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GEOCHEMICAL EVOLUTION AND FIELD RELATION OF MIGMATITES AROUND DIR, BAUCHI, NORTHEASTERN NIGERIA

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ABSTRACT

The migmatite rocks around Dir, in Bauchi Local Government Area of Bauchi State were studied with the interest to determine the geology, field relation, geochemical evolution and morphology of the study area. The geological mapping indicated various morphological units of migmatites; Diatexite migmatites occurring as Melanocratic-diatexite, Mesocratic-diatexite and Leucocratic-diatexite. Field studies showed the presence of the various rock forming minerals which comprises of plagioclase, quartz, biotite, microcline and muscovite. Geochemically, a slight inverse correlation between SiO_2 and few oxides is observed. This suggests that the classic model of fractional crystallization is not the principal process influencing the lithological diversity but partial melting in which the correlation patterns are controlled by the geochemistry of the solid phases been added to the melt. Correlation of the geochemical data and their field occurrence reflects that the leucocratic-diatexite has highest amount of added fluid. The geochemical variations observed for the migmatites showed they were formed within the volcanic arc granite and oceanic ridge granite tectonic setting. A model was used to determine the parents of the migmatites in the study area. In the plot the migmatites fell within sedimentary and igneous field which suggests that the protoliths of the migmatites are of sedimentary and igneous rocks.

KEYWORDS:
Migmatite,
Diatexite,
Metatexite
Evolution,
Geochemical.

1. Introduction

The outcropping migmatites belong to the Migmatite Gneiss Complex of Nigerian Geology. The study area is around Dir and environs forms part of the Nigerian Basement Complex of Bauchi area that forms part of the Neoproterozoic Trans-Saharan belt formed between 700Ma and 580Ma by accretion of terranes between the converging West African Craton, the Congo Craton, and the East Saharan Block (Ferre and Caby, 2006). The study area is located in the south-western part of Bauchi sheet 149SW and lies between latitudes N10^{0}10’45.8’’ to N10^{0}11’16.7’’ and longitudes E9^{0}42’03.5’’ to E9^{0}52’53.2’’. It covers an area of about 30 square kilometers on a scale of 1:25,000 and rise to the height of about 601 meters above mean sea level in some places (Fig.2), the study area also hosts a stream that flows in S-W direction (Fig.3). Geographically, the area is located along the Bauchi–Dass road around Bauchi Local Government Area of Bauchi State (Fig.1). The area is mainly accessible through the Bauchi–Dass road and some un-tarred roads with minor footpaths linking hamlets and farm lands within the area. This study is aimed at understanding the geology, field relationship, and geochemical imprints of the rock units in the study area with a view to ascertain the process under which they were formed.

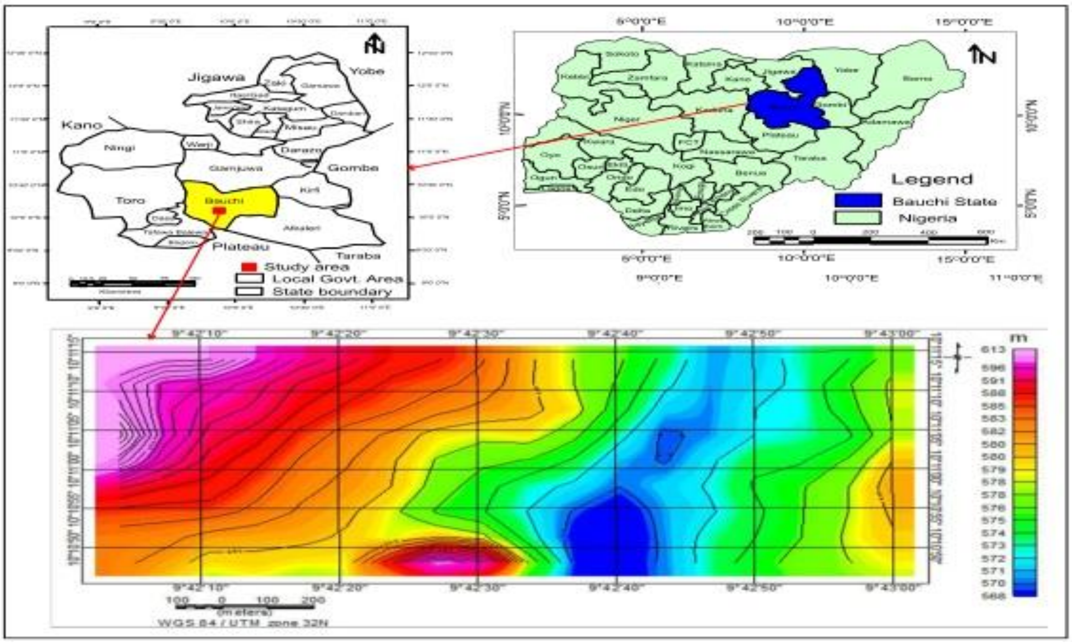


Figure 1: Location of the Study Area (Global mapper)

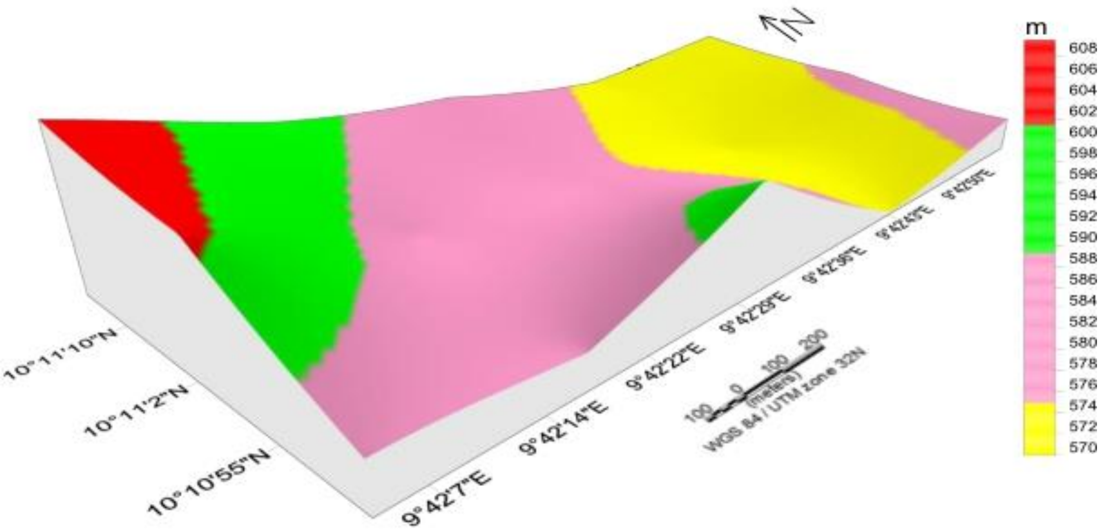


Figure 2: Digital Elevation Model of the Study Area (Surfer 13)

2. Geological Background

The entire belt lies in the reactivated margin of the West African Craton and the active Pharusian Continental margin (Burke and Dewey, 1972; Black and Girod, 1972; Caby et al., 1981). Nigeria is situated within the Pan-African mobile belt and sandwiched between the West African Craton to the west, the Tuareq Shield to the north and the Congo Craton to the southeast (Figure 4). About half of the total area of Nigeria landmass is underlain by rocks of the Precambrian age known in the country as the Basement Complex. The remaining half is covered by Cretaceous to Quaternary sediments and volcanics. The Nigerian basement was affected by the 600Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700Ma), the Eburnean (2,000Ma), the Kibaran (1,100Ma), and the Pan-African cycles (600Ma). The first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. The basement complex is divided into two provinces (Ajibade, 1979). The Western Province and the Eastern province. The Western Province is approximately west of longitude 8^{o}E, typified by N-S to NNE-SSW trending schist belts separated from one another by migmatites, gneisses and granites. This trend is believed to be the result of Pan African orogeny involving collision between the West African Craton and the Pan African mobile terrain with and eastward dipping subduction zone. The schist belts are differently interpreted as small ocean basins (Ajibade, 1989) or synclinal remnants of an extensive supracrustal cover (Barley, 1989). The Eastern Province lies approximately east of longitude 8^{o}E and is more nearly NE-SW. When followed eastward into Cameroon, the trend changes to ENE-WSW (e.g Ngaoundere, mylonite zone and the schist belts near Batare). The Eastern Province comprises mainly migmatites, gneisses and large masses of Pan-African granitoids (Older Granites) intruded in Jos plateau, by Jurassic peralkaline granites. Except for smaller schist occurrences around Madagali (Hawal Massif), Toungo and Gayam (Adamawa Massif) and Oban Massif in southeast, the Eastern Province is marked by the absence of major schist belts. Precambrian Basement Complex rocks underlie three areas of Nigeria: North-central area including the Jos Plateau; South-west area adjacent to Benin; and south-east area adjacent to Cameroon. The rocks of the North-central area are composed of gneisses, migmatites, granites, schists, phyllites and quartzites.

3. Methodology

For the purpose of this study, geological field work was conducted on a scale of 1:25,000. Various field measurements were carried out during the mapping. Global Positioning System (GPS) was used for geographical positioning with respect to various outcrops available in the area. Field descriptions and observation were recorded in a field book. 25 representative samples were collected in the field and 13 samples were sorted and selected for geochemical analysis. For the geochemical analysis, fresh portion of the rock samples were chipped out for pulverization; each of the dried samples were pulverized in order to obtain powdered samples to pass 75 micro mesh sieves, then powder obtained from each rock samples was mixed thoroughly to ensure homogeneity and 5gram of each of the pulverized sample was weighed with 1gram of binding aid which was further mixed to ensure homogeneity and pressed under high pressure in order to be pelletized, labeled and packaged, then samples were taken to Research and Development Laboratory of the Nigerian Geological Survey Agency Kaduna, for preparation and analysis. Geochemical analysis of the samples was carried out at Geological Survey Agency Laboratory, for major oxides and trace elements composition determination, using X-ray Fluorescence Spectrometry (XRF). Geochemical data were interpreted using Petrograph and GCDKit software packages.

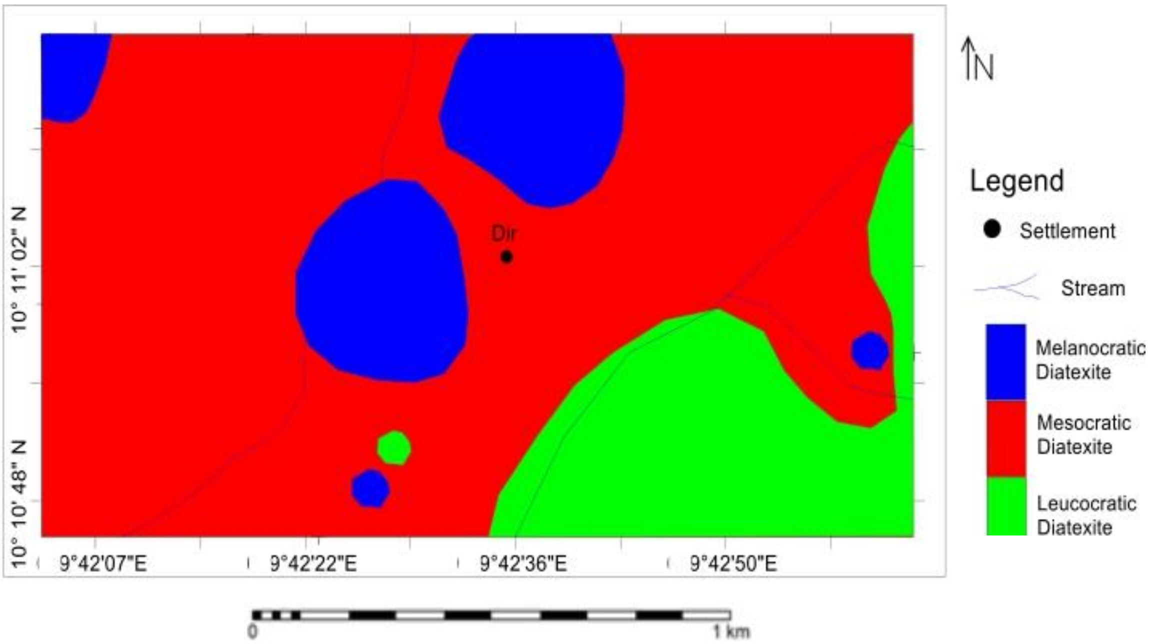


Figure 3: Geologic map of the study area

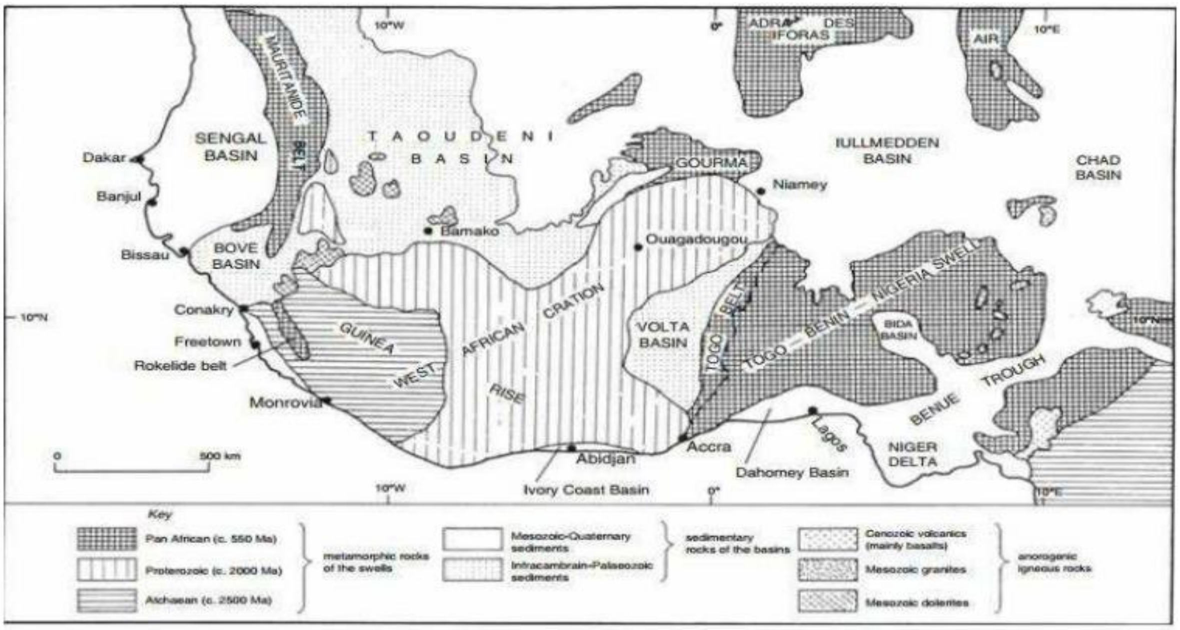


Fig.4. Geological map of parts of West Africa showing the position of Nigeria and its Pan- African basement, the Congo-Gabon craton, the West African craton and the Tuareg Shield (adopted from Wright et al., 1985)

4. Results and Discussion

The study area is underlain basically by one lithomorphological form of migmatite, diatexites with infinitesimally small traces of metatexites. The metatexites in the study area occur as patch metatexites. Patch migmatites are rare and in this case they occur with diatexites as patches. This texture is seen when melting occurs at discrete sites to form small, scattered patches of non-foliated in situ neosome. The diatexites found in the study area show a mappable range in morphology from melanocratic to leucocratic diatexites.

4.1. Field relationship and macroscopic description

4.1.1. Diatexite:

Diatexites are migmatites that have lost structural coherency and disaggregated (Sawyer, 2008).

The diatexites in the study area are the most abundant morphology in the area and they occur as massive rock unit and are associated with one another.

All have undergone textural homogenization that has destroyed the pre-migmatization structures (e.g., bedding and foliation). The diatexites found in the study area show a mappable range in morphology from mesocratic to melanocratic through to leucocratic diatexites and they are associated with one another (Plate 2(A1)). The melanocratic diatexite is characterized metre-scale biotite rich schlieren patches/smaller rafts of stromatic migmatite, its composition overlaps that of metasedimentary rocks or may be similar to the metatexites (Plate 1(A1)). The mesocratic and leucocratic diatexites occur together and differ mostly in the amount of mafic components, 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. The contacts (Fig.3) are inferred. The mesocratic diatexite which is predominant in the study area and leucocratic 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.

4.1.1.1. Melanocratic diatexite

The melanocratic diatexite is medium to fine grained (0.5-1mm) and has high content of dark colored minerals with scanty light ones as quartz and feldspars (Plate 1 (A1&A2)). The dark colored may be as a result of high ferromagnesian minerals.

4.1.1.2. Mesocratic diatexite

The rocks are relatively medium grained (0.5-2mm). They are composed of about equal percentage of mafic and felsic minerals. Quartz, feldspar and biotite are visible with a strong preferred orientation of the mafic minerals, suggesting a magmatic or submagmatic foliation (Plate 2 (A1&A2)).

4.1.1.3. Leucocratic diatexite

The rocks are medium to coarse grained (1-2mm). They are composed of higher percentage of quartzofeldspatic minerals mostly quartz and feldspars, with relatively small amount of ferromagnesian minerals mostly biotite with a preferred orientation suggesting a magmatic foliation (Plate 3 (A1&A2)).

Plate 1: (A1) Field occurrence of Melanocratic diatexite

Plate 1: (A2) Hand Sample of Melanocratic diatexite

Plate 2: (A1) Field occurrence of Mesocratic diatexite

Plate 2: (A2) Hand Sample of Mesocratic diatexite

Plate 3: (A1) Field occurrence of Leucocratic diatexite

Plate 3: (A2) Hand Sample of Leucocratic diatexite

5. Geochemistry

Whole-rock major and trace elements data of representative rock samples of the diatexite migmatites are represented in Table 1. The rocks display a wide range in SiO_2 content (64.43 – 80.13 wt %), and high Al_2O_3 content in a range of (11.42 - 15.11 wt %), also K_2O content in the range of (1.24 - 22.00 wt %,) while Na_2O content is in the range of (0.74 - 2.00 wt %). It has Fe_2O_3 content in the range of 1.00 - 12.11 wt % and MgO content in the range of 0.01 – 1.00 wt%, and CaO content which is 0.06 - 0.3 wt %. The rocks are generally depleted in SO_3, P_2O_5, TiO_2 and MnO. The concentration of the major elements is expressed in wt. % while the concentrations of the trace elements are expressed in ppm as shown in Table 1.

Table 1: Major and trace elements composition of Migmatites of the Study Area

Oxides Composition %	Melanocratic Diatexite					Mesocratic Diatexite					Leucocratic Diatexite		
	L 1B	L 16	L 15A	L 11	L 6	L 11B	L 15B	L 14	L 18A	L 20	L 5	L 7	L 13A
SiO_2	64.43	68.40	70.40	70.40	70.43	72.48	72.81	73.50	73.66	74.40	75.50	75.52	80.13
CaO	0.20	Nd	0.30	0.30	0.18	0.20	0.06	0.10	0.09	0.43	0.06	0.08	0.26
MgO	0.06	Nd	Nd	Nd	0.06	0.03	0.01	0.73	0.01	1.00	Nd	0.01	Nd
SO_3	0.03	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
K_2O	4.43	22.00	18.40	1.24	5.11	5.34	5.64	2.40	1.30	1.26	3.04	5.64	2.46
Na_2O	1.62	0.74	1.60	2.00	1.28	1.60	1.00	0.84	1.86	2.00	1.60	1.00	1.00
TiO_2	1.30	0.08	0.11	0.68	0.84	0.38	0.02	0.42	0.21	1.20	0.70	0.02	0.12
MnO	0.08	Nd	0.04	0.05	0.02	0.04	Nd	0.03	0.02	0.04	0.06	Nd	Nd
P_2O_5	Nd	Nd	Nd	Nd	0.01	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Fe_2O_3	12.11	1.76	3.43	5.11	8.19	4.40	1.63	2.40	4.11	3.10	2.04	1.30	1.00
Al_2O_3	12.02	15.11	14.40	12.86	13.00	13.60	14.00	13.66	13.33	12.74	13.16	13.11	11.42
H_2O+	3.24	2.21	2.00	2.12	2.40	2.00	1.56	1.30	1.74	1.10	1.24	1.56	1.03
V	483.00	495.06	381.00	251.50	508.00	500.00	501.00	420.00	476.00	515.0	385.00	421.00	248.00
Cr	213.20	230.00	114.25	104.55	200.00	124.50	230.50	124.00	215.50	230.0	114.00	202.20	110.50
Cu	679.00	468.00	365.00	365.00	465.00	370.00	470.00	342.00	467.00	463.0	382.00	440.00	440.00
Sr	1020.00	990.00	987.00	780.00	1100.00	965.00	998.50	975.00	985.00	980.0	985.00	1034.00	820.00
Zr	980.00	734.00	941.00	640.00	1340.00	970.00	734.00	1140.00	934.00	1140.0	1040.0	966.00	730.00
Ba	1700.00	1000.0	780.00	560.00	1130.0	1730.00	854.00	950.00	1630.00	830.0	750.00	721.00	630.0
Zn	260.00	300.00	80.00	120.00	130.00	130.00	733.00	165.00	140.00	150.0	160.00	50.00	130.00
Ce	24.00	57.00	64.00	34.00	37.00	9.00	68.00	34.00	5.00	27.00	24.00	50.00	44.00
Pb	19.00	57.00	29.00	15.00	57.00	19.00	32.50	19.30	40.00	7.50	29.00	21.00	17.00
Bi	2.01	2.20	2.00	7.00	2.00	8.00	3.45	0.600	5.00	0.85	3.00	2.01	2.00
Ga	19.40	21.00	19.50	12.00	32.00	19.00	30.00	19.50	35.00	12.00	29.50	29.00	11.00
As	9.50	14.50	11.50	11.50	7.00	15.00	6,00	6.50	24.00	7.50	6.00	5.00	4.50
Y	28.50	7.00	8.00	8.00	57.00	8.00	58.10	46.50	4.00	55.00	48.00	43.00	7.50
Ir	30.50	5.00	3.00	0.80	25.00	0.60	16.00	33.50	0.20	29.00	33.00	28.00	0.60
Au	0.001	<0.001	<0.001	0.010	0.009	0.025	0.040	<0.001	0.032	0.002	0.001	0.023	0.006
Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.00	<0.001	<0.001	0.001
Rb	5.00	3.00	5.00	5.00	1.60	5.70	2.45	3.50	13.50	2.60	3.00	5.00	7.50
Mo	40.00	21.00	40.00	20.00	21.00	40.00	32.00	30.00	11.50	25.00	40.00	52.03	10.50
Co	<0.001	0.001	<0.001	<0.001	0.001	<0.001	0.003	<0.001	0.008	0.001	<0.001	<0.001	0.001
Cd	0.340	0.002	0.005	0.35	0.640	0.45	0.013	0.10	1.00	0.40	0.340	0.045	0.70
Ru	0.008	<0.001	0.003	0.002	<0.001	0.003	<0.001	0.001	0.004	<0.00	0.005	0.008	<0.001
Eu	1.00	0.40	0.03	1.00	1.40	1.00	2.30	1.50	0.40	1.80	1.00	1.00	0.45
Re	16.50	3.50	6.50	6.50	23.00	16.50	23.10	26.70	23.50	23.50	16.80	20.00	2.00
Nb	13.80	20.60	13.45	13.55	10.00	23.20	20.50	15.50	25.00	11.00	13.80	13.22	17.00
Ag	0.50	0.40	0.15	0.55	0.40	0.50	0.40	0.40	0.45	0.35	0.45	0.50	1.00
Ta	61.00	40.00	60.00	51.50	40.00	41.00	40.20	52.50	52.00	48.00	32.00	71.00	45.50
W	6.50	12.50	6.00	6.00	8.35	6.00	12.00	5.40	12.35	6.05	6.00	6.06	12.50
Hf	16.45	18.00	20.00	20.00	18.00	20.50	18.09	26.00	18.00	18.50	20.00	20.00	18.59
Yb	0.05	0.06	0.05	0.01	0.26	0.10	0.20	0.10	0.06	0.20	0.19	0.10	0.06
In	2.00	0.10	0.30	0.30	5.10	0.30	4.00	2.35	0.10	3.40	5.30	2.10	0.35
Se	0.70	0.100	0.25	0.25	0.110	0.20	0.100	0.15	0.100	0.11	0.25	0.25	0.15
U	0.010	<0.001	0.004	0.020	<0.001	0.001	<0.001	0.020	<0.001	<0.00	0.010	0.018	<0.001
Th	0.20	0.53	0.18	0.20	0.040	0.22	0.03	0.09	1.00	0.010	0.08	0.24	0.03
Sb	1.45	12.50	4.00	4.00	12.50	4.00	12.00	14.00	2.00	12.00	4.00	2.00	2.00
Ge	2.50	4.20	8.00	8.00	4.10	4.50	4.10	3.00	3.15	4.00	8.00	6.50	4.00
Sn	7.40	42.30	50.00	7.05	14.00	27.35	40.60	15.80	30.60	17.00	17.30	47.60	4.50

Protolith

The sedimentary and igneous nature of these rocks are supported by their position in the diagram such as TiO_2 vs SiO_2 discrimination diagram (after Tarney, 1977) as shown in Figure 5, this also confirms that they were sourced from the S and I-type by partial melting of the lower crust with minor input from the mantle under granulite metamorphism during the Pan-African orogenic event (Abdulmajid, 2021).

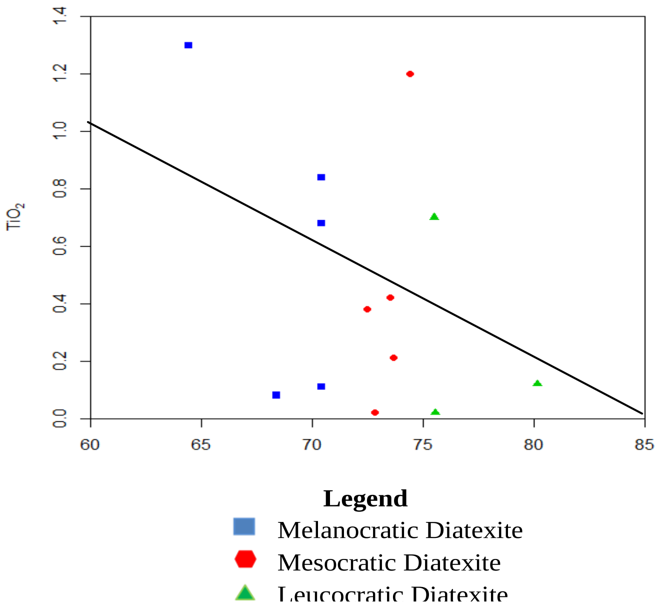
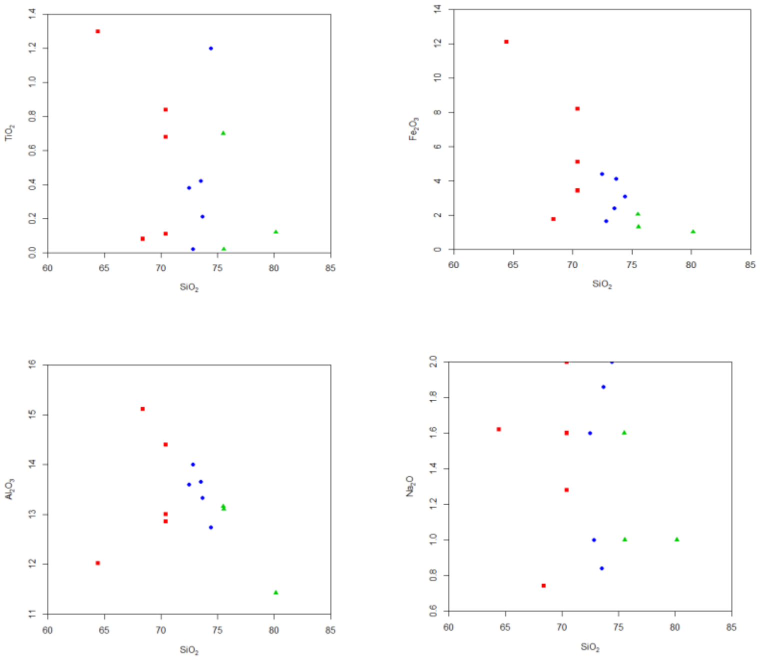


Figure 5: TiO_2 versus SiO_2 Discrimination Diagram (after Tarney, 1977) Showing the Protolith of Diatexite Migmatites in the Study Area

Variation Diagram

Harker diagrams are used to understand the chemical variations of major oxides and the correlation patterns between selected major oxides with SiO_2 provide an indication in this regard since they are generally related to mixtures of magmas, addition or subtraction of solid phases by contamination or fractional/partial melt crystallization **(**Figure 10**)**. In the case of partial melting the correlation patterns are controlled by the geochemistry of the solid phases that are being added to the melt. In the case of fractional crystallization with assimilation, the patterns of correlation show variability which is related to the inclusion of country rock in the magma during fractionation (Rollinson, 1993). In this case we are dealing with metamorphic rocks i.e. the case of partial melting.



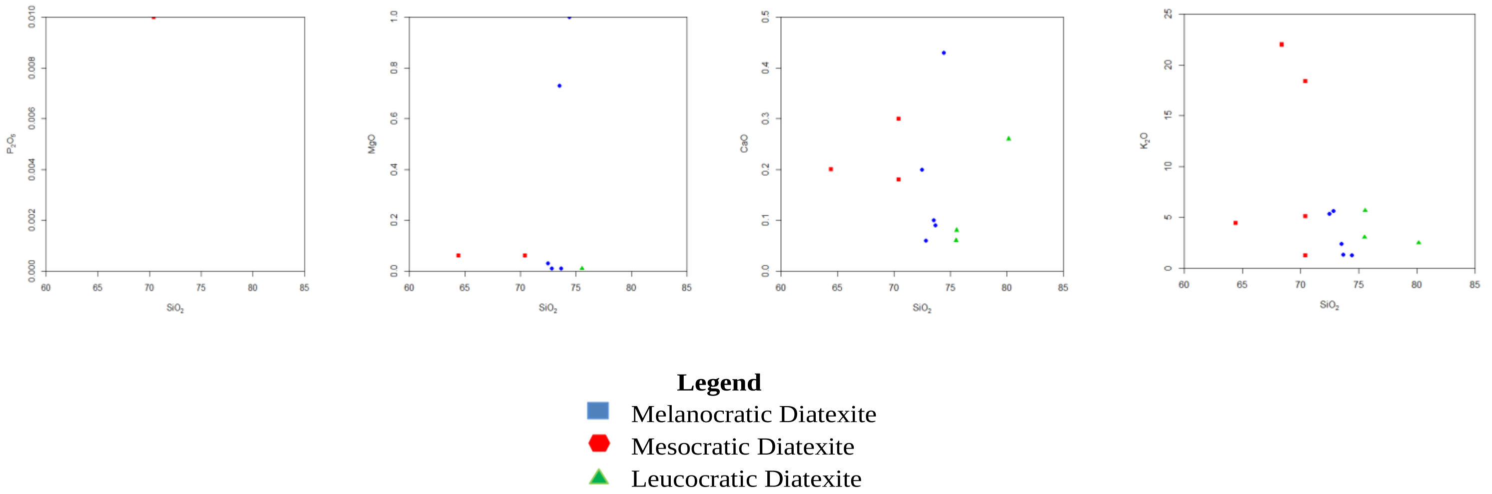


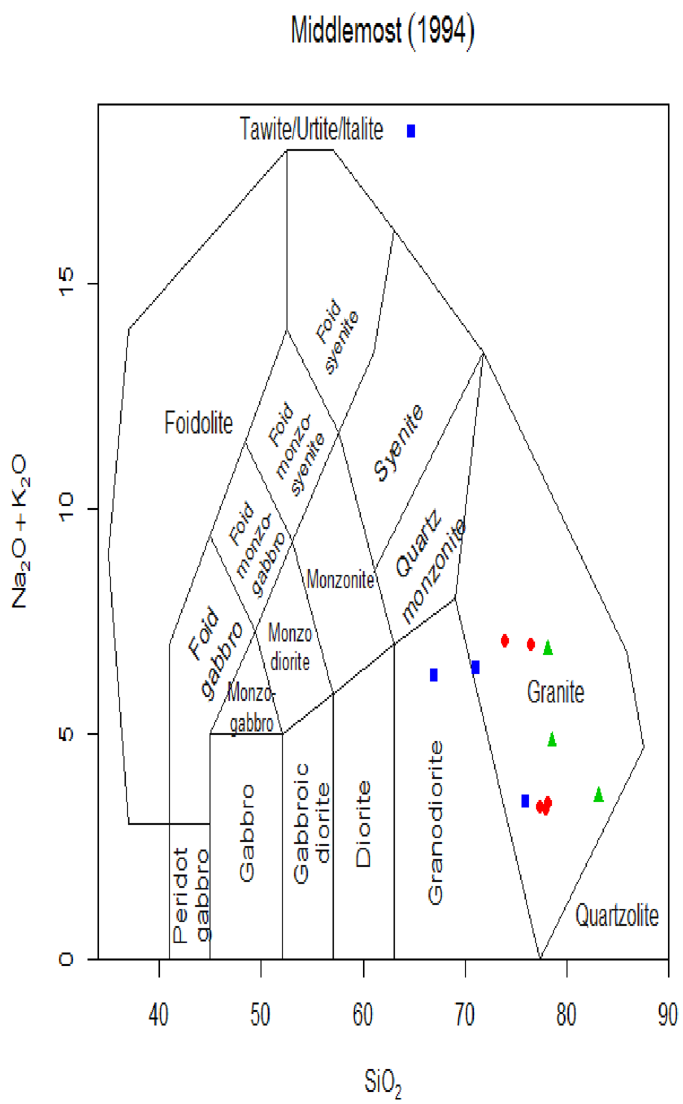
Figure 6: Harker Diagrams of Major Elements for the Diatexite Migmatites

Total Alkali vs Silica Diagram

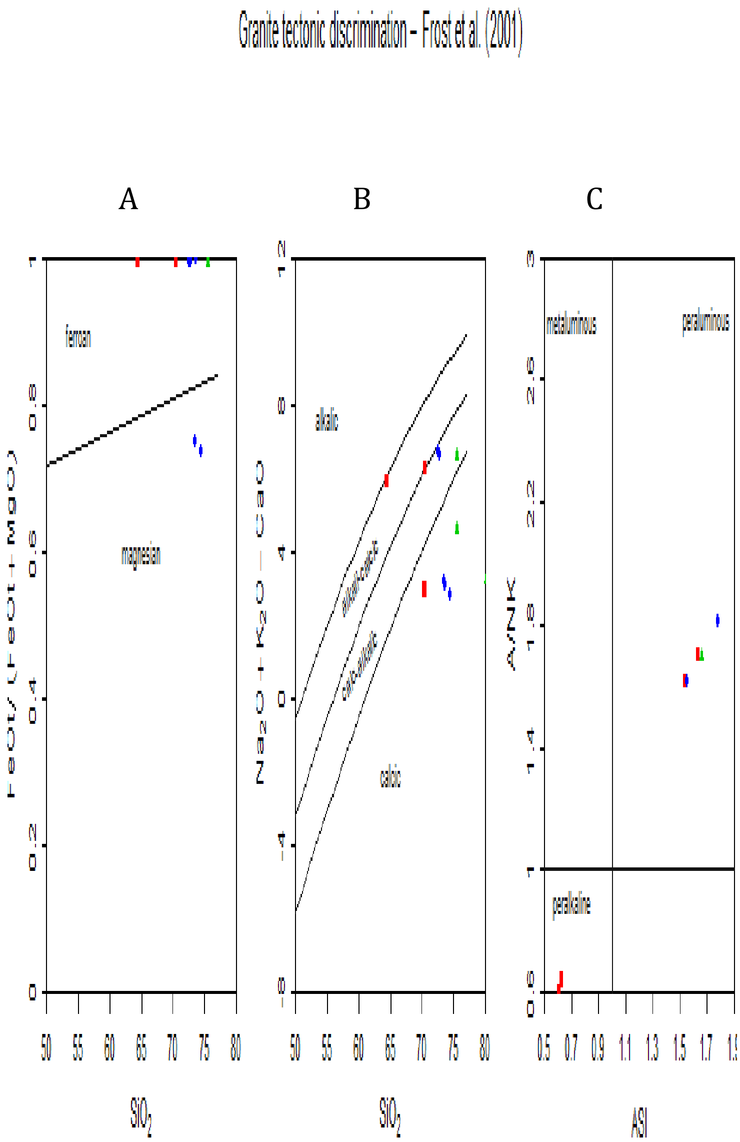
About 90% of the samples fell within the granite field while one sample of melanocratic diatexites fell within each of the granodioritic and Tawite/Urtite/Italite fields **(**Figure 7**).** Partial melting of granodiorite and tonalite under vapour-absent conditions will generate A-type granite magmas similar to the studied rocks in the area, and A-type granites can also be sourced from partial melting of S and I-type, from this geochemical signature the diatexite migmatites in the study area are petrogenetically related to the A-type granites, therefore the diatexite migmatites studied can be considered to be part of A-type granitoids of Bauchi.

Tectonic discrimination

Figure 8A shows that the diatexite migmatites belong to the ferroan group but two samples of mesocratic diatexite belong to magnesian group. In SiO_2 (wt. %) vs. (Na_2O+K_2O+CaO) (wt. %) diagram (modified alkali lime index, MALI) of Frost et al., 2001, with increasing SiO_2 composition, the diatexite migmatites are of alkali-calcic, calc-alkalic and calcic (Figure 8B). The diatexite migmatites are strongly peraluminous to weakly peralkaline (Figure 8C).



Legend
Melanocratic Diatexite
Mesocratic Diatexite
Leucocratic Diatexite



Legend
Melanocratic Diatexite
Mesocratic Diatexite
Leucocratic Diatexite

Figure 7: Total Alkali vs Silica Plots of Middlemost, 1994

Figure 8: Plot of tectonic discrimination (Frost, 2001)

Discriminant plot (boundaries modified after Pearce, 1984)

The diatexite migmatites, as shown in (Figure 9) are thought to have originated from the volcanic arc granite, oceanic ridge granite and post-collisional tectonic settings.

AFM Diagram

The "AFM" diagram proposed by Irvin and Baragar (1971) can discriminate tholeiitic, calc-alkaline affinity of Subalkaline rocks. On the AFM diagram, the rock samples plot within the tholeiite and calc-alkaline series. All the samples on AFM diagram show low MgO values but high total alkali and Fe_2O_3) values (Figure 10). The diatexite migmatites show a trend parallel to the AF side of the AFM diagram, indicating crystallization may be under low oxygen fugacity.

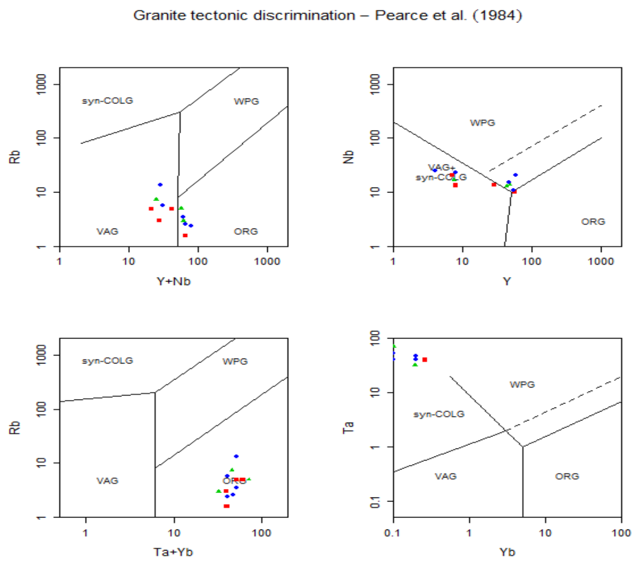


Figure 9: Rb vs. Y+Nb Discriminant Plot (boundaries modified after Pearce, 1984)

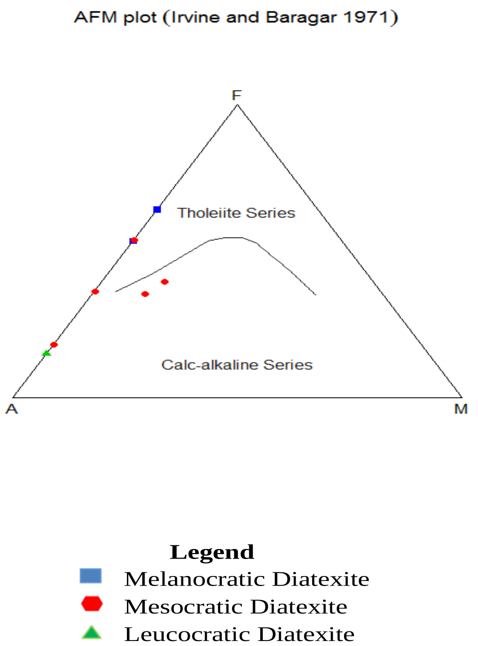


Figure 10: AFM diagram (after Irvine and Baragar, 1971)

Spider Diagram

In this diagram, compatibility increase from left to right. Chondrite normalized spider pattern of diatexite migmatites of the study area shows relative enrichment in the incompatible element with respect to chondrite (Thompson, 1982). The diatexite migmatites show enrichment in Ba, K, Ta, Sr, Zr, Hf, Y, and negative Th, P, Ti, and Yb anomaly (Figure 11).

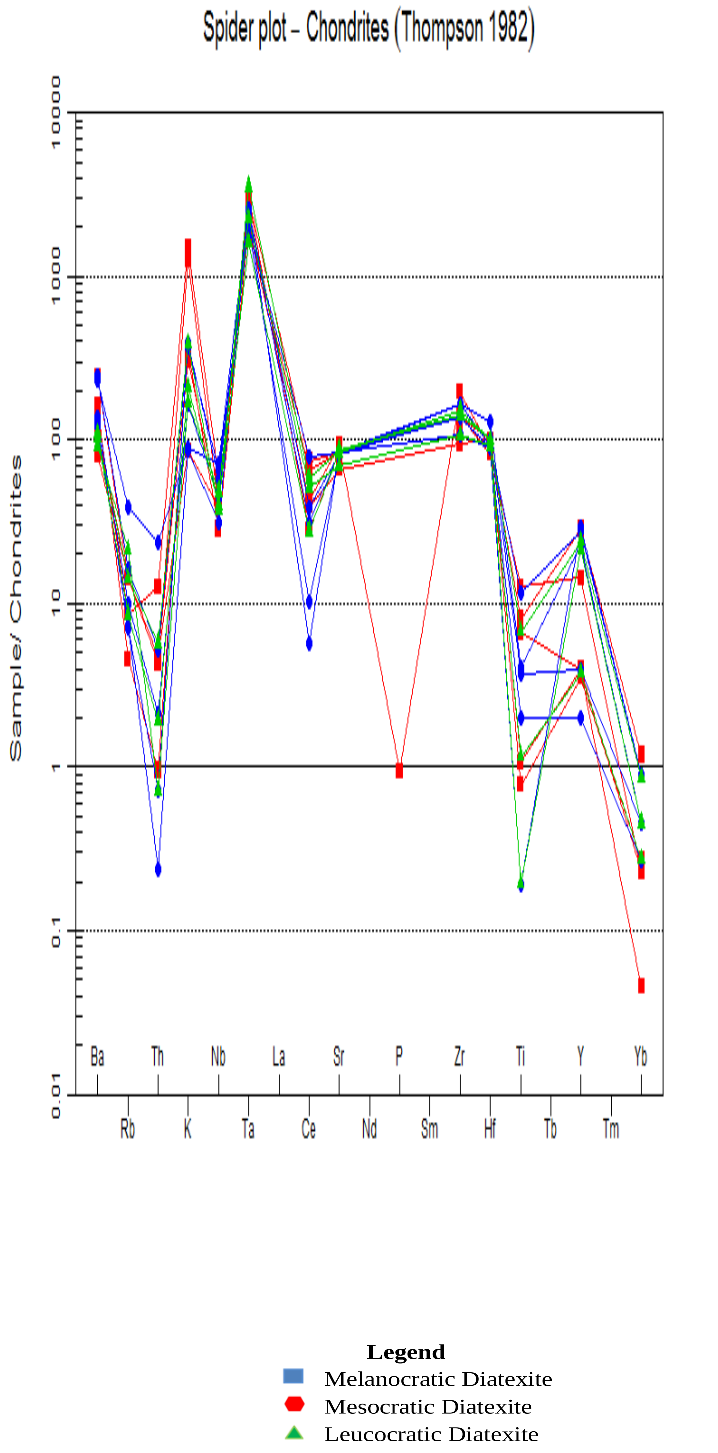


Figure 11: Chondrite-normalized incompatible elements pattern for diatexite migmatites Normalization values from Thompson (1982)

6. Conclusion

The following conclusions can be drawn from the evaluation of geochemical data and field/morphological parameters of the study area:

1. The study area has diatexite migmatites as major mappable morphological units occurring as melanocratic, mesocratic and leucocratic diatexites having clear contact relationship with each other while the metatexite migmatites occurring as patches representing patch metatexites in the study area but in traces and scanty.

2. The preferred elongation of biotite and abundance of metamorphic mineral assemblages indicated grade of metamorphism from metatexites to the diatexites and also indicated by the range in grain sizes of quartz.

3. The rocks show S and I-type affinity (highly peraluminous to weakly peralkaline), with relatively high content of SiO_2, Al_2O_3 and Fe_2O_3 and low content of CaO, MgO.

4. The geochemical plot of discrimination diagram of tectonic environment shows that the rocks in the study area are majorly associated with volcanic arc granite and ocean ridge granite environments.

5. The rocks are of sedimentary and igneous protoliths and the transformation process from one morphological form to another is the cause of their lithological diversity and heterogeneity.

6. The textural imprints of partial melting processes are widespread in metatexites and in diatexites rocks and the abundance of biotite and plus or minus orthopyroxene and silliminite are added indicators. The correlation patterns of Harker variation diagrams are controlled by the geochemistry of solid phases that are added to the melt.

7. The diatexite migmatites were formed under granulite facies conditions ascertained by granulite mineral assemblages while the traces of patch metatexites in the study area have been deformed from amphibolite facies conditions.

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