Petrography, Field Relationship and Morpholgical Classification of Migmatites Around Gada Biyu- Maiturare, Northeastern Nigeria Part of Sheet 148 Toro S.E

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D.O.I: 10.56201/ijgem.v10.no3.2024.pg345.369

Abstract

The study area is located within the Pan African Older Granite and is located in Rimin zayam East of Toro L.G.A in Bauchi state and is accessible through Bauchi-Jos Road. Using Sawyers classification of migmatites, the study area has various morphological units of migmatites, that are mainly metatexite (Banded Orthogneisses and Stromatic), diatexite (Schlieren and Nebulitic diatexite) and rhyolites occurring as dyke. Petrographically, the presence of metamorphic mineral garnet, sillimanite, hornblende, orthopyroxene and cordierite minerals in the rock's morphologies suggest a high metamorphic grade. The change in morphologies is due to change in partial melting rate. Extinction observed on quartz grains in all slides suggests an intra-crystalline deformation and the polycrystalline nature of the quartz grains suggest a high temperature deformation as a result of grain boundary migration. The presence of structures like the ptygmatic folds, crenulation cleavage, Gneissic foliation are all evidence of complex shearing episode has affected the study area. The grade of metamorphism increases from metatexites, which is indicated by preferred elongation of biotite and abundance of biotite + muscovite + hornblende, through to the diatexites, which is indicated by the general coarsening of quartz grain size and depletion of the paleo-structure of the schist. 160 foliation planes were measured and plotted on a rose diagram to know the trend and stereographic projection to determine the beta and s-pole of the planes which gave a NW-SE Trend.

***Keywords**: Gada Biyu, Metatexite, Rimin Zayam, Foliation, Stromatic, Basement Complex, Schist*

1. Introduction

Migmatite outcrop in all part of Nigeria, they belong to the termed Migmatite Gneiss Complex of the basement component of Nigerian Geology. Migmatites are the most widespread of the component units in the Nigerian basement, which makes up about 60% of the surface area of the Nigerian basement (Rahaman and Ocan, 1978). They are the least understood and most understudied unit of the Nigerian basement. The study area Gada Biyu- Maiturare and environs forms part of the Nigerian Basement Complex of Bauchi area that forms part of the Neoproterozoic Trans Saharan belt formed between 700 and 580 Ma by accretion of terranes between the converging West African Craton, the Congo Craton, and the East Saharan Block (Ferre and Caby, 2006).

The study area is located within the Pan African Older Granite and lies between latitudes 10° 9' 00"N and 10° 12' 00"N and longitudes 9° 19 00"E and 9° 22' 30"E, it is part of Toro sheet and covers an area of about 35.48km². The study area is located in Rimin zayam East of Toro L.G.A in Bauchi state and is accessible through Bauchi-Jos Road. (Fig.1)

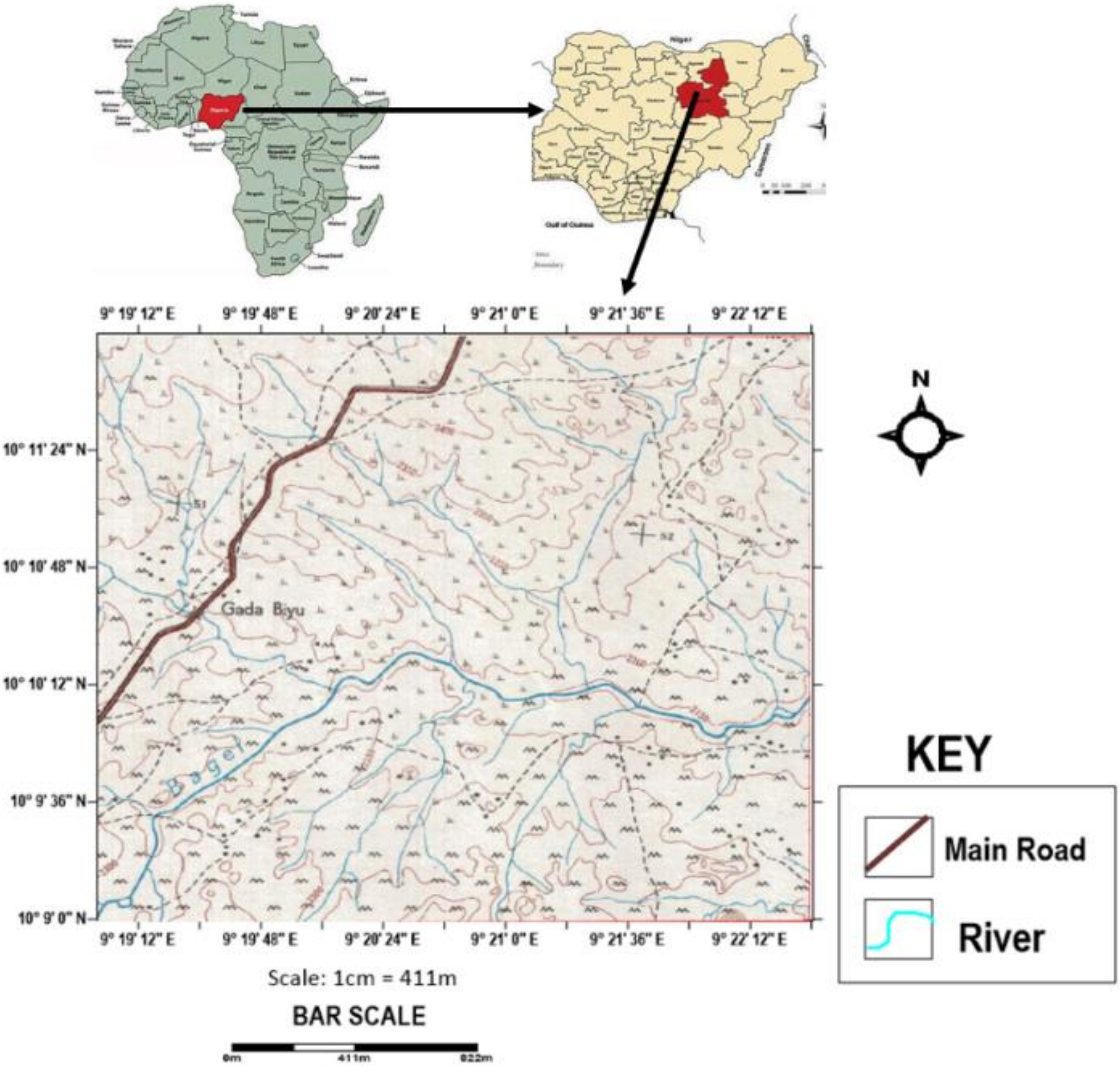


Fig.1: Location Map of the area

The currently accepted location of the studies is based mainly on its lithological, metamorphic, structural, and geochronological constraints, and its complication by an anastomosing network of high strain zones (e.g. deformation zones) that bound and intersect the various rocks and by a series deformational and metamorphic imprints of events). River Bagel is the only major river in the study area and has its snore sources in the highland around the Jos Plateau. It is however fed by many tributaries (Fig.3). The area is characterized by sheet erosion. The drainage pattern is dendritic, with small streams controlled by foliation planes of the outcrops.

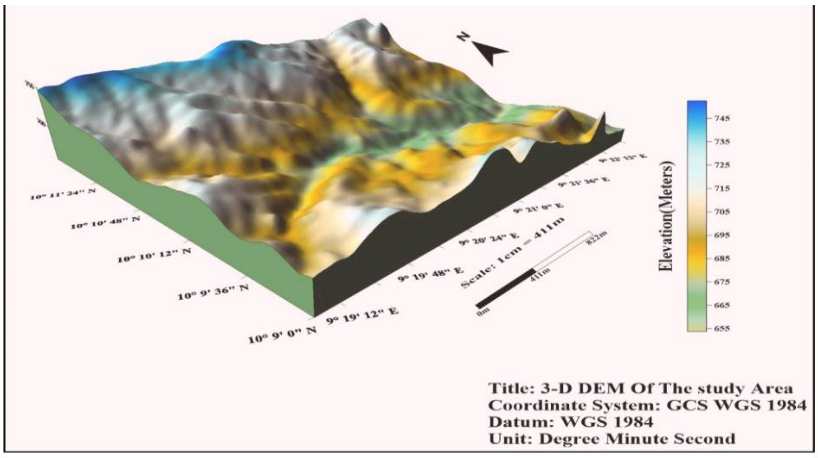


Fig. 2: 3-D Digital Elevation map of the study area

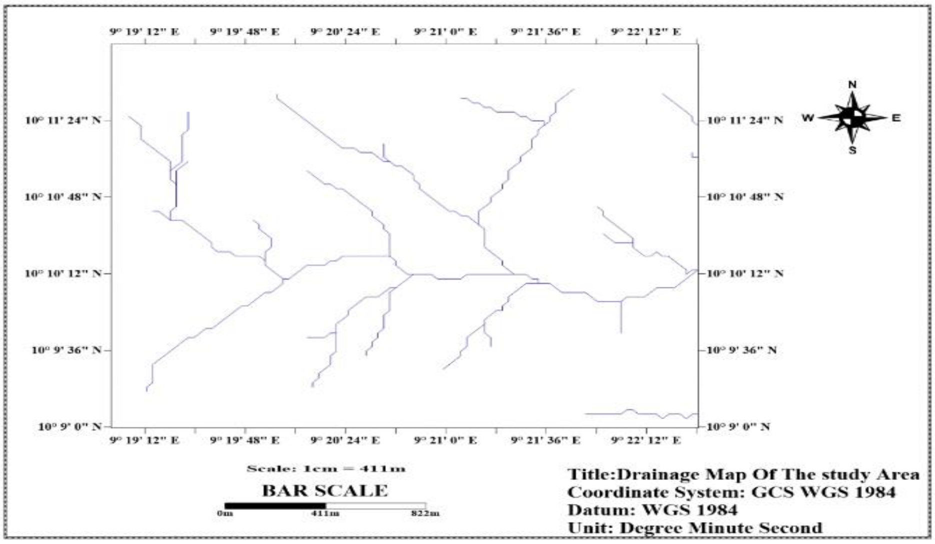


Fig. 3: Drainage map of the study area

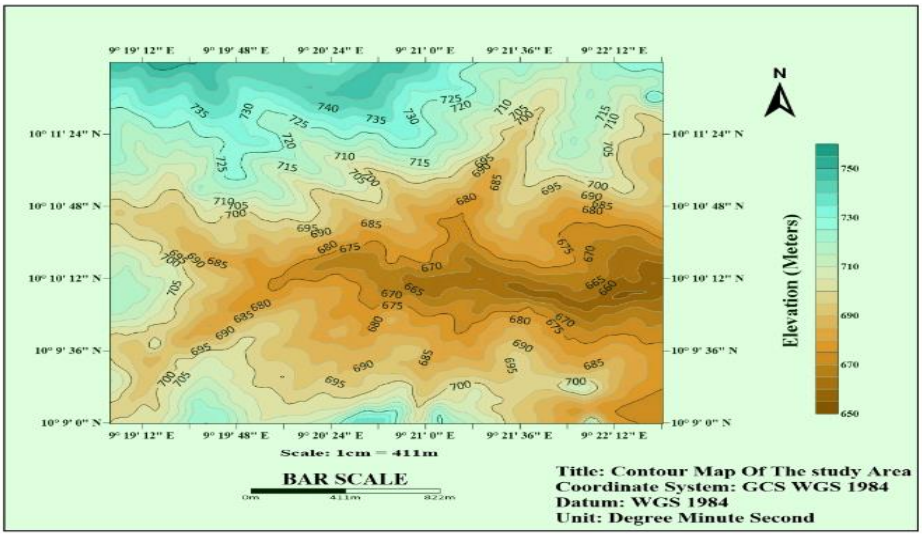


Fig. 4: Contour map of the study area

2. General Geology of the Northern Nigeria Basement Complex

The term 'Pan-African' was coined by W.Q. Kennedy in 1964 (Kroner & Stern 2005) on the basis of an assessment of available Rb-Sr and K-Ar ages on mobile belts formed in Africa *500* Ma ago. The term Pan-African is now used to describe tectonic, magmatic, and metamorphic activity of Neoproterozoic to earliest Palaeozoic age. Kroner and Stern (2005) described eastern part of the belt to consist of a high-grade granite gneiss terrain of the Nigerian province partly consisting of Palaeoproterozoic rocks which were migmatised at 600 Ma. This deformation and metamorphism are considered to have resulted from oblique collision of the Nigerian shield with the West African Craton basement, followed by anatectic doming and wrench faulting (Kroner and Stern, 2005) (Figure 4). The Nigerian basement complex forms part of the Pan-African mobile belt and lies between the West African and Congo Craton and south of Tuareg shield (Burke & Dewey, 1972; Black, 1980; Dada, 2006).

Ajibade *et al.,* (1989) geologically divided the Nigerian basement complex into the western and eastern provinces and geographically into three *viz*; the western Nigerian basement complex, the eastern Nigerian basement complex and the northern Nigerian basement complex.

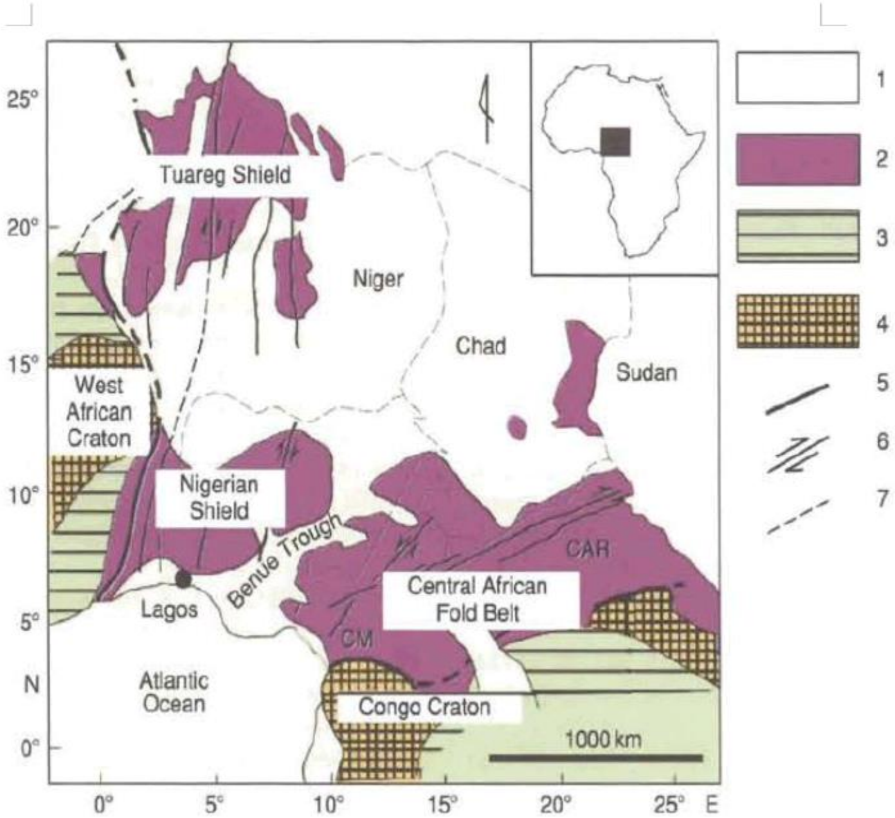


Fig. 5 : A Sketch Map Showing Pan-African Domains in West Central Africa. 1, Post-Pan-African Cover; 2, Pan-African Domains; 3, Pre-Mesozoic Platform Deposits; 4, Archaean to Palaeoproterozoic Cratons; 5, Craton limits; 6, Major Strike-slip Faults; 7, State Boundaries. CAR, Central African Republic; CM, Cameroun.

Source: Kroner and Stern, (2005).

These basement complexes occupy three geographical regions in the country (Figure 5). The western Nigerian basement complex constitutes the southwestern part of the country and extends into the Republic of Benin. The eastern Nigerian basement complex, believed to be a westward extension of the Cameroon basement complex into Nigeria, occupies three regions (Hawal Massif, Adamawa Massif and the Oban Massif) along the country's eastern border with Republic of Cameroon (Okezie, 1974; Ajibade *et al.*,1989; Elueze, 1999; Haruna, 2016). The northern Nigerian basement complex covers an extensive area north of rivers Niger and Benue and is composed of schist belts in the western part and large masses of granitoids in the central and eastern parts intruded by the younger granites around Jos. The three basement regions are separated from one another by Cretaceous to Recent sedimentary basins. The granitoids of Bauchi are part of a large volume of crystalline rocks in the eastern margin of the northern Nigerian basement complex also intruded by the younger granite of Zaranda and Burra-Ningi-Warji-Gwaram-Shira ring complexes (Haruna, 2016). The basement rocks occupy about half of the land mass of the country (Black, 1980).

The migmatite–gneiss complex (MGC) is generally considered as the basement complex sensu stricto (Rahaman, 1988; Dada, 2006) and is also referred to as migmatite-gneiss-quartzite complex (Rahaman & Ocan, 1978). It is the most widely spread of the component units in the Nigerian basement, with heterogeneous assemblage of migmatites, orthogneises, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. Evidence of Pan African reworking have been seen in petrographic studies displaying medium to upper amphibolites facies metamorphism. The migmatite–gneiss complex has ages ranging from Pan-African to Eburnean. Lithologically, similar rocks in other parts of Nigeria especially in the northeast and southeast, have given only Pan-African age (Tubosun, 1983).

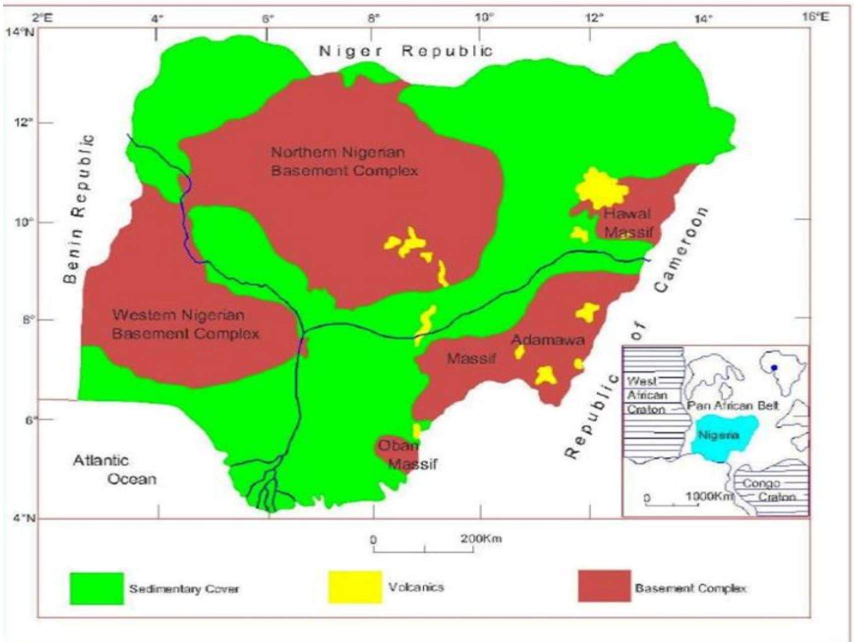


Fig.6: The Nigerian Basement Complex Provinces

Source: Haruna (2016)

The Bauchi area has foliations running through it, which was deduced from field data, SLAB images and previous maps (Wright, 1971) (Fig. 7). It has in place the biotite-muscovite granite rocks which form elongated plutons parallel to the regional structures, suggesting a syn-tectonic emplacement, while the biotite-hornblende granites have more rounded shapes molded in conformity with the country rock structures suggesting a late tectonic emplacement (Ferre et al., 1998). Injection of granitic magma driven along foliation plane is thought to have triggered anatexis

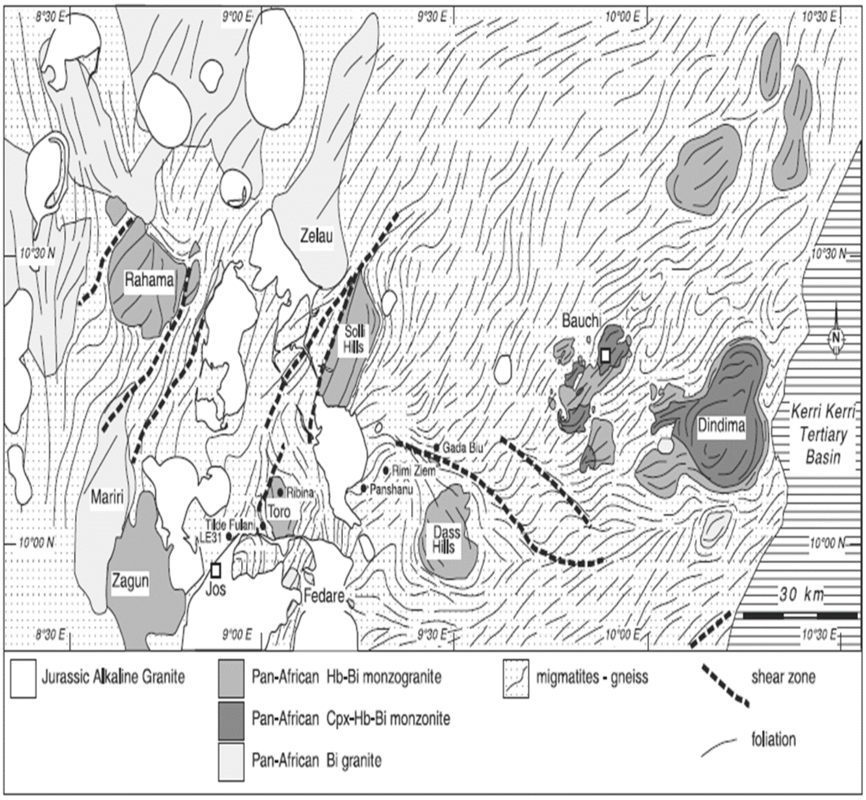


Fig. 7**:** Geological Map of the Jos–Bauchi Area. Foliations Compiled from Field Data, SLAR Images and Previous Maps. Source: Wright, (1971).

Mehnert (1971) employs migmatite terminology based on their macroscopic appearance and classified the rocks as metatexites and diatexites, while Hasalová *et al*. (2008) use the two major deformation events recorded in the gneiss-migmatite complex. The deformation phase D1 resulted in formation of steep, west dipping solid-state foliation S1, represented by compositional layering in the banded orthogneises (Fig. 8), and the D2 deformation led to the development of a large crustal-scale shear zone and was associated with reworking and folding of S1 compositional layering that is locally preserved in elongated relict domains (Fig 8).

With regards to the above findings, Hasalová *et al.* (2008), classified migmatites into four (4) groups based on structural deformation on the mineral assemblages as follows:

(a) The banded orthogneiss characterized by monomineralic banding, defined by recrystallized K-feldspar, plagioclase aggregates and quartz bands, alternating with layers rich in biotite, garnet, sillimanite and apatite.

(b) The stromatitic migmatite which is marked by the onset of disintegration of the original monomineralic banding and is composed of plagioclase and K-feldspar aggregates with subordinate quartz. These aggregates are rimmed by biotite locally overgrown by fibrolitic sillimanite.

(c) The schlieren migmatite, which has K-feldspar– quartz-rich and plagioclase–quartz-rich aggregates. The original banding is distinguishable only from the modal content of the mineral phase dominant in these feldspar aggregates.

(d) The nebulitic migmatite that represents the most isotropic rock type, completely lacking relics of the original gneissosity. The migmatite occurs as irregular flat bodies or elongated lenses.

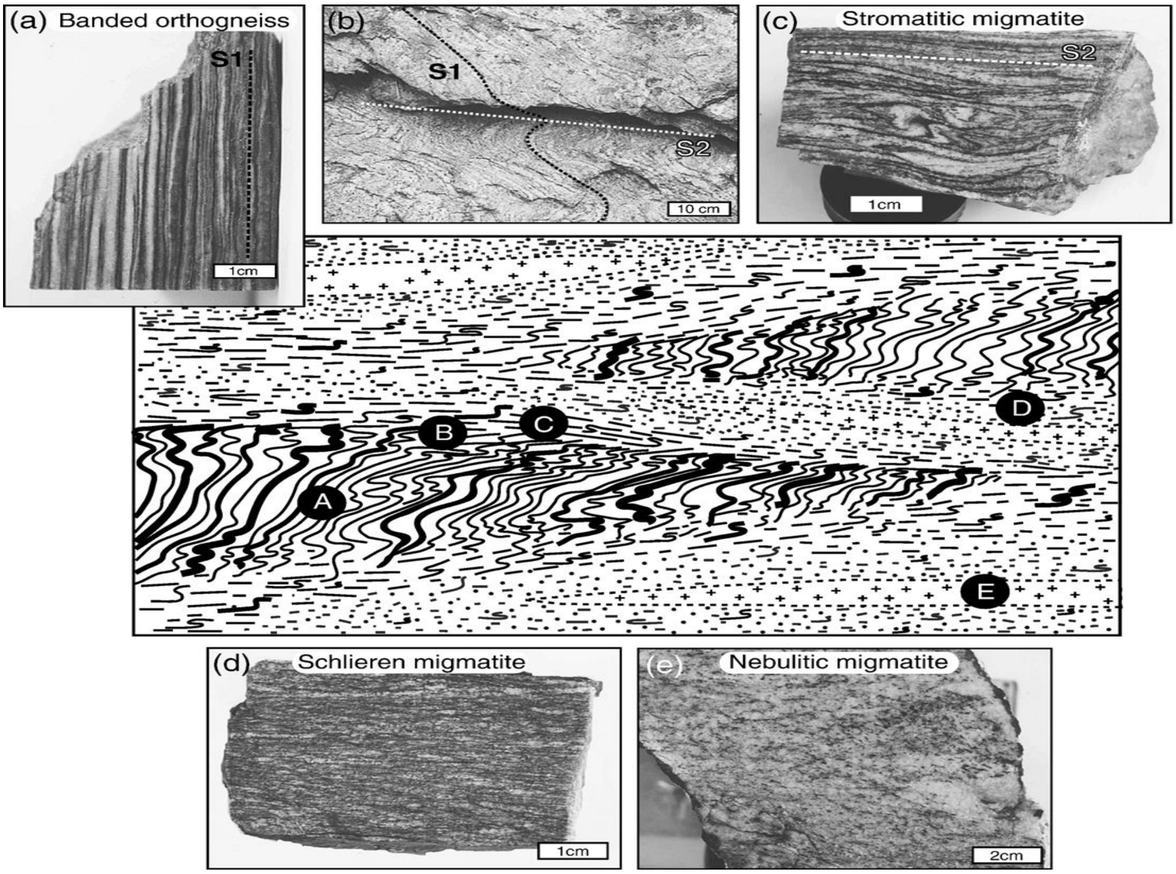


Fig. 8: Sketch Showing the Individual Gneiss and Migmatite Types and Their Relationships Within an Outcrop. Banded Orthogneiss with Distinct S1 Compositional Layering (a) is Folded and Transposed (b) to the Stromatitic Migmatite (c) that Passes Gradually to the Schlieren Migmatite (d) and Finally to the Completely Isotropic Nebulitic Migmatite with no Relics of Gneissosity

Source: Hasalová et al., 2008.

2.2 Review of Literatures

Caby (1989) was able to establish the region has a Proterozoic metasedimentary cover with Pan-African metamorphism and the rocks fall between the upper green schist to granulite facies metamorphism. He was able to give an insight into the metamorphic grade and source of metamorphism; however, he couldn't classify the migmatites structurally.

Ferre et al. (2006) was able to establish the presence of anatectic metapelitic gneisses, and also that the metatexite and diatexite derived from greywacke volumes varies from <10 to ≥40% volume depending on bulk composition and distance from the diatexite and pluton. It was also established that metatexites are characterized by muscovite-free, garnet-cordierite mineral assemblages and the highest temperatures recorded are above 800^0C and thus established the rocks as orthopyroxene-bearing lithologies. He however didn't establish the structural properties of the migmatites.

Haruna (2016) established that the area is underlain by three broad lithologic units *viz*: migmatite/gneiss, bauchite and granites of various textures, but couldn't establish the relationship of structures and the classes of migmatites and addressed the diatexites as granites.

F. Abdullah et al (2023) The rocks are predominantly migmatite morphologies, which are characterized by consolidated rock matrix forms of secondary aquifers. The metatexites are finely grained in texture, banded, foliated, and very resistant to weathering having biotite and plagioclase with minor quartz and garnet as the most abundant minerals. The presence of foliation in this rock morphology makes it to be the most potential lithology for having pathway geometry that serves as a feeder to the fracture that cut across the rock lithology, hence making it the best conduit in groundwater exploration.

3. Materials and Method

Geological mapping of the area was conducted on a scale of 1: 25,000. Particular attention was taken for the location, physical characteristics structural elements and associated rocks of the migmatites. Various field measurements were used during the mapping. Global Positioning System (GPS) was used for geographical positioning with respect to various outcrops available in the study area. Field descriptions and observation were adequately recorded in a field notebook.

The sample sorting was carried out using Sawyer (2008) first- and second-order morphological classifications of migmatite. Representative sample was selected for petrography and Geochemical analysis. For the petrographic studies, the rock samples were cut into chips with a micro cutting machine and subsequently polished on glass ground plate using carborundum to obtain required thickness and a perfectly smooth surface; the cut rock samples were, thereafter, mounted on a clean glass slide with adhesive. The prepared slides were examined under the petrological microscope to identify mineralogical features of the rock samples on a microscopic scale.

The thin section of the sample was viewed in two modes the first with the analyzer out to produce or give the plane polarized light. In this mode the following properties were checked:

-Colour, pleochroism, form, cleavages, relief and alteration

After which the slides were viewed with the analyzer in, producing the crossed-polarized light, the following properties of the minerals were checked in this mode:

-Interference colours, extinction angle, twinning, birefringence.

Structures are also identified after which the samples are snapped using the camera to have photomicrographs.

4. Results and Discussion

The study area is underlain by two lithomorphological form of migmatite, metatexite and diatexites. The metatexites in the study are the dominant in form of the banded orthogneisses and some patches of Stromatic migmatites the diatexites are found at the far northwest of the area close to Suntumi hill which is part of the rimi zayam ring complexes, the diatexites found in the study area show a transition between metatexites and diatexites. Forming schlieren type of migmatite. The nebulite exibits irregular large grains of quartz and feldspars. Rhyolite dykes/ridges are mostly seen within the nebulites cutting across all the morphologies in the study area. (Fig.9)

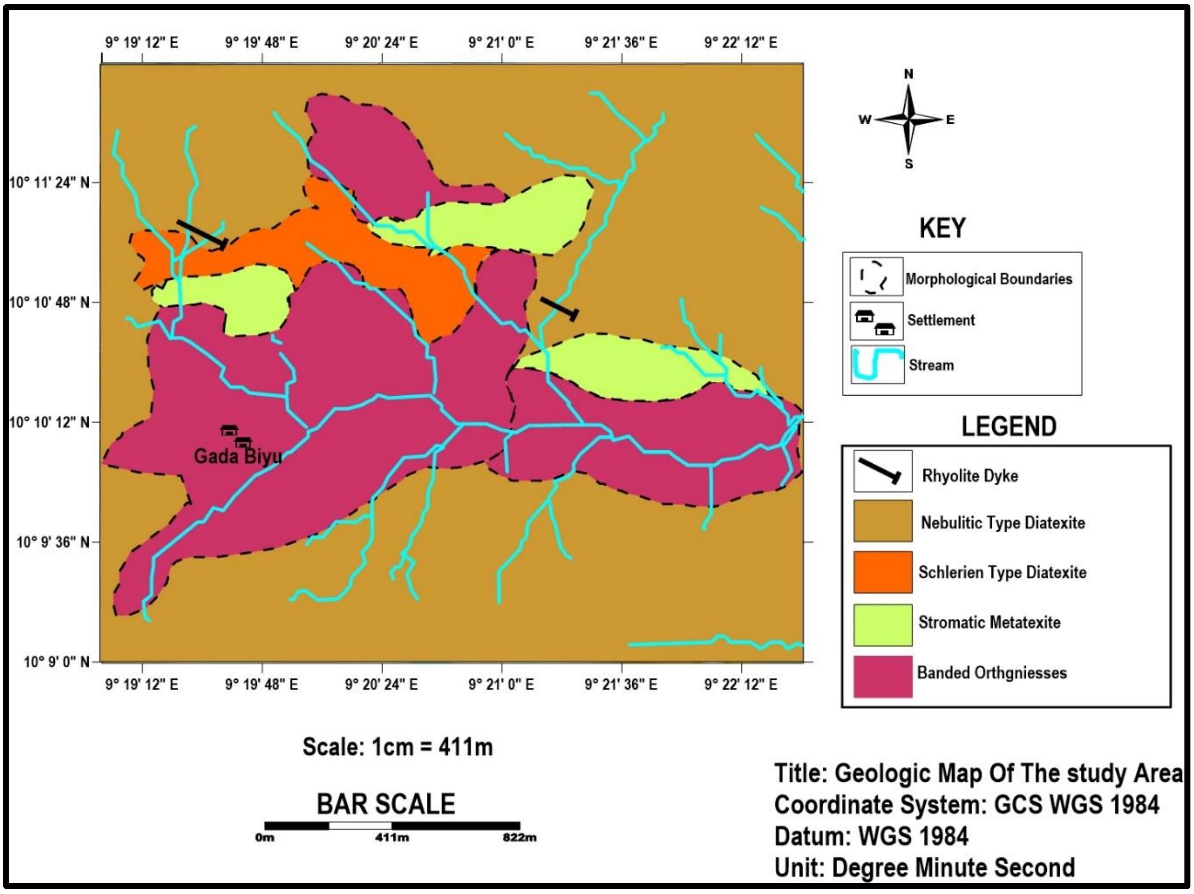


Fig. 9: Geologic Map of the study area

The results will be discussed under two categories which are: Field Observations, Petrographic Studies

4.1 Petrographic Studies

The various slides produced were analyzed with the analyser out (plane polarized light) to view their colour, pleochroism, form, cleavages, relief and Alteration to identify the minerals and then analyse with the analyser in (Crossed polarized) to view their interference colours, extinction angle, twinning and birefringence after which the minerals are named.

The minerals quartz, biotite, microcline, plagioclase and chlorite were the main minerals identified in the rocks; mineral biotite is seen to be associated with the deformed part of the slides. Mineral inclusions are found within the garnets which signifies the granulite facie metamorphism. Stresses on minerals are also identified at microscopic level as evident by the pleochroic halo of quartz and myrmekites intergrowths.

Table 1: Minerals Properties Under Plane and Cross Polarized Light

Minerals	Plane Polarized light	Cross Polarized Light
Quartz	It is colourless, not pleochroic, generally exhibit no cleavages.	It shows low order interference colour (Colourless to Gray), it is anisotropic with no twinning.
Biotite	It shows brown to brownish red colour, with pleochroism, it exhibits low relief, it has very good one-directional cleavage.	It is characterized by brownish – brownish red interference colours, it is anisotropic with generally no twinning. It usually alternates to light bluish mineral (Chlorite).
Microcline	Generally, colourless and non-pleochroic,	It shows 1st order white interference colour, it exhibit carlsbad twinning and at some point perthite and albite twinning intersecting to form tartan twinning.
Plagioclase	Generally Colourless and non pleochroic	Usually exhibit albite twinning
Silliminite	Silliminite is colourless in Plane Polarized Light	Silliminite has second order interference colour of bluish
Cordierite	Cordierite is colorless, have low relief, commonly found as anhedral grains	Cordierite has first order interference colour of white to grey

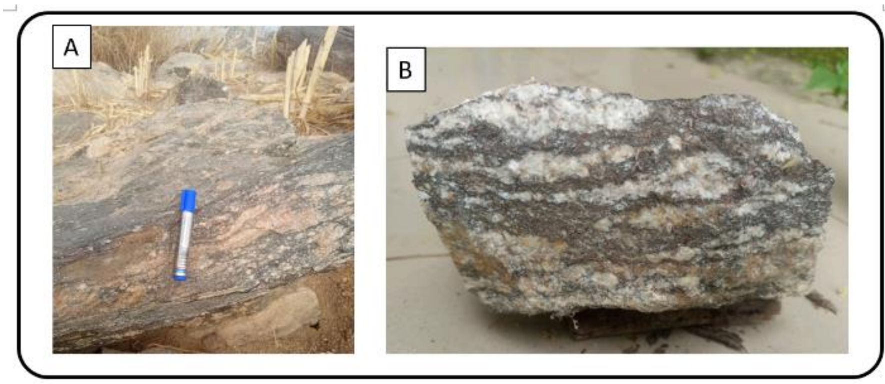


Plate.1: Photograph of showing (a) Field View of Banded Orthogneiss (B) Hand spacement

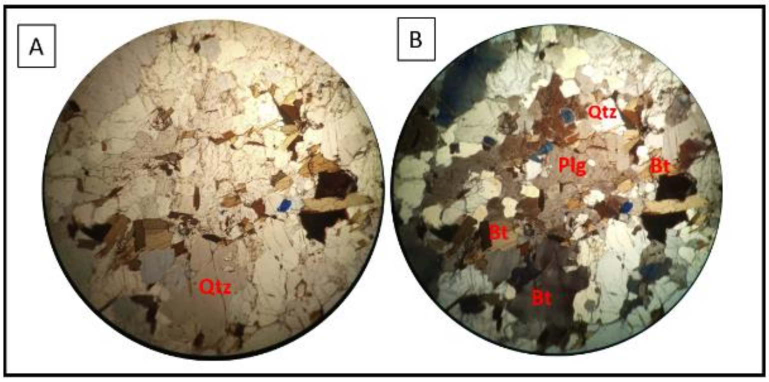


Plate.2: Photomicrograph of a sample of banded orthogneiss (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Bt= Biotite, Plg= Plagioclase.

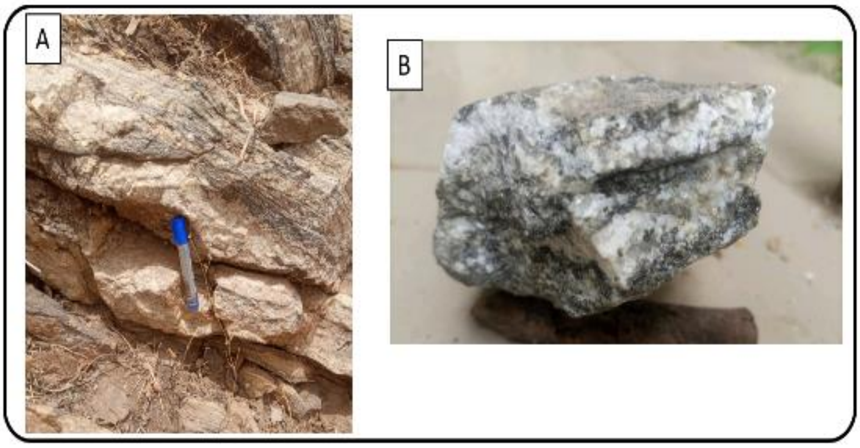


Plate.3: Photograph of showing (a) Field View of Banded Orthogneiss (B) Hand spacement

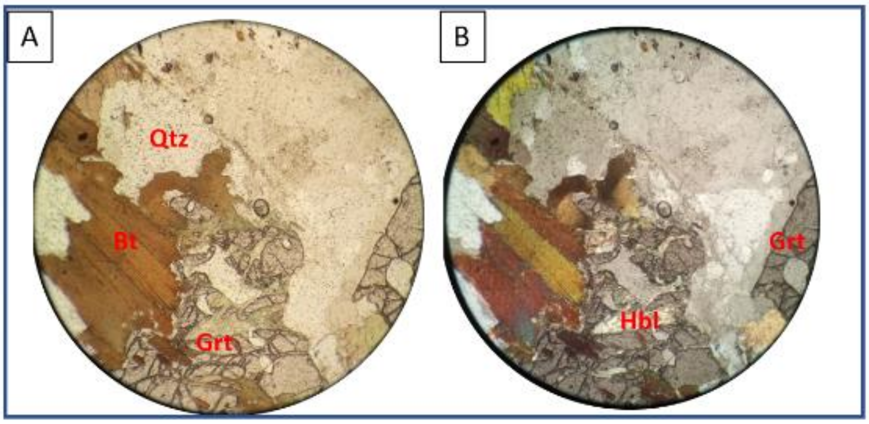


Plate.4: Photomicrograph of a sample of banded orthogneiss (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Grt= garnet, Hbl= Hornblende

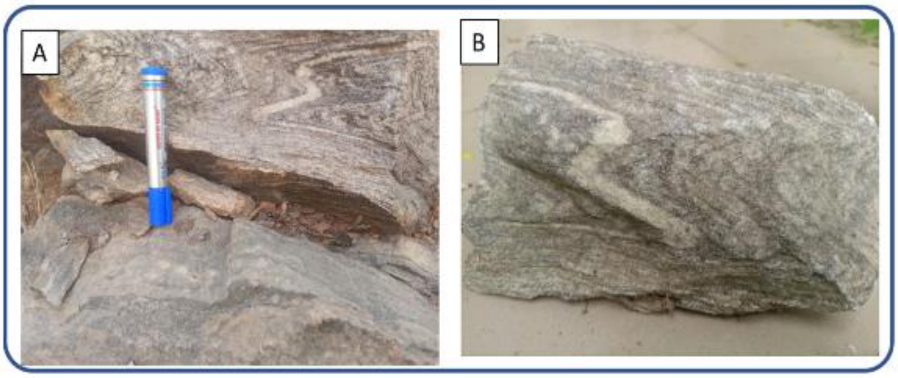


Plate.5: Photograph of showing (A) Field View of Stromatic Metatexite (B) Hand spacemen sample

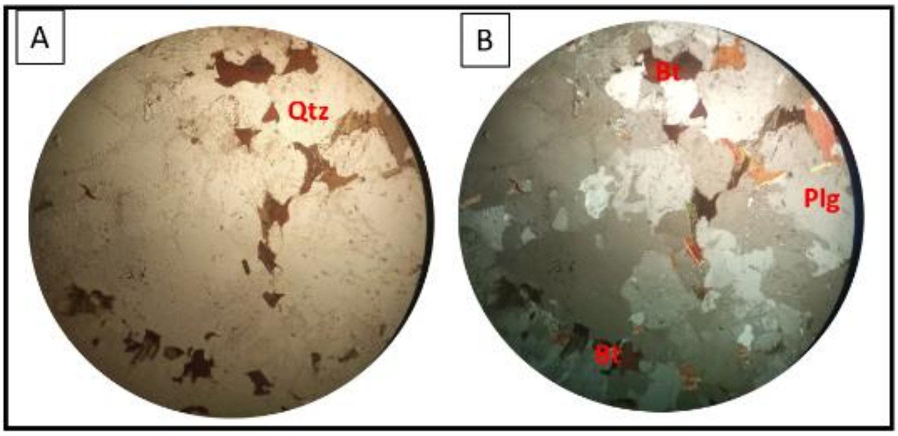


Plate.6: Photomicrograph of a sample of Stromatic Metatexite (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Bt= Biotite, Plg= Plagioclase.

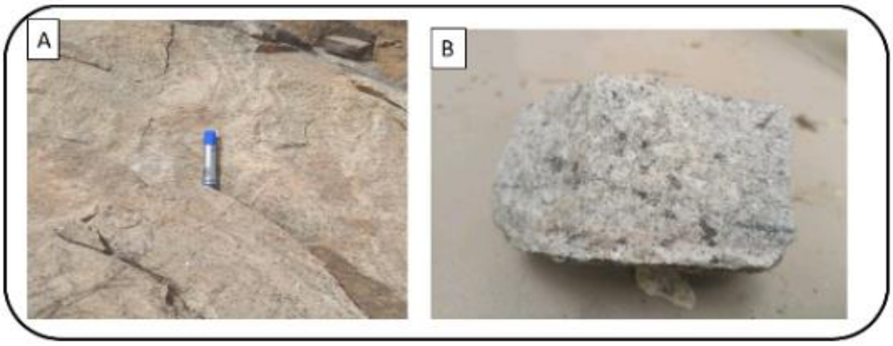


Plate.7: Photograph of showing (a) Field View of Schlieren type diatexite (B) Hand spacemen sample view

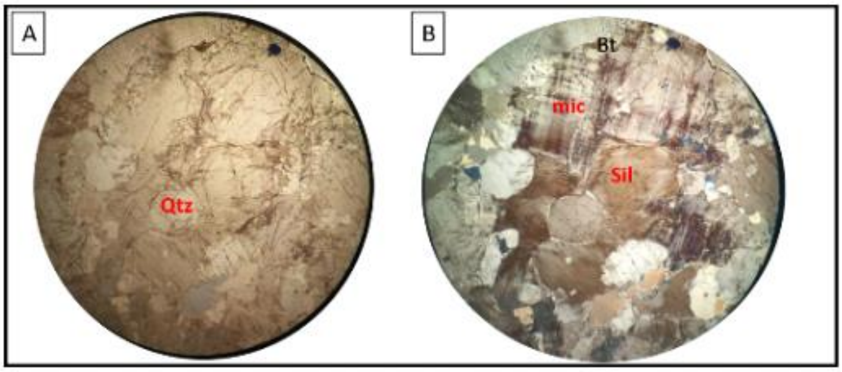


Plate.8: Photomicrograph of a sample of Schlieren type diatexite (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Mic= Microcline, Sil= Silliminite.

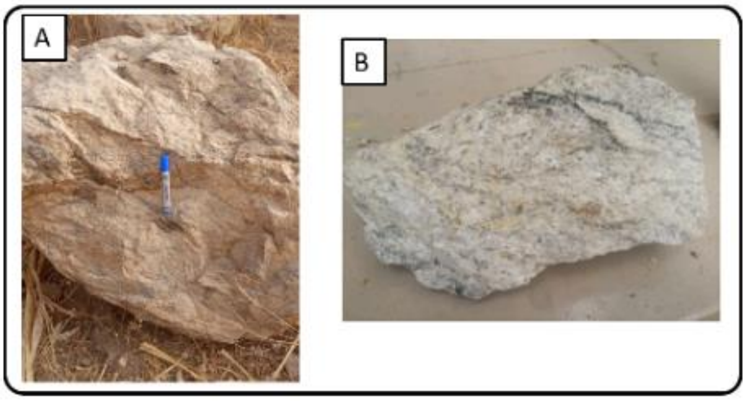


Plate.9: Photograph of showing (a) Field View of Schlieren type diatexite (B) Hand spacemen sample view

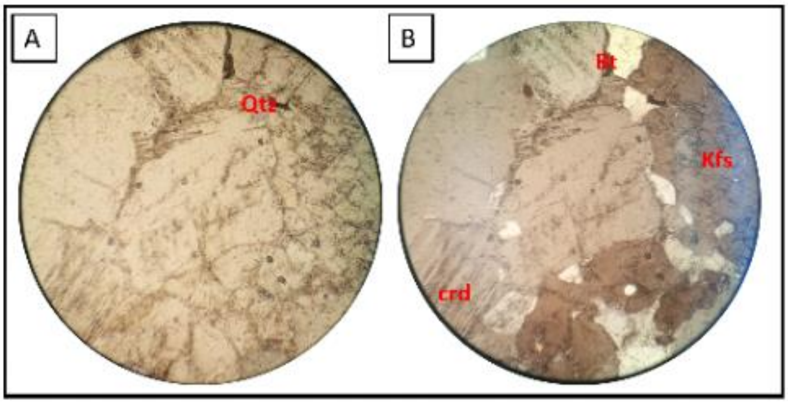


Plate.10: Photomicrograph of a sample of Schlieren type diatexite (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Kfs=K-feldspar, Crd= Cordierite, Bt= Biotie.

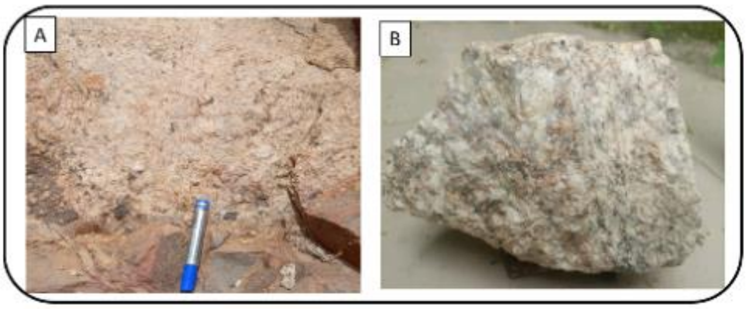


Plate.11: Photograph of showing (a) Field View of Nebulitic diatexite (B) Hand spacemen sample view

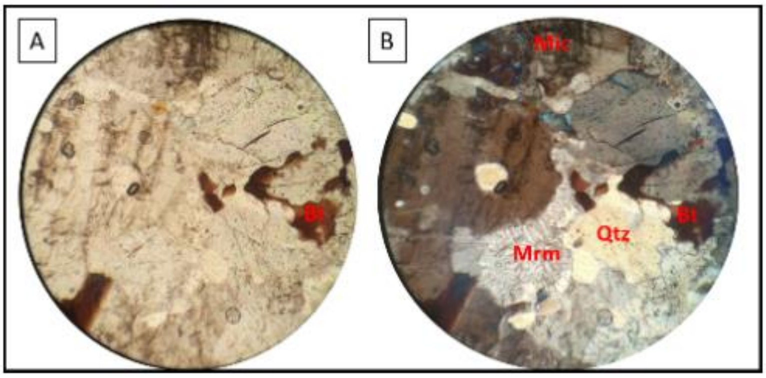


Plate.12: Photomicrograph of a sample of Nebulitic diatexite (a) under plane polarized light (b) under crossed polarized light. Qtz= quartz, Mic= Microcline, Mrm= Myrmikite, Bt= Biotite

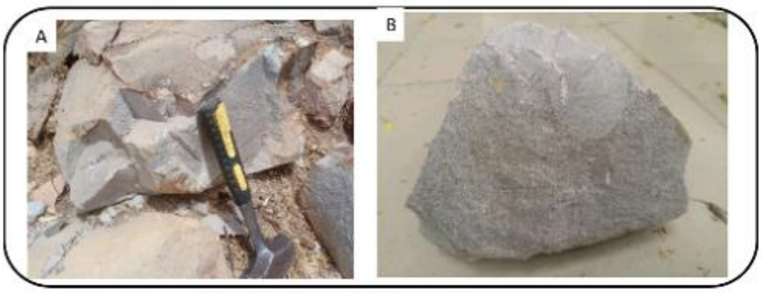


Plate.13: Photograph of showing (a) Field View of Rhyolite (B) Hand spacemen sample view of Rhyolite

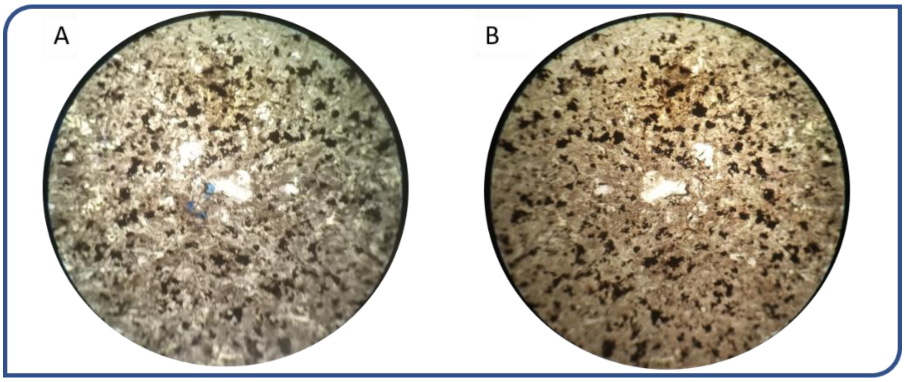


Plate.14: Photomicrograph of a sample of Rhyolite (a) under plane polarized light (b) under crossed polarized light.

4.2 Field Observations

Adjudging by the structural enrichments of the study area, a lot of interesting geological structures are associated with the area, ranging from gneissic foliation planes, ptygmatic folding, crenulation cleavages, pinch and swell (boudinage structures), rhyolitic dyke.

4.2.1 Crenulation cleavages

Crenulation Cleavages (plate15) shows asymmetrical crenulation in which a new cleavage domain (Mica domain), and an old cleavage domain with a microlithon domain (quartz and feldspars domain) co-existing. This is formed as a result of two or more deformational regimes.

Plate.15: Crenulation Cleavage found in Stromatic Metatexite.

4.2.2 Pinch and swell (bouldinage) structures

The Bouldinage structure (plate16) is formed as a result of extensional stress that acted on rock body that contains both competent and incompetent layers of rock. The competent layer is imbedded in between two incompetent layers of rock. When stress acts on the rock, it tends to stretch it and cause the competent layer to pinch at a point which when stress persists, may be separated from the rest of body while the other part remains swollen. The pinch and swell structure alternate each other and depend on the length of the entire competent body.

Plate.16: Showing pinch and swell structure in Metatexite

4.2.3 Ptygmatic folding

Ptygmatic folding (Plate17) was formed as a result of tensional stress which acted on a body of rock. The rock has competent layer imbedded in between incompetent layer such that when tensional stress acted on the rock, the competent layer got folded (disharmonic fold) while the incompetent layer behaved elastically. The materials that occupied the ptygmatic structure are felsic (leucosome).

Plate.17: ptygmatic folding found in stromatic metatexite

4.2.4 Rhyolitic and dyke

The Rhyolitc dyke is trending N292°W and it is found as a dyke withing the nebulitic diatexite but as ridge within Banded orthogneisses, the rhyolite can be linked with ring complex neighboring the study area (i.e Rimin Zayam Ring complex) (Plate.18)

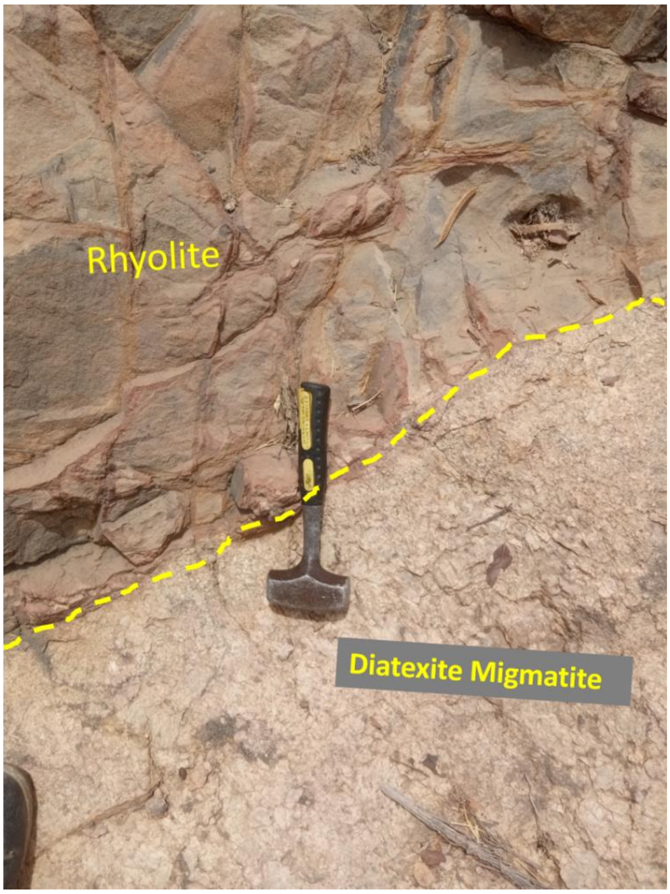


Plate.18: showing a rhyolite dyke

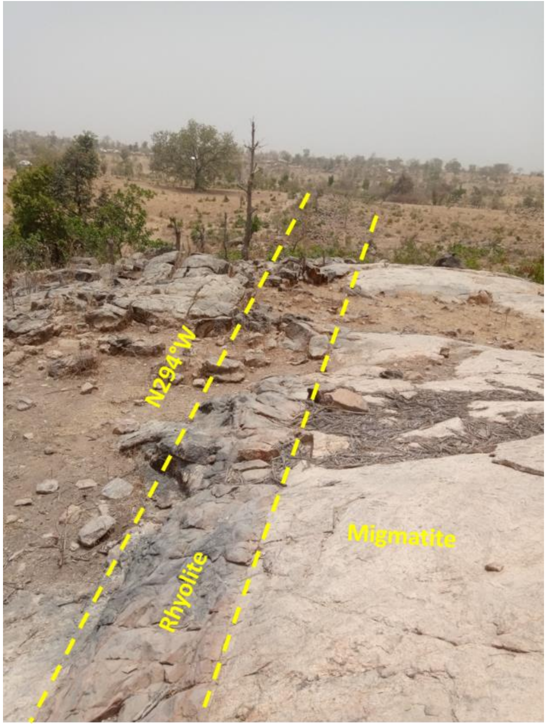


Plate.19: Showing a rhyolite dyke trending N294°W Cross cutting the migmatite

4.2.5 Gneissic foliation plane

These are foliation planes in the study area that show felsic and mafic bands aligning, in the study area they are found in the banded orthogneisses which are characterized by monomineralic banding, defined by recrystallized K-feldspar, plagioclase aggregates and quartz bands, alternating with layers rich in biotite, garnet, sillimanite. (Plate20a and 20b)

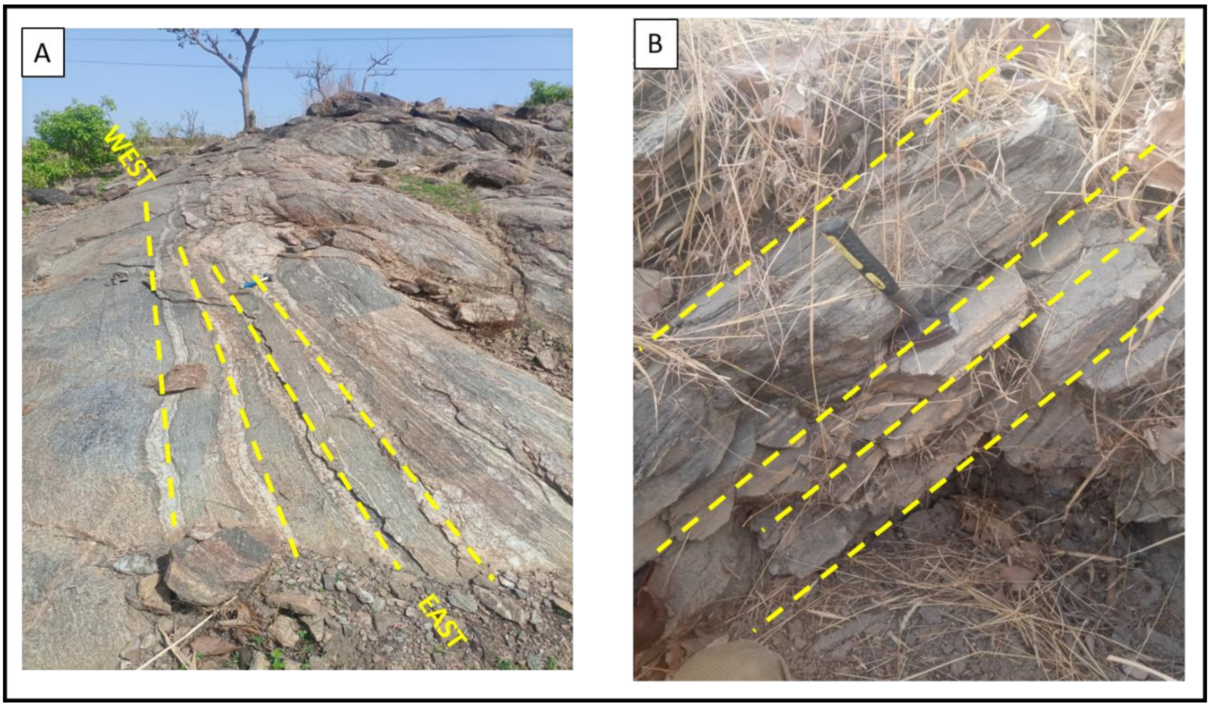


Plate.20: Foliation planes that characterizes the banding of felsic and mafic materials. (A) in situ gneissic foliation (B) Inclined Gneissic foliation

4.2.6 Paleosome (patches of schist)

Schist occurs as patches (Plate21) and is found in many places within the study area. The heat of the intruded magma metamorphosed the schist to banded gneiss and when the temperature persisted it formed other classes of migmatites in the study area. Sporadic occurrence of schist as patches in the study area suggests that the preexisting rock in the area was schists.

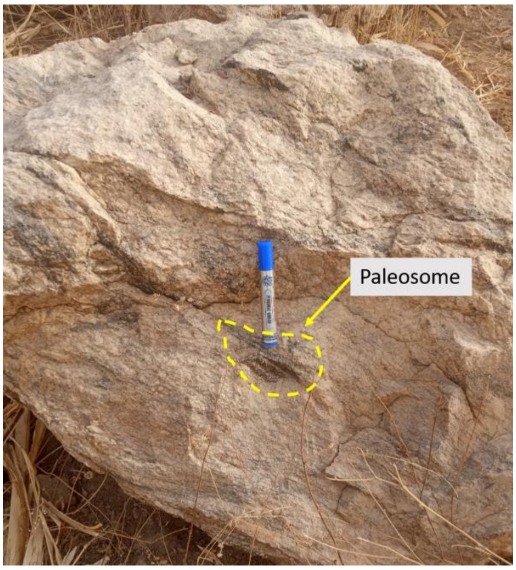
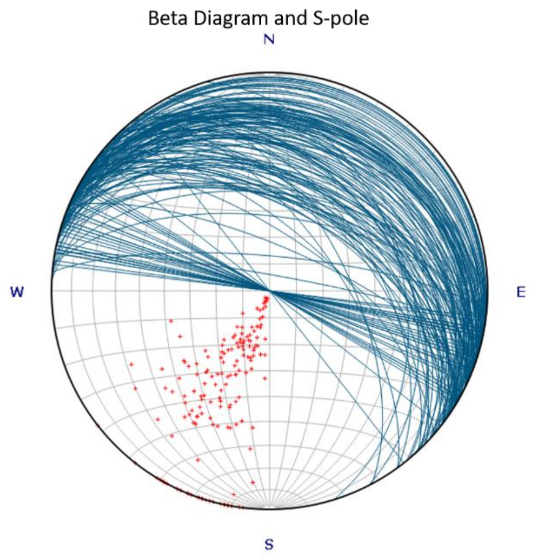


Plate.21: Patch schist found in Schlieren type Diatexite

Structural plots

Attitude readings were measured throughout the study area to determine the general trend of the foliation planes especially within the metatexite. A total of 160 planes were measured and plotted on a rose diagram to know the trend and stereographic projection to determine the beta and s-pole of the planes.



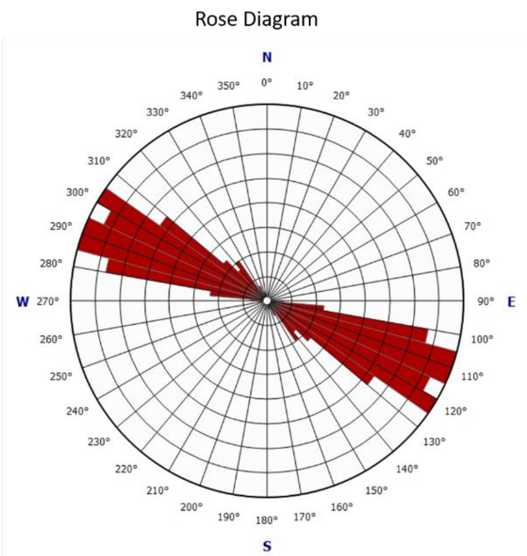


Fig 10: Combine beta and s-pole diagram of the foliation planes.

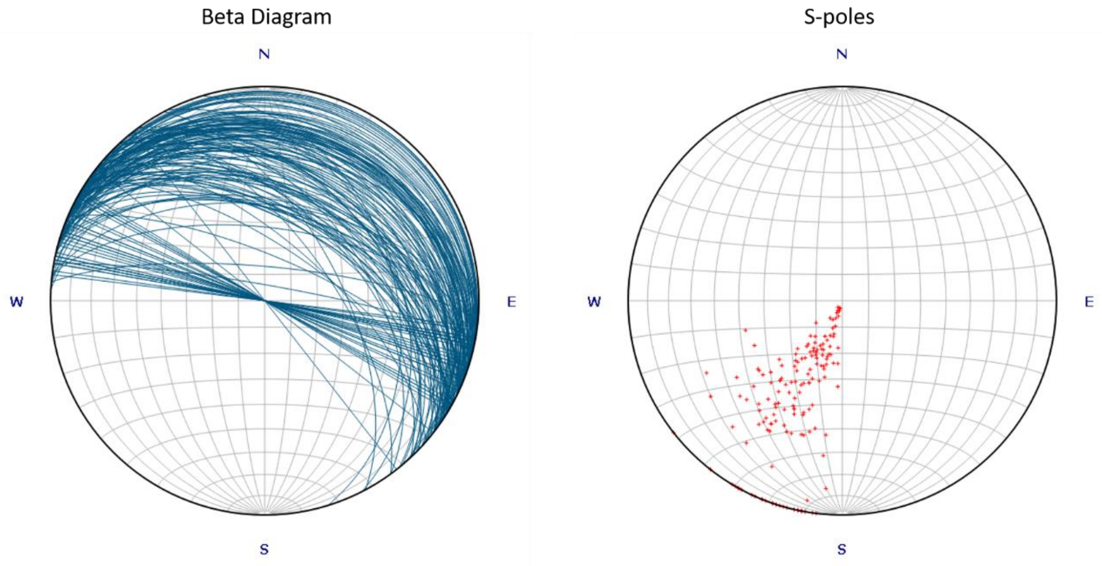


Fig 11: Beta and s-pole plots of the foliation planes in the study area.

4.3 DISSCUSSION

From the Field Relationship, Morphology and Petrography, five representative rock groups were established within the study area, these are: metatexites; Banded orthogneiss and Stromatic Metatexites, Schlieren type diatexites and nebulites. The metatexites constitutes hornblende, quartz, orthopyroxene, biotite and plagioclase as major minerals. The Schlieren type diatexites are composed of orthopyroxene, quartz, microcline, plagioclase, biotite, muscovite, cordierite and sillimanite. The nebulites are made up of cordierite, quartz, plagioclase, orthoclase and myrmikites intergrowth

- The presence of structures like the ptygmatic folds, crenulation cleavage, Gneissic foliation are all evidence of complex shearing episode has affected the study area (Plates: 17, 15,20).
- Microstructural texture such as myrmekites (vermicular intergrowth between quartz and Ca-rich plagioclase along with K-feldspar grain) (Plate 12) shows that the environment is of medium temperature or close to peak of metamorphic condition
- Petrographically, the presence of metamorphic mineral garnet, sillimanite, hornblende, orthopyroxene and cordierite minerals in the rock's morphologies suggest a high metamorphic grade. (Plate 2 and plate 4)
- The change in morphologies is due to change in partial melting rate. Extinction observed on quartz grains in all slides suggests an intra-crystalline deformation and the polycrystalline nature of the quartz grains suggest a high temperature deformation as a result of grain boundary migration.
- Undulose extinction and twining obliteration in quartz and feldspars suggests intra crystalline deformation.
- From the stereographic plots the general trend of the foliation plane is NW-SE Trend with coincides with the trend of the rhyolite dyke(Plate 19) found within the diatexite and metatexite in the study area which gives the impression that the rhyolite dyke is occupying the foliation plane that makes it a sill not a dyke.

4.4 Conclusion

The combination of petrography and field/morphological data, evaluation of several parameters of the study area from the petrography the following conclusions can be drawn:

1. The study area has various morphological units of migmatites, that are mainly metatexite (Banded Orthogneisses and Stromatic), diatexite (Schlieren and Nebulitic diatexite) and rhyolites occurring as dyke.
2. The presence of petrographic properties such as undulouse extinction in quartz, preferred elongation platy Biotite, Metamorphic minerals like orthopyroxenene, Silliminite (Plate) and Microstructures like the Mymerkites (Plate12), indicate the study area to be a metamorphic terrain that has undergone shearing.
3. The grade of metamorphism increases from metatexites, which is indicated by preferred elongation of biotite and abundance of biotite + muscovite + hornblende, through to the diatexites, which is indicated by the general coarsening of quartz grain size and depletion of the paleo-structure of the schist (Plate.21)
4. Mineral inclusions found within the garnets (Plate 4) shows there is economic prospects in the area
5. Rhyolite dyke found within the migmatites conform to the general trend of the foliation planes which is the NW-SE direction (Fig 10 and 11)

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