PETROGRAPHIC AND MINERALOGIC CHARACTERIZATION OF THE BETSIAKA GROUP, NORTHERN MADAGASCAR

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ABSTRACT

The Betsiaka Group is one of the four groups forming the Bemarivo Domain in northern Madagascar. This domain represents a juvenile Neoproterozoic volcanic arc with some older, pre-Neoproterozoic components. Along with the Sahantaha Group, the Betsiaka Group represents the oldest formations in the Bemarivo Domain. Sahantaha Group is in the southern part of the domain, whereas the Betsiaka Group is found in the northernmost region. Betsiaka group is composed of metamorphic felsic rocks, amphibolites, and impure marbles. It is separated from the Permo-Triassic sedimentary cover to the north by a normal fault and is adjacent to the juvenile Neoproterozoic volcanic rocks of the Milanoa Group to the south. This study aims to redefine and recharacterize the Betsiaka Group and its formations through field observations, petrographic, and mineralogical analyses. Petrographic and mineralogical studies together offer a thorough understanding of rocks and minerals, enabling accurate rock classification and tracking of geological events. Samples from the Betsiaka Group have been analyzed under transmitted light of petrography microscope in combination with EDS analyses. These studies, combined with field observations, have allowed us to categorize the Betsiaka Group into two distinct formations: the Mantalimanera and Andafialava formations. The Mantalimanera Formation consists of metasedimentary sequences, including felsic rocks, impure marble, and calcsilicate rocks, which are only slightly affected by fluid alteration. In contrast, the Andafialava Formation features mafic orthoamphibolite sequences interlayered with biotite micaschist and some paragneiss. These mafic sequences are strongly affected by fluid alteration. Textural and mineralogical analyses reveal retrograde metamorphism within the Betsiaka Group, a characteristic also observed in other groups of the Bemarivo Domain.

Keywords: *Andrafialava Formation, Mantalimanera Formation, felsic magmatism, mafic magmatism.*

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1. INTRODUCTION

The Betsiaka Group is situated in a narrow belt, stretching approximately 50 km in NW-SW direction and up to 6 km width in the northwest part of the Bemarivo Domain [1]. It is a Paleoproterozoic terrain, covered discordantly by Phanerozoic rocks to the west and northwest and with a tectonic contact to the other units of Bemarivo Domain along its eastern boundary [2,3]. This group is dominated by metamorphic rocks with different protoliths. Those rocks were previously divided into three units: the Mantalimanera Formation, ortho-amphibolite, and para-amphibolite, along with separate units for calcsilicate rocks and marble [1]. In this study, we have reclassified the Betsiaka Group into two formations. The first is the Mantalimanera Formation, as defined by earlier researchers (e.g. [2 1]), which now also includes the marble unit. The second formation, newly introduced, is the Andrafialava Formation named after the village where the amphibolites are well exposed. The Andrafialava Formation encompasses the para-amphibolite and ortho-amphibolite units. We present the results of petrographic studies and Energy-Dispersive X-ray Spectrometer (EDS) mineral analyses of the two formations.

2. GEOLOGICAL SETTING

Madagascar's geological formations are broadly divided into two main categories: one-third of the western part of the country is covered by Phanerozoic sedimentary rocks, while the eastern two-thirds consist of Precambrian bedrocks [4]. The most recent geological maps of Madagascar's crystalline basement [1] divide the Precambrian Abasement into six geodynamic domains, from south to north: Vohibory, Anosyen-Androyen, Ikalamavony, Antananarivo, Antongil-Masora, and Bemarivo (Fig -1). Each domain is characterized by distinct metaplutonic suites and metasedimentary groups, or by a unique history of tectono-metamorphic reworking during the latest Archean or Paleoproterozoic [5]. Antongil-Masora and Antananarivo domains are seen as an extension of the Greater Dharwar Craton in India (combined India and Madagascar) accreted during the Neoarchean [13]. During the Proterozoic, three exotic terranes accreted to the Greater Dharwar Craton: the Vohibory Domain, the Anosyen-Androyen Domain, and the Bemarivo Domain.

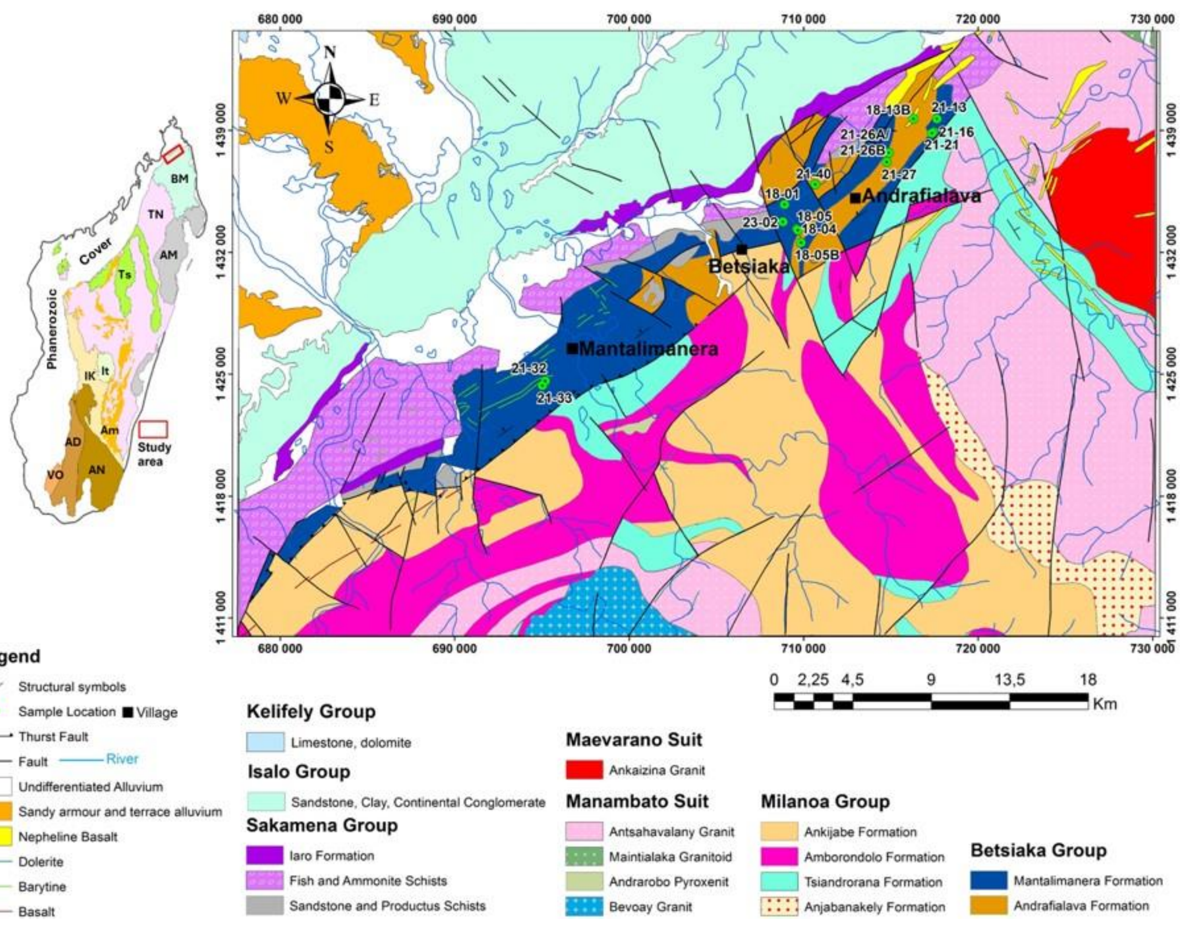

Fig -1: Geological map of the Betsiaka Group and surroundings (compiled from [6]; [7]; [8] and own fieldwork) with sample locations. BM=Bemarivo Domain; AM = Antongil Masora Domain TN = Antananarivo Domain; Ts=Tsaratanana Sheet; It=Itremo group; Ik, Ikalamavony Domain; Am=Ambatolampy Group, AD= Androyan Domain; AN= Anosyan Domain; Vo= Vohibory Domain.

The study area belongs to the Bemarivo Domain, which is divided into two terranes. Those two terranes are separated by the Antsaba shear zone which is oriented east-west [3,9]. To the south, Marojejy terrane croups out, which is composed of metasedimentary sequences from the Sahantaha Group intruded by the Antsirabe Nord Plutonic Suite. The Sahantaha Group primarily consists of metasedimentary sequences including interbedded quartzites, calc-silicates, and metapelites, which have undergone high-grade metamorphism up to the granulite facies with temperatures of 500-600 °C in west and the eastern part higher temperatures up to 740 °C. The GASP geobarometer records pressures of 6-8 kb throughout the area, but in some places, there are much lower pressures of 3-5 kb [10, 11, 2, 3, 12]. The metamorphism occurred in two distinct stages: the first between 563 and 532 Ma, and the second between 521 and 513 Ma. The Antsirabe Nord Suite consists of foliated calc-alkaline plutonic igneous rocks, ranging in composition from gabbro and diorite to tonalite and granodiorite, up to granite [3].

The north of the Bemarivo Domani is formed by the Bobakindro terrane, comprising the Daraina, Milanoa and Betsiaka Groups, and intruded by the Manambato suite [3,9]. The Daraina Group consists of a series of volcanic and volcaniclastic units metamorphosed under greenschist facies. Those rocks include mafic volcanic rocks, meta-sedimentary rocks and acid to intermediate volcanic rocks [2]. They are divided into three formations: (1) Ambanja Formation dominated by Amphibolite, mafic volcanic rocks (including tuffs), mineral composition are Plagioclase-hornblende biotite-chlorite epidote±quartz±K-feldspar, (2) Ambodimadiro Formation comprises of Quartzofeldspathic metasedimentary rocks with mineral composition Quartz-feldspar chlorite±opaque minerals±garnet and (3), Ambatojoby Formation composed by acid to intermediate metavolcanic rocks Quartz-feldspar biotite±hornblende±glass [3]. The Milanoa Group includes metasedimentary and metavolcanic units metamorphosed under amphibolite facies conditions, with some migmatization. This group contains Quartzofeldspathic paragneiss ± sillimanite ± garnet, Paragneiss of granodioritic composition with epidote, garnet mica schist ± sillimanite, hornblende paragneiss and migmatite [2]. The metamorphic grade distinguishes the Daraina Group from the Milanoa Group, although the two successions are speculatively considered to be nearly contemporaneous [3]. Both, the Daraina and Milanoa Groups reveal geochemically subduction-related magmatism [3]. The Betsiaka Group is primarily composed of mica schists and quartzites but also contains minor units of amphibolite and calc-silicate gneiss. To the west and northwest, the Betsiaka Group is unconformably covered by Phanerozoic rocks, while the eastern contact with other units of the Bemarivo belt is tectonic [3]. Geothermobarometric analyses of three garnet amphibolite samples yielded metamorphic peak pressures of 12 kbar using the Gt-Hb barometer and temperatures around 650°C using the Hbl-Plag thermometer [2].

3. ANALYTICAL METHODS

Mineral chemical analysis was conducted using the Electron Microprobe Analyzer (EMPA) JXA-8100 at RWTH Aachen University. EPMA has used crystal diffractors with gas detectors of Wavelength-Dispersive Spectroscopy (WDS) and/or solid-state detectors of Energy-Dispersive Spectroscopy (EDS) to measure the characteristic of X-rays produced by an electron beam. Both methods were utilized with a filament source, operating at 5 kilo-electron volts (keV), and data were processed using JEOL software. WDS can detect elements ranging from beryllium (Be) to uranium (U), while EDS covers elements from boron (B) to uranium (U). Quantitative analyses were performed using the ZAF correction method. Detection limits vary by element. Two representative samples of amphibolite and one sample of garnet muscovite gneiss were analyzed using EDS techniques.

4. RESULTS

4.1 Petrography

- The Mantalimanera Formation consists of highly foliated metasedimentary sequences rich in muscovite. It contains thin layers, ranging from 0.5 to 2 meters thick, of black quartzite occasionally containing feldspar (Fig -2a), white quartzite, fine-grained biotite-muscovite schist (Fig -2b), medium-grained muscovite-biotite schist (Fig -2c), and augen gneiss (Fig -2d). Micaschists are frequently interbedded with quartzites, with augen gneisses commonly alternating with black quartzite layers, while light quartzite layers are intercalated with muscovite-rich micaschist (Fig -2b). Some rocks within the Mantalimanera Formation contain garnet, and staurolite is occasionally found in the micaschists. The formation is intersected by pre-Permian baryte veins in the southwestern region.

Fig - 2: Outcrops within the Mantalimanera Formation; a) foliated black quartzite intercalated with white quartzite, b) Layered micaschist and white quartzite, c) medium gain muscovite micaschist, d) strongly foliated augne gneiss interlayered with black quartzite.

Quartzite in the Mantalimanera Formation exhibits three distinct types, all characterized by a granoblastic texture: The first type consists of 80-90% quartz (Q) and 10-20% chalcedony (Cal). Some of the quartz grains are elongated and some have subhedral equidimensional shapes; chalcedony grains are bigger and not elongated, indicating that they are newly crystallized (Fig -3a). The second type is composed entirely of recrystallized quartz (100%) with irregular boundaries, formed by grain boundary migration (Fig -3b). The third type contains 75-80% polycrystalline quartz aggregates, likely developed predominantly by sub-grain rotation recrystallisation, with 10-15% muscovite (Mus) present in the interstices (Fig -3c). Zircons are commonly found as accessory minerals in these quartzites.

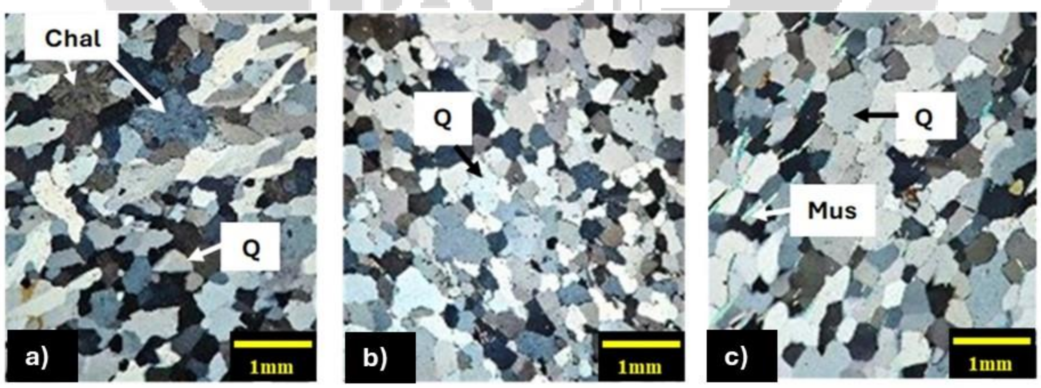

Fig - 3: Microphotographs under Crossed Polarized Light (XPL) a) quartzite with calcedony (sample number) 21-32, b) black quartzite, note the irregular boundaries (sample number 18-13B), c) quartzite with polycrystalline quartz (sample number 21-13).

Based on mineral composition, the micaschists of the Mantalimanera Formation contain two rock types: (1) Medium-grained muscovite micaschist consisting of approximately 50% muscovite and 50% quartz (Fi. -2c). (2) Two-mica micaschist which exhibits fine- grained granolepidoblastic texture, comprising about 50% quartz, 40% muscovite, and 10% biotite (Fig -4a).

Augen gneisses are a type of orthogneiss characterized by a “mortar texture”, with porphyroclasts of plagioclase (Pl), microcline (Mic), and perthite. The matrix displays a fine-grained, banded fabric and includes minerals such as microcline, plagioclase, quartz (Q), muscovite (Mus), biotite (Bt), and chlorite (Chl) (Fig -4b). The approximate mineral composition is as follows: quartz ~30%, plagioclase ~20%, microcline ~20%, muscovite ~15%, chlorite ~10%, and biotite ~5%. Occasionally, leucosomes or quartz veins are observed parallel to the rock's foliation (Fig-4c).

Paragneiss is a foliated, fine-grained rock with an approximate mineral composition of 50% quartz (Q), 20% plagioclase (Pl), 20% microcline (Mic), and 10% muscovite (Mus) (Fi- 4d). Garnet is also present in the paragneiss, and quartz exhibits undulose extinction (Fig -4e).

The marble is impure with granoblastic texture and medium grain size. It consists of approximately 70% calcite, 20% wollastonite, and 10% augite, located in the interstices. Calcite shows deformed twin structures (Fig -4f).

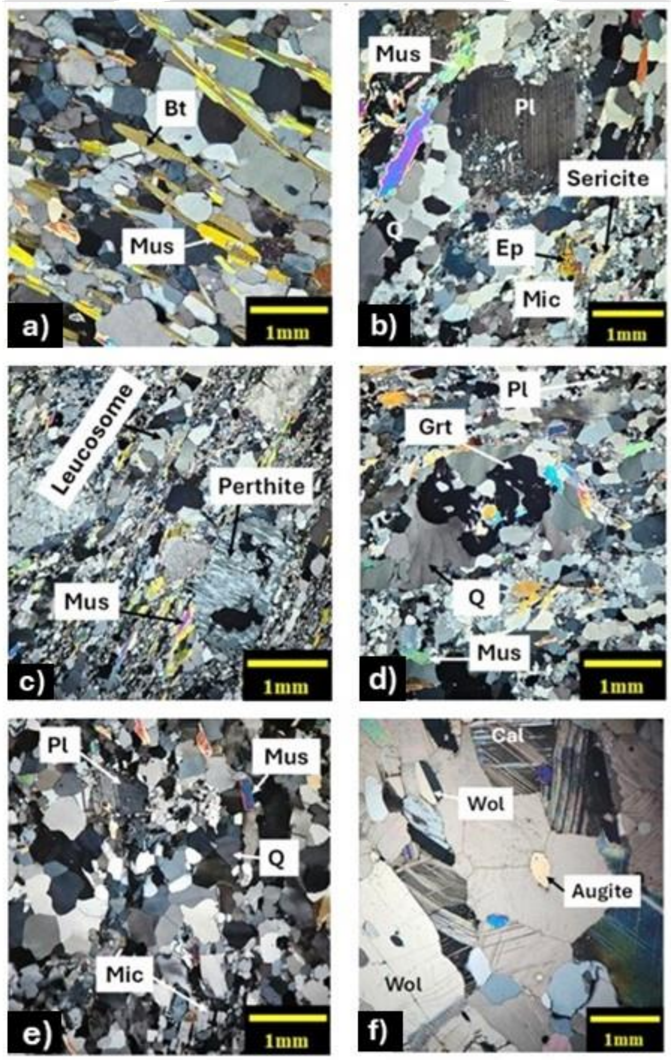

Fig - 4: Microphotographs under XPL of a) micaschist rich in Bt (sample number 18-05), b) Augen gneiss with Plagioclase porhyroclast (sample 21-26B) c) augen gneiss with perthite porhyroclast and layered parallel leucosome vein (sample 21-16), d) garnet gneiss (sample 21-26A), e) Gneiss leucocrate (sample 21-21) f) Marble impure (21-33).

- Andrafialava Formation: This formation primarily comprises a sequence of amphibolites, calc-silicate rocks, and paragneisses, with orthoamphibolite being the most dominant type. The amphibolites of the Andrafialava Formation are frequently interlayered with micaschist and quartzite from the Mantalimanera Formation, particularly in the northeastern part of the group (Fi. -1). Notably, the micaschist associated with the amphibolite is rich in biotite (Fig -7a). Some amphibolites have undergone mylonitization (Fig -5a). The entire formation has been affected by alteration, with plagioclase transforming into epidote, and some amphibolites are rich in garnet (Fig -5b). The calc-silicate rocks are formed from the contact between marble and orthoamphibolite, and paragneiss is interlayered with amphibolite.

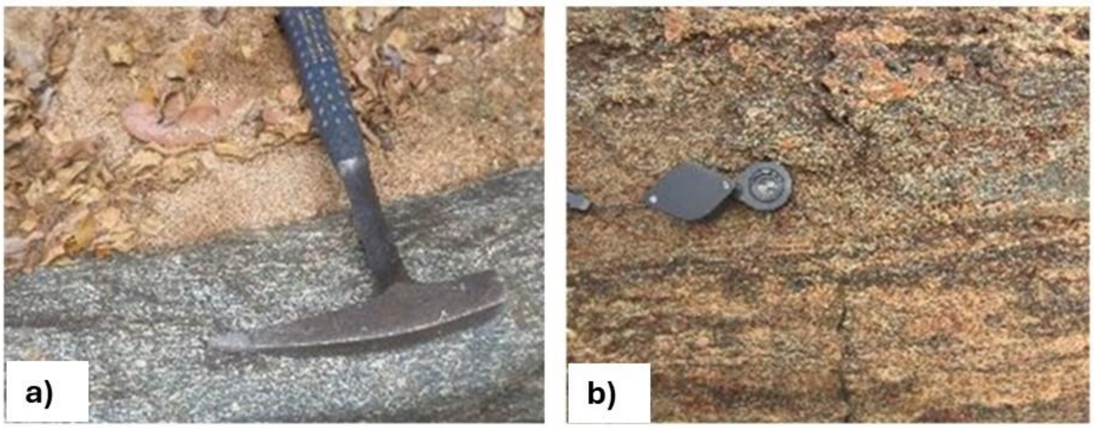

Fig - 5: Amphibolite rocks of the Andrafialava Formation a) mylonitized amphibolite, b) garnet rich amphibolite

Microscopic observations reveal that most amphibolite in the Andrafialava Formation is foliated, with amphibole having retrogressed to actinolite and epidote. Some amphibolites with retrogressed amphibole exhibit fine-grained textures composed of tschermakite, actinolite, clinozoisite, epidote, plagioclase, garnet, and quartz. These samples often display symplectite and coronitic textures, with garnet grains surrounded by symplectite consisting of epidote and plagioclase (Fig -6a). Garnet in these samples is typically inclusion-free, though some grains contain quartz, amphibole, or titanite inclusions. Other samples of amphibolite have plagioclase which undergone saussuritization and sericitization, resulting in rocks predominantly composed of hornblende and epidote, with epidote acting as a pseudomorph for plagioclase (Fig -6b). These rocks exhibit a nematoblastic texture (Fig -6c). Calcite, as a later phase, fills fractures within the amphibolite. Mylonitized amphibolite retains relics of plagioclase or pseudomorphs of epidote-zoisite as porphyroclasts (Fig -6d). Surrounding the amphibolite, calcsilicate rocks form an aureole and are medium-grained, consisting of diopside, hornblende, plagioclase, epidote, and quartz.

In addition to amphibolite, the Andrafialava Formation also contains micaschist interlayered with amphibolite. Unlike the micaschist of the Mantalimanera Formation, which is rich in muscovite, this micaschist is predominantly biotite-rich without muscovite. Its composition includes approximately 50% biotite (Bt), 30% quartz (Q), 10% epidote (Ep), 9% chlorite (Chl), and 1% titanite (Ti). These rocks are fine-grained with a garnolepidoblastic texture (Fig -6e).

Paragneiss within the formation contains about 25% quartz (Q), 20% biotite (Bt), 10% muscovite (Mus), 20% orthoclase (Or), 10% microcline (Mic), 10% plagioclase (Pl), 5% chlorite (Chl), and 2% calcite (Cal). It is a foliated, fine-grained rock where calcite appears at the latest phase, filling fractures in the other minerals (Fig -6f).

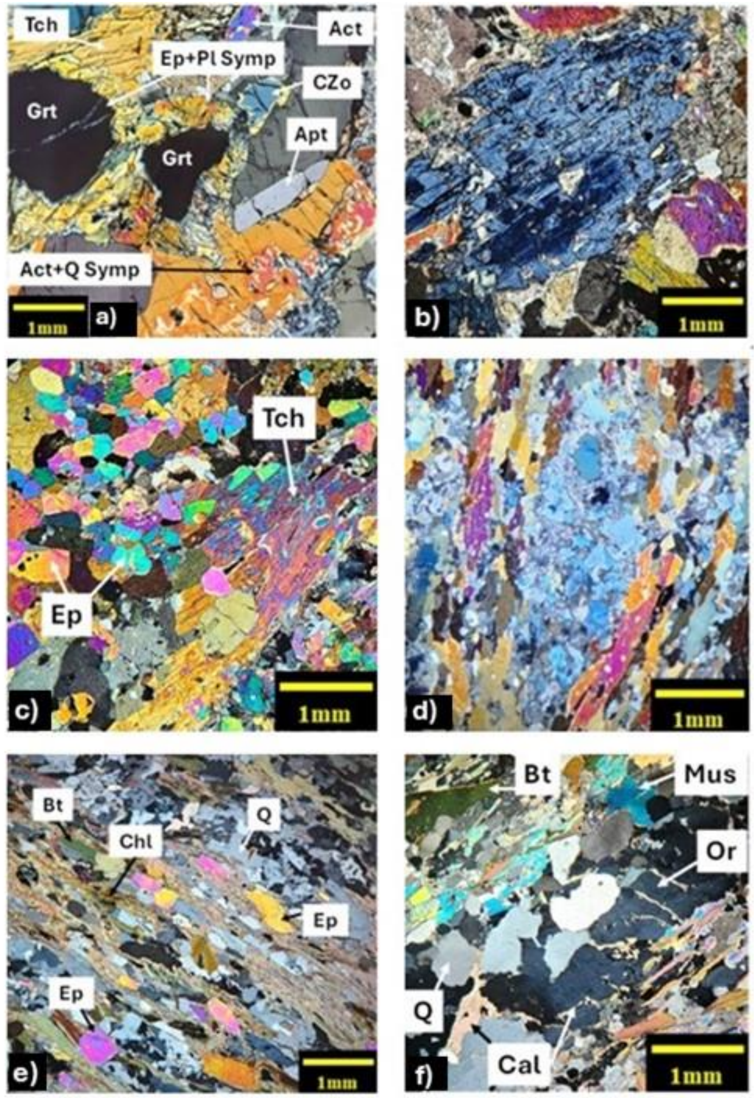

Fig - 6: Microphotographs of amphibolite a) garnet amphibolite with corona and symplectite texture (sample 21-40), b) deep blue interference color of Clinozoisite replacing Plagioclase (Sample 23-02), c nematoblastic texture of Ep amphibolite (sample 18-01, d) mylonitezed amphibolite, note the porphyroclast of plagioclase alterted into Clinozoisite and sericite (sample18-04), e) biotite micaschist note the mixture of Chl and Bt (sample 21-27), f) Paragneiss with calcite filing the fractures of Or (sample 18-07B).

4.2. EDS analysis

Analysis of two samples from the Andrafialava Formation, labeled 21-40 and 23-02, using Energy Dispersive Spectroscopy (EDS) techniques, reveals notable mineralogical details. The analysis identifies a significant presence of amphiboles from the calcic amphibole group, which are Tschermakite and actinolite. Tschermackite has a silica content of approximately 6.6 atoms per formula unit (a.p.f.u) and a magnesium-iron ratio (XMg) around 0.6, and the actinolite has a higher silica content of about 7.6 a.p.f.u and an XMg value of approximately 0.7. Within the amphibolite, some of this amphibole has retrogressed into actinolite as confirmed by petrographic observations. The samples also exhibit two types of plagioclase: albite, with Na = 0.91 a.p.f.u and Ca = 0.03 a.p.f.u, and oligoclase, with Na = 0.66 a.p.f.u and Ca = 0.33 a.p.f.u. This variation is likely a result of hydrothermal alteration of Tschermakite, a process particularly evident in samples displaying symplectite textures. Alongside actinolite and plagioclase, the alteration process produces clinozoisite and epidote, which may have originated from the plagioclase or amphibole.

Accessory minerals present include iron-calcium rich garnet, chlorapatite, titanite, and quartz appearing as a minor component. The chemical formulas for these minerals, derived from EDS data, are detailed in Table 1, which also includes the number of oxygens used in the normalization procedure.

Table - 1: Estimated chemical formula from EDS analysis of the amphibolite ofAndrafialava Formation. (Min.=Mineral)

# O	Number of cations											Formula	Min. name
	Si	Al	Ca	Fe	Mg	Mn	Na	K	P	Cl	Ti		
2	1											Si_1	Q
12.5	3.15	3.04	1.64	0.00								$Ca_{1.64} Al_{3.03} Si_{3.15} O_{12}$ (OH)	CZo
12.5	2.28	3.65	2.05	0.41								$Ca_{2.05} Fe_{0.41} Al_{3.65} Si_{2.28} O_{12}$ (OH)	Ep
23	7.65	0.57	1.95	1.25	3.64							$Ca_{1.95} Fe_{1.25} Mg_{3.64} Al_{0.57} Si_{7.65} O_{22}$ (OH)	Act
23	6.61	2.22	1.82	1.52	2.76		0.64	0.07				$Ca_{1.82} Fe_{1.52} Mg_{2.76} Al_{2.22} Si_{6.61} O_{22}$ (OH)	Tch
8	2.99	1.03	0.03				0.91					$Na_{0.91}Ca_{0.03}Al_{1.03} Si_{2.99} O_8$	Ab
8	2.67	1.33	0.33				0.66					$Na_{0.66} Ca_{0.33} Al_{1.33} Si_{2.66} O_8$	Oli
12	3.00	1.94	1.11	1.38	0.48	0.11						$Ca_{1.11} Fe_{1.38} Mg_{0.48} Mn_{0.11} Al_{1.94} Si_{3.00} O_{12}$	Grt
25			4.72						3.1	0.09		$Ca_{4.72} P_{3.1} Cl_{0.09} O_{12}$	Apt
5	0.99	0.05	1.00								0.97	$Ca_1 Ti_{0.97} Si_{0.99} O_5$	Ti

Sample 21-26A from the Mantalimanera Formation, identified as a garnet gneiss, has been analyzed using Energy Dispersive Spectroscopy (EDS). The estimated chemical formulas, detailed in Table 2, reveal a complex mineralogy. The sample contains three types of plagioclases: oligoclase (Na=0.87 a.p.f.u. Na=0.87 a.p.f.u., Ca=0.10 a.p.f.u. Ca=0.10 a.p.f.u.), microcline (Na=0.96 a.p.f.u. Na=0.96 a.p.f.u., Ca=0.02 a.p.f.u. Ca=0.02 a.p.f.u.), and albite. In addition to these plagioclases, the mineral assemblage includes muscovite, quartz, epidote, garnet, and apatite.

The main minerals in this sample are albite, muscovite, and quartz. Microcline is observed as an inclusion within the garnet, while oligoclase is occasionally found as an inclusion in garnet but is not always associated with it. The garnet is notably iron-manganese rich. Epidotes are a minor phase, visible only in backscattered electron images. Importantly, the apatite in this sample is fluorine-rich, contrasting with the chlorine-rich apatite observed in the Andrafialava Formation.

Table - 2: Estimated chemical formula from EDS analysis of the gneiss of the Mantalimanera Formation. (Min.=Mineral)

# O	Number of cations										Formula	Min. name
	Si	Al	Ca	Fe	Mg	Mn	Na	K	P	F		
11	3.19	2.48		0.29	0.12		0.04	0.94			$Fe_{0.29} Mg_{0.12} Na_{0.04} K_{0.94} Al_{2.48} Si_{3.19} O_{10}$ (OH)	Mus
12.5	3.07	2.64	2	0.4							$Ca_{2.00} Fe_{0.40} Al_{2.64} Si_{3.07} O_{12}$ (OH)	Ep
8	2.89	1.1	0.1	0.02			0.87				$Na_{0.87} Ca_{0.10} Al_{1.10} Si_{2.89} O_8$	Oli
8	3	1.01	0.02				0.96				$Na_{0.96} Ca_{0.02} Al_{1.01} Si_{3.00} O_8$	Ab

8	3.01	0.99						0.98			$K_{0.98} Al_{0.99} Si_{3.01} O_8$	Mic
12	3.01	1.96	0.21	1.34	0.12	1.35					$Ca_{0.12} Fe_{1.34} Mg_{0.12} Mn_{1.35} Al_{1.96} Si_{3.01} O_{12}$	Grt
12			4.51						2.98	1.07	$Ca_{4.51} P_{2.98} F_{1.07} O_{12}$	Apt
2	1										Si_1	Q

5. DISCUSSIONS

According to [2], the Betsiaka Group lithological unit includes strongly foliated metasedimentary sequences comprising micaschist, gneiss, and quartzite. These rocks vary from fine to medium grain and occasionally exhibit granitic textures. Our study corroborates these findings that Betsiaka Group is primarily composed of felsic metasedimentary sequences from the Mantalimanera Formation, and the metamafic Andrafialava Formation. In contrast to the adjacent Milanoa Group, the Betsiaka Group's felsic rocks lack high-grade metamorphic indicators such as sillimanite or kyanite, suggesting that the Betsiaka Group has experienced low to medium-grade metamorphism. This is further supported by the presence of two distinct types of quartzite: Sample 18-13B, exhibiting irregular boundaries due to grain boundary migration, suggests a low metamorphic grade and sample 21-13, with polycrystalline quartz aggregates, reflects an increasing metamorphic grade. Metamorphic grade appears to increase from southwest to northeast within the Betsiaka Group. Like the Milanoa Group, neither the base nor the top of the metasedimentary sequences in the Betsiaka Group has been identified.

Intense retrograde metamorphism has significantly affected the eastern coastal region of Madagascar, impacting rocks in the Antongil Block, Masora Block, Bemarivo Domain, and Manampotsy Complex [2]. This metamorphism is also evident in the Betsiaka Group, in the Mantalimanera Formation, where the texture and the presence of chalcedony in quartzite samples sample 21-32 indicate retrograde metamorphism. Further evidence is found in the Andrafialava Formation, where analysis of mineral textures and Energy Dispersive Spectroscopy (EDS) data reveals that Tschermakite has retrogressed into actinolite, which in turn has retrogressed into clinozoisite and epidote. The garnets in this formation, which lack inclusions of the matrix, crystallized prior to the other phases and exhibit a coronitic texture, suggesting their involvement in the retrogression process. This corona texture supports a sequence of mineral reactions consistent with retrograde metamorphism. In the amphibolite samples of the Andrafialava Formation, chlorite is absent, whereas biotite-rich micaschists contain chlorite, further reflecting the retrograde metamorphic conditions.

In contrast to [1], which identifies a predominance of para-amphibolite in the Andrafialava Formation, our findings indicate that the formation is primarily characterized by ortho-amphibolite. This distinction is supported by the presence of chlorine-rich apatite and the absence of early-phase calcite minerals. The specific mineral textures observed suggest that the amphibolite is of magmatic origin. The calcite present in the amphibolite appears as a later phase, filling voids within the rock, which suggests that these alterations are likely the result of fluid circulation during the East African Orogeny. Additionally, the sericitization and saussuritization of plagioclase further confirm the influence of fluid interactions. The maximum metamorphic grade in the Betsiaka Group is estimated at 12 kbar using the garnet-hornblende barometer and temperatures around 650°C using the hornblende-plagioclase thermometer [2]. This retrograde metamorphism impacts the entire Bemarivo domain.

6. CONCLUSION

Various samples from the Betsiaka Group have been collected and subjected to petrological and mineralogical analysis. Based on these studies and field observations, the samples can be categorized into two distinct formations: the felsic metasedimentary sequences of the Mantalimanera Formation and the mafic metaigneous sequences of the Andrafialava Formation.

The Mantalimanera Formation comprises various metasediments and metaigneous rocks, includingparagneiss (quartz-plagioclase- microcline-muscovite ± chlorite ± garnet ± epidote), orthogneiss (quartz-plagioclase- microcline-muscovite-biotite ± chlorite ± epidote), muscovite-biotite micaschist (quartz-muscovite-biotite ± chlorite ± epidote) marble and quartzite.

The Andrafialava Formation contains amphibolite (quartz- plagioclase ± tschermakite ± actinolite ± clinozoisite± epidote ± garnet ± apatite± titanite), biotite micaschist (quartz-biotite ± chlorite ± epidote) paragneiss.

Textural and mineralogical studies indicate the different grade of metamorphism from low to medium grade of metamorphism Betsiaka Group suggesting that this group metamorphosed from schist to amphibolite facies. Like the other groups of Bemarivo Domain, the Betsiaka Group has undergone a retrograde metamorphism and is strongly affected by fluid alteration.

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