Petrology and Morphology of Migmatites Around Dogon Koli Part of Sheet 148 Toro Se Area of Bauchi State

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Abstract
The study area is located within the pan African older granites and is located in Dogon Koli East of Toro LGA in Bauchi state of Nigeria and is accessible through Bauchi Jos Road. Using Sawyers classification of migmatites, the study area has various morphological units of migmatite that are mainly metatexites(banded orthogneiss and stromatic), diatexites (schlieren and nebulite), and rhyolite occurring as dyke. Petrographically, morphology suggested to have the most potential of hosting mineralization is the diatexites among other morphology, the presences of metamorphic minerals, garnet, hornblende, orthopyroxene in the rocks morphologies suggest a high metamorphic grade. The change in the morphologies is due to the change in partial melting rate. Extinction observed on quartz grains in all the slides suggest an intra-crystalline deformation and the polycrystalline nature of the quartz grains also suggest a high temperature deformation as a result of grain boundary migration. The presences of structures like Isoclinal fold, crenulation cleavages, gneisses 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+hornblend, through to the diatexites, which is indicated by the general coarsening of quartz grains size and depletion of the paleo structure. The protolith is characterized by Eburnean indicating metasedimentary paleo rocks.

Keywords: *Dogon Koli, Metatexites, Diatexites, Banded Orthogneisses, Stromatic, Schlieren, Nebulite, Rhyolite, Isoclinal fold, Crenulation cleavage,*

INTRODUCTION

Migmatite are unique rock formation that results from the partial melting of metamorphic rock under high temperature and pressure condition. They are commonly found in areas of intense crustal formation and can serve as a potential host for various mineral deposit due to their complex mineral assemblages and diverse geo-chemical composition.

The spatial distribution of metamorphic faces across orogenic belts is generally used to infer dynamic process (e.g Saggerson & Tuner, 1980). Yet, the identification of high temperatures granulite or upper amphibolite's facies assemblages in the high-grade granulite or upper amphibolite's facies assemblages in the high grade gneisses can be difficult where regional metamorphism and plutonism are broadly contemporaneous. Thus, the emplacement of two-pyroxene diorites (igneous charnockites) in orthopyroxene-bearing gnersies and other granulite's, relatively common in Proterozoic orogenic domains, is a situation where

distinction between regional and intrusion-related effects can be problematic.
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).

The Bauchi area has foliations running through it, which was deduced from field data, SLAB images and previous maps (Wright, 1971). 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 that formed migmatites of Pan African age in NW and SE Nigeria (Ajibade 1988; Ekwueme 1991).

In Ganaja, Kogi State, North Central Nigeria, the structure has probably developed as a result of tectonic differentiation and metamorphic segregation. The preferred orientation of the foliation is dominantly in the NW-SE trend, which is indicative of the Pan African Orogeny (Imasuen, et al 2013). In Ago-Iwoye, Southwestern Nigeria, the rosette plotting of strikes of foliation values and veins indicates a NW-SE trend of dominant tectonic forces that affected rocks in the area. The general interpretation is that the groundwater flow pattern is expected to be in NE-SW direction in line with the direction of joint. This could be understandable since basement aquifers are controlled mainly by fractured or weathered rock. The joint shows EW directional response to the dominant tectonic stress that produced it (Folorunso et al, 2013). Statistical diagrams that show attitudes of many different joints within a given region can help to identify dominant joint orientations in a region (Van der Pluijm & Marshak, 2004). Though folding and faulting are not prominently displayed on the rocks, the fact that the rocks were fractured (jointing) is an evidence of paleo-tectonic magmatic cycle associated with the Pan-African Orogeny (Obaje, 2009). On the structural measurements, the resultant orientation of foliations and vein shows a NW-SE trending analogous to the direction of tectonic event responsible for the metamorphism and/or fracturing of rock in the region (Rahaman, 1989; Obaje, 2009). In a region of systematic jointing that is oriented North–South, groundwater is also expected to flow faster and/or with larger discharge in the North–South direction than in the East–West direction (Van der Pluijm & Marshak, 2004).
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 , 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.

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.

The Bauchi area is underlain by migmatite-gneiss which is the oldest rock in the Nigerian Basement Complex (Rahaman, 1988). The relationship of the present rocks can be defined in that the effect of metamorphism of the gneiss that resulted into shoot and was later intruded by older granites (Bauchite). The heat from this intrusion led to metamorphism that formed later gneiss showing a polycyclic cycle of metamorphism (Bruguier *et al.,* 1994). In a discussion on the Bauchite – Biotite hornblende granite transition by Oyawoye (1961) he suggested that the charnockiitic rocks (Bauchite) are formed under local pyroxene-hornfels facies conditions in regions of amphibolite facies metamorphism (Oyawoye, 1965). These conditions may be induced either by a reduction in pressure with the con comitant rise in temperature and/or by the introduction of hydrothermal fluids.

Also, Bowden (1969) suggested that Bauchite who melted by a linear zone of high heat flow from the Manthe during the disruption of Gondwanaland.

The Neoproterozoic Trans-Saharan Belt in which the study area falls within was suggested to be formed between 700Ma and 580Ma by accretion of terranes between the converging West African Craton, the Congo Craton and East Saharan Block, which was probably a craton until 700Ma (Black and Liegois, 1993) when it was widely and largely reactivated, except in few areas.

It has been discovered that an extensive sampling of metasedimentary gneisses of the Bauchi area (Jos-Bauchi transect) has revealed several occurrences of granulite facies rocks within high temperature amphibiolite facies rocks and anatexites (Ferre and Caby, 2006). Haruna (2016) has declared the area is underlain by three broad lithologic unit viz: Migmalite/gneiss, Bauchites and granite of various texture.

Despite the above findings, there is no work that investigates the mineralization potentials of the migmatites in Dogon Koli area, therefore, this work will attempt to use surface mapping, structural analysis, petrographic and geochemical studies to classify, analyse and provide more information on the migmatization in the area.

METHODOLOGY

Study Area

The study area lies within latitudes N 10^0 9^1 17.88” and N 10^0 12^1 42.79” and longitudes 9^0 21^1 19.97” E and 9^0 23^1 59.48” E as seen in figure 1. The area covers about 30.65km^2, which forms part of sheet 148 Toro SW.

The area is accessible along Bauchi Jos Road, the major road linking Bauchi to Toro, and out crops is accessible through minor roads and footpaths. The study area forma part of the Northern

Nigeria Basement Complex (Haruna, 2016), the study area is located on a shear zone that are mainly migmatite rocks. Ferre *et al.*, (2006) declared the rocks in the area on granulite facies rocks, formed from high grade metasedimentary rocks.

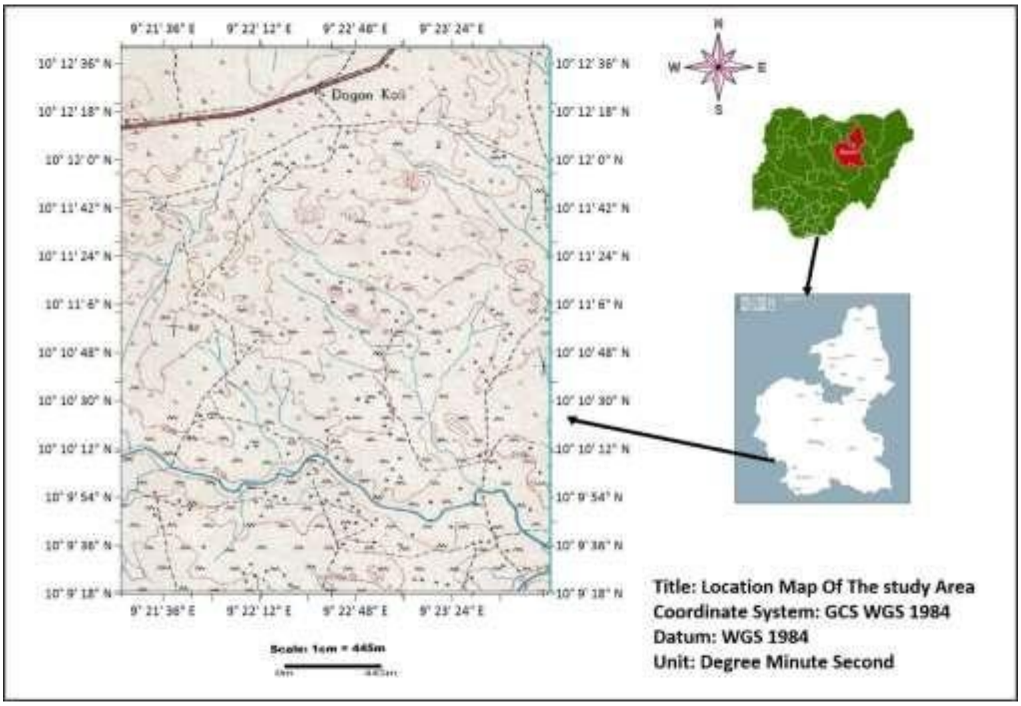


Figure 1: Location Map of the Study Area

1.8.1 Climate and Vegetation

The climate of the area consists of a wet (rainy season) which extends from May/June to early October with temperature of 25^o to 37^o degree Celsius (data from NIMET 2004) and a dry season which is characterized by the Harmattan from November/December to April/May with a temperature range of 29^o to 45^o degree (data from NIMET 2004).

The vegetation type is savannah and comprises of scattered trees, shrubs and mostly flat lying grasses seen in the field, with a unique plant growing mostly on the ridge of the outcrops trending s/w direction called farow (Hausa name). The plant dried peals are use for medication for treatment of pile (field guide).

1.8.2 Settlement and Land Use

The major land use in the area is farming and cattle rearing (Grazing) in some places not used for the farming purpose. The product of the weathering of the rocks in the area provides fertile soil farming and the drainage systems provides soil moisture. These two factors make the area agriculturally viable. Some of the people were seen practicing artisan mining along the river channels as source of income to earn living. The settlement here is mostly nucleated with scattered villages. The prominent village in the study area is the Kambel Village.

1.8.3 Relief and Drainage

The area has appreciable relief and is characterized by single and low level (Altitude) outcrops. The heights ranges of 630m to 734 metres above sea level, most of the structural information where visible at low level outcrops.

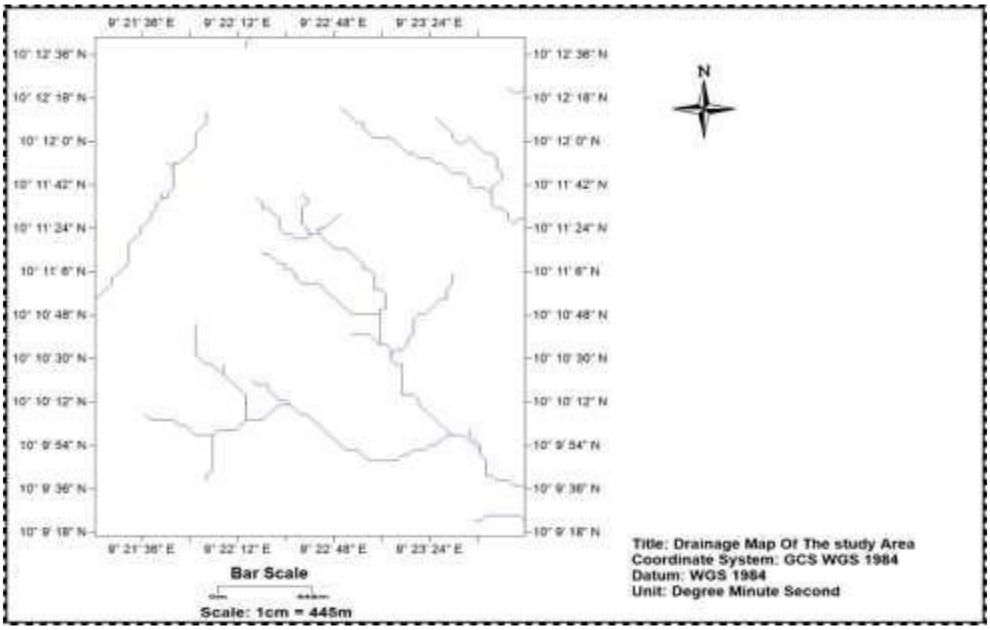


Figure 2: Drainage map of the area

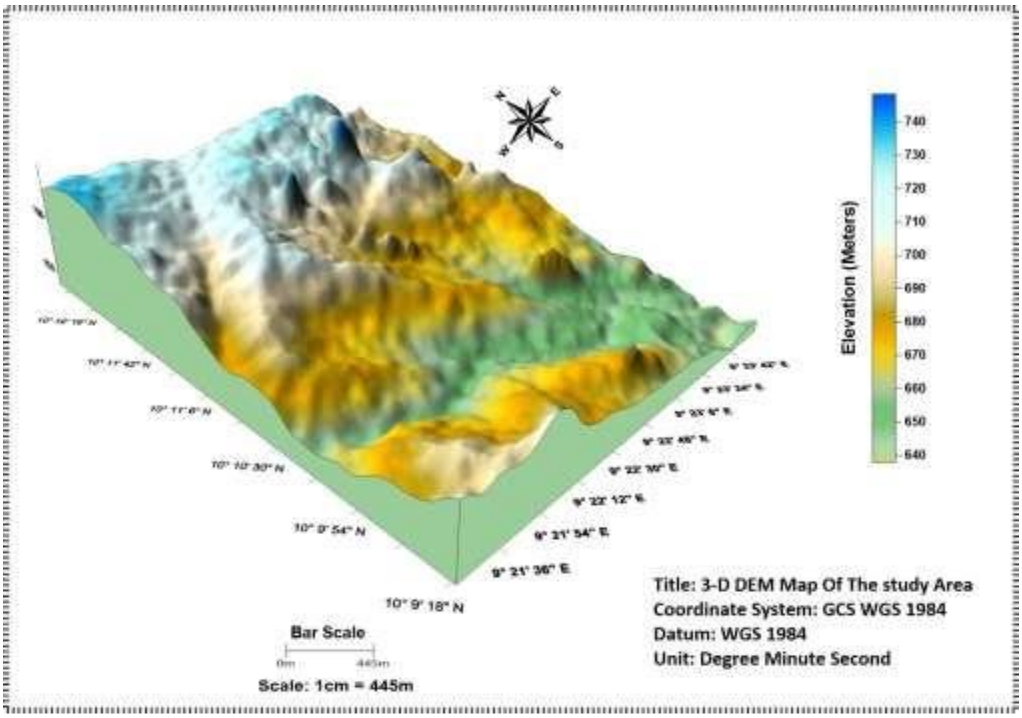


Figure 3: 3-D digital Elevation Model of the Area

3.2 Materials

The apparatus used (materials) in the course of the field work and lab work include:
Global Positioning System (G.P.S)

1. Compass clinometers
2. Hand lens
3. Masking tape
4. Measuring tape and ruler
5. Topographic map
6. Geologic Hammer
7. Permanent marker
8. Samples bag
9. Note book
10. Pencil and eraser
11. Calculator

3. 2 Method

Methods employed in the course of the work can be broadly divided into two, field methods and laboratory methods.

3. 2. 1 Field Methods

These are the various methods employed in the field to acquire data, take samples and also interpret in the fields:

a. Direction and Bearing

The bearing of various outcrops were measured using compass and the location, elevation coordinates in terms of longitude and latitudes using GPS (Global Positioning System) usually in the Mini datum configuration mode. Compass alongside clinometers is used in taking the dips and strike of the beds, the clinometers give the dip angles and the compass gives the strike analysis.

b. Distance

Distance between the locations were taken using GPS (Global Positioning System) in terms of latitudes and longitudes and recorded for further references.

c. Rock Sampling

Rock samples are taken using the Geologic Hammer, after the fresh samples might have been taken it is labelled and later described in terms of lithology as well as in their mineralogy, textures and relationship between them are also analysed from the samples gotten from the fluid:

Ground transversing was the method used, and the following steps were applied:

- The investigators first observed and collected data
- Then formulate a hypothesis to explain the collected data using structures seen on field and physical properties of samples taken.
- The test of the hypothesis is the laboratory using the microscope.
- The end result of the test or adoption of another before conclusion and inferring of the sample unit.

d. Line of Zero Dip

These is to get the accurate dip and strike of the various structures in the field, these is done by setting the compass to a 270-90 position such that the clinometers is on zero to get the strike line, the line perpendicular to these strike line is the dip, and the amount is measured.

3. 2. 2 Laboratory Methods

Knowing that the results collated from the field are tentative and inferred there is need for them to be confirmed using the appropriate methods in the laboratory, these studies involved the following.

a. Petrographic Study

Petrographic analysis involves the description of a rock sample in thin section using the optical microscope in the lab. This is more detailed than the macroscope study, which involves looking at the rock sample with naked eye or through a hand lens to observe the color, texture, mineralogy and composition. This is known as hand specimen study, the structures can also be such as foliation, banding, cross bedding etc., under the microscope the sample is viewed both under plane as cross polarised light. Properties analysed under plane polarized light are colour, pleochroism, relief, cleavages shapes (morphology), while these analysed under crossed polarized light are interference colours, extinction angles exsolution.

3. 3 Laboratory procedure for thin sectioning

Firstly, the sample to use for the thin section is selected. In election finer samples are chosen as to give more information of the rock rather than coarse samples, also representative samples are taken such that it shows all or almost all of the mineral's assemblages for the rock type. After selecting the samples then it is taken to the lab where the following processes are conducted to produce the thin section.

1. Using rock cutting machine, cute side of interest from the rock sample.
2. Ensure removal of bubbles by carefully heating the slider after pressing out air bubbles using forceps.
3. Eliminate air bubbles by gently rubbing the surface using mounting pin.
4. Label slide, ready for other studies.

Precautions to be taken in thin section production:

1. Ensure to remove all air bubbles in the slide.
2. Take care of overheating as it causes cracking of glass.

3. 4 Slide Viewing Technique Under the Optical Microscope

The thin section of a sample is to be viewed in two modes. The first with the analyser out to produce or give the plane polarized light, in this mode you can view the following properties:

a. Colour
b. Pleochroism
c. Forum
d. Cleavages
e. Relief
f. Alteration

After the above method you now view same slide this time with the analyser in producing the cross-polarized light, you can see (observe) the following properties:

a. Interference colours
b. Extinction angle
c. Twinning.

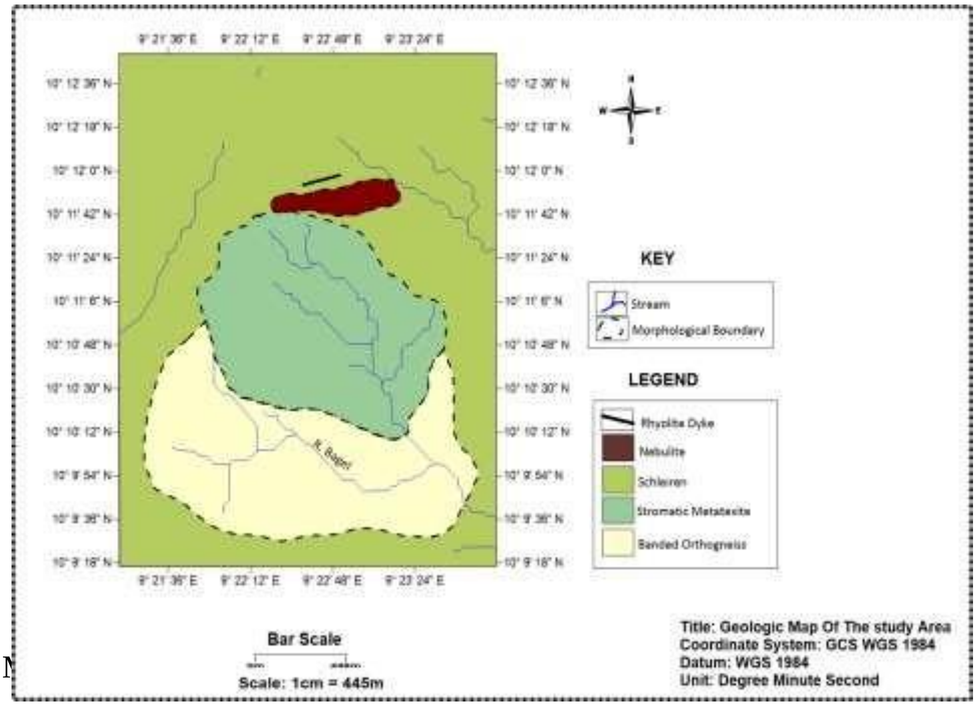
3. 5 Data Analysis

From the field studies and macroscopic identification of rocks, the rocks were classified based on the first and second order classification of migmatite by Sawyer (2008). For the petrographic studies, the prepared slides were examined under the petrological microscope to identify mineralogical features and microstructures on a microscopic scale.

RESULT AND DISCUSSION

4. 1 Field Occurrence

The various rock samples obtained from the field are grouped into 5 as thus:
A, B, C, D and E and were studied with hand lens to see minerals which are visible and later subjected to thin section/ petrographic studies under microscope to determine the minerals and other important information like twining as well as microstructures. The metatexites in the study are the dominant form, outcropping as banded orthogneisses and stromatic migmatites. The diatexites are found surrounding the metatexites, the diatexites found in the study area show a transition between metatexites and diatexites, forming schlieren type of migmatite. The nebulite have 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.The encountered rocks are shown in(*Figure 4:)* plates



4. 2

4.2.1 Sample A: Banded Orthogneiss

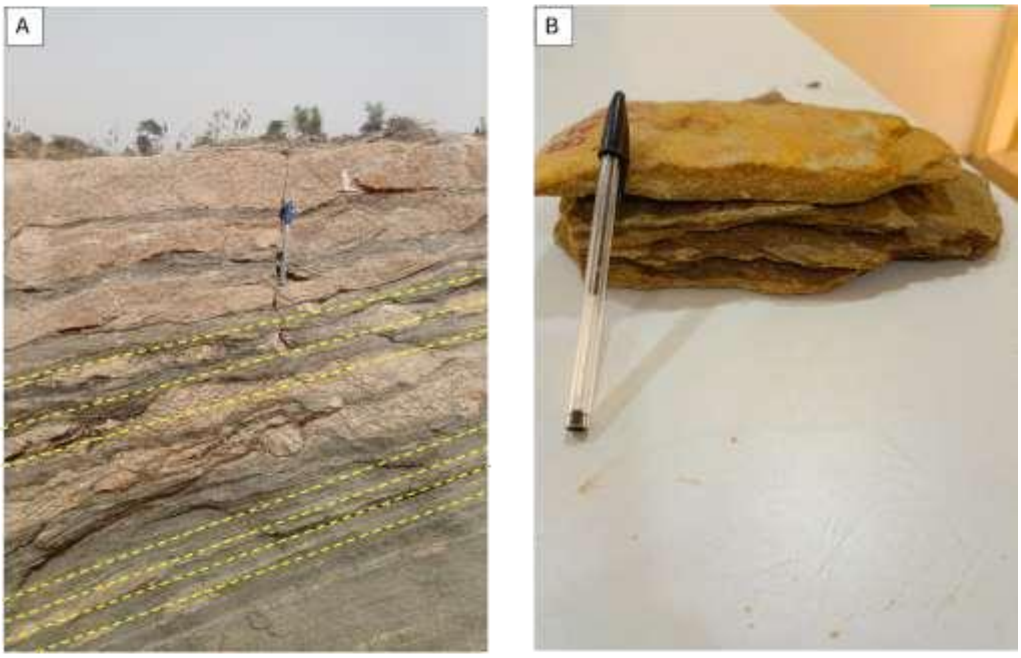


Plate I: A= Field view of Banded orthogneisses, B= Hand specimen view of Banded orthogneisses

The sample has a banded structure and a medium to coarse grained with poorly developed schistosity, less than 50% of the minerals show preferred parallel orientation, the common minerals are feldspar and quartz.

4.2.2 Sample B: Nebulite

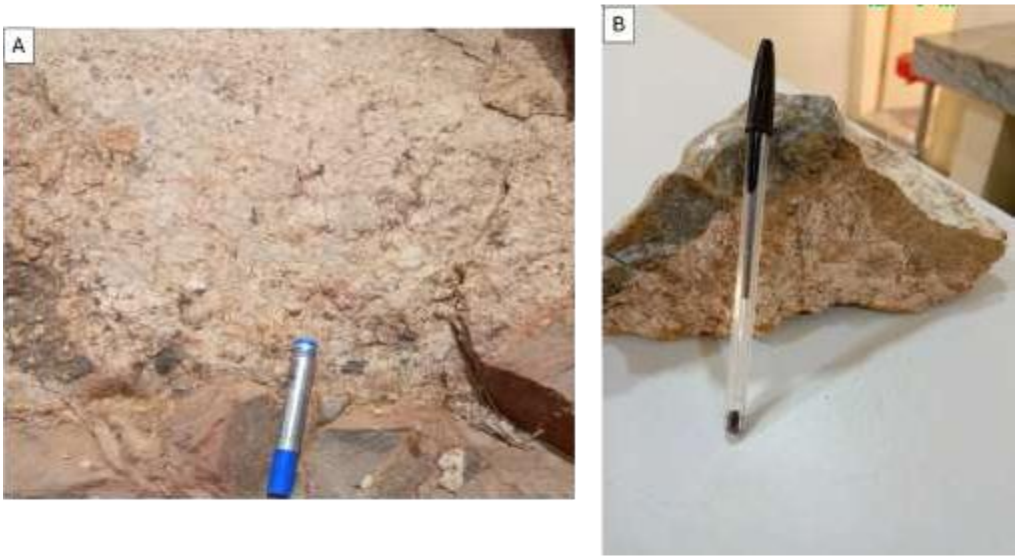


Plate II: A= Field view of Nebulite, B= Hand specimen view of Nebulite

The rock sample is coarse grained (2-10mm) and is composed of large grains of quartz and biotite. Morphologically the rock is nebulitic

4.2.3 Sample C: Stromatic

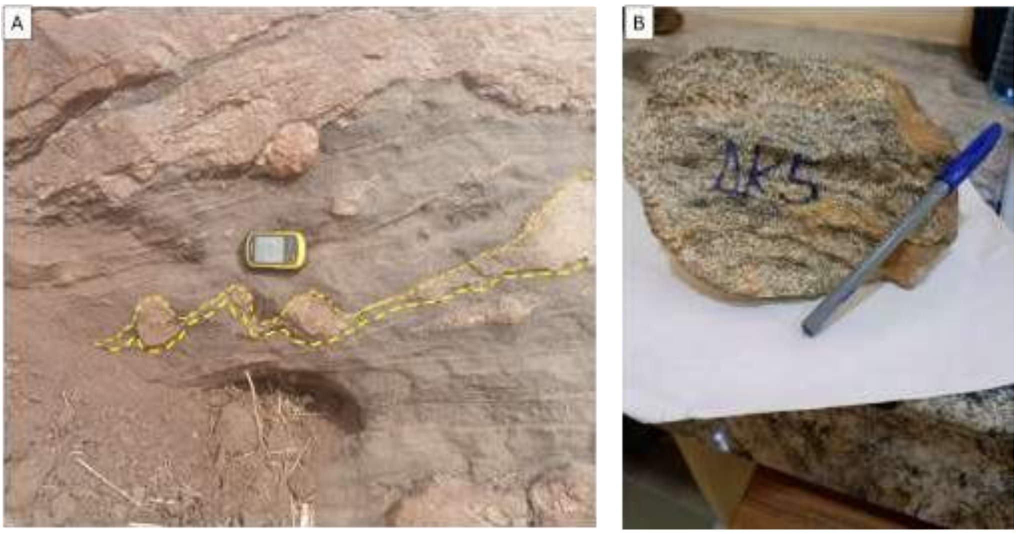


Plate III: A= Field view of Stromatic migmatite, B= Hand specimen view of Stromatic Migmatite

The sample contains numerous thin and laterally continuous bands of leucosome that are oriented parallel to the major plane of anisotropy in the palaeosome, which are typically compositional layering or a solid-state foliation.

4. 2. 4 Sample D: Schlieren

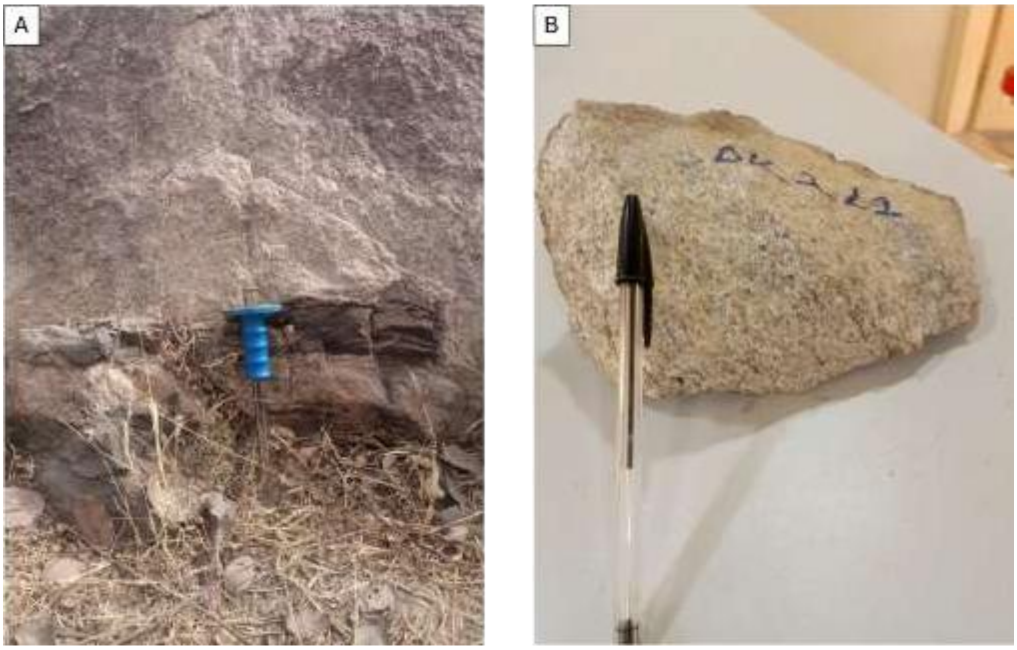
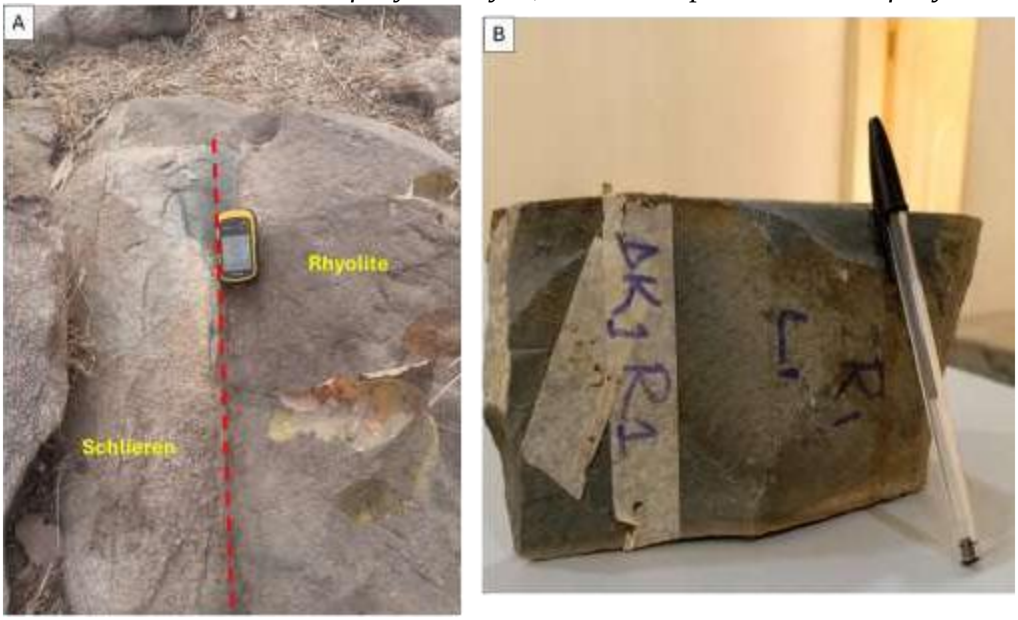


Plate IV: A= Field view of Schlieren, B= Hand specimen view of Schlieren

The sample is characterized by well-developed, flow-induced structures, defined by thin layers of aligned platy or prismatic minerals, which are known as schlieren. The schlieren are most defined by biotite.

4.2.5 Sample E: Rhyolite

Plate V: A= Field view of rhyolite dyke, B= Hand specimen view of rhyolite dyke



The sample occurs as a dyke in the study area and is characterized by a fine grain dark minerals and was seen trending in S266°W direction.

4.3 Field Relationship

This area is characterized by flat-lying foliation and E-W sub horizontal stretching lineation corresponding to a crustal event.

The symmetrical arrangement of biotite rich restite layers on either side of leucosomes layers indicates that the migmatization resulted from in situ partial melting.

The stability of hornblende and biotite in the leucosome suggest an anatexis under amphibolite facie conditions. Early structures are deformed by isoclinal folds and cut by mafic dykes injected along the axial planes of fold. These dykes associated with N-S supervertical dextral strike-dip leucosomes, this shows that migmatization occur also during a regional episode of localised high temperature ductile deformation.

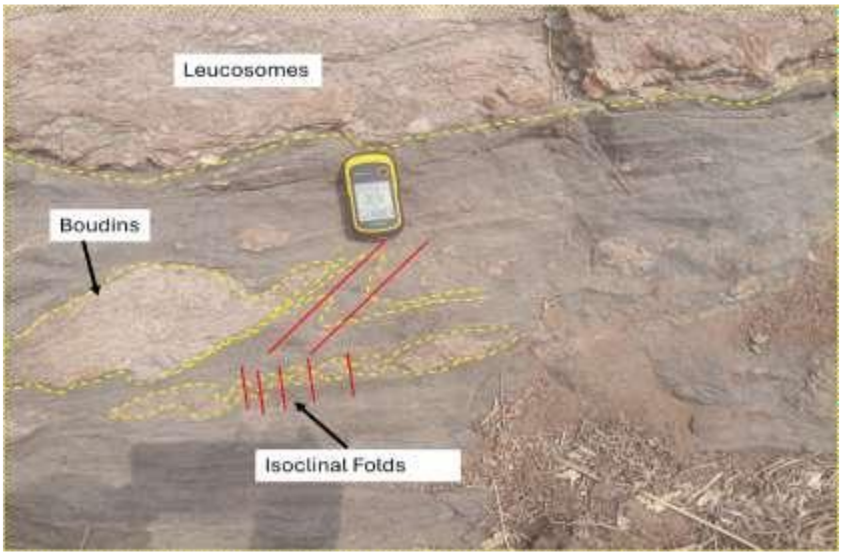
Plate VI: showing crenulation

Crenulation Cleavages (plate) 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 VII: Showing foliation planes

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 quartz bands, alternating with layers rich in biotite.

Plate IX: Pinch and swell structure found in stromatic metatexites



The Boudinage structure (plate IX) 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.

4. 3. 1 **Petrography**

The various slides produced were analyzed with the analyzer out (plane polarized light) to view their color, pleochroism, form, cleavages, relief and alteration to identify the minerals and then analyze with the analyzer in (Crossed polarized) to view their interference colors, extinction angle, twinning after which the minerals are named.

The minerals quartz, biotite, microcline, plagioclase and orthopyroxene were the main minerals identified in the rocks; mineral biotite is seen to be associated with the deformed part of the rock. A lot of structural deformation and shearing were also seen at microscopic level indicating deformation usually controlled by mineral biotite, and further confirming the structural capabilities of rocks in the area and metamorphism that affected study area. The properties of minerals seen are presented in Table 1 and photomicrographs of slides presented in Plates. the deformation seen in the quartz also suggests pathways for fluid movement and fracturing in the study area.

Table 1: General optical properties of the rocks in the study area minerals

	PPL	XPL
Quartz	Quartz is Colourless with low relief and no cleavage under PPL.	Wavy Undulose extinction indication of dislocation walls in mineral grains.
Biotite	Biotite showing Perfect Cleavage in One direction, and brownish.	Elongated platy Brown with one

		directional cleavage.
Garnet	Brownish subhedral grain.	Pale Greenish subhedral grain.
Plagioclase	Plagioclase Colourless	Twinning visible
Orthopyroxene	Fibrous Pale greenish	Fibrous Pale greenish
Orthopyroxene		
Microcline	Microcline show Colourless	Cross hatch twinning
Opaque	Black Opaque Mineral	Black Opaque Mineral

Source: 2024 Field Work

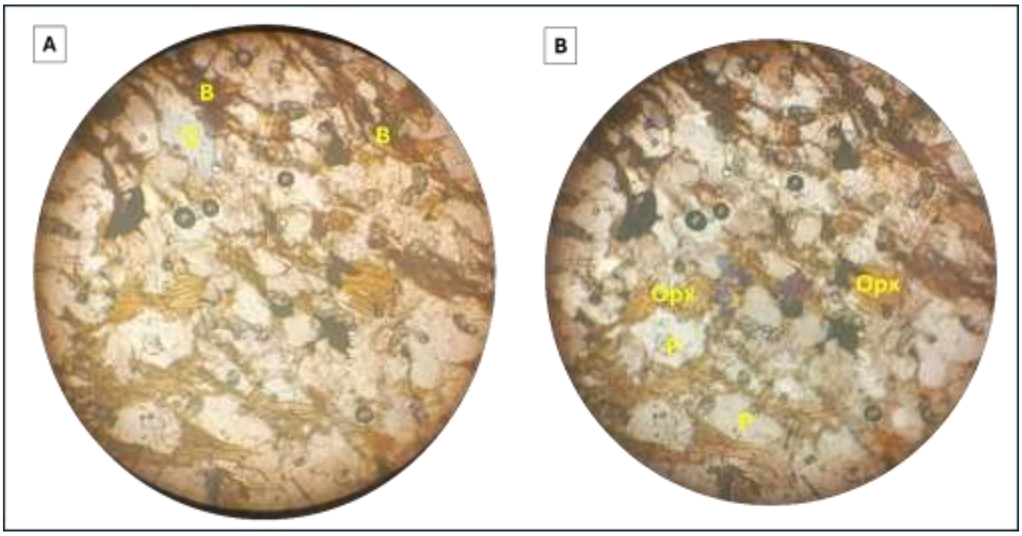


Plate X: Photomicrograph of sample DK 7a (Banded orthogneisses) A= under plane polarized light B= under crossed polarized light

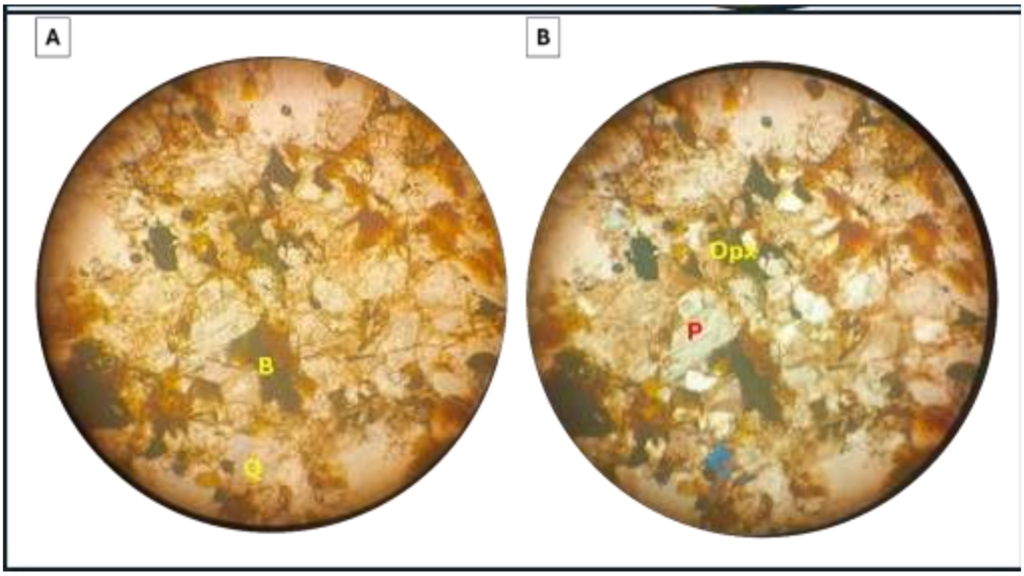


Plate XI: Photomicrograph of sample DK 7B (Nebulite) A= under plane polarized light B= under crossed polarized light. B= biotite, Opx= Orthopyroxene, P= plagioclase Q= Quartz.

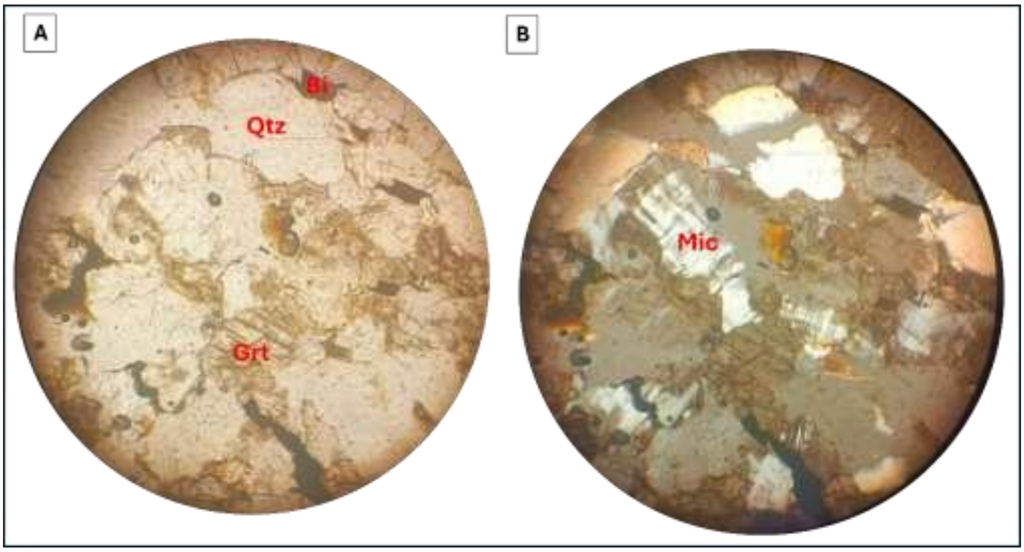


Plate XII: Photomicrograph of sample DK 4 (Banded orthogneisses) A= under plane polarized light B= under crossed polarized light. Qtz = Quartz, Bi= Biotite, Mic= microcline, Grt= garnet

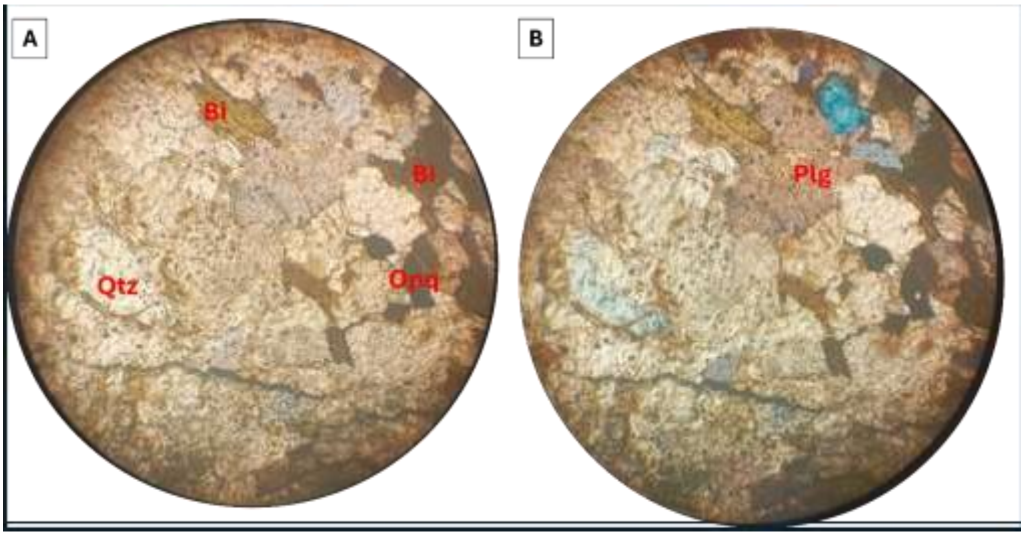


Plate XIII: Photomicrograph of sample DK 5 (Stromatic metatexite) A= under plane polarized light B= under crossed polarized light. Bi= biotite, Opq= Opaque, Plg= plagioclase Q= Quartz.

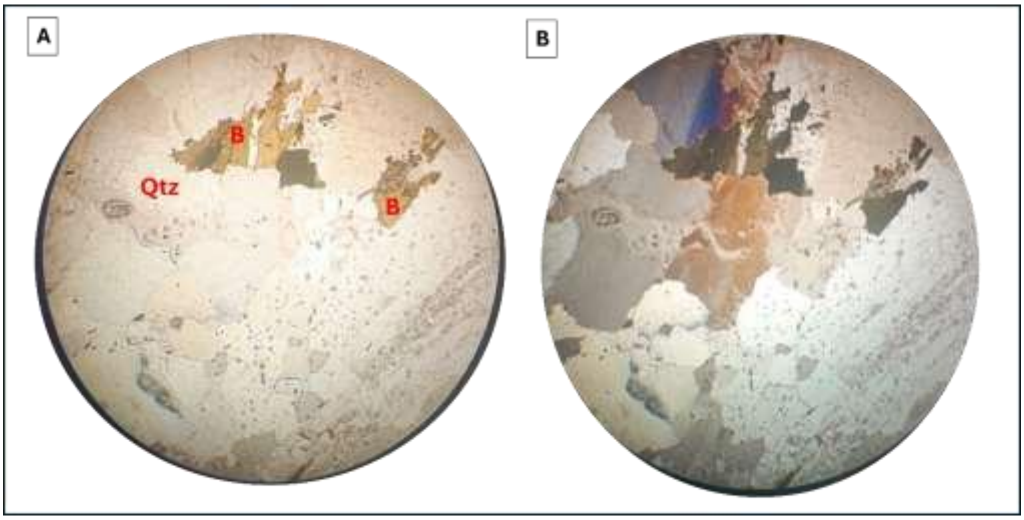


Plate XIV: Photomicrograph of sample DK 9 (Stromatic metatexite) A= under plane polarized light B= under crossed polarized light. B= biotite, Q= Quartz

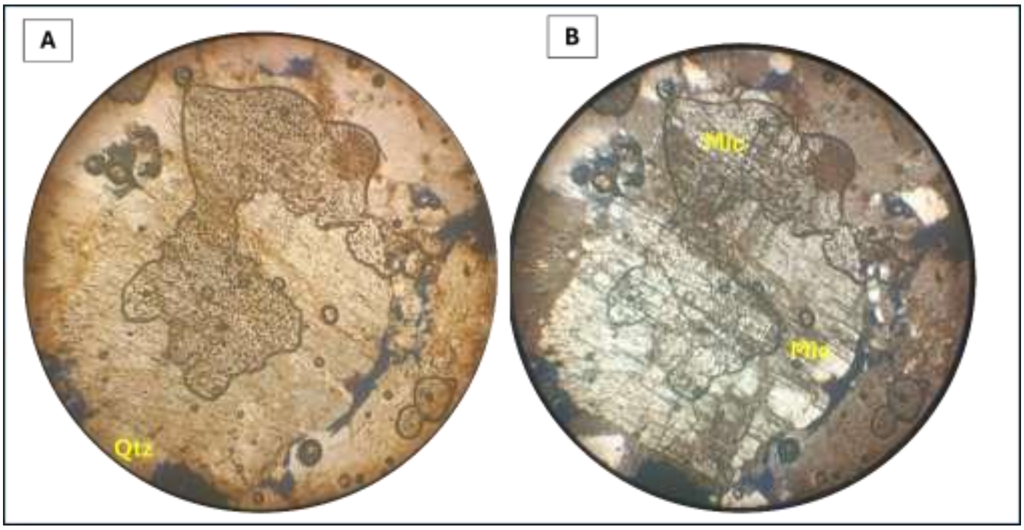


Plate XV: Photomicrograph of sample DK 2 (Schlieren) A= under plane polarized light B= under crossed polarized light. Qtz= Quartz, Mic= microcline

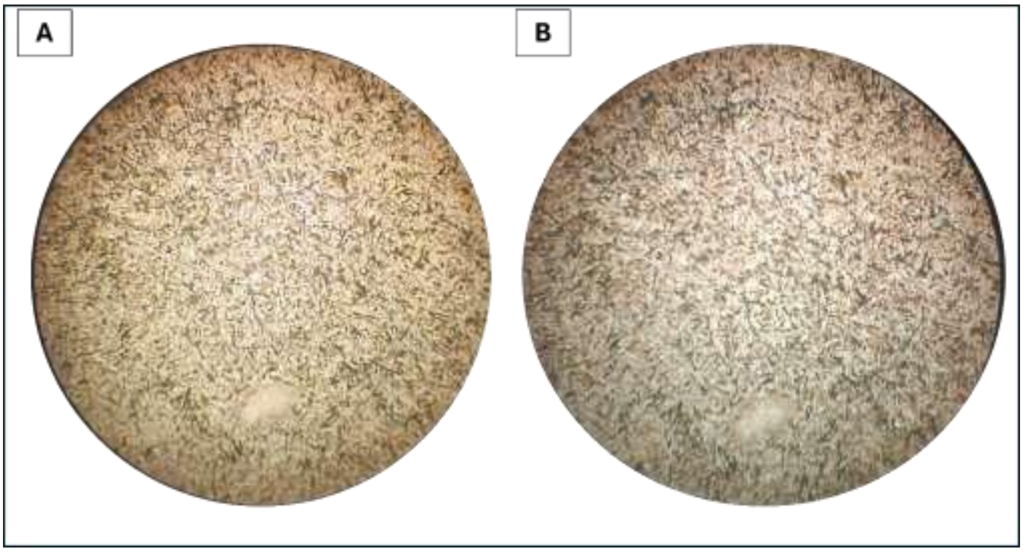


Plate XVI: Photomicrograph of sample DK1 R1 (Rhyolite) A= under plane polarized light B= under crossed polarized light. Biotite, k-feldspar and quartz are minerals associated with rhyolite but because of it fine grain and glassy nature of its texture, the minerals are difficult to be identified under the microscoline.

4. 4 Discussion

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 consist of hornblende, quartz, orthopyroxene, biotite, and plagioclase as major minerals. The schlieren type diatexites are composed of orthopyroxene, quartz, microcline, plagioclase, biotite. The nebulites are made up of quartz, orthoclase.

The presence of structures like the crenulation cleavage, isoclinal folds, gneissic foliation are all evidence of complex shearing episode has affected the study area (Plates 6 and plate 7).

Petrographically, the presence of metamorphic mineral garnet, hornblende, orthopyroxene, minerals in the rock's morphologies suggest a high metamorphic grade. (Plate 11 and plate 12)

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.

Petrography studies show that the study area protolith (paleosome) is from sedimentary origin, the graph plots all point to the fact that, the presence of minerals such as biotite, orthopyroxene, microcline and plagioclase shows the degree of metamorphism of the study area is of high grade from metatexites through to diatexites based on sawyers modern scheme of classification.

Conclusion

Morphologically, the migmatites in the study area have both metatexites and diatexites, variation alongside associated rhyolite dyke. The mineral assemblages were determined through petrographic analysis, migmatites are form by partial melting of the paleo rocks, the metamorphic grade is high due to the intra crystalline deformation and polycrystalline nature of the quartz grains, the diatexites are suggested to be the morphology to host mineralization.

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