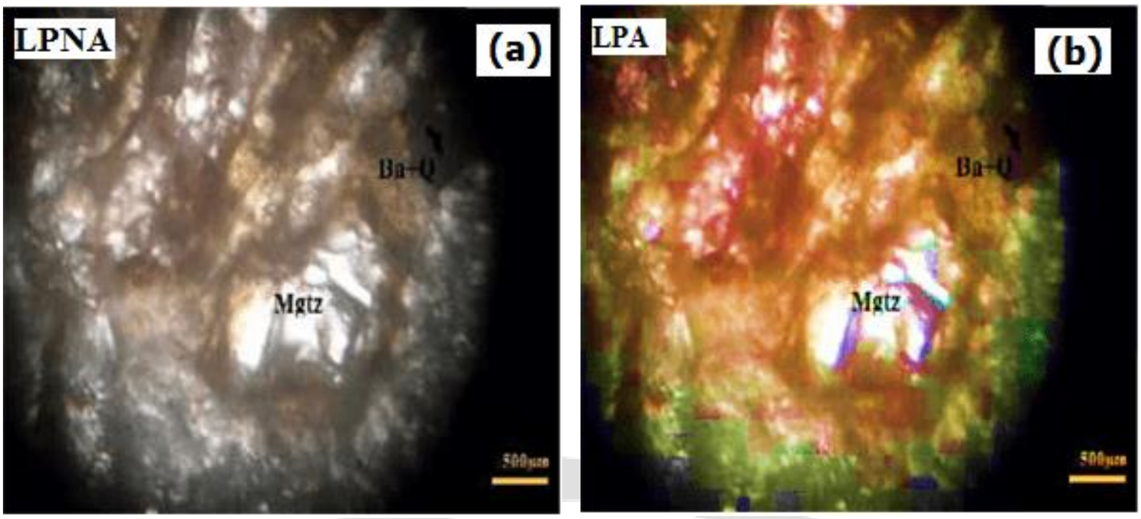


Photo 5: Quartzo-barite microphotographs

(a): Unanalyzed Polarized Light

(b): Analyzed Polarized Light

The crystals are generally atypical, with small pieces and no defined shape. In light polarized by the analyzer, quartz exhibits low birefringence and polarized white or gray hues. Some crystals may show rolling quenching, which indicates deformation.

Photo n° 6: Ambatomanitry vein zone (contact zone of granite and quartzo-Barite); Source: Namana D.V. 2018

- **Gneiss**

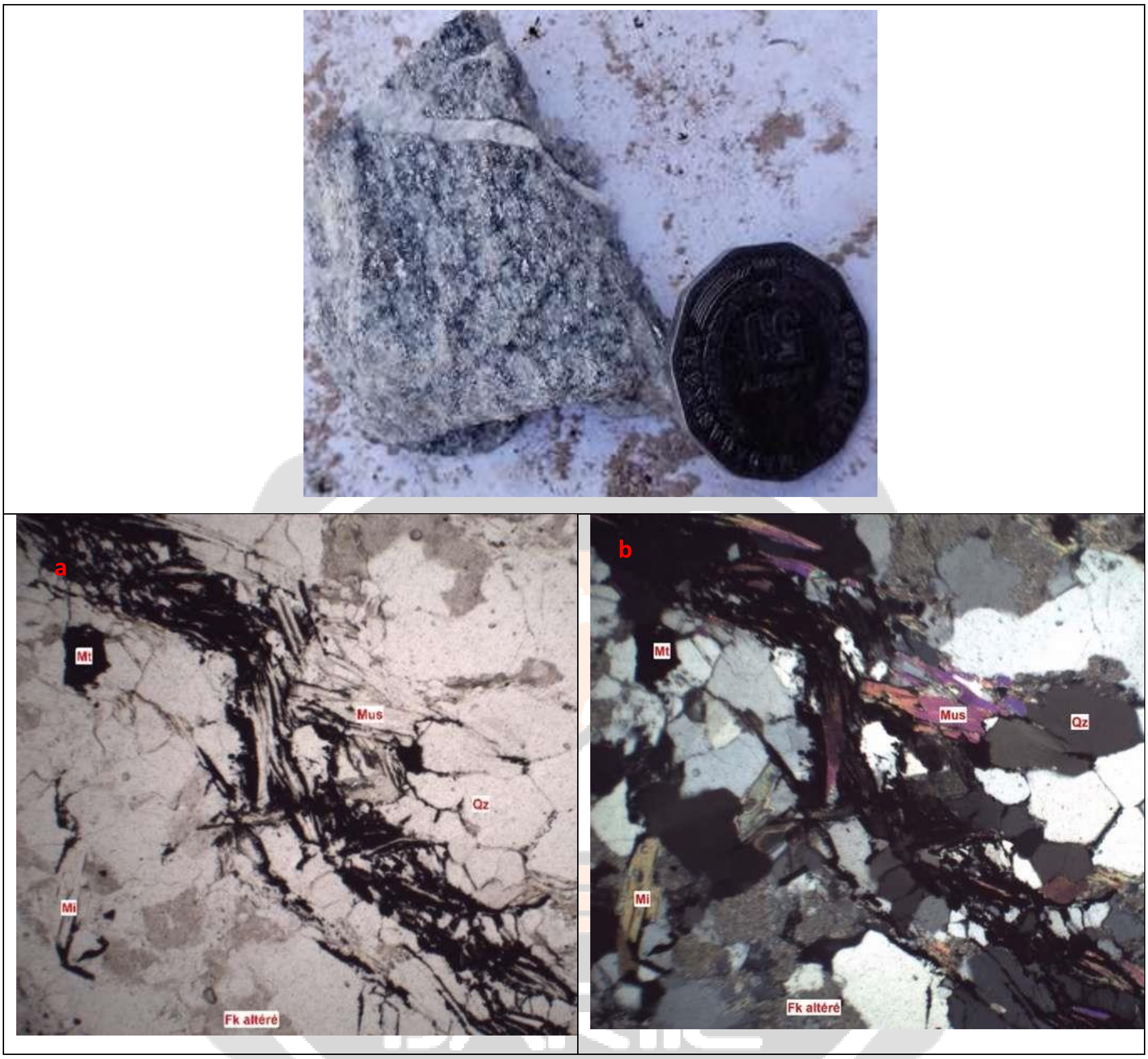


Photo 7: Gneiss: (X: 644410.5425m, Y: 1377254.557m) (Mus.: Muscovite; Fk.: Feldspars; Mt: Magnetite; Qz: Quartz)

(a): Photomicrograph of syenite in Unanalyzed Polarized Light (10x20)

(b): Photomicrograph of syenite in polarized light (10x20)

The gneisses of the Betsiaka region are characterized by a very altered appearance. This distinguishes them from other gneisses.

Gneisses are metamorphic rocks containing quartz, albite, altered feldspar and magnetite, all identifiable to the naked eye. The ubiquitous laminas can alternate between small light layers and thin dark layers (this is called metamorphic laminae). The light layers consist mainly of quartz, plagioclase and feldspar. They have a granite structure. The dark layers are microcrystalline and hornblende may be present. Lepidoblastic structure.

3.2.3. CHARACTERISTIC OF HYDROTHERMAL LEAD

The Andavakoera veins were developed during several successive phases: silicified vein, jaw quartz vein, quartzo-barite vein. And, these three types of veins can exist separately, most often they are combined.

In the perimeters of Ranomafana, the quartz-barytic veins were set up in all the faults and fractures. Between its two parameters, only the main direction of fracture is mineralized.

In the crystalline, moving away from the contact, the quartzo-barytic veins give way to silicified veins. Pyritic stockworks are abundant in the Permian sandstones of the Mantalimaro sector.

The veins appear to have been formed in three phases which are successively: first the silico-pyritic phase, then the quartzose sulphide phase, finally barytic.

The jaw quartzes found independently of the silicified zones correspond to a particular quartz phase.

Pyrite is rarely crystallized at the bottom (fine pyritization of the walls). The high temperature of the first hydrothermal occurrences did not allow it to be deposited, but it was telescoped by the Permian sandstone cover. The barite which generally fills the central zone of the veins appears to constitute the last hydrothermal occurrence.

We encounter fillings of opaque barite between two walls of jawed quartz, the thickness of these quartz walls is remarkably constant. This arrangement can be modified by the successive rejections and filling of the veins. Fragments of veins or spherulites of jawed quartz are found in barite.

And, at depth, there is a type of vein made up of an aggregate of quartz crystals which contain sulphides, galena, blende, chalcopyrite.

Sulfide does not have a preferential location, because sulfides are found in thin layers or in small aggregates in the silicified walls, in the quartz sablends and in the barite which is found at the heart of the veins. And, systematic surface prospecting showed that there was no notable concentration of sulphide.

- **Silicified vein**

These veins are sometimes formed of breccia elements composed of jaw quartz, gneiss linked in a siliceous pat with secondary development of fine quartz crystals in the interstices.

In certain cases, the gneisses themselves have been intensely silicified at the edge of the cracks giving large veins of very hard and compact rocks with very rarely diffuse injection of barite.

Jaw quartz veins are formed by successive deposits of silica in open cracks, made up solely of quartz crystals layered together, in superimposed layers giving a so-called “comb” structure. Sometimes they are completely closed, sometimes open and form geodes with beautiful crystallization of the quartz giving the impression of real jaws. Their power rarely exceeds 0.4 meters.

In these veins, the barite forms filling by covering the jaw quartz, sometimes spreading them disproportionately, giving a very lenticular appearance with powers varying from 10 cm to 3 meters. It is worth noting the regular thickness of jaw-forming quartz; in this case, wall of the barytic gangue.

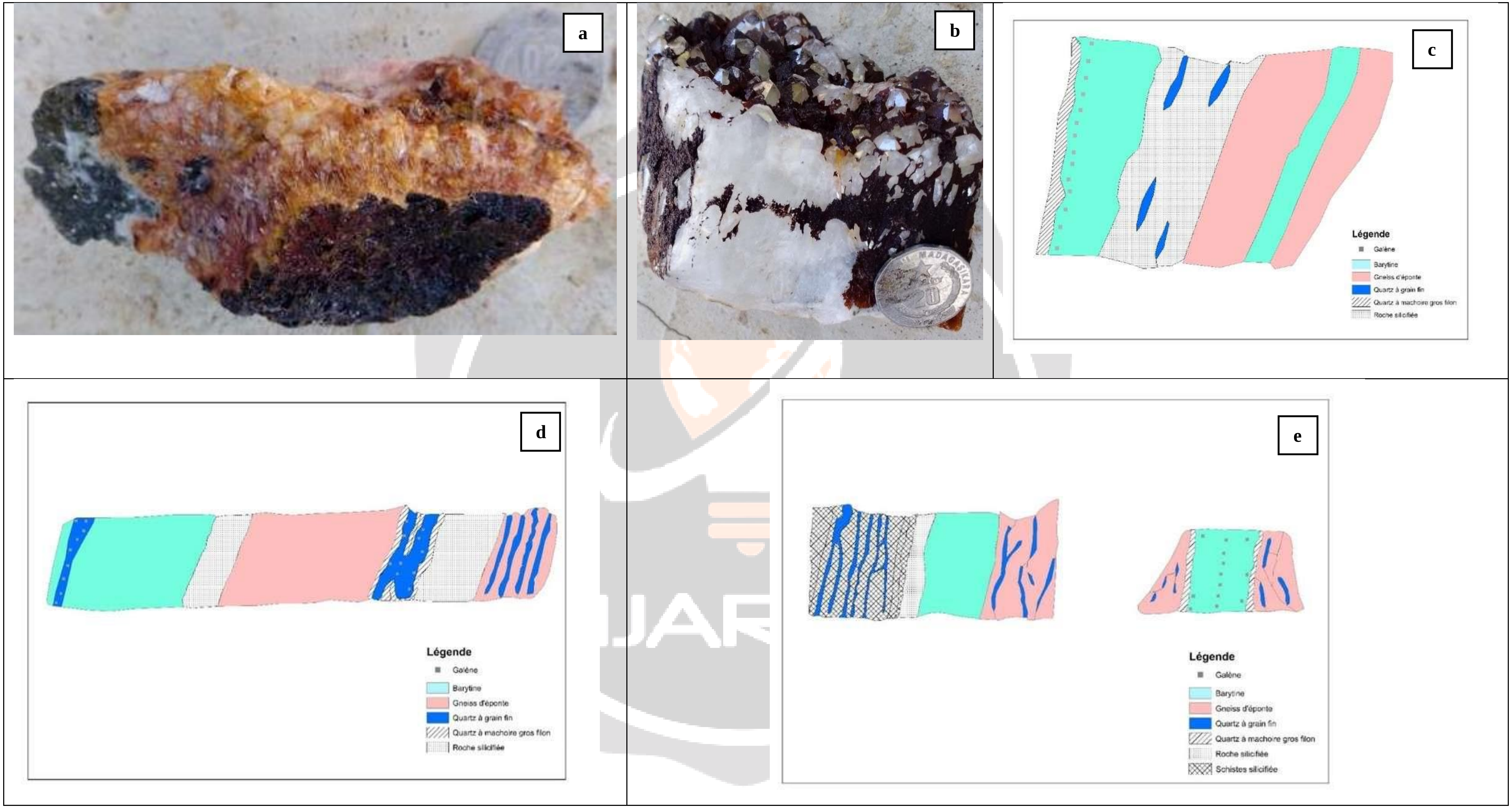


Photo 8: Betsiaka quartzo-barite vein: (a) and (b): Jaw quartzo-barite vein (Betsiaka); (c) and (d) and (e): cross section of quarzo-barite vein

4. DISCUSSIONS

The Bemarivo Domain is a distinct block in the northern tip of Madagascar. It essentially comprises calc-alkaline metasedimentary and plutonic rocks (Tucker et al. 1999; Thomas et al. 2009). This study confirms Tucker's hypothesis, because according to the petrographic study, we have three large groups:

- A metamorphic rock: foliated like mica schist and non-foliated like amphibolite
- Finally post-tectonic calc-alkaline hyperpotassic intrusions including granite The structure in the Betsiaka area is oriented NW-SE contrasts with that N-S of the Archaean shield and this area also differs on the lithological and geochemical levels. Thomas et al. (2009) considers that this domain can be divided into two parts with, to the north, a young terrain comprising intrusive plutonic rocks and volcanic rocks. This study confirms Thomas' hypothesis that this domain is divided into two, because in the field faults have been identified, which have different orientations (fault group with NE-SW and NW-SW orientation).

Two options are proposed for mineralization depending on the petrographic and geochemical study:

- Choice I: Gold mineralization occurred following tectonic shearing, with the main gold anomalies. Around the upper part of the basement rocks, the lower part of the Permian sandstones and the unconformity zone between the two, the main mineralization took place, which could have led to a decrease in the pressure of the ascending fluids and a drop in temperatures. Further erosion exposed and removed the upper part of the mineralized sequence, while the lower and middle mineralized zones were preserved.
- Choice II: There has been gold mineralization throughout the sheared zone as a result of tectonic shearing, mainly below the main gold anomalies, and perhaps also further to the northwest. The Triassic shales regulated the main mineralization by sealing the mineralization compartment at its top and reinforcing the mineralization of the sandstones below. Through late erosion, the mineralized zone had been deeply cut and the main orebodies were removed in the structurally high areas, leaving behind numerous residual gold anomalies on the surface. To the northwest of the main surface anomalies, it is possible that gold mineralized zones have been spared by erosion.

CONCLUSION

In conclusion, the mineralization is epithermal, as evidenced by the presence of barium in the mineralogical composition of the vein. This suggests that the barite cases are barren veins, with the exception of the northwestern part of Betsiaka, known as "Betainkilotra".

Most veins are found in zones of hydrothermal alteration (Permian sandstones), where secondary dispersion is very common, as in the case of Korimalandy around the rural commune of Betsiaka. Gold-rich quartz vein areas.

Primary veins lie beyond the Permian sandstones.

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