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Geology and Compositional Variation of Migmatitic Rock Association around Kadage, Bauchi, Nigeria: Implication for Migmatite Provenance.

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ABSTRACT

This research work focused on the petrological and geochemical characteristics of the migmatite morphology in part of Bauchi. Migmatitic rocks association constitute the major rock components of the Earth's continental crust, which suggested to be formed in different geologic environments. The different types of morphologies their compositional characteristics, tectonic settings and magma sources are outlined. Detailed field geology and mapping (field observation, structural and metamorphic structures) and petrographic description have been used to investigate the geology and petrology of genetically related migmatitic rocks association in the study area. structural features such as stromatic bands, ptygmatic folds, crenulation cleavage, mineral alignment and foliation which is used to describe the different rock units in the study area and to ascertain their genetic relationship. The study area is dominated by metatexites, diatexites, charnockites (Bauchite) and granodiorite. The rocks consist of Biotite, Quartz, Plagioclase, Garnet, cordierite, Orthopyroxene, Sillimanite, and Muscovite all displaying metamorphic imprint (both texturally and structurally) with minor accessory minerals which include Zircon, Ilmenite, Apatite, Hematite Rutile and Corundum. Geochemically, the migmatites suites are ferroan, alkalic to calc-alkaline, slightly metaluminous to peraluminous, post-collision S-type granites and were derived through partial melting of crustal rocks. The different correlations of most major element with increasing acidity (SiO2) on the Harker diagram suggest that fraction crystallization has played a significant role in the evolutionary history of the rocks, even though erratic indicate partial melting and fractionation nature of these rocks during metamorphic and magmatic differentiation. The provenance reconstruction indicate that the source of these partially melted rocks is from a metapelitic to grey-metawacke source. The enrichment of LILE and depletion in HFSE indicates partial melting and crustal contamination of magma above Volcanic Arc and Syn-collisional granitoids. The rocks are S-type, strongly peraluminous in nature. The rocks thus provide a genetic relationship between metamorphism and compositional variation and similarities.

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1. 1.0 INTRODUCTION

Migmatites are high-temperature metamorphic rocks formed by anatexis (partial melting) in continental middle and lower crusts which it structural mineralogical or chemical heterogeneity depend on the protolith (source rock) composition (Sawyer & brown 2008). Migmatites and granites generated by crustal anatexis form the core of eroded orogenic belts of various age (e.g. Brown 1993; Meinhert 1968; Powell 1983). The link between high grade metamorphism, migmatites and partial melting has led many workers to propose a model for high grade metamorphism. 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 Nigerian Basement Complex is characterized by different episodes of metarmophism, orogenies and structural modifications (Odeyemi, 1981; Rahaman *et.al*., 1983; Caby, 1989) which is reflected in its complex petrological and structural composition. The geology of the area is characterized by rocks of high-grade granulite facies metamorphic terrain, predominantly migmatites, granulitic granitoid, pegmatite and charnockite. Ferre & Caby 2006 reported that the development of granulite facies Pan-African rocks in Bauchi was possible due to the heat supplied from the abundant anhydrous charnockites and monzodiorites. This work was therefore necessitated by the need for the delineation of the various morphological types of the different migmatite units in the area, as well as the need for detailed petrographic and geochemical studies on the rocks for assessment of their composition. Thus, the need for this research to bridge the knowledge gap therein. This will avail us a holistic view of the study area, which will help unravel significant information about migmatites within the study area.

2. 2.0 The Study Area

3. 2.1 Location

The study area Kadage lies within latitudes N10^{0}9’00” to N 10^{0}11’00” and longitudes 9^0 41’00” E to 9^{0}43’30” E which forms part of sheet 149 Bauchi SW (Figure 1). The study area Kadage covers approximately 48 square km. The area is accessible through the major road linking Bauchi to Dass, and the outcrops are accessible through minor roads and footpaths that give access the remote areas within the study area.

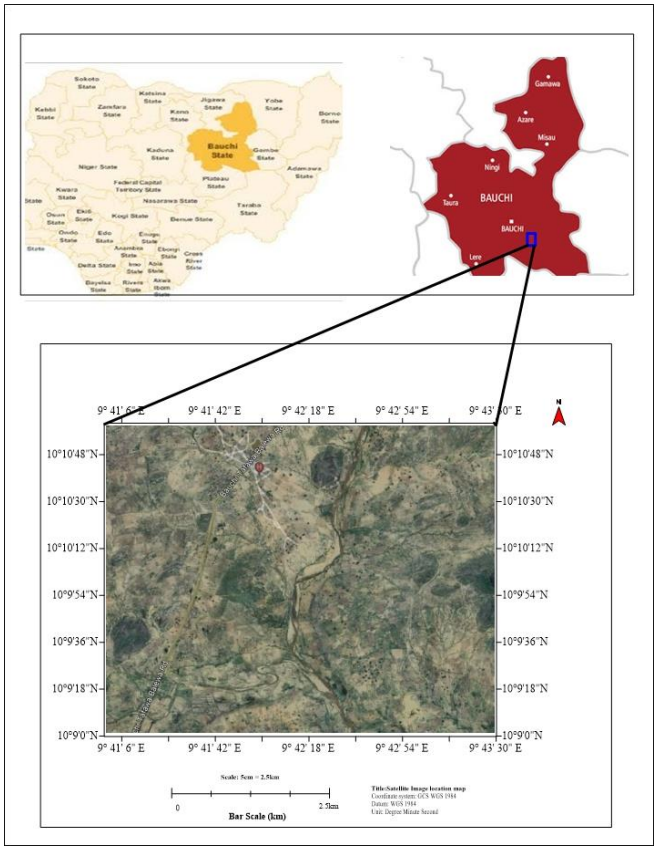


Figure1: Location map of study area (Source: Google earth)

3.0 Geological setting

3.1. Regional Geology

The Precambrian Basement Complex of Nigeria lies within the Pan-African mobile belt, east of the West African craton and northwest of the Congo-Gabon craton. Evidence from the eastern and northern margins of the West African craton indicates that the Pan-African belt evolved by plate tectonic processes which involved the collision of the passive continental margin of the West-African craton and the active margin of the Pharusian belt (Tuareg shield), about 600 Ma (Burke and Dewey, 1972; Leblanc, 1981; Black *et. al*., 1979; Caby *et. al*., 1981) (fig 2). The collision at this plate margin is believed to have led to the reactivation of the internal region of the Pan-African belt. The Nigerian Basement Complex lies within the reactivated part of the belt (Rahaman,1976). Radiometric ages indicate that the Nigerian Basement Complex is polycyclic and includes rocks of Liberian (2700±200Ma), Eburnean (2000±200Ma), Kibaran (1100±200Ma), and Pan-African (600±150Ma) (Black *et. al*., 1979; Caby *et. al*., 1981). In recent times, using the International Geological Time Scale (2002) in Gunter and Mensing (2005), these ages can be referred to as, "Paleoarchean to Mesoproterozoic (3600 to 1600 Ma)" for Liberian and Eburnean, "Mesoproterozoic to Neoproterozoic (1600 to 1000 Ma)" for Kibaran and "Neoproterozoic to Early Paleozoic (1000 to 545 Ma)" for Pan-African (Obiora, 2008).

The evolution of the Nigerian Basement complex during the Pan-African can best be discussed in the regional context of the Pan-African orogenic belt of West Africa. Geological and geophysical evidence from the western province of the belt and the cratonic margin has been used to erect geophysical evidence for the evolution of the belt (Grant, 1970; Burke and Dewey, 1972; Bertrand and Caby, 1978; Black *et. al*., 1979; Caby *et. al*., 1981). Essentially, the evolution of the belt is seen as a collision type orogeny with an eastward dipping subduction zone. Initial crustal extension and continental rifting at the West African cratonic margin, about 1000 Ma, led to the formation of graben-like structures in the western Nigeria and the subsequent deposition of the rocks of the Schist belts.

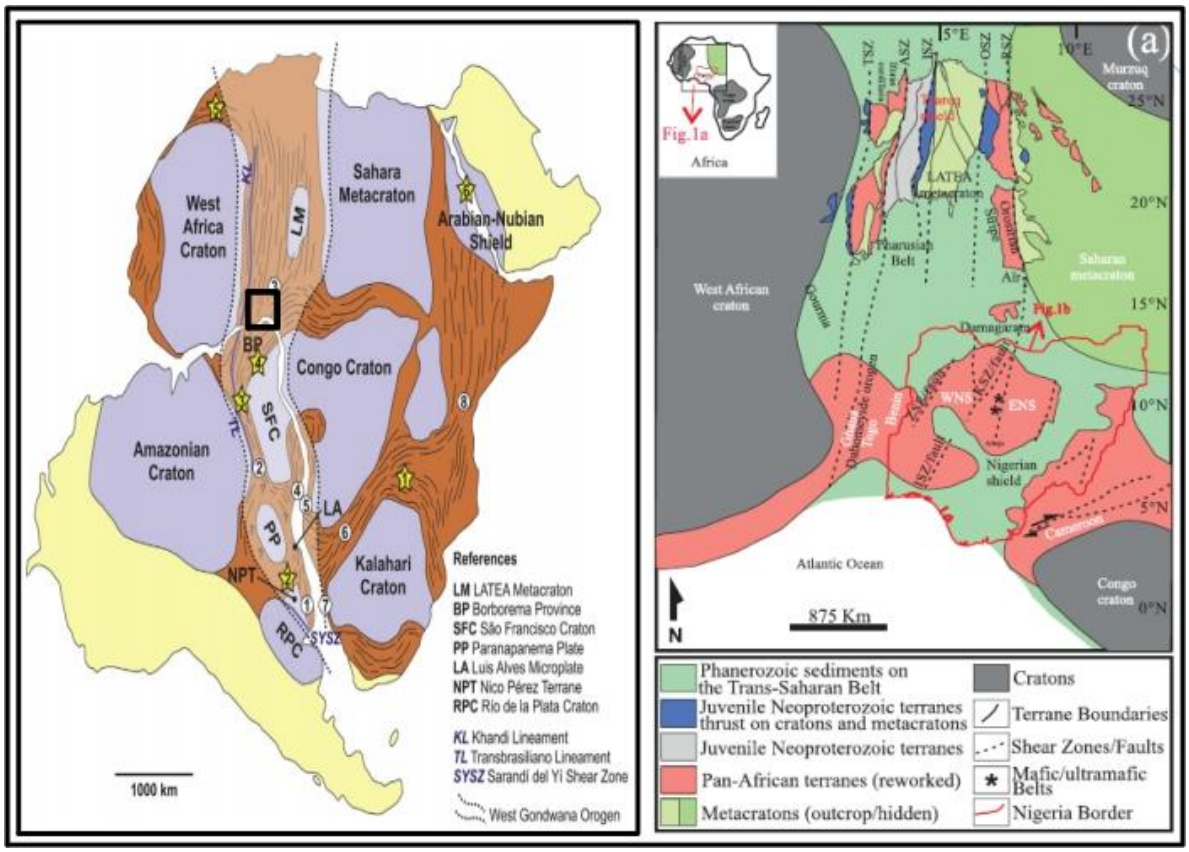


Figure 2: Geology of Nigeria at the context of West Africa (Wright,1985)

margin, about 1000 Ma, led to the formation of graben-like structures in the western Nigeria and the subsequent deposition of the rocks of the Schist belts. Closure of the ocean at the cratonic margin, about 600 Ma and crustal thickening in the Dahomeyan led to the deformation of the sediments, reactivation of the pre-existing rocks and the emplacement of the rocks of the Pan-African granites (McCurry, 1976). The granitoids have been emplaced within both the migmatite-gneiss complex and the Schist belts, and they occur in all parts of the Nigerian Basement Complex, though the extent of the Pan-African plutonism had not been fully understood (Rahaman 1976). Fitches *et. al.* (1985) has shown that the Older Granites are high level intrusions emplaced by stoping and diapiric processes in different parts of the country.

3.2 Local Geology

Bauchite is a part of the Neoproterozoic belt (Pan African) of NorthernEastern Nigeria where there is a distribution of metamorphic facies (Mac-Leod *et'al,*1971; Deleris *et' al,* 1996). High grade metasedimentary rocks reached granulite facies condition and survived as large lenses and pendants interlayered within anatexites and migmatitic granites. The geology of the area is characterized by metamorphic rocks of Neoproterozoic which are termed as Pan-African Granitoids (Older granite) and associated granitic rocks (Fig. 3). These rocks are mostly migmatite, Charnockite, and other granitic rock that made up the geologic suite (Fig. 3).

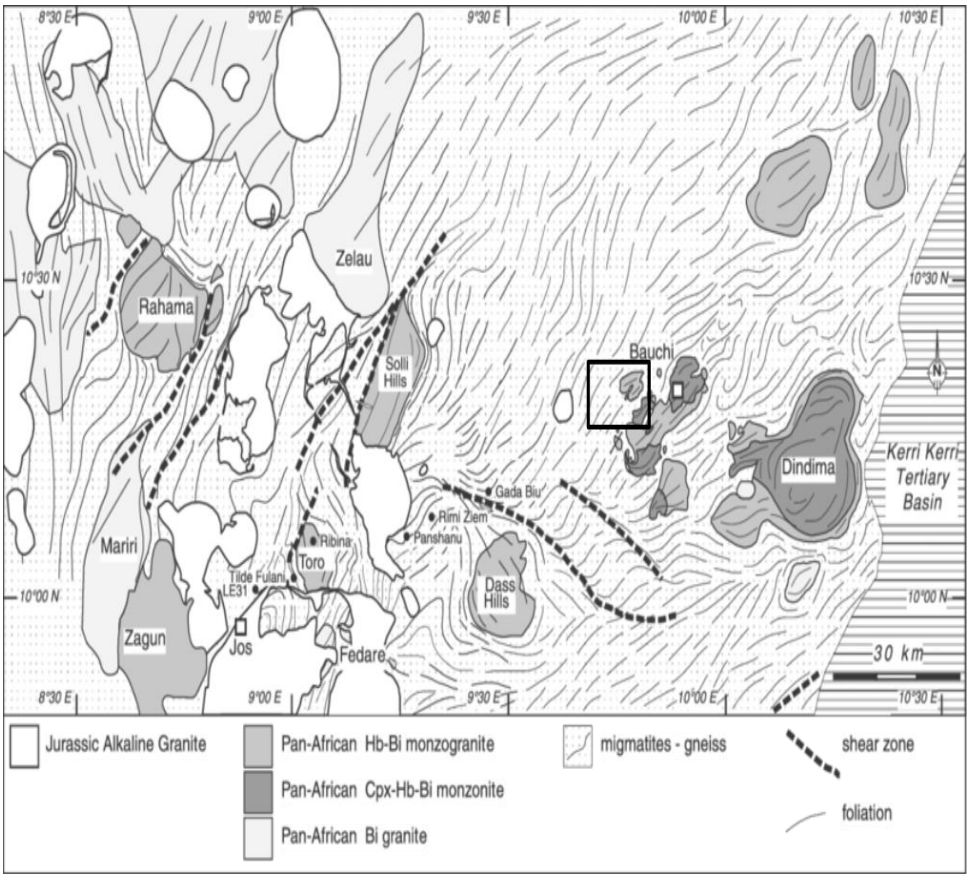


Figure 3: Geological map of the Jos–Bauchi area. Foliations compiled from field data, SLAR images and previous maps (Wright,1971). The biotite–muscovite granites form elongate plutons parallel to the regional structures suggesting a syn-tectonic emplacement. The biotite–hornblende granites have more rounded shapes moulded by country rock structures in conformity envelopes, suggesting a late- tectonic emplacement (Adopted after Wright, 1971)

The rock in the study area is characterized by metamorphic features such as magmatic foliation, mineral lineation which are due to the effect of partial melting. Oyawoye described them as charnockite and

locally named Bauchite after Bauchi town (Fayalite bearing quartz monzonite) by the introduction of some ferrous iron rich juvenile solution, which he said that they have granulites or amphibolites ghost relics (Schlieren) in them. The charnockite in the study area show a greenish coloration in fresh exposure but brownish to Yellowish white where weathered (Oyawoye, 1964). In a discussion on the Bauchite-Biotite hornblende granite transition by Oyawoye (1962) he suggested that the charnockitic rocks (Bauchite) are formed under local pyroxene-hornfels facies conditions in regions of amphibolites facies metamorphism (Oyawoye, 1965). Ferre and Caby (2006) reported that the development of granulite facies rocks in Bauchi was possible due to the heat supplied by abundant anhydrous charnockite and monzodiorite.

4. Sampling and Analytical Techniques

Field descriptions and observation were recorded in a field notebook. A total of 15 representative samples were collected and group using Sawyer (2008) first and second-order morphological classifications of migmatite for both petrographic and geochemical analysis. Petrographic analysis was conducted at petrographic laboratory Abubakar Tafawa Balewa University Bauchi. Geochemical analysis of the samples was conducted at Geological Survey Agency Laboratory, for major oxides and trace elements composition determination, using Energy Dispersive X-ray Fluorescence Spectrometry (EDXRF). Geochemical data were processed using ioGAS and GCDKit software package for various geochemical plot and discrimination diagrams.

5. Results and Discussion

5.1 Morphology and Field/Relationship

According to the field relation/morphology and petrographic observation, the rock in the study area were divided into six different types (Fig 4):1. Stromatic Metatexite 2. Diatexite (Meso-, Melano- and Leucocratic), 3. Bauchite and Quartz Diorite. All migmatites morphologies in the study area show lithological heterogeneity and intricate relationship.

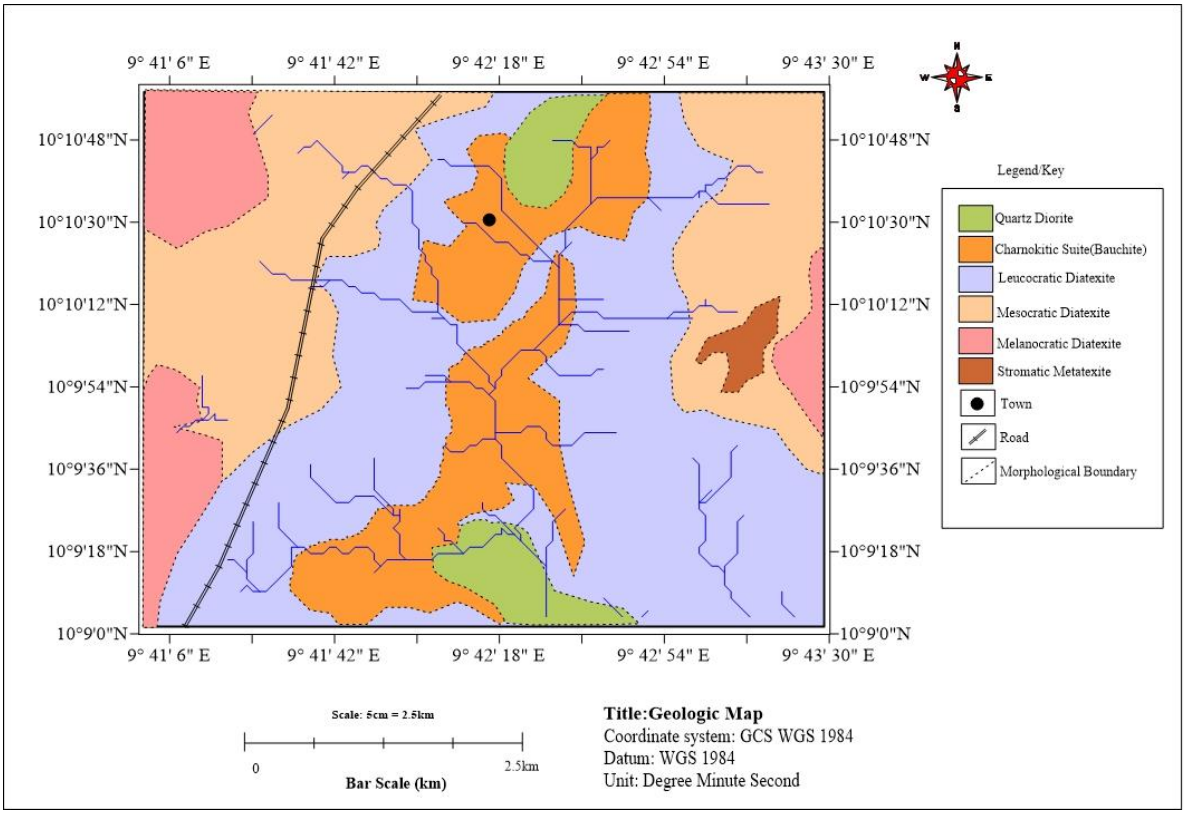


Figure 4: Geologic map of the study area

5.1.1 Stromatic Metatexite

The metatexite in the area is stromatic showing evidence of contorted fold (Plate I: A1). This medium- to coarse-grained, mesocratic to leucocratic rock is characterized by alternating layers of dark- and light-coloured minerals, otherwise described as a banded structure with beautiful folds. It is weakly foliated granitic rock which is leucocratic with few porphyroblasts of feldspars and garnet (Plate I: A2) in a medium to coarse-grained, equigranular matrix. The matrix consists of interlocking crystals of biotite, muscovite, quartz, garnet, and feldspar. Its less expose and show a sharp contact with diatexite

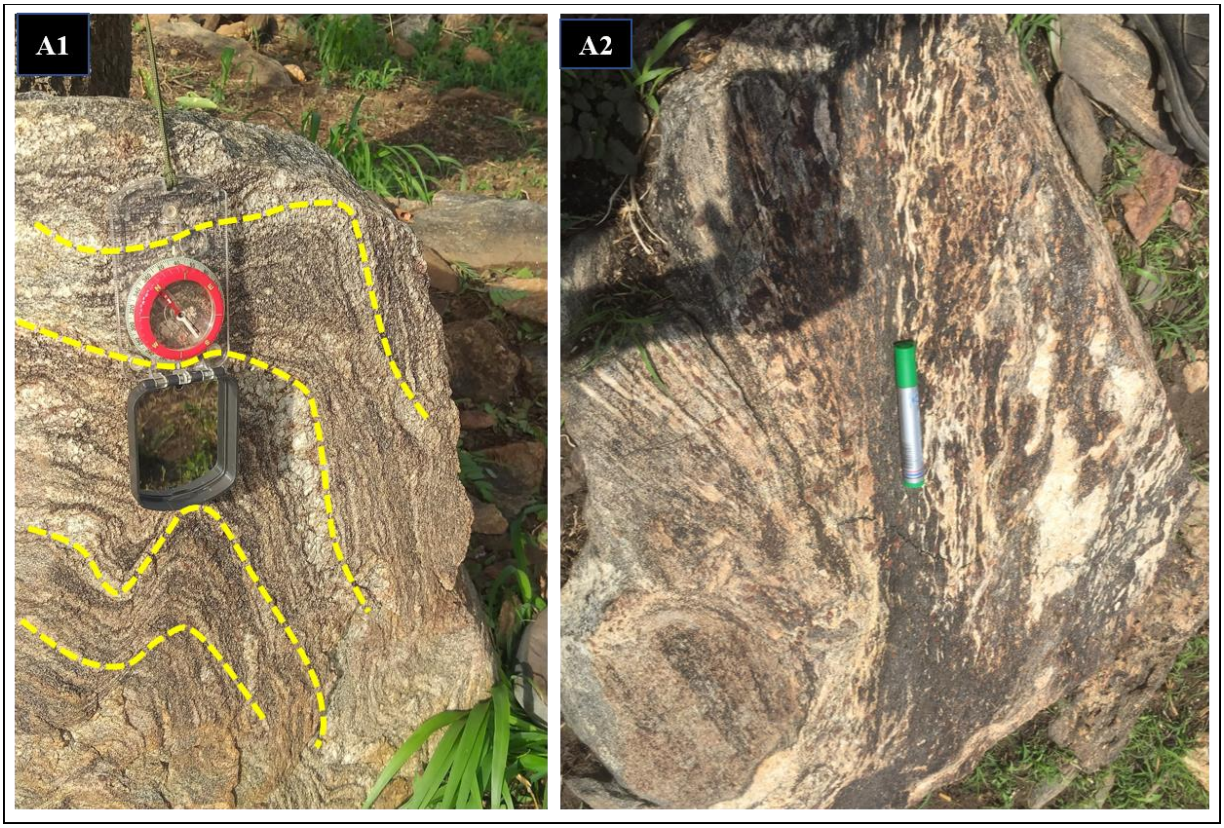


Plate I: Field photograph showing stromatic metatexite. A1) stromatic metatexite showing ptygmatic folding A2) stromatic metatexite showing garnet porphyroblast.

The metatexites are fine to coarse grained characterized by predominantly melanosome over leucosome. Leucosome consists of small scattered patches < 2cm dispersed in the melanosome and generally surrounded by dark selvedges (Plate II: A1). Melanosome minerals are aligned forming bands separated from each other by leucosome, developing a gneissic foliation. Melanosomes are composed of biotite + plagioclaseThe foliation is imparted by parallel to sub-parallel arrangements of the micas (biotite and muscovite) which are not segregated from the felsic components (quartz and feldspars). and plagioclare (Plate II). include biotite, muscovite, quartz, microcline, plagioclase and garnet. Garnet has neutral colour and high relief. It occurs in subhedral to euhedral hexagonal crystals. Undulous extinction in Quartz

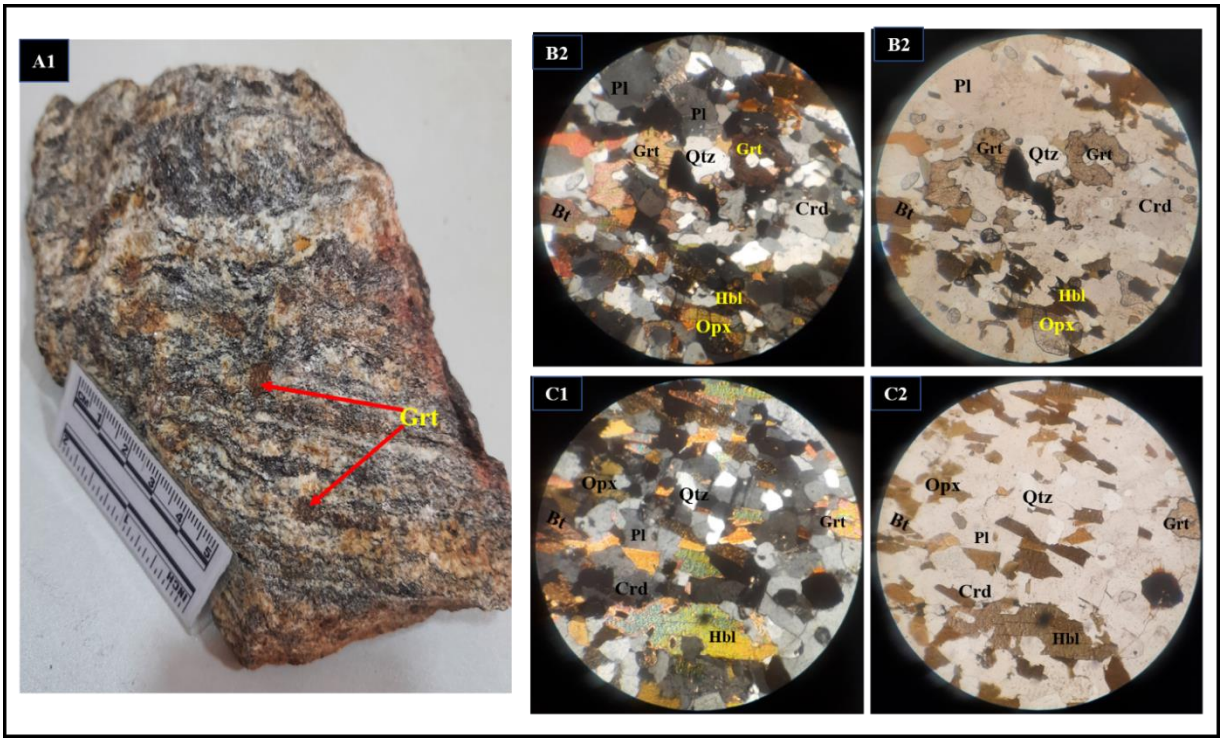


Plate II: General characteristics of Stromatic Metatexite. A1: Hand description, B-C.: Photomicrograph of metatexite on plane & cross polarized lights.

The rock occasionally contains large porphyroblasts of quartz which are irregularly arranged while the flaky minerals (muscovite and biotite) cluster in some roughly parallel bands. The dark-coloured layers consist mainly of biotite and occasional hornblende which are arranged in a parallel to sub-parallel manner. The light-coloured layers, on the other hand contain feldspars, and quartz, with tiny specks of biotite. The petr ographic analysis shows that the rock is mainly composed of Orthopyroxone¸ Sillimanite, Quartz

5.1.2 MELANOCRATIC DIATEXITE

This diatexite type above, reveals a sharp boundary between the leucocratic layer (Plate III). Its highly micaceous and is medium to coarse-grained bearing it melanocratic name with a greenish black ting. It consists dominantly of biotite, with minor amounts of muscovite and quartz.

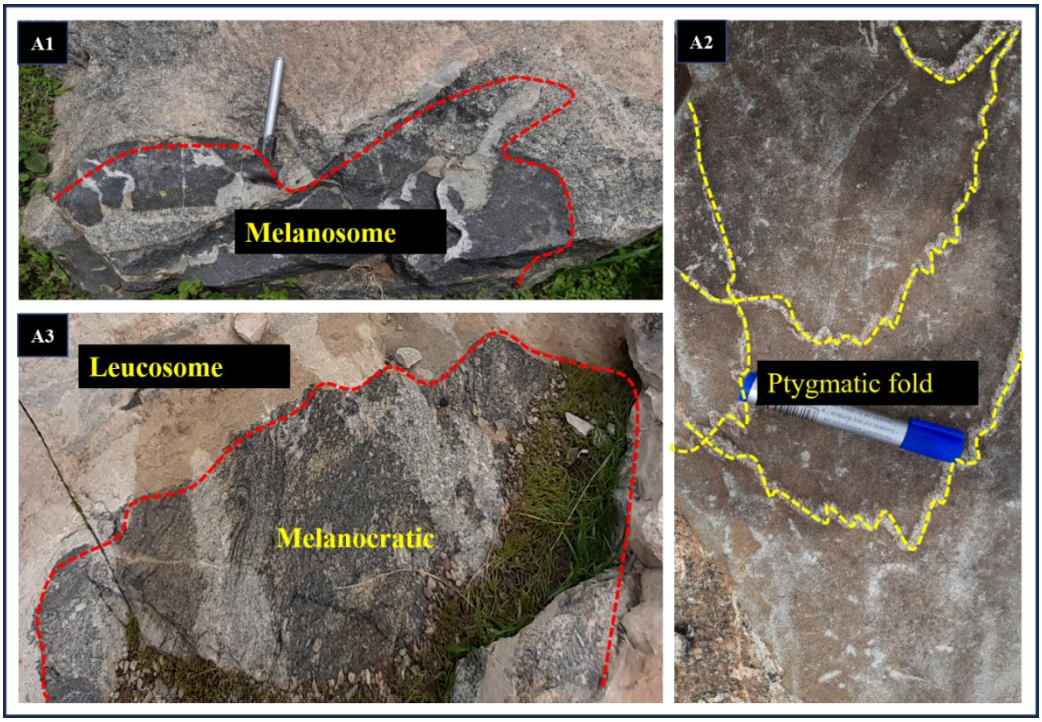


Plate III: Field photograph of melanocratic diatexite samples showing different structural element and mineralogical specifity.

Its fine to coarse grained characterized by predominantly melanosome and paleosome. These rock shows high percentage of ferromagnesian mineral especially biotite and it occurs patch within adjacent rock showing evidence of magmatic mineral lineation and foliatiation in hand specimen which occur occasionally (plate IV).

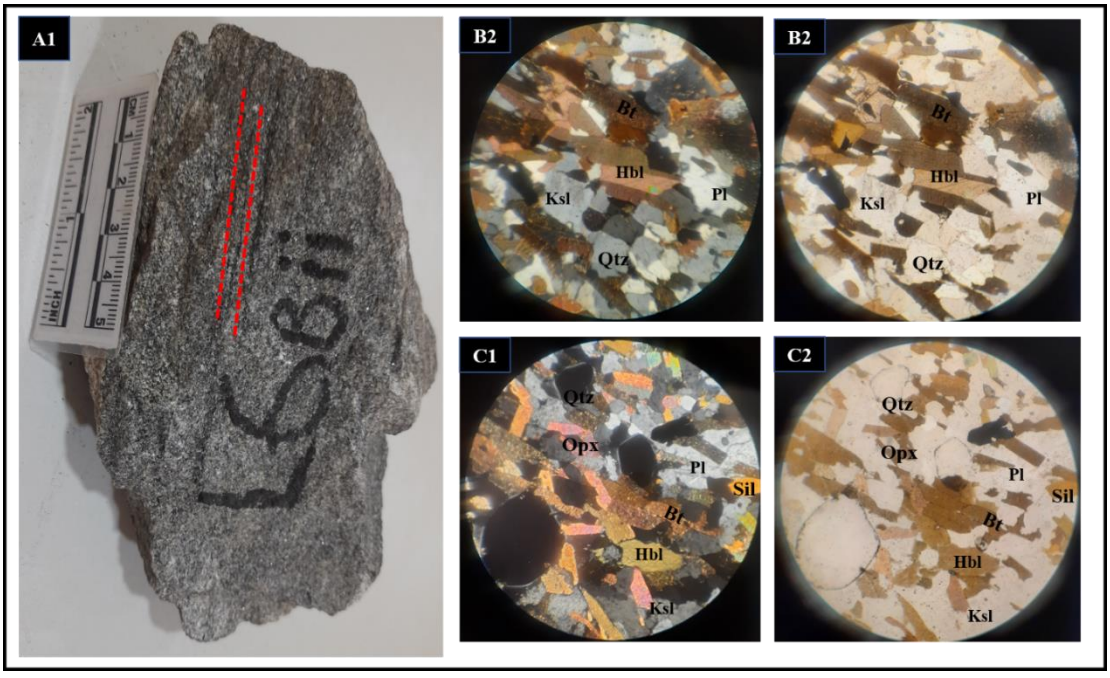


Plate IV: General characteristics of melanocratic Diatexite. A1: Hand description, B-C.: Photomicrograph of metatexite on plane & cross polarized lights.

This is a melanocratic, medium to coarse grained rock showing preferred orientation of the constituent minerals in parallel to sub-parallel manner. The petrographic analysis shows that the rock is mainly composed of Bt+Hbl+PL+Ksl+Qtz as the major mineral association and Sil+Opx+Hbl as minor mineral association (Plate IV). The rock has a dominance of mafic minerals. The minerals show Low relief, yellowish to brown in color and are subhedral in form, Undulous extinction in Quartz and Obliteration in albite twinning (Plate IV). The plagioclase feldspar has bold albite twin laminae and maximum extinction angle

5.1.3 MESOCRATIC DIATEXITE

It is a weakly foliated diatexite type morphology which is mesocratic with few porphyroblasts of feldspars in a medium to coarse-grained, equigranular matrix (Plate V). The matrix consists of interlocking crystals of biotite, muscovite, quartz and feldspar.

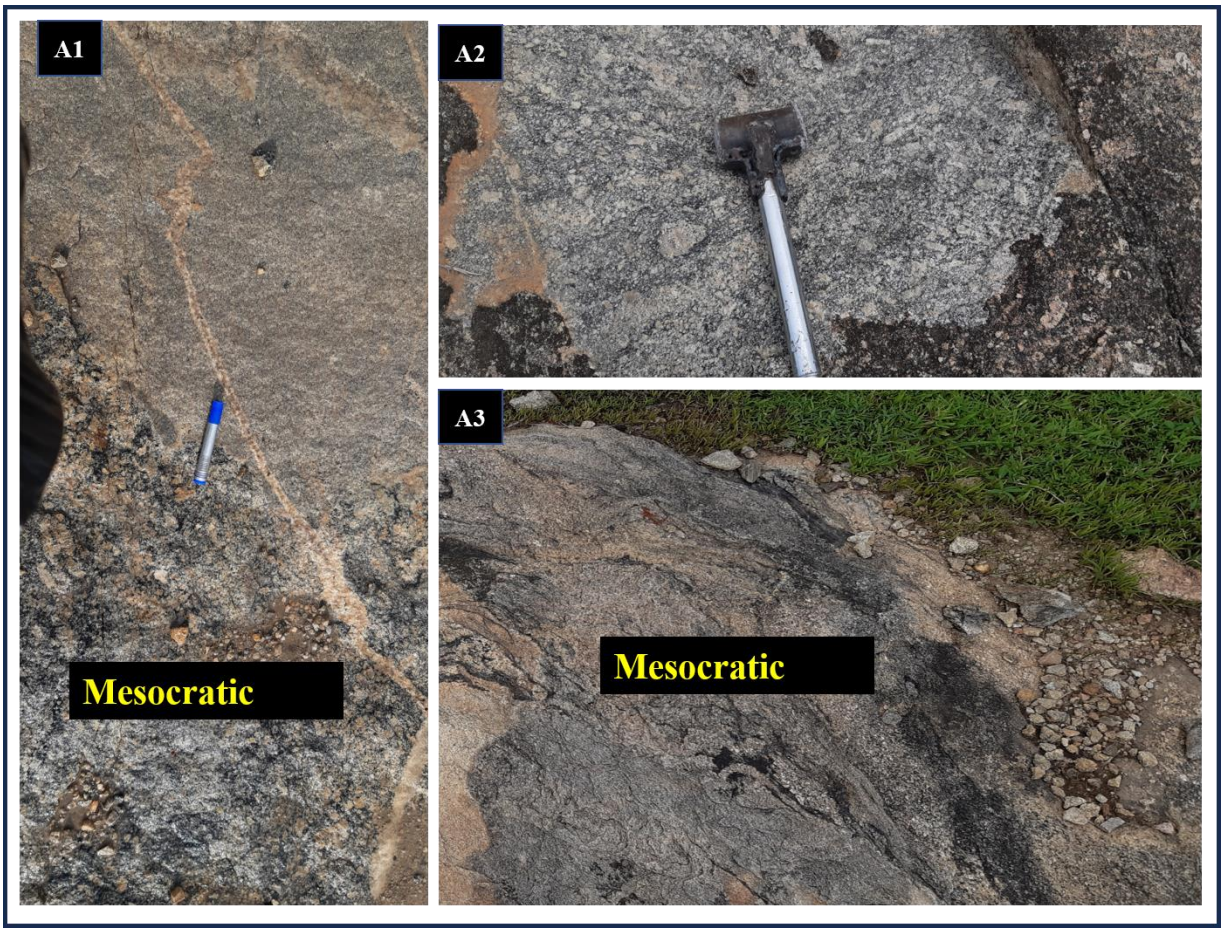


Plate V: Field photographs showing several aspects of Mesocratic diatexites. In the vicinity of leucocratic diatexite

This rock shows almost equal percent of ferromagnesian and felsic mineral and it contain almost high cumulate of melanosome in it than leucosome of the newly formed morphological part (Plate V). It consists of melanosome and leucosome band called the neosome and patch palesome (Plate V: A3). The petrographic analysis shows that the rock is mainly composed of Orthopyroxone¸ Sillimanite, Quartz and plagioclase. The minerals show Low relief, yellowish to brown in color and are subhedral in form (Plate VI: B&C).

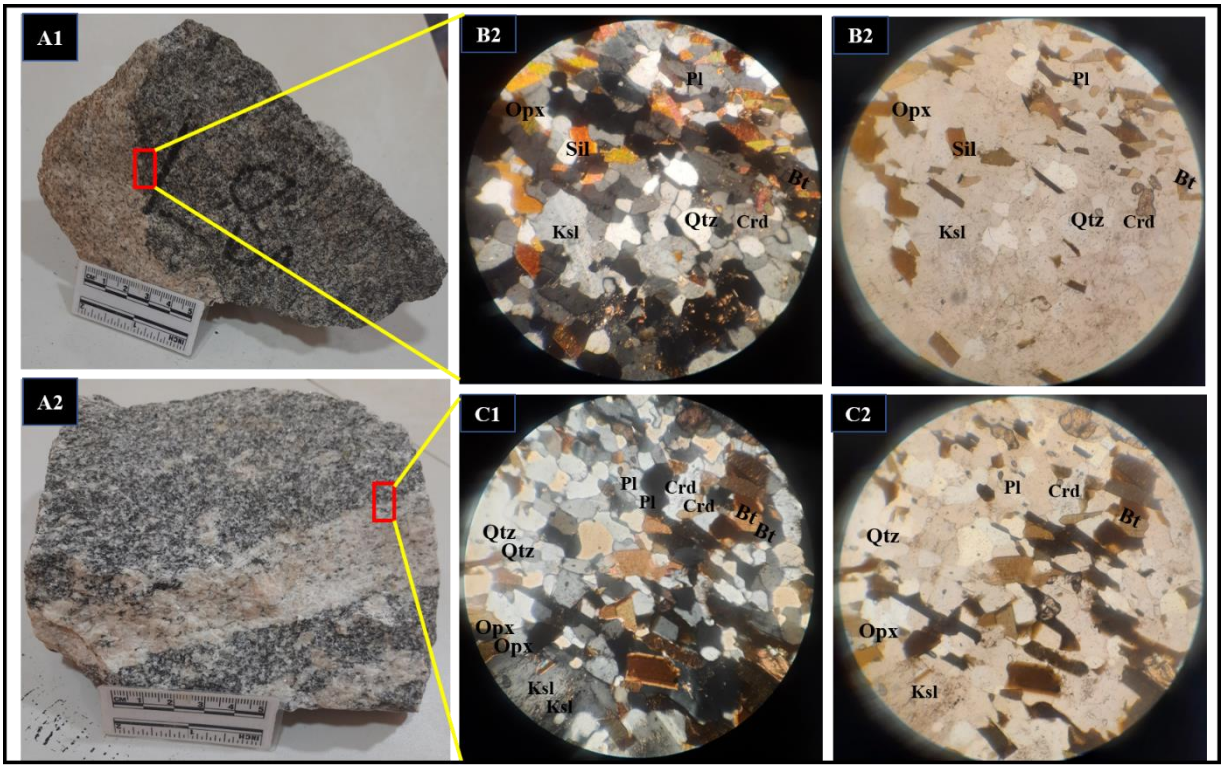


Plate VI: General characteristics of Mesocratic Diatexite. A1: Hand description, B-C.: Photomicrograph of metatexite on plane & cross polarized lights.

Biotite occurs largely as poikilitic crystals characterized by inclusion of apatite. However, few biotite crystals occur as interstitial crystals between hornblende crystals with no inclusion. Hornblende occurs as large crystals sandwiched between biotite and quartz. The crystals are xenomorphic and appear green in colour. Plagioclase occurs as colourless subhedral crystals. The mineral is easily distinguished by the characteristic of carlbad twinning (Plate VI: B2; C1). while microcline occurs as subhedral crystals which are easily distinguished by their characteristic of cross-hatch twinning.

5.1.4 LEUCOCRATIC DIATEXITE

They are generally extremely coarse-grained and leucocratic and constituted by quartz, feldspars, and minor biotite (Plate VII). The pegmatite neosome exposed here is very leucocratic, coarse grained, and equigranular. It contains minerals such as, quartz, feldspars, not in an equal proportion. patch of schlieren. This rock is coarse to fine grain in texture and it is well defined by igneous textural appearance (Plate). It contains more K-feldspar than the other type of diatexite (Plate VIII: A) in the study area with less Ferromagnesian mineral.

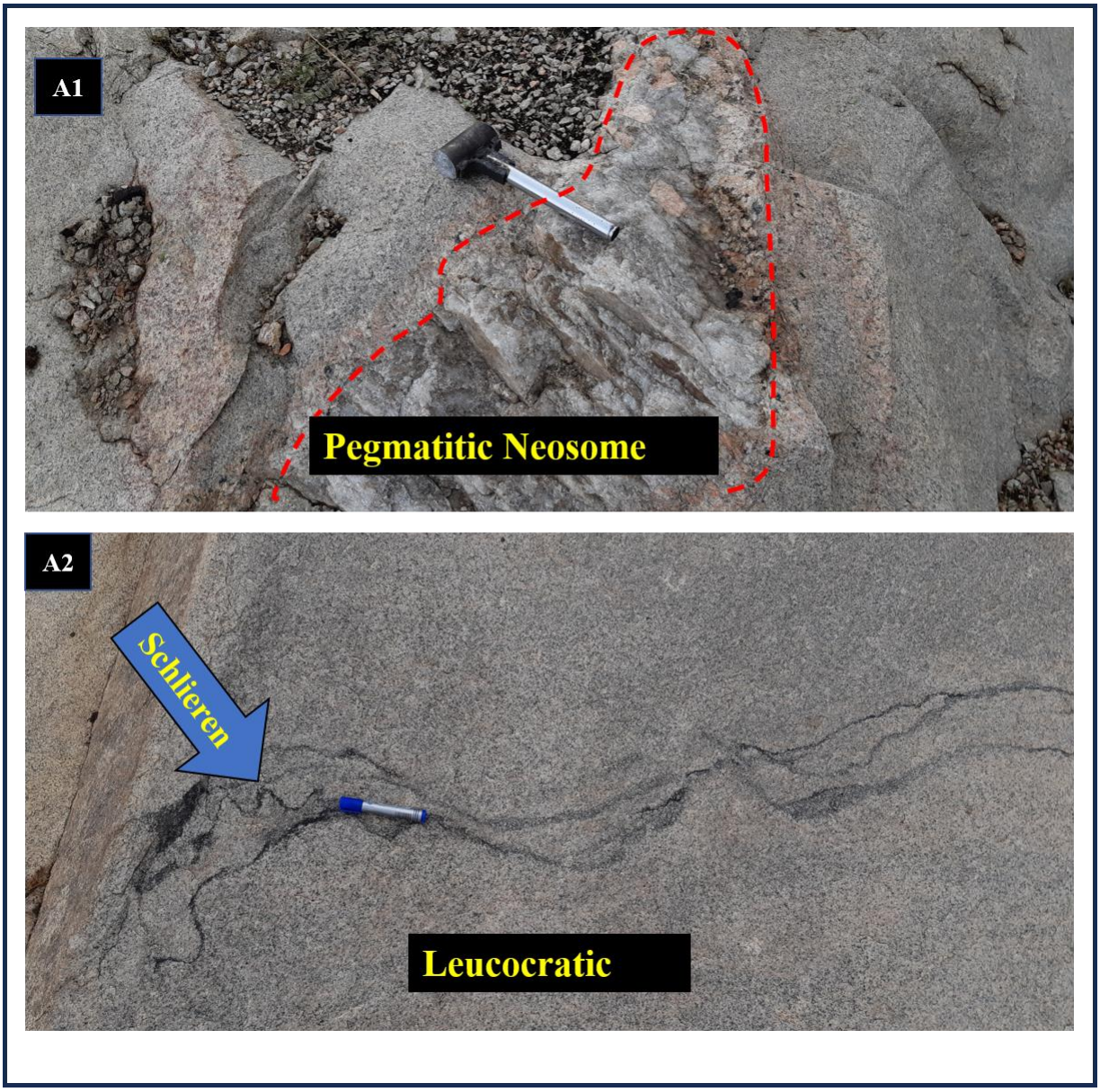


Plate VII: Photograph of leucocratic diatexite intruded by quartzofeldspathic pegmatitic neosome and

It occurs in vicinity of pegmatitic neosome with less grained texture than the former. This is a leucocratic, coarse-grained rock containing a large proportion of quartz and feldspar (plagioclase and microcline) with subordinate specks of biotite, muscovite, tiny crystals of garnet and cordierite. The rock is generally inequigranular and shows interlocking of the constituent minerals

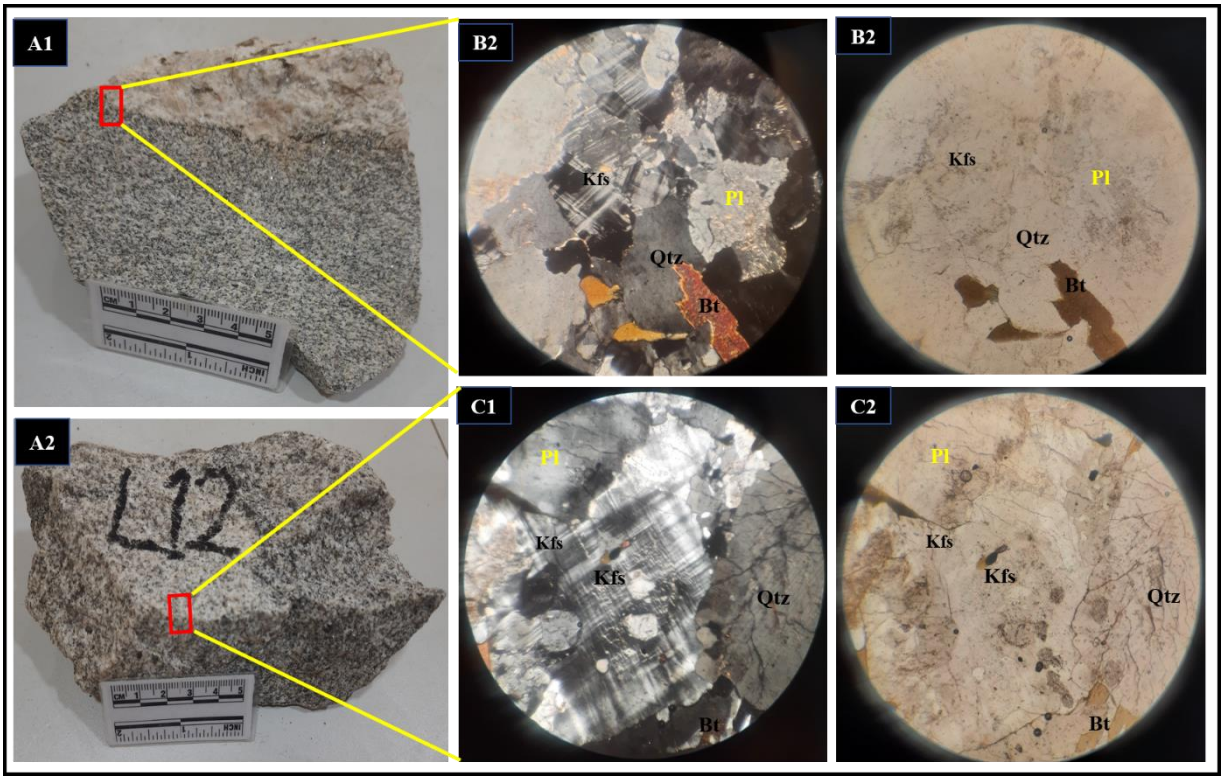


Plate VIII: General characteristics of Leucocratic Diatexite. A1: Hand description, B-C.: Photomicrograph of metatexite on plane & cross polarized lights.

It has low birefringence with maximum interference colour of first order grey. Zoning and twinning are also present (Plates VIII: B & C). Some portions of the mineral have been altered to silky-tread-like (Carlsberg twinning) mineral which is colourless with low relief and whose extinction angle could not be determined due to its irregular-coiling nature and Undulous extinction in Quartz is common (Table 4). It possesses few inclusions of sericitic minerals with a cloudy surface portion, it has cleavage traces which is faint but in one direction. myrmekitic intergrowths are also common in these varieties.

Quartz occurs as discreate crystals characterized by very faint undulatory extinction, cracks and inclusion of feldspar are common within the larger quartz grains. Microcline is the most dominant mineral and it is characterized by cross-hatch twinning. Plagioclase ranges from albite to sodic oligoclase and occur as discrete crystals with carlbad twining characteristic. Biotite constitutes a very small proportion of the major mineral; it is light brown in colour and pleochroic from light brown to dark brown under PPL.

5.1.5 Bauchite (Charnokite)

Bauchite occurs in the vicinityof the diatexite showing a gray to brownish colour and scarcity of biotite minerals. The grain size varies from medium to coarse grain (Plate IX: A1). It is composed mainly of quartz and k-feldspar. The minerals are elongated and are foliated both in fresh and weathered type (plate IX: A2) which shows that they exhibit the structure of the pre-existing rock that undergoes partial melting, whose produced melt formed them. It has been deeply weathered leaving behind breccia-size crystals of mainly quartz and a few feldspars in a matrix of deep reddish lateritic soil occasionally.

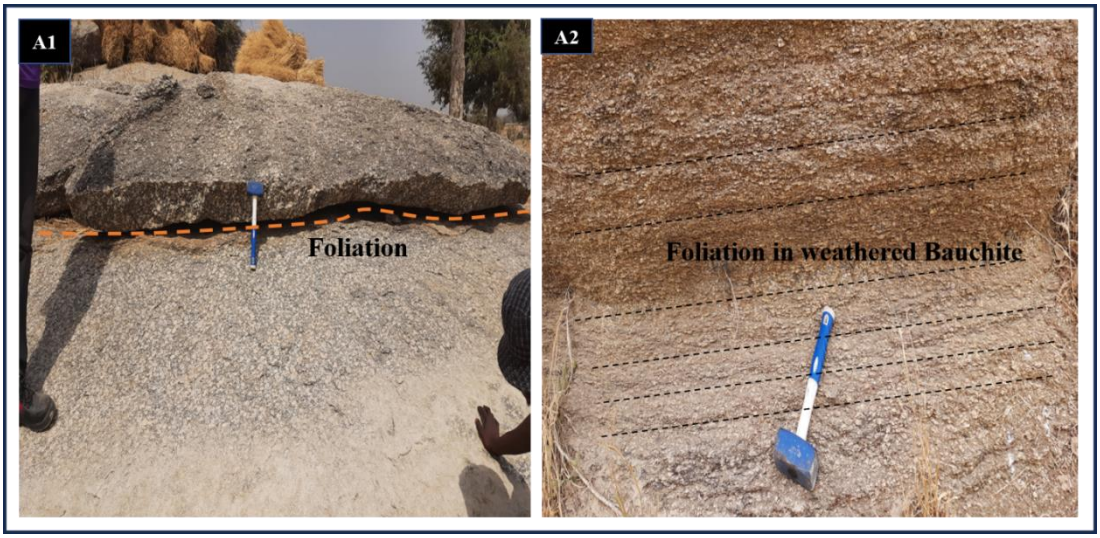


Plate IX: Field photographs showing several aspects of charnockite (Bauchite); A & B) showing foliation planes both in fresh and weathered type.

It is composed mainly of quartz and k-feldspar. The minerals are elongated and are weakly foliated which shows that they exhibit the structure of the pre-existing rock that undergoes partial melting, whose produced melt formed them (Plate X: A). It occurs mostly closer to diatexite. It shows brownish to gray coloration. It composed mainly of quartz & K-Feldspar & contains biotite (Plate X: B & C). It foliated which makes it to exhibit structure of the protolith. The foliation concludes that it is metamorphic.

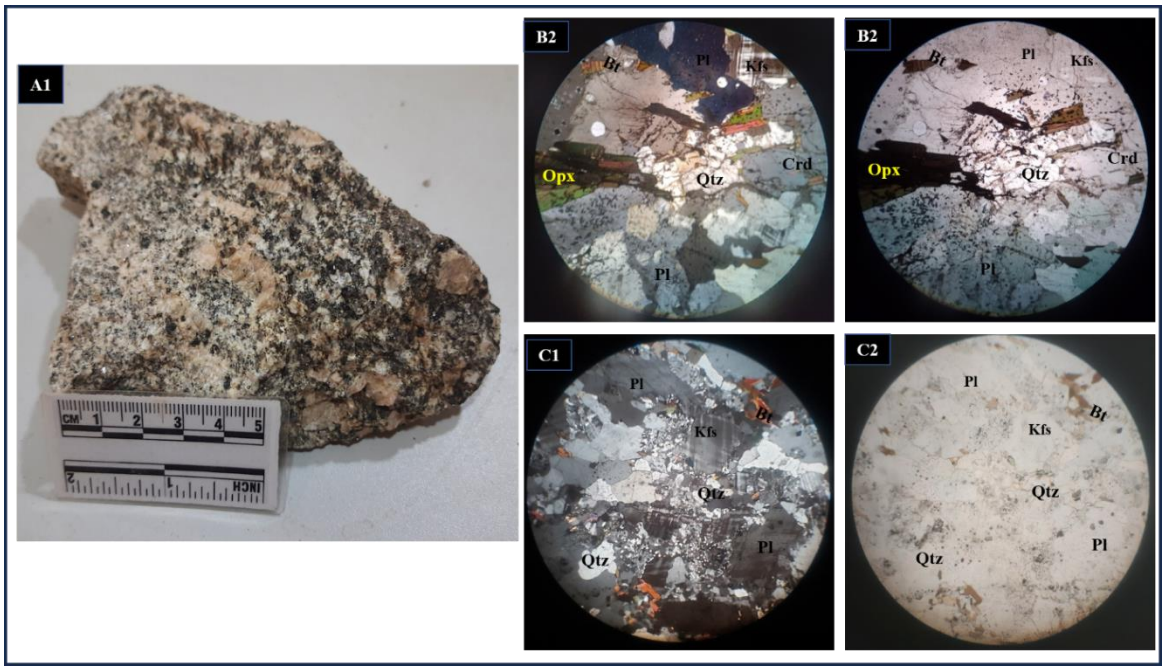


Plate X: General characteristics of bauchite samples both in; (A1) Hand sample and photomicrograph under plane polarized light (B2 and C2) and cross polarized light (B1 and C1) Q=Quartz, B=Biotite, Plg=Plagioclase, Opx= Orthopyroxene, Kfs= Orthoclase, Sil= Sillimanite

The petrographic analysis shows that the rock is mainly composed of Orthopyroxone¸ Sillimanite, Quartz and plagioclare (Plate X: B & C). This is weakly foliated rock which contains almost high amounts of light-coloured minerals. Biotite is the commonest dark-coloured mineral. The light-coloured minerals are quartz, feldspar and orthopyroxene. The minerals show Low relief, yellowish to brown in color and are subhedral in form. Undulous extinction in Quartz and Obliteration in albite twinning is prominent.

5.1.6 QUARTZ DIORITE (NEBULITE)

These rocks are found in the vicinity of the diatexites and charnockites. The quartz diorite exhibit a feature of granite having quartz feldspar and some biotite as their dominant mineral as observed (Plate XII:A1). They show a coarse grain texture, they are leucocratic in colour. Quartz, k-feldspar and biotite are the dominant minerals with few plagioclase (Plate XII: A1) and it is well defined by igneous textural appearance.

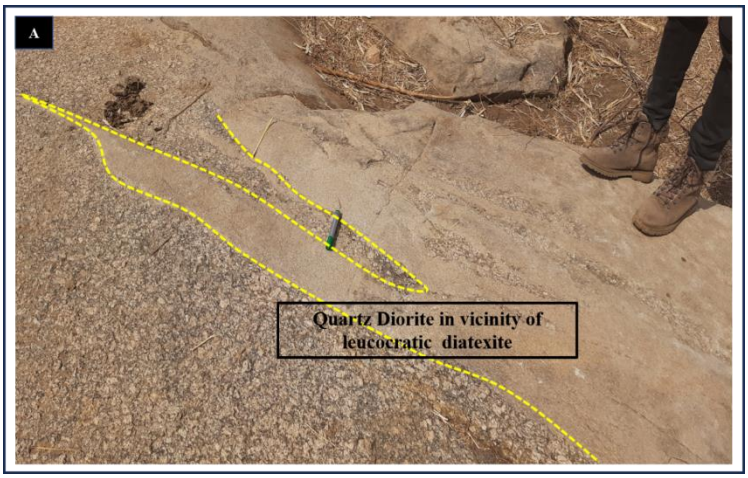


Plate XI: Field photographs showing several aspects of Quartz Diorite

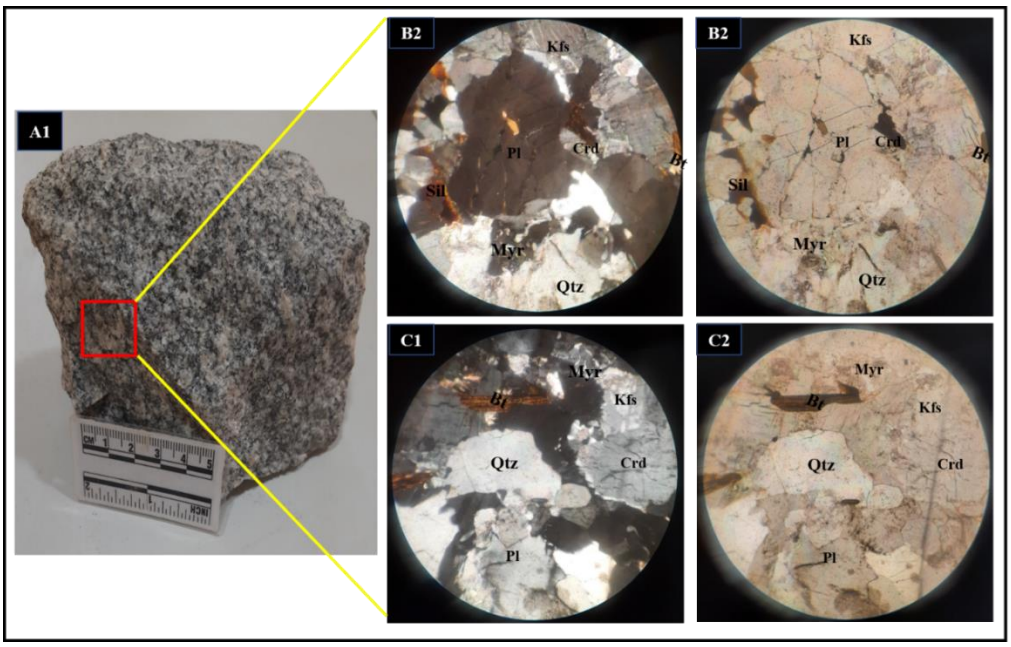


Plate XII: General characteristics of Quartz Diorite. A1: Hand description, B-C.: Photomicrograph of metatexite on plane & cross polarized lights.

The petrographic analysis shows that the rock is mainly composed of Orthopyroxone¸ Sillimanite, Quartz and plagioclare (Plate XII B&C). Obliteration in albite twinning and Myrmekitic intergrowths are also common in these varieties. The minerals show Low relief, yellowish to brown in color and are subhedral in form

5.2 GEOCHEMISTRY

A total of fifteen whole rock samples were analysed for major, minor and trace elements. These include representative sample of each of the migmatites, Bauchite and Quartz Diorite sample. The major and trace elements were analysed by X-Ray fluorescence (X.R.F). CIPW norms were calculated from the major element data using software (Table 1).

PROVENANCE RECONSTRUCTION FROM GEOCHEMICAL STUDY

The lithological diversity of the partially melted rock (metasedimentary rock) is the major cause of differences in the geochemical composition of the rock in the study area. Major element geochemistry was applied to give an idea that causes the geochemical differences.

On the ternary diagram of Laurent et al (2014) (Fig 5), the rocks show a wide spread on both the metasedimentary fields as well as in figure (13) where the rock in greywacke to arkosic source, the major chemical difference between the meta-greywacke to arkose as observed in this study is shown in their major element geochemistry where the greywackes (Fig 6) show higher silica content relative to the arkose and lower Al_2O_3, Fe_2O_3(t), and Mg relative to the arkose.

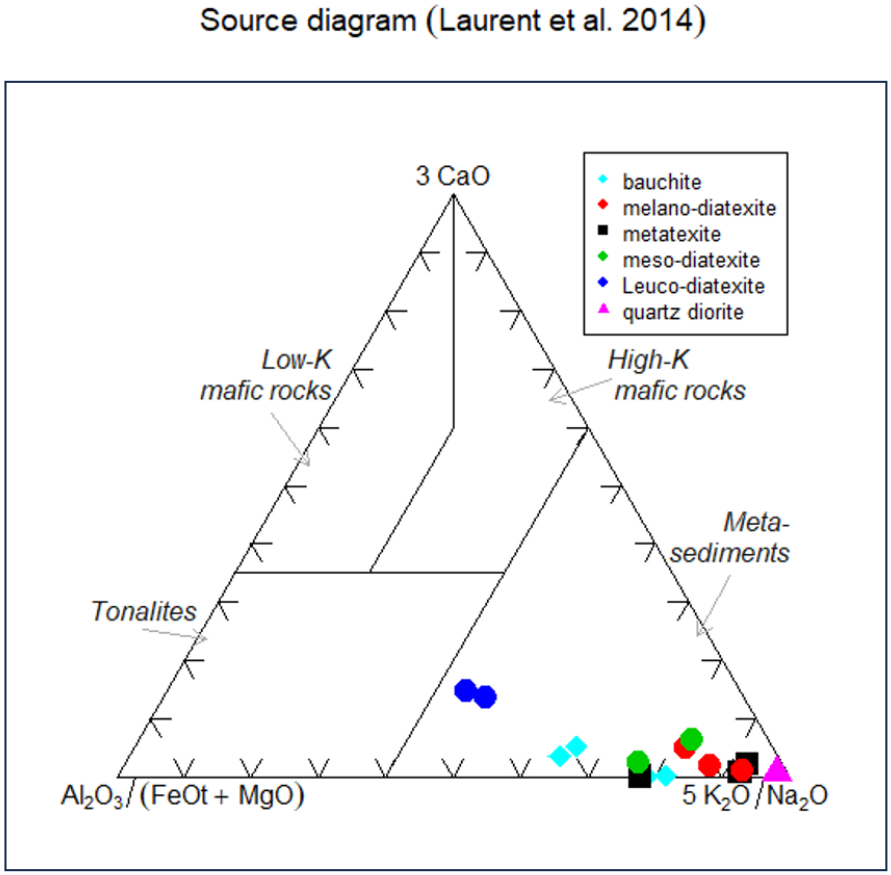


Figure 5: geochemical classification of provenances after Laurent et al. 1988

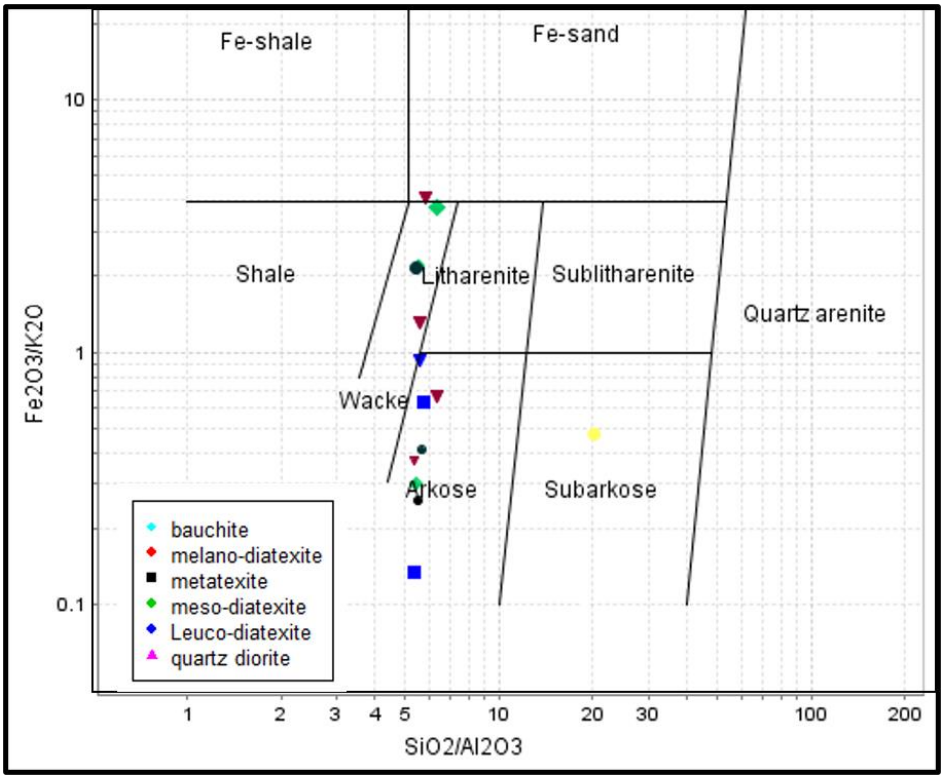


Figure 6: geochemical classification of terrigeneous shale and sandstones after Herron (1988)

The diagram of Tarney (1976) and Barells and Mackenzie (1971) using the ratio of Na_2O/Al_2O_3 vs K_2O/Al_2O_3 (Fig 7) was used to distinguish the partial melted rock that cause the diversity as either of igneous or metasedimentary source which reveal they are of metasedimentary source. All the rock under study falls in the metasedimentary domain which we conclude that the rocks that cause the lithological diversity is metasedimentary

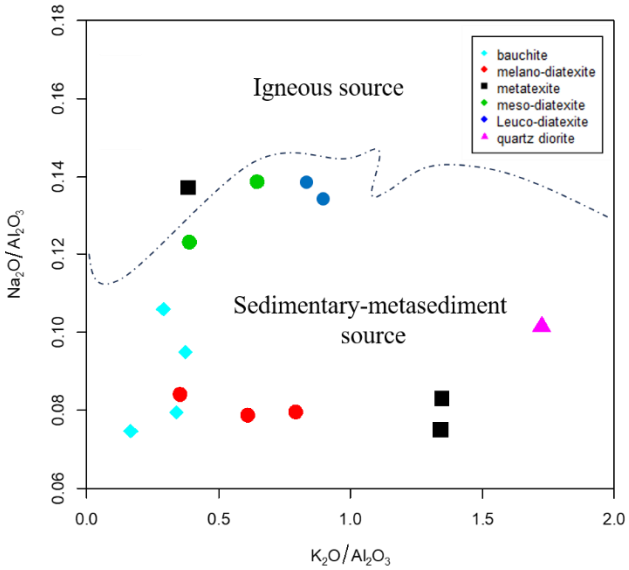


Figure 7: Diagram of Na_2O/Al_2O_3 vs K_2O/Al_2O_3 of Tarney (1976) and Garrels and Mackenzie (1971).

5.2.1 VARIATION DIAGRAM

The essence of variation diagrams is used ascertain the geodynamic processes that happen during the formation of magma using SiO_2 as an index of differentiation. Major element provides a correlation pattern that is used to indicate whether they are generally related to magma mixture or fractional / partial melt crystallization There is a strong correlation evidence between major or trace elements and the SiO_2 contents whereby major element composition of all the rock morphologies plotted on Harker. The variation diagram (Fig 9) shows positive correlation between MgO, CaO, , FeO_2, and Al_2O3 with SiO_2 and positive between Na_2O, CaO, TiO_2,, $K_2O$with SiO_2 indicating the abnormal magma crystallization trends. (Thornton & Tuttle, 1996). There is a slight correlation between SiO_2 and $Na_2O_3$and K_2O as being observed. Such linear trends might be the result of either hybridization or fractionation (Hassanen *et al.,* 1996). Potassium Al_2O_3 show somewhat opposite behavior, it increases with increase in SiO2. This suggests that fractional crystallization model is not the principal process that influenced the lithological diversity. Potassium Al_2O_3 show somewhat opposite behavior, it increases with increase in SiO_2 (Fig 8). This suggests that fractional crystallization model is not the principal process that influenced the lithological diversity.

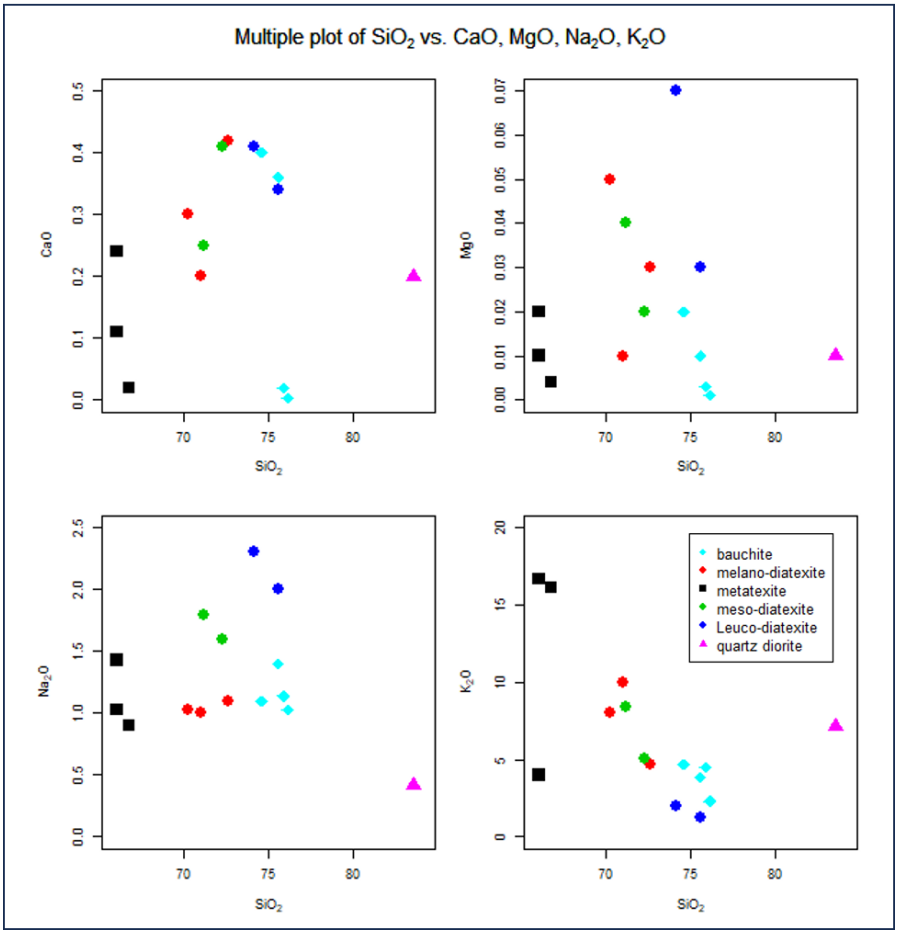


Figure 8: Harker diagrams projecting major elements versus silica content (SiO_2).

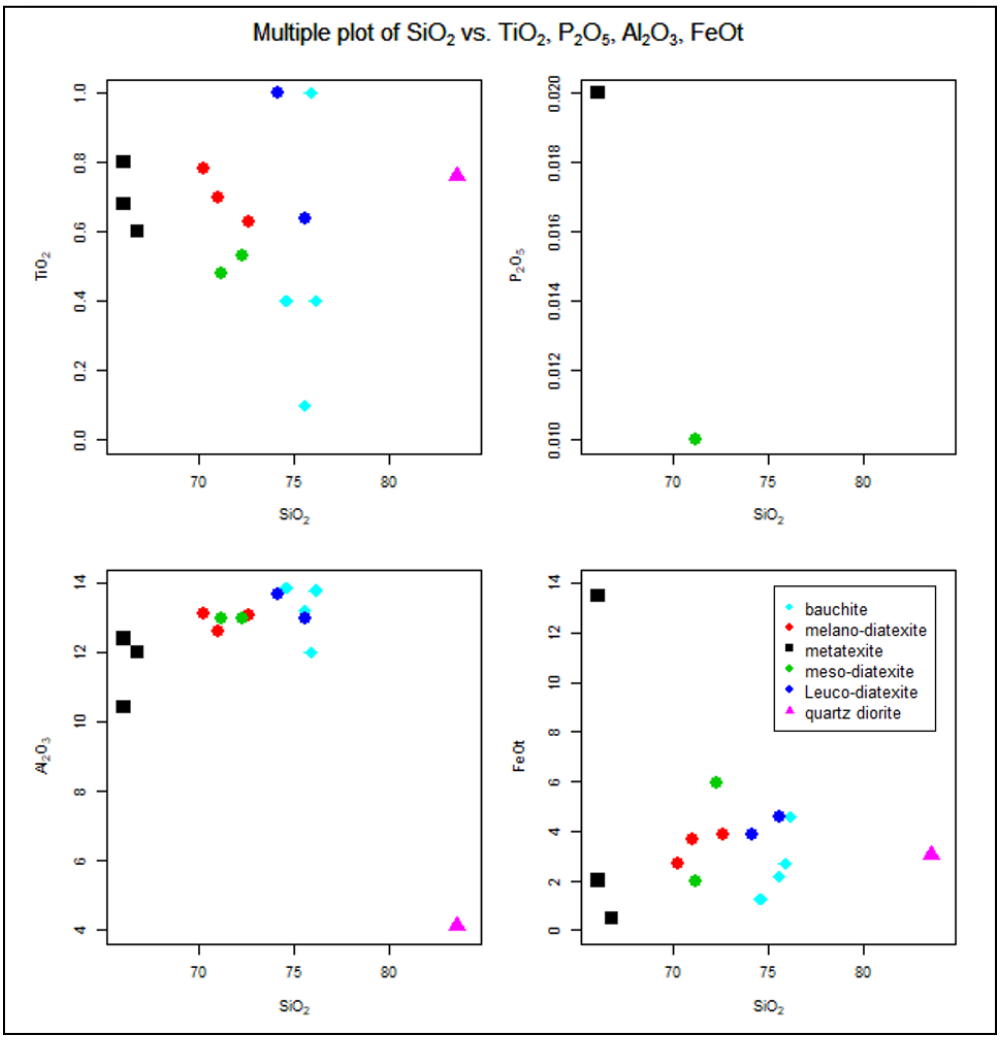


Figure 9: Harker diagrams projecting major elements versus silica content (SiO_2).

Trace Element Characteristics

Trace elements play significant roles in revealing the petrogenetic and evolutionary history of rocks. It has been observed that major element composition in rocks tend towards uniformity and it is only their trace element compositions and ratios that provide clues to their unique differences and petrogenesis (Butler *et al.*, 1962; Baba 1990). The trace elements composition are presented in (Table 1)

Multi-Element Discrimination (Spider Plot)

Trace elements play significant roles in revealing the petrogenetic and evolutionary history of rocks. It has been observed that major element composition in rocks tend towards uniformity. Spider diagram in the study area shows a high fold enrichment in the LILE (1-1000) while the HFSE were low to slightly enrich under the primitive mantle normalization (Fig 10). This behavior is typically associated with collisional margins (Sun and MacDonough, 1989).

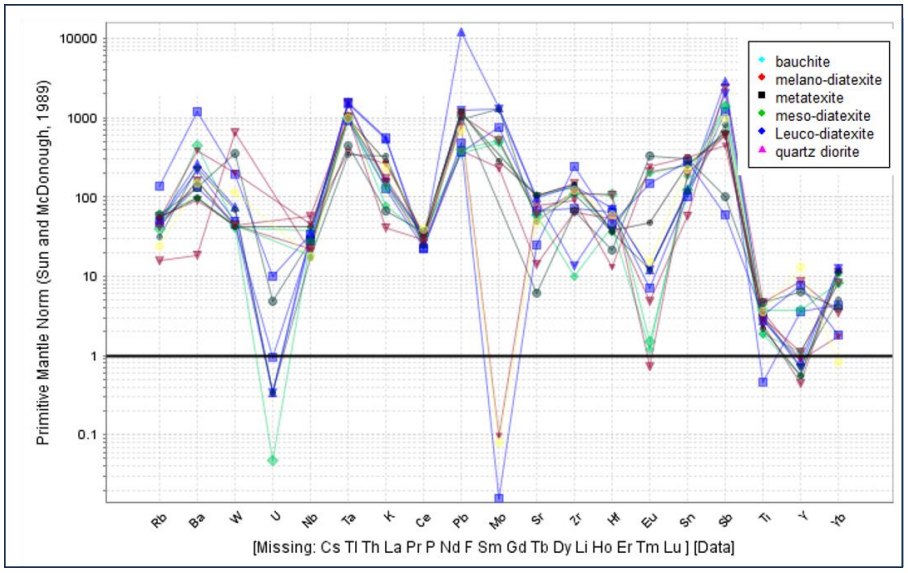


Figure 10: Spider plot (Sun and McDonough, 1989)

5.2.2
Chemical and Mineralogical Classification Scheme

Total Alkali Silica

The studied area sample shows distribution mainly in the granite field, to granodiorite in the Total Alkali-Silica (SiO_2 versus $Na_2O + K_2O$) diagram (middlemost 1985; Fig 11). The stromatic metatexite fall in the granodiorite domain.

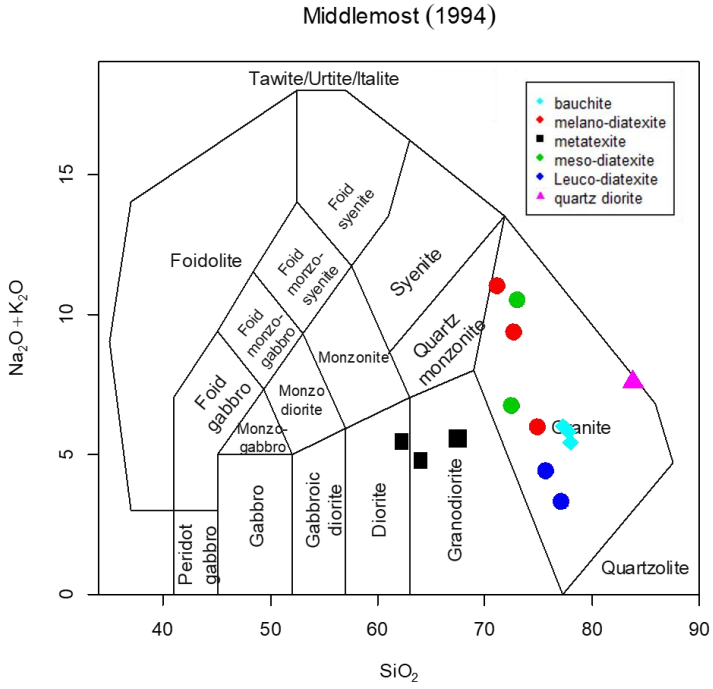


Figure 11: SiO2 versus Na2O + K2O diagram (Middlemost, 1985).

On SiO2 – K2O plot (Peccerilloand Taylor 1976), metatexite plot in the tholeiitic series, mesocratic diatexite, bauchite and quartz diorite in the calc-alkaline to High-K calc-alkaline Series (Fig 12).

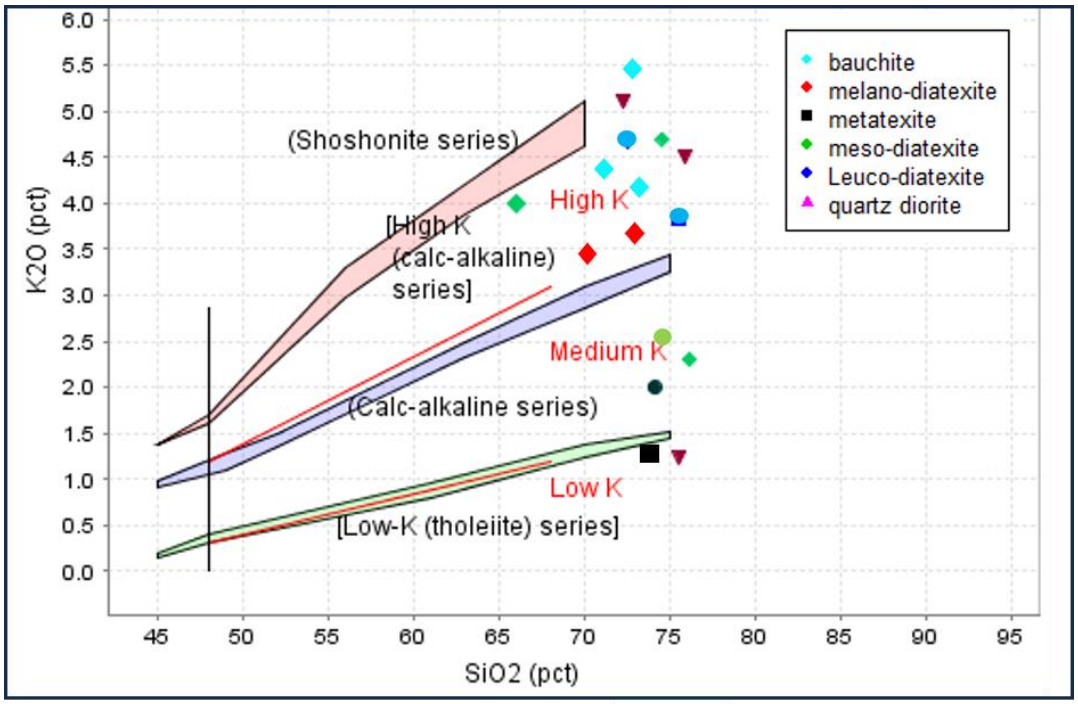


Figure 12: Diagram of K_2O vs $SiO_2$with fields after Rickwood (1989)

B-A Diagram Proposed By Debon & Le Fort 1983, Modified By Villaseca 1988

This classification diagram is employed for various types of peraluminous and metalumous rocks designed by Villaseca *et al.* (1998) based on calculated millications. The B=Fe+Mg+Ti parameter reflecting mafic mineral content A=Al–(K+Na+2Ca) parameter reflecting the amount of Al content incorporated in feldspars. Millications are used for the calculations. All the rocks under study (diatexites and bauchite) fall within the high peraluminous (h-p) with the exception of one sample (i.e. quartz diorite and metatexite) which falls within the metaluminous (Fig 13) this is due to its alkali elements.

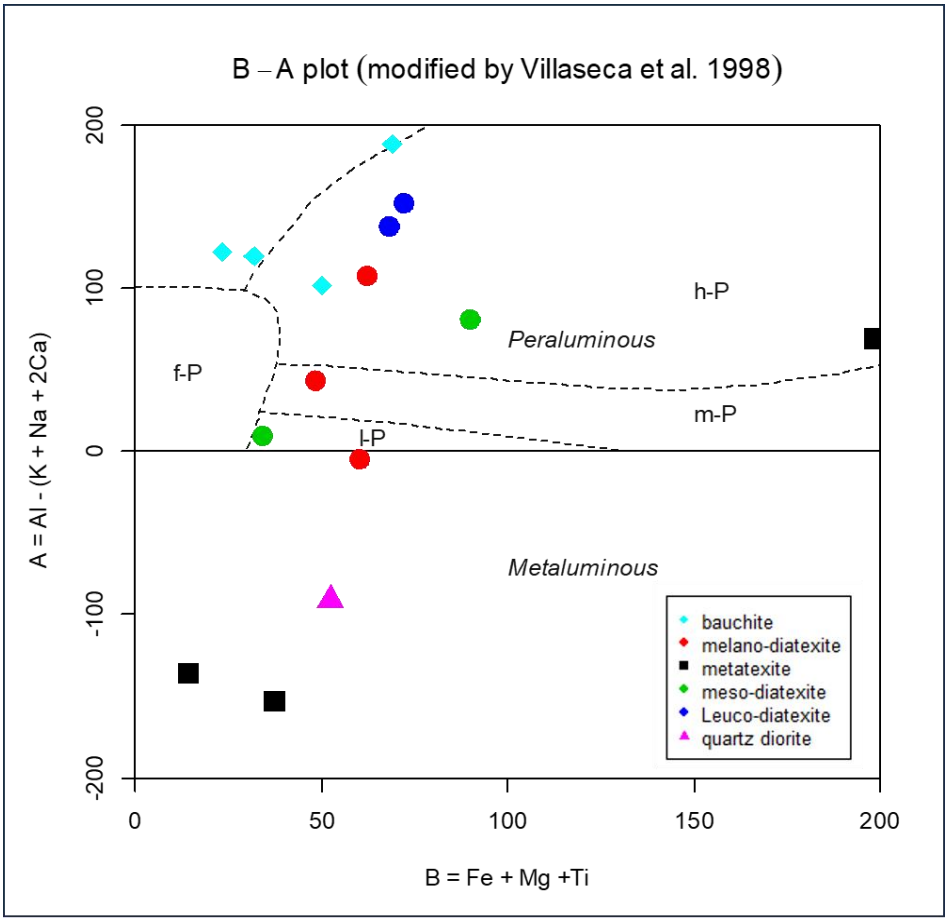


Figure 13: B-A diagram proposed by Debon & Le Fort (1983) modified after Villaseca *et' al* (1998) with fields for various peraluminous rock types. Abbreviations: L-P = Low peraluminous; m- P – moderate peraluminous; h-P – high peraluminous and f-P felsic peraluminous.

Frost *And Frost* 2008

Iron Index (Fe)

Fe-number (FeOtot/ (FeOtot+MgO=Fe*) distinguishes ferroan granites, which manifest strong iron enrichment, from magnesian granites which do not (Frost *and frost 2008).* The Fe enrichment used to distinguish between granitoids from different tectonic environment. Plot of the granites and granodiorite on FeOtot/ (FeOtot+MgO versus SiO2 discrmination diagram after Frost *et al*., (2001) (Fig 14a), shows that the all the rocks which have higher values of Fe-number (0.86-0.980) plot within the ferroans field. The Fe number determines whether the rocks are mainly magnesian or ferroan and this provides a clue on the differentiation history of granitic magma.

Modified Alkali Lime Index (Mali)

The rock morphology is further be classified into alkali, alkali-calcic, calc-alkalic and calcic on the basis of their modified alkali-lime index (MALI) content (Frost *and Frost 2008*). The Plot discrimination diagram reveals that both rocks are calc-alkalic to calcic (Fig 14b).

Aluminium Saturation Index (ASI)

All the rocks under study are peraluminous showing ASI > 1 ranging from 1.29 to 2.45. The peraluminous granitoids have more aluminium that can be accumulated in the feldspars and must have another aluminium phase present. The Quartz diorite plots within the Pera-alkaline due to the low aluminum accommodated with the feldspar (Fig 14c&14d).

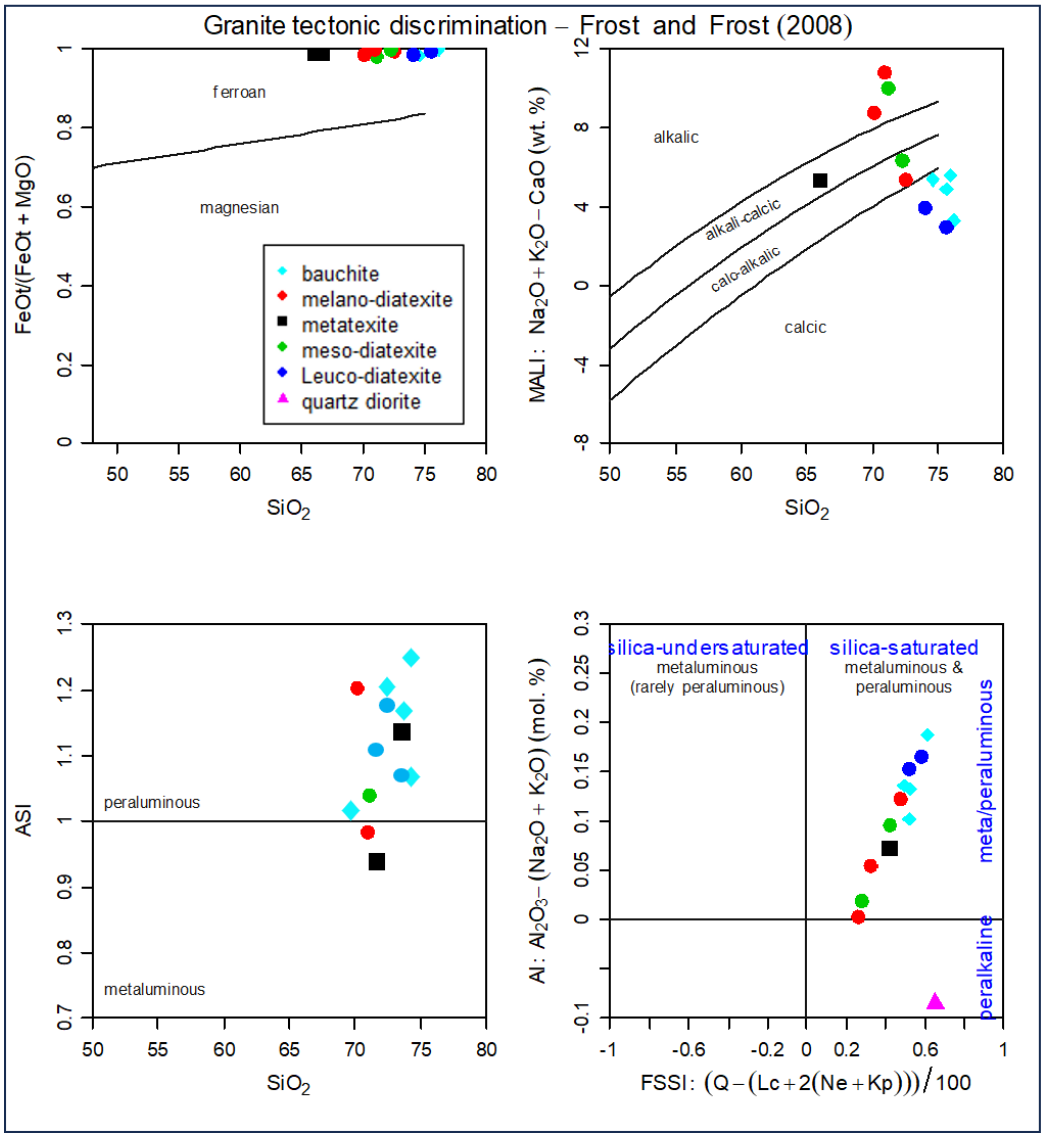


Figure 14: Frost *and Frost 2008* classification scheme for (a) Fe index. (b) Classification scheme for MALI. (c) classification scheme for ASI (2001)

Implication For Tectonic Discrimination Diagram

Tectonic discrimination diagrams are diagrams used to distinguish magma that are produced in different tectonic environment based on their chemical (Pearce *et 'al,* 1984). The essence of this chemical data is to distinguish the geodynamic content of granitic rock emplacement. Trace elements can also indicate tectonic affinities of granitic rocks. On the granites discrimination diagram after Pearce *et al.*, (1984), all the rock plotted in the syn-collisonal and within Plate/Orogenic granite domain (Fig 15).

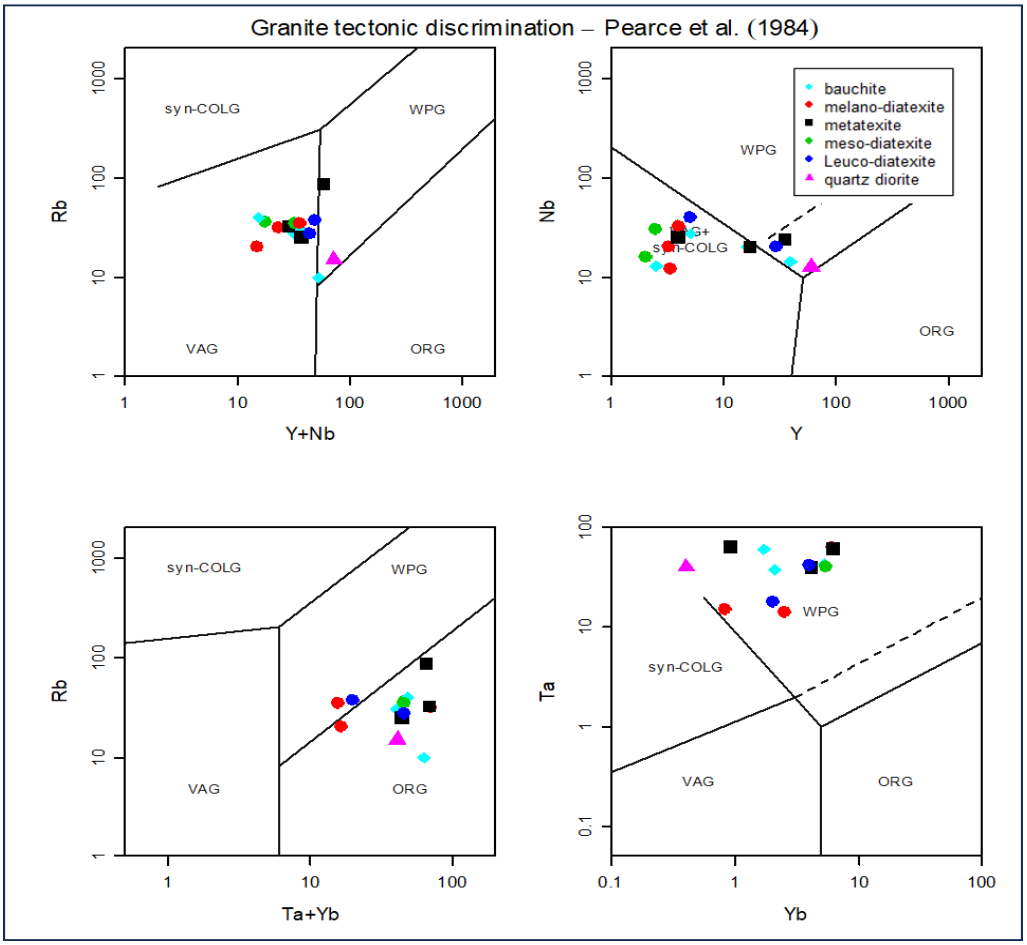


Figure 15: Discrimination diagram for geotectonic environment by Pearce *et' al* (1984). Abbreviation: ORG - Ocean Ridge Granites; VAG - Volcanic Arc Granites; WPG - Within Plate Granites; syn-COLG – syn-Collisional Granites.

6. Discussion

Field, petrographic and geochemical studies are the basic criteria for discern the petrogenesis of rocks. This chapter will discuss on the geochemical, morphological and petrographic solutions of the rocks under studies.

Field Relationship/morphological and description

Based on field relationship, The transitional contact relationships between the various rocks suggest the lithologic unit had been formed by the same process. The rock in the study area shows changes in their in their textural appearance from relatively fine to coarse in texture. There is a gradational change from migmatite to granodiorite rocks (Sawyer, 2008; Brown, 2000). The principal foliation planes and mineral lineation (Plate) suggest that the rock exhibit the structural of the former protolith which makes it to be metamorphic This causes heterogeneity in their appearance. (The contact between different morphological characteristics of the changes from metatexite (Plate I) to leucocratic diatexite (Plate VIII & IX)with different structural features with metatexite shows stromatic bands of felsic materials while the diatexite shows raft of the protolith. The charnockite (Bauchite) in the area shows magmatic foliation (Plate X) which suggest that they are metamorphic rock retaining the structure of the partially melted rock (protolith) (Pate XI) which supported the work of Frost and Frost, 2001, & that charnockite are metarmorphic.

The petrographic studies conclude that the samples from different rock unit are accompanied with major minerals of quartz, biotite, orthopyroxene, plagioclase, cordierite,

sillimanite, orthoclase as their main and rutile and ilmenite as their accessory minerals (Plate I to XII). The presence of undulous extinction in quartz and obliteration of twinning in feldspar conclude they are subjected to pressure and temperature and presence of Myrmekite signify a tectonic deformation.

Chemical Affinities

The occurrence of paleosomes, and abundant quartzo-feldspathic veins and dykes suggests that the diatexites morphologies were affected by partial melting (anatexis), which commonly occurs at the highest grade of metamorphism. The modal composition of ferromagnesian mineral (biotite and hornblende) and plagioclase decreases from the less felsic to more felsic end of the spectrum in the rock suites in the area. This suggests that partial melting and crystallization dominated by fractionation of plagioclase and biotite has played a significant role in the evolution of the rocks. The decrease in the concentration of FeOt, MgO and CaO with increasing acidity (SiO2) supports the metamorphic crystallization. The slight correlation between SiO_2 and $Na_2O_3$and K_2O observed might be the result of either hybridization or fractionation (Hassanen *et al.,* 1996). Potassium Al2O3 show somewhat opposite behavior, it increases with increase in SiO2. This suggests that fractional crystallization model is not the principal process that influenced the lithological diversity. The ASI vs SiO plot (Fig 13 & 14) shows an erratic increase of silica values. This increase may indicate assimilation of metasedimentary source rock (Clarke *et al.*, 2005) or assimilation and fractional crystallization of a genetically related sedimentary source with involvement of sedimentary country rock (Azevedo & Nolan, 1998). Geochemical classification of the studied rock sample shows different consistent chemical affirming. The TAS diagram (Fig 11) of Middlemost (1995), shows the stromatic morphology shows diorite to granodiorite chemical composition while the diatexite and charnockite shows granitic composition. This is consistent with petrographic result of modal component. According to the indexes of Frost & Frost 2008 the rocks shows both magnesian and ferroan signature in the Fe index and showing similar trend in MALI having alkalic to calcic nature (Fig 14b), and metaluminous (two metatexite samples) to peraluminous (diatexite, charnockite and quartz diorite). In the tectonic discrimination diagram of Pearce *et al.* (1985) (Figure 20) indicate that the tectonic environment of the formation of the rock is syn collisional + volcanic arc supporting the Himalayan type collision which result to the formation of the rock in the study area during the Pan- Africa orogeny. The enrichment of LILE relatively to HFSE could result from a high degree partial melting in the movement of element during alteration processes, contamination by crustal materials or interference of crust in the forming region rocks (figure 10) (Sajona *et' al* 1996).

Provenance Reconstruction (Protoliths)

The available data indicate the rocks in the area ware derived from partial melting of metasedimentary crustal protolith having ASI>1 and abundant & fractional crystallization of igneous source with significant involvement of sedimentary rock having ASI<1 (Figure 14c & 14d). However, the metaluminous to peraluminous nature of the migmatites morphologies in the study area, particularly precludes an origin from the melting of a strongly peraluminous sedimentary protolith. This character requires a metaluminous protolith such as the mantle or other igneous sources (Ferre, *et al.,* 1998). Like S-type granitoid, most of the rocks are peraluminous. Those that fall above 1.0 are formed from partial melting of metasedimentary protolith (Fig 14). The diversity as either of igneous or metasedimentary source which reveal they are of metasedimentary source of greywacke to arkosic origin (Fig 16) In conclusion, it could be ascertained that the S-type signature (Fig 6 & 7) of the rocks have originated from partial melting of crustal protolith with change in composition in a deforming activity.

A Proposed Petrogenetic Model

A genetic relationship between migmatites and granite was supported by Read (1956), Sawyer (1998), Solar and Brown (2000) and Milord *et'al* (2001) who demonstrated that some migmatites are transitional to granites. This model is adopted and modified after Sawyer (1998) (Fig 16) explaining the origin and genetic relationship between migmatites, charnockites in view of field, morphological, petrographical and geochemical evidence.

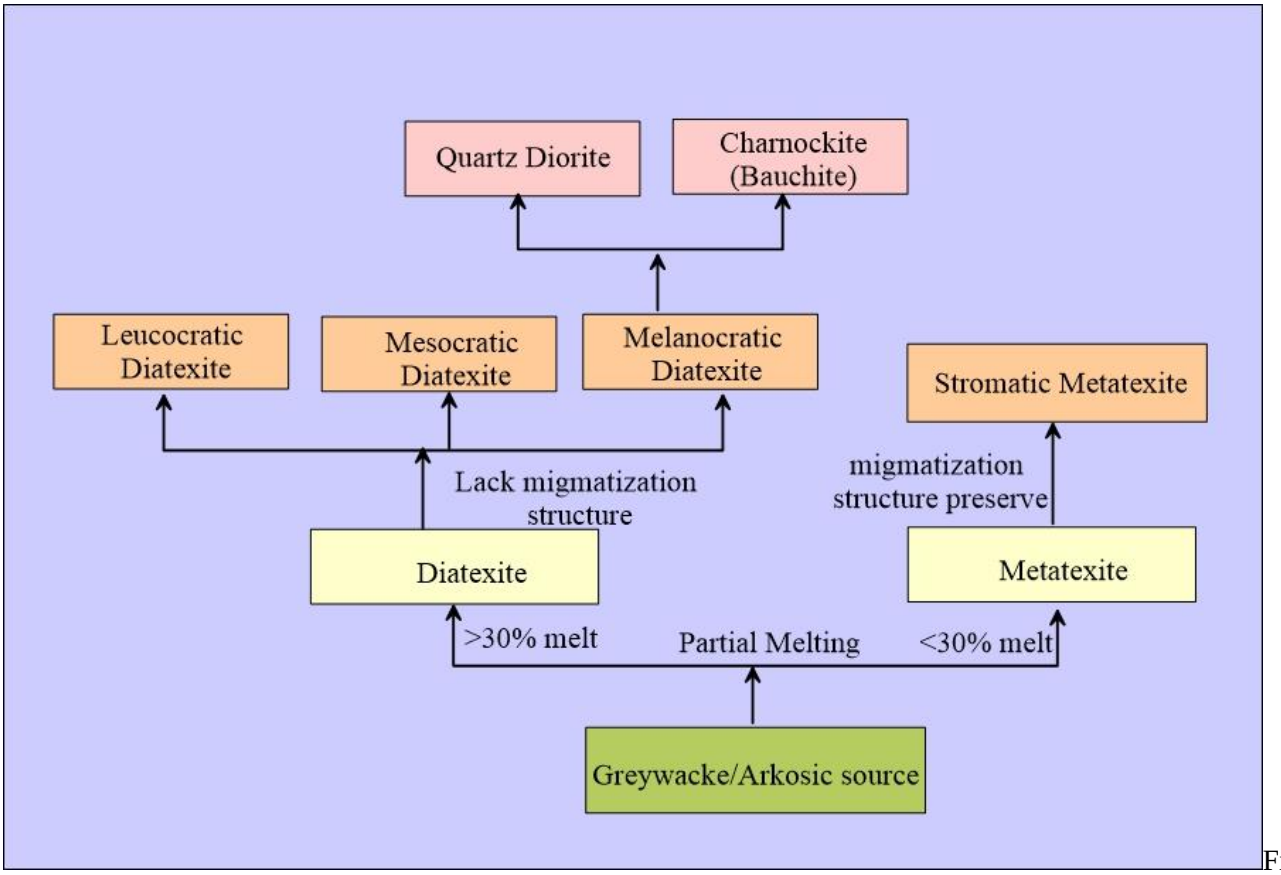


Figure 16: Conceptual model Summarising the origin of migmatitic rock and its associated granitic rock in the study area (modified G.E Bahariya, 2009 and Sawyer 1998).

7. CONCLUSION

1. Textural evidences of partial melting processes are widespread both in metatexites and in diatexite. Moreover, the abundance of peritectic cordierite and relicts of sillimanite + biotite in leucosomes support an anatectic origin.
2. Contact relationship between the various rock types are commonly sharp to gradational contacts.
3. Petrographic studies revealed that The groundmass of the rock samples is mainly composed of plagioclase, Quartz, K-feldspar, biotite and index granulite facies mineral (sillimanite, cordierite and orthopyroxene). Accessory mineral include: zircon, Apatite, rutile, magnetite, illminite.
4. The migmatites suites are ferroan, alkalic to calc-alkaline, slightly metaluminous to peraluminous, post-collision S-type granites and were derived through partial melting of crustal rocks.
5. The metamorphic migmatite Complex rocks in this study originated from sedimentary protoliths of greywacke and arkose compositions.
6. The major element oxides, trace element compositions of the rocks suggest that their progenitors were derived from a cratonic/crustal source;
7. Mineral assemblages recorded in the migmatite and it associated granitic rock in the area indicate that the conditions of metamorphism range upper amphibolite to granulite facies. Features that suggest partial melting are also present. Retrograde conditions were imposed on these

high-grade rocks. These conditions of metamorphism have also been recorded in similar rocks of the migmatite rock suite in other parts of Nigeria.

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Conflict of Interest:

Author declares that there is no conflict of interest in the present research.

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