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Geology, Petrography and Geochemistry of Diatexites around Firo, Northeastern Nigeria

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Abstract:
The Study area is located in Firo, in Ganjuwa Local Government Area of Bauchi State. Bounded by latitude N10^{0} 25'00'' and N10^{0}28'.00'' and longitude E9^{0} 51'.00'' and E9^{0} 55' 00'', it forms part of Bauchi sheet 149NE. The study addressed the geology and geochemistry of the study area. The geological mapping indicated three (3) morphological units of migmatite;Metatexite, diatexite and Leucosome band. Petrographic studies showed the presence of the various rock forming minerals which include - plagioclase, quartz, biotite, microcline and orthopyroxene as observed within the field of view under plane and crossed polarized light. Variation diagrams show negative correlation between MgO, CaO, TiO_2, FeO_t and SiO_2 but positive correlation with Na_2O, K_2O indicating the normal magma crystallization trends. Careful correlation of the geochemical dataand their field occurrence reflects that the leucosome band has highest amount of added fluid. The geochemical variations observed for the migmatites they were formed within the syn-collisional/Volcanic arc granite tectonic setting with fractional crystallization as the dominant process in their petrogenetic evolution.
***Key Word**: Metatexite, Diatexite, Leucosome band, Microcline,Firo,*

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I. Introduction

The study area is located in the north-eastern part of Bauchi sheet 149NE and lies between latitudes N10^{0} 25'00'' to N10^{0}28'.00'' and longitude E9^{0} 51'.00'' to E9^{0} 55' 00''. It covers an area of about 36.75 square kilometers on a scale of 1:25,000 and rise to the height of approximately 556m above mean sea level in some areas, it also hosts a large body of water called "Gubi/Firo Dam" which flows in an E-W direction(Fig. 1 and Fig.2). Geographically, the area is located along the Bauchi – Firo road around in Ganjuwa local Government area of Bauchi State. However, it is mainly accessible through the Bauchi – Firo road and some un-tarred roads with other major and minor footpaths linking hamlet to hamlet and farm lands within the area. This study is aimed at understanding the field relationship, petrography and geochemical signatures of the rock units in the study area with a view tounravel the process by which they were formed.

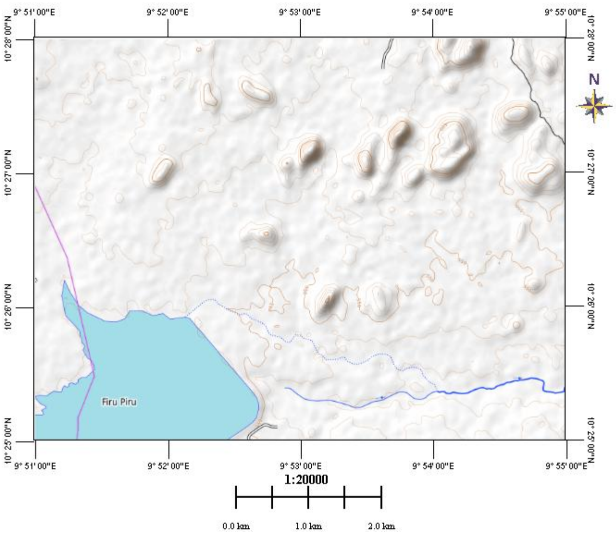

Figure 1. Location of the Study Area (Global mapper).

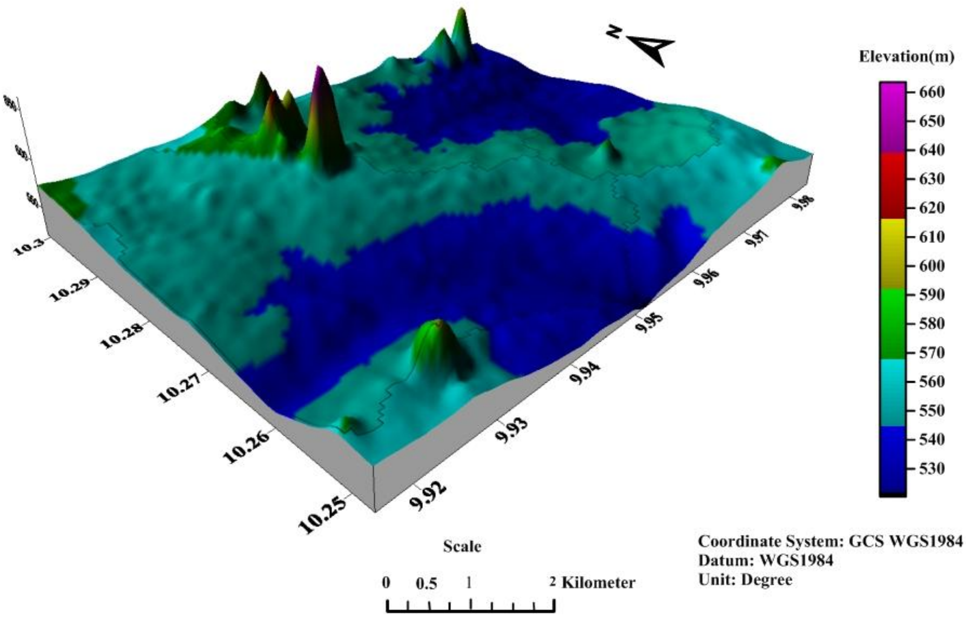

Figure 2: Digital Elevation Model of the Study Area (Surfer 13).

II. Geological Background

The study area is part of the northern Nigeria Neoproterozoic Trans-Saharan belt which resulted from accretion of terranes between the converging West African Craton, the Congo Craton and the East Saharan Block between 700 Ma and 580 Ma[7]defined by heterogeneous rock assemblages including metasediments, migmatites, medium-grained biotite-hornblende granite, medium-grained biotite granite, biotite-hornblende granite, fayalite-quartz monzonite, pegmatite, and quartz diorite (charnockitic)[2]. They constitutes an important group of the metamorphic rocks of northern Nigeria, in that they underlie the greater part of the region typified by high-grade gneisses[7]. The close relationships between regional tectono-metamorphic evolution of the gneisses, regional anatexis and emplacement of syn-kinematic plutons from the Pan-African monzodiorite–charnockite association; suggests a monocyclic metamorphic history for the rocks[3].Rocksof the adjoining areas have been describedas high grade (granulite facies) metamorphic rocks hosting migmatites which range from metatexites, diatexites and nebulites [29].

Brown[9], divided migmatites into two broad types, metatexites and diatexites.Metatexites are characterized by the preservation of pre-migmatite structures and involve the efficient segregation of melt into centimetre-scale dilatant sites[9,20,21,23,]The efficient segregation and loss of melt from its source means that even at extreme temperatures and degrees of partial melting most migmatitic rocks remain metatexites. Diatexite migmatite characterized by the obliteration of pre-migmatite structures, form when the melt content of a rock increases sufficiently that the solid matrix loses cohesion and the rock gains the rheology of a magma[22]. The proportion of melt required for this textural and rheological transition will vary, depending on crystal shapes, melt distribution, the viscosities of the melt and the solids and the nature and intensity of strain[24,28,27,26,19]Partial melting in pelitic to felsic rocks typifies the onset of upper amphibolite facies metamorphism. Under these conditions, melting first occurs at water-rich, vapour phase and continues via dehydration– melting reactions with further increase of temperature. It is assumed that the amount of melt produced by upper amphibolite facies rocks is insufficient to be able to produce diatexite migmatites in which magma flow can occur. Thus the mechanisms for increase in the melt fraction have been advanced by some authors viz: (i) the injection of melt or magma from elsewhere to increase melt content[13], (ii) the redistribution of melt within a melting system to locally create zones with higher melt content[5,15], and (iii) the addition of hydrous fluid to enhance melt production and produce in situ diatexite and granite[16]. Each of these three mechanisms should result in a compositionally distinct and possibly texturally distinct type of diatexite.

III. Methodology

For the purpose of this study, geological fieldwork, rock sample collection, petrographic studies, geochemical analysis and interpretation were employed. 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 powder to obtain required thickness and a perfectly smooth surface; the cut rock samples were, thereafter, mounted on a clean glass slide with adhesive[18] (Rollison, 1992). The prepared slides were examined under the petrological microscope to identify mineralogical features of the rock samples on a microscopic scale. Furthermore, the geochemical analyses was carried out using XRF method. The samples were broken down to aggregates, then pulverized, homogenized and pressed into pellet. For the emission—transmission method usually a 150 or 200 mg pellet is prepared (25 mm diameter) with or without a binder (chromatographic cellulose, boric acid or starch are used as a binder in a proportion 1:10 by weight and in some cases a liquid binder might be used). The samples for this work were analysed at the National Geoscience Research Laboratories (NGRL) Kaduna. The results were then used to generate geochemical plots using software (GCDkit and Petrograph).

IV. Result

Field Relationships

The mapped outcrops are divided intothree broad morphological types, metatexite, diatexiteand Leucosome bands, which occur as mappableunits.The boundaries of each morphological unit are gradational, so thecontacts shown on the maps (Figure. 3) are inferred. The metatexite generally occur as pockets within the other diatexite units. The leucocratic diatexite which is predominant in the study area and mesocratic diatexite zones are always separated by a zone of schlieren (melanocratic) diatexite. The size/width of the melanocratic patches differs from one outcrop to another and ranges from 1–5 m.

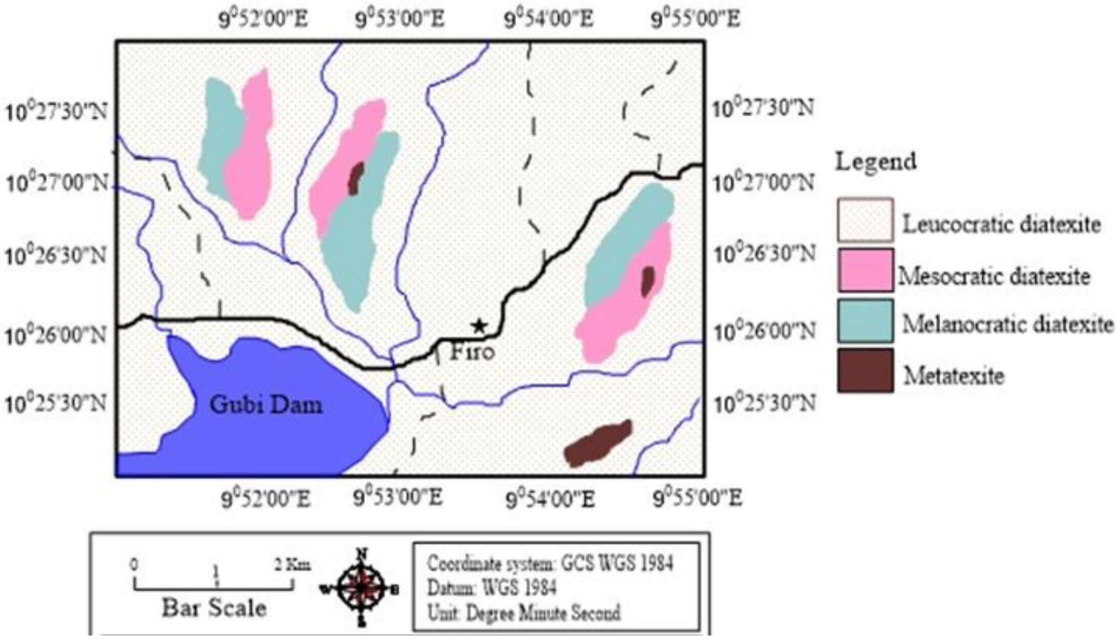

Figure 3. Geologic map of the study area

Metatexite: The metatexite, here is typified by the preservation of primary compositionallayering and the preservation of folds andparallel leucosomes, falling within the stromatic migmatite of Hassalova and Sawyer's (2008) classification(Fig.4). They are melanocratic, fine grained 0.25–1 mm, containing about 30% leucocratic portions of quartzofeldspathic composition. The leucocratic portions contain quartz, plagioclase, k-feldspar, and minor biotite and coarser grained (0.5–2.0 mm) than the melanosomes.

Figure 4. Field occurrence of Metatexite

The Diatexite

The diatexite is divided into three (3) subgroups depending on the amount of mafic components:

i. Melanocratic
ii. Mesocratic and
iii. Leucocratic diatexite

All have the pre-existing structures (e.g., bedding and foliation) destroyed, having undergone a textural homogenization. In general, diatexite migmatite is characterized by increased grain size (0.5–5 mm), relative to the metatexite. The melanocratic diatexite is characterized metre-scale biotite rich schlieren patches/smaller rafts of stromatic migmatite,its composition over laps that of metasedimentary rocks or may be similar to the metatexites (Figure 4). The mesocratic and leucocratic diatexite occurs together and differ mostly in the amount of mafic components, they both are characterized by lack of patches of stromatic migmatite or foliation but may they contain centimetre-scale layering or few schlieren and parallel oriented felsic leucosomes.

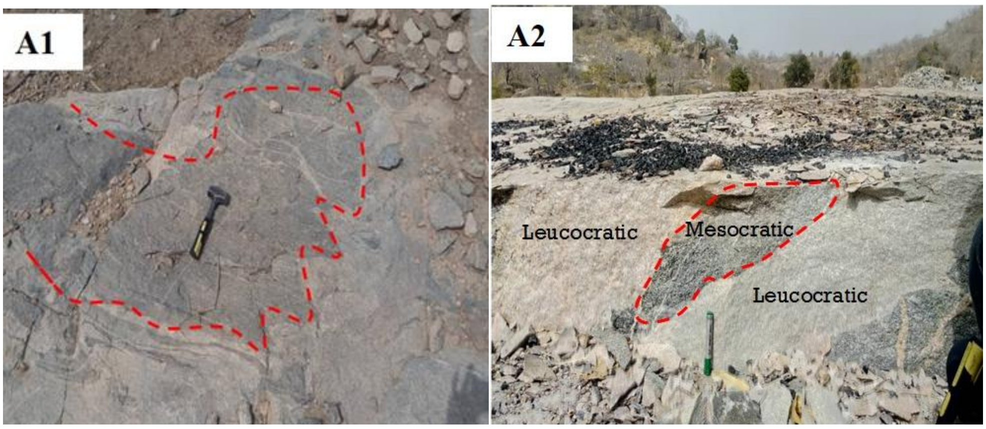

Figure 5: (A1) Field occurrence of Mesocratic diatexite
(A2) Outcrop scale occurrence of leucocratic and mesocratic diatexite.

Leucosome band

These rocks are typically coarser grained than those of the metatexite and other diatexites, with the exception of some leucosomes in the diatexite zone. In particular, the K-feldspar grains up to 1 cm long, a feature only found in the coarsest- grained parts of the leucocratic diatexite. This overall coarser grain size gives it the lighter-coloured appearance compared with much of the diatexite and metatexite, it may occur alongside disaggregated scheileren diatexite within the same outcrop as found in the study area (Figure 6).

Figure 6: Aand B) Field occurrence of nebulite/ leucosome band along with rafts of disaggregated metatexite.

Petrographic Study

Representative samples were collected from the different rock units in the study area and studied petrographically.The rocks contain the mineral assemblage quartz-plagioclase-biotite ± orthopyroxene ± K-feldspar ± muscovite, and the varying textural relationships between from fine grained crystals in the metatexite and the phenocrysts of Quartz and K-feldspar in nebulite. The proportion of the minerals in samples of the Leucocratic diatexite, mesocratic diatexite and nebulite is similar (Plates1and 2). However, on a photomicrograph scale, there may be substantial differences in modal compositions, such as between metatexite and diatexite, orthopyroxene in the diatexite and abundant K-feldspar in the Leucosome band/nebulite.

Metatexite

The metatexite is finer grain and rich in biotite and plagioclase but poorer in quartz and K-feldspar than other units (Plate1a and b). It is dominated by plagioclase, biotite and quartz, with minor K-feldspar. Biotite commonly exhibits preferred elongation direction.

Mesocratic Diatexite

The mesocratic diatexite in hand specimen, generally has a medium to coarse grain size with relatively uniform texture. Petrographic studies revealed that the rock contains quartz, plagioclase, orthopyroxene, biotite, and exhibits a granoblastic texture. The biotite is dark brown while the orthopyroxene exhibits a grey to pale brownish green colour with strong pleochroism. It generally exists along the outlines of the plagioclase porphyroblast.The plagioclase shows albite twinning and some shows sign of deformation or strain (Plate 1(d)), while Quartz grains show strain and exhibits undulose extinction.

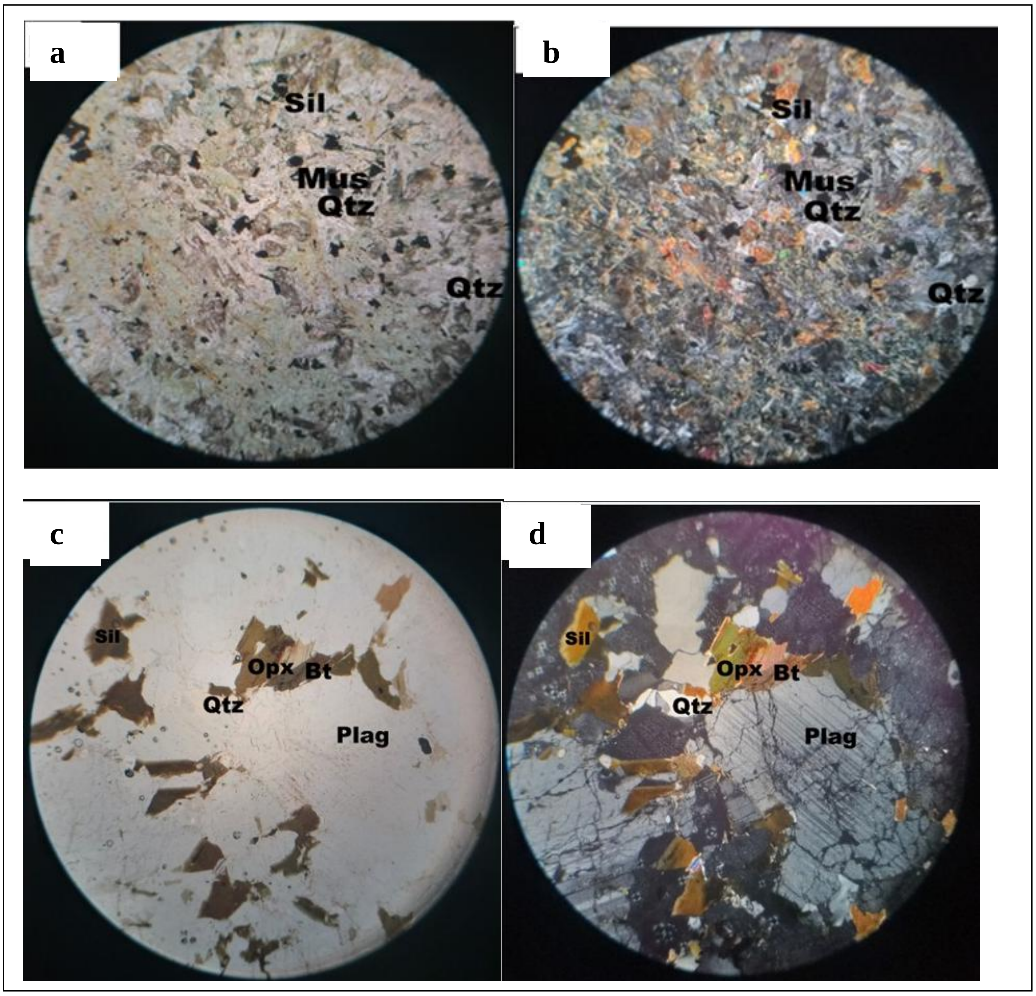

Plate 1:a-b Photomicrograph of metatexite sample under plane polarized light (a) **and** cross polarized light (b) (c-d) Photomicrograph of Mesocratic diatexite samples under plane polarized light (c) **and** cross polarized light (d)
Qtz=Quartz, Bt=Biotite, Plg=Plagioclase, Sil=Sillimanite

Leucocratic Diatexite

Leucocratic diatexite contains more k-feldspar than the other types of diatexite, forming small cross-cutting dykes as well as much large concordant and subcordant sheets. It is leucocratic (pink), inequigranular in texture on outcrops scale. The leucocratic diatextite has the highest K-feldspar/plagioclase ratio and the lowest biotite content and represent the most evolved types of diatexite. Petrographic analysis shows that the rock has a grano-blastic texture and is composed predominantly of microcline, biotite, and quartz. (Plate 2b). The microcline exhibits cross-hatched twinning,biotite exhibits strong pleochroic halos, though very scantyand it sometimes occurs as interstitial grains, while few grains of silimanite exhibits high relief and parallel extinction.

Leucosome Band

The rock hosts simple pegmatitic veins and is mostly weathered although fresh outcropped were observed in the rock quarries. In hand specimen, the phenocrysts are pink in colour with the longer axis aligned parallel to the biotite flakes thus giving a gneissose appearance to the rock. In thin section it contains predominantly of quartz, biotite and muscovite. Where the biotite and muscovite grains are found interstitial of the quartz porphyroblasts (Plate 2d)

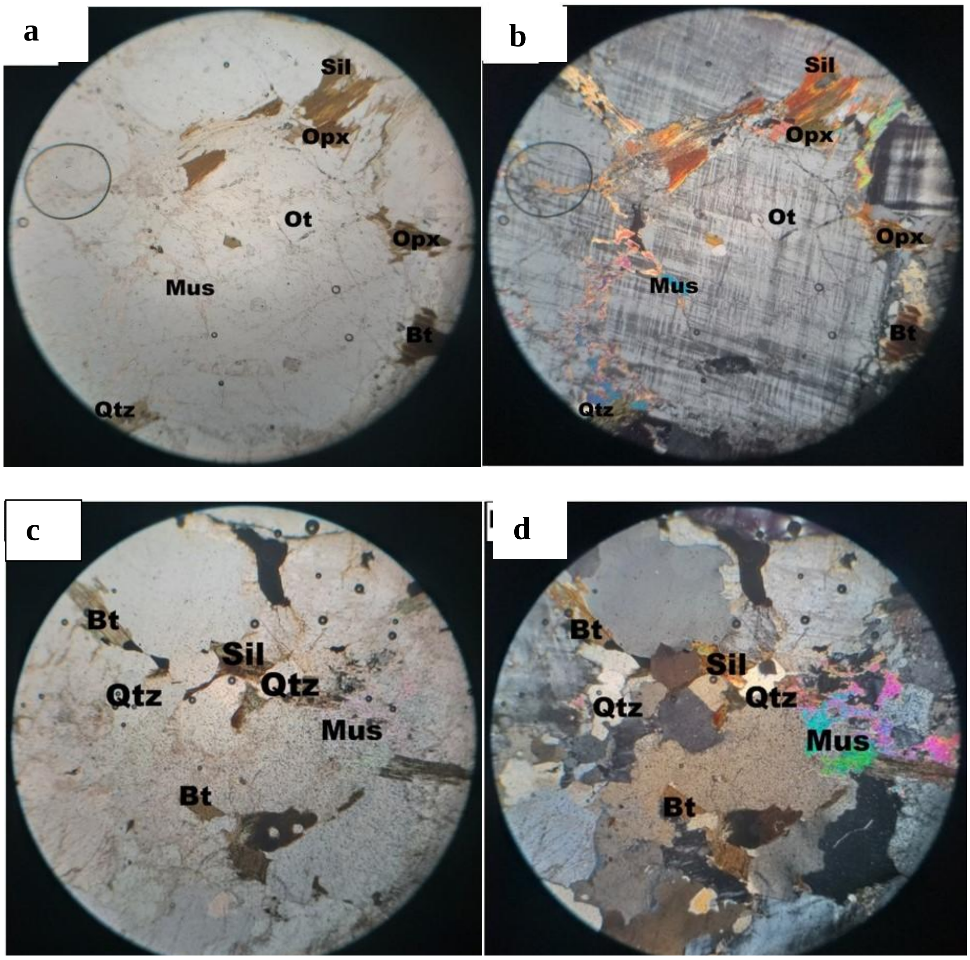

Plate 2:a-b Photomicrograph of Leucocratic diatexite samples under plane polarized light and cross polarized light (a and b)
c-d) Photomicrograph of leucosome band under plane polarized light and cross polarized light (c and d)
Qtz=Quartz, Bt=Biotite, Plg=Plagioclase

GEOCHEMISTRY

The geochemical data for ten representative rock samples from the study area are presented and analyzed to conclude on the different morphological forms of migmatite, understand their tectonic history and the grade of metamorphism of the migmatites.

Characteristic of Major oxides

The Harker plots (Fig. 7) shows the geochemical variations in the behaviour of the major oxides and in turn gives idea about their mobility during partial melting and their compositionaldifferentiation within the rocks. E.g CaO (0.40-8.10 wt %), MgO (0.06-6.36wt %), Fe_2O_3 (0.44-10.8 wt %), TiO_2(0.25-2.30wt %), Na_2O (0.20-1.60wt %), K_2O (0.10-1.20wt %), Al_2O_2 (12.00-21.40wt %).

Table 1. Whole Rock Geochemical Data for Major, Minor and Trace Elements

Petrology	**Metatexit e**	**M-diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**L-Diatexit e**	**Leucos ome band**
Major Oxides(wt %)										
SiO_2	54.40	67.90	73.60	74.10	74.14	74.40	74.50	74.70	76.10	81.60
CaO	8.10	ND	3.30	2.05	ND	2.12	3.50	0.40	ND	0.41
MgO	6.36	ND	1.00	1.00	ND	0.89	1.03	0.06	ND	0.32
SO_3	0.078	ND	0.063	0.062	0.070	0.048	0.063	0.052	0.080	0.081

K_2O	ND	0.90	0.14	0.23	1.20	0.20	1.00	0.10	0.90	1.00
Na_2O	ND	0.87	0.21	0.21	1.60	0.24	0.20	0.21	1.08	1.20
TiO_2	2.30	0.86	1.21	0.88	0.39	0.77	0.92	0.32	0.341	0.25
MnO	ND	0.03	0.12	0.06	0.032	0.077	0.06	0.02	0.02	ND
P_2O_5	0.20	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe_2O_3	10.80	2.51	3.13	2.71	0.64	1.90	1.91	1.76	2.60	0.44
Al_2O_3	13.30	21.40	15.00	14.84	18.06	17.00	14.34	18.73	16.40	12.00
LOI	4.30	6.42	1.22	1.23	1.60	1.64	1.46	1.48	1.02	0.84
Trace element (ppm)										
V	250.00	60.20	30.00	60.20	80.00	200.21	60.00	240.00	240.00	8.40
Cr	330.40	21.00	16.20	40.11	16.33	180.00	6.21	100.20	101.00	<0.01
Cu	390.00	390.00	340.00	270.00	300.00	270.00	260.00	330.00	230.00	250.00
Sr	2800.00	284.00	2520.00	2000.00	1460.00	2130.00	2360.00	1760.00	1910.00	1170.00
Zr	890.00	200.00	1000.00	660.00	640.00	680.00	710.00	420.34	360.00	160.00
Ba	<0.01	5900.00	16.00	28.16	8.48	10.10	12.00	200.20	7.20	2.34
Zn	280.00	90.22	181.83	260.20	18.40	150.00	60.24	50.06	310.11	91.00
Co	<0.01	31.00	<0.01	<0.01	1.70	1.84	<0.01	0.50	1.10	1.40
Pb	<0.01	440.00	400.00	410.00	330.00	300.00	410.00	300.00	330.00	98.00
Ga	<0.01	13.00	12.00	0.60	0.99	19.20	0.80	1.20	0.30	3.01
As	<0.01	60.00	0.01	0.01	0.90	0.60	0.10	1.03	0.60	0.95
Y	<0.01	1.80	<0.01	1.38	1.38	2.10	<0.01	2.00	1.20	1.40
Rb	25.14	130.00	160.00	146.00	93.70	159.00	48.00	182.00	70.00	57.34
Nb	12.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ta	6.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
W	2.20	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Hf	39.40	31.60	34.81	31.02	43.22	41.68	40.16	36.00	39.40	12.00
Sn	0.73	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.84	<0.01
Sb	1.24	<0.01	0.42	<0.01	<0.01	<0.01	<0.01	<0.01	1.70	<0.01
Bi	<0.01	<0.01	<0.01	<0.01	<0.01	20.00	<0.01	<0.01	<0.01	<0.01
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ge	<0.01	<0.01	<0.01	0.11	0.50	<0.01	<0.01	<0.01	<0.01	0.70

***ND = Not Detected, M = Mesocratic Diatexite, L= Leucocratic Diatexite**

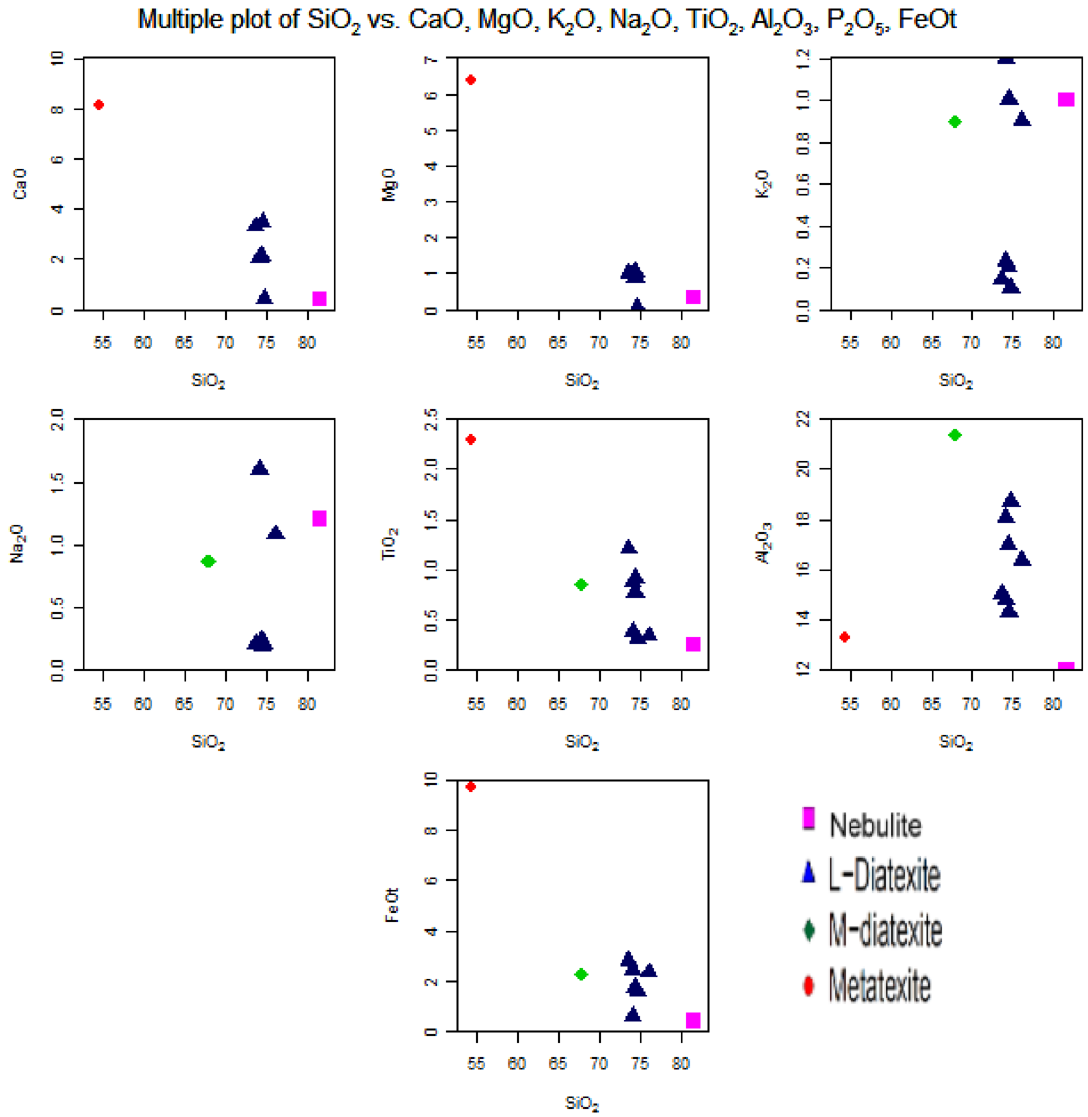

Figure 7: Major oxides (wt %)/SiO_2 variation plots (after Harker et al., 1996)

The metatexite sample has the lowest content of SiO_2 constituting about 54wt% and shows a more varied appearance as compared to diatexite samples having the range of 67-76wt% SiO_2 (Table 1) and further cluster as a group occupying certain portions of the plots(Figure 7). The main chemical variation seems to be SiO_2. Plots of major elements versus SiO_2 shows varying trends in ferromagnesian elements with Plots of TiO_2, Fe_2O_3, MgO, CaO showing decrease alongside increase in SiO_2, an indication of melt depletion in metatexites. Na_2O, K_2O and Al_2O_3 increases with increasing SiO_2 in diatexites indicating melt enrichment attributable to their mobility during metamorphism in such rocks. This composition is more consistent within the diatexites compared with those of the metatexite and Leucosome bands.

Trace Elements Geochemistry

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.

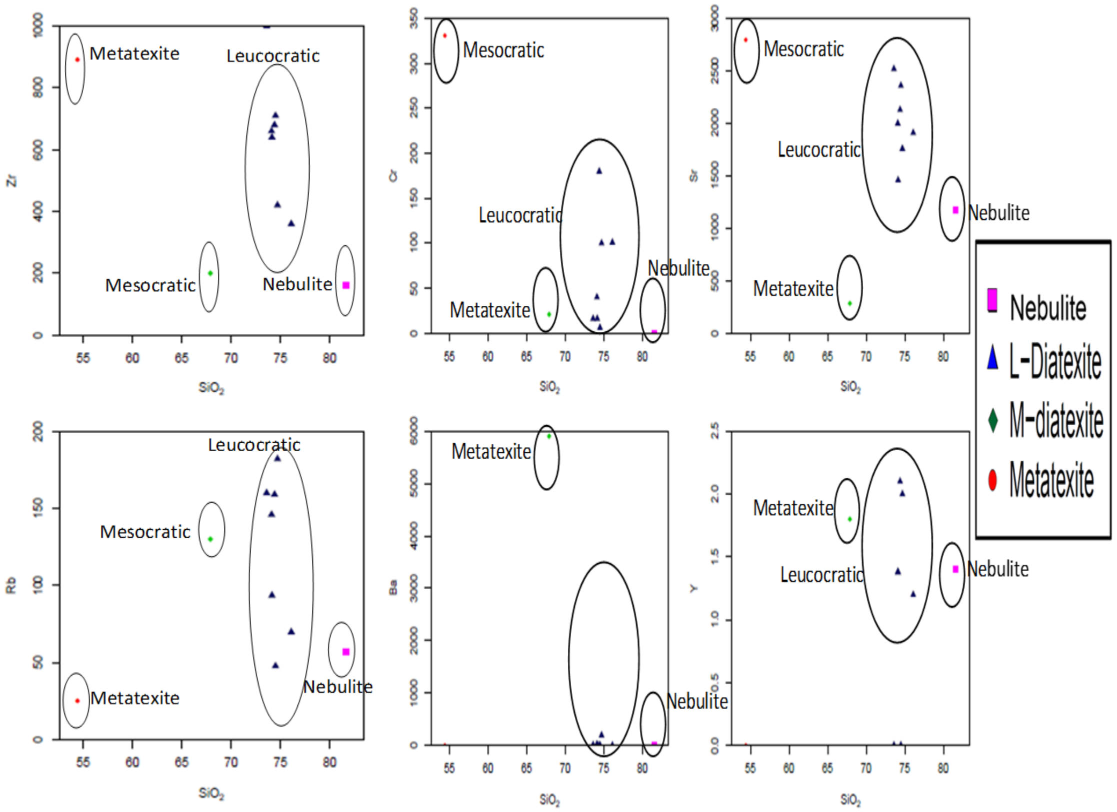

Figure 8: Minor element (ppm)/ SiO_2 variation plots

Tectonic Setting

The geochemical data were plotted on various major tectonic discrimination diagrams. On the Rb vs Y + Nb and Nb vs Y tectonic discrimination diagram, all the sample were grouped within the Syn-collisional and Volcanic Arc Granite domain (figure 9).

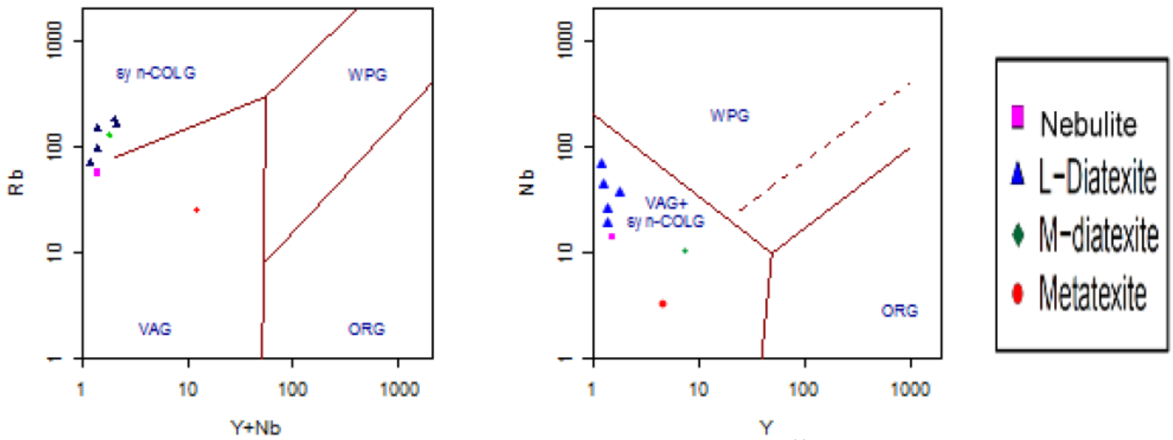

Figure 9. Plots of the analysed rocks on the tectonic discrimination diagram[11] (a) Rb vs (Y+Nb) (b) Nb vs Y.

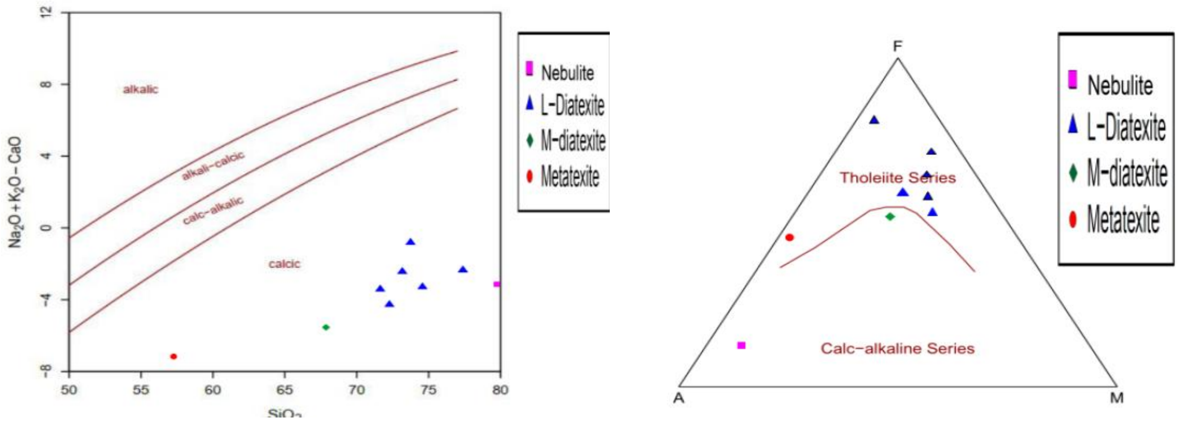

Figure 10: (a) Tectonic discrimination diagram[10]
(b) AFM plot of tholeiite and calc-alkaline series[14]

V. Discussion

The field occurrence (Figures 4, 5 and 6) revealed a transition from the metatexite to thenebulite, characterized by highly heterogeneous behaviour of the different parts of the rocks, from changes in their textural appearance of relatively fine to coarse to an increase in disaggregation of the rocks towards lecosome bands indicating that they had been formed by the same process. The metatexite shows stromatic bands of felsic materials (Figure 4) while the diatexite shows raft of disaggregated metatexite (figure 6). These rafts may represent more highly melted equivalents of the areas in the metatexite that contained limited melt segregations. The presence of leucosomes in these rafts reflects segregated melt that have flowed down pressure gradients into dilatant sites resulting in a rock with a heterogeneous distribution of melt. With continued melting, these dilatant sites could potentially form an interconnected network[17]. The Leucosome bands (figure 6) shows abundant phenocrysts of K-feldspars giving it a more felsic appearance and suggesting rapid cooling of the melt.The phenocrysts appear to be products of exsolution of volatiles from the leucocratic diatexites. The leucosome bands sometimes occur within the leucocratic diatexites but devoid of any sharp contact that might imply their being injected[29]. The petrographic studies showed the presence of major rock forming minerals ranging from quartz, plagioclase feldspar, biotite, orthopyroxene and microcline.The preponderance of ferromagnesian mineral (biotite) and plagioclase in the metatexiteand melanocratic diatexite (plate 1) and increase in quartz and K-feldspar in the diatexites (Figure 7) suggests that partial melting and crystallization, dominated by fractionation of plagioclase and biotite; have played a significant role in the evolution of the rocks. Undulous extinction in quartz, presence of orthopyroxene and sillimanite (plates 1 and 2) are indication that the rocks were formed under high metamorphic conditions.The geochemical data (Table 1) shows varying compositional behaviour of the major, minor and trace elements including high SiO2 (54.4% to 81.0wt%) high K_2O, and Al_2O_3 in the diatexites alongside decrease in the ferromagnesian minerals. Opposite of such is found in the metatexite CaO (0.40-8.10 wt %), MgO (0.06-6.36wt %), Fe_2O_3 (0.44-10.8 wt %), TiO_2(0.25-2.30wt %) the ferromagnesian element decreases with increasing SiO_2. The plots of K_2O Vs SiO_2 and Na_2O vs SiO_2 in diatexites is in accordance with crystallization of K-feldspar and gradual potash enrichment with progressive differentiation[4]. For the minor elements Sr and Zr shows decrease with increasing SiO_2 while Rb and Y shows increases with increasing SiO_2(Figure 8).The migmatites in the study area are characterized as calcic based on tectonic discrimination plot of Frost et al, 2002 (figure 10). They occupy the the Syn-collisional and Volcanic Arc Granite portion[11](figure 9).The Na_2O+K_2O – CaO plot, show the diatexites fall within the calcic portion while falling in the Tholeitic portion of the AFM [14] (Figure 10), with the exception of the melanocratic diatexite and the leucosome band which fall within the calc-alkaline portion of it.

VI. Conclusion

The rocks in the study area are predominantly diatexite migmatite with minor occurrence of metatexites and leucosome band units. The Spatial variations in the amount of fluid that interacted with the partially melting rocks resulted in the different morphological units.

The transition from metatexite to diatexite was transitional, evidenced by an increase in melt production, owing to the disaggregation of the metatexites to form diatexites and leucosome band. The leucosome bands reflects the highest degree of melting, characterized by textural homogenization and the growth of phenocrysts. The petrographic studies this transition through abundance of K-feldspar in the leucocratic diatexites and general coarsening of quartz grain size. The geochemical variations observed for the migmatites reflects that they formed as syn-collisional/Volcanic arc granite tectonically, with fractional crystallization as the dominant process in their petrogenetic evolution.

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