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Geochemistry of metatexite and diatexite migmatite within Zongor northeastern Nigeria: constraints on petrogenesis and tectonic environment

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Abstract: *The geology of the Zongor area comprises of migmatites that appears to have undergone varying degree of metamorphism and multiple phases of deformation. This has resulted in preservation of original protolith structures such as foliation in some parts of the study area and absence of such structures in other parts of the study area. The geochemistry of these rock suites is analyzed using X-ray Fluorescence (XRF) geochemistry which allows for quantitative determination of major and trace elements. The geochemical signatures of the migmatites are typically continuous within the diatexites but show a slight variation from the metatexite (stromatic migmatites). The diatexites show high silica content with a range of 75% to 79% from the melanocratic diatexite to the leucocratic diatexites while the metatexite has the lowest content of SiO2 constituting about 52% but shows the hightest content of ferromagnesian with MgO and FeO constituting 6% and 13% respectively. The variation of magnesium oxide and iron oxide with silica for all the diatexites shows an even trend with low content of MgO and CaO corresponding to high silca content. The geochemical data are plotted on major tectonic discrimination diagrams to distinguish the nature of original magma content. This paper aims at characterizing the two migmatites types of the Zongor area in terms of field occurrence, texture, mineralogy and whole-rock geochemistry and further attempts to discriminate their tectonic history based on their geochemistry*.

Keywords: *Metatexites, Diatexites, Partial melting, Protolith*

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I. Introduction

Tomoyuki et al, 2002 describes metatexite migmatites as layered migmatites that are made up of leucosome and melanosome with metamorphic fabrics, while diatexites are massive and more homogeneous type and has plutonic igneous textures. For proper understanding of partial melting and processes of melt transport within the middle to lower continental crust, the study of migmatites in high temperature metamorphic terranes is key (Tomoyuki, 2002). The Zongor area is zone of high-grade metamorphism as indicated by the occurrence of high temperature minerals like anorthite which could indicate granulite facies metamorphism. The area covers approximately 68km square and lies between longitudes E09º56’00’’ to E10º 00’00’’ and latitudes N10 º 21’ 00’’ to N10 º 25’00’’ (Figure 1). This study is focused on investigation of the geochemical characters of rock units within the Zongor area to infer the nature of the original protolith and original rock structure left during partial melting as well as characterize the two migmatites types of the Zongor area in terms of field occurrence, texture, mineralogy and whole-rock geochemistry.

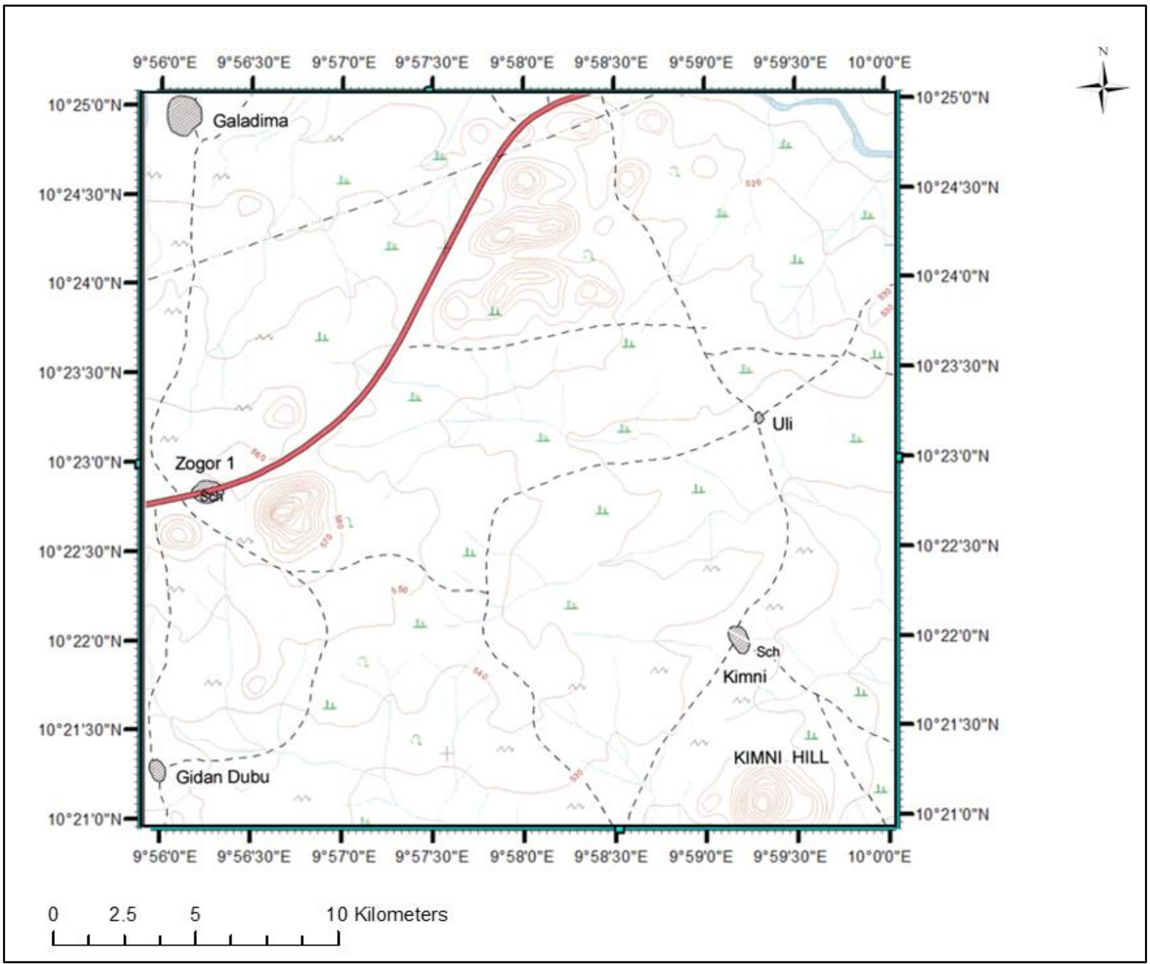

Figure 1: Section Topographic map of the study area

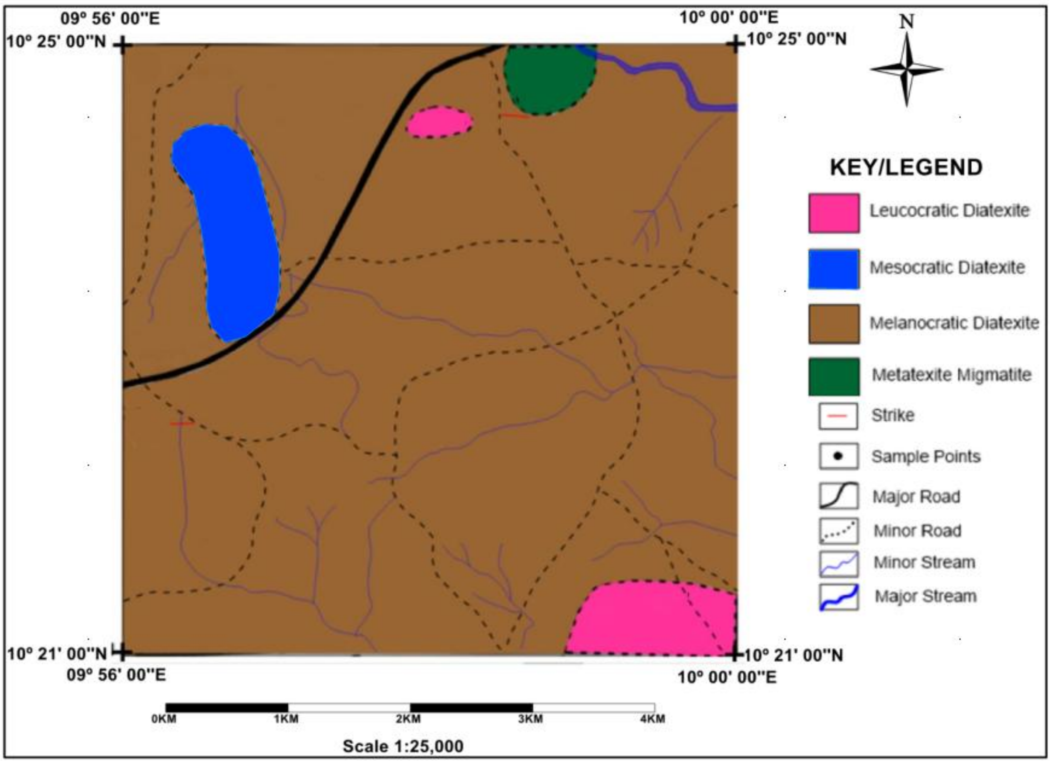

Figure 2: Geological map of the study area showing the different migmatites types

II. Geological Background

The study area is part of the northern Nigeria Neoproterozoic Trans-Saharan belt (Figure 2) 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 (Ferre, 2006). The metamorphic rocks of northern Nigeria which underlie the greater part of the region consist mainly of monotonous granite–high-grade gneisses and migmatites penetrated by large Pan-African monzogranite plutons (Ferre, 2006). The migmatites therefore constitutes an important group of the metamorphic rocks of northern Nigeria. The metatexite migmatites can be distinctly identified as having a planar structure constituting several layers with separate layers having different mineralogy and texture. The metatexite migmatite formed from melt residuum separation at low degrees of partial melting and consequently, low melt fraction. (Milord, 2000). It is important to note that the formation of the diatexite migmatite is based on melt fraction being higher i.e., where the molten rock material has almost been changed entirely to melt (Milord, 2000). The increase in the melt fraction is as a result of an increase in metamorphic temperature, injection of another melt from a different source and the melt being redistributed within the melting layer. These reasons were reported by Brown, 1973, Greenfield et al., 1996 and Sawyer, 1998 respectively. Where the metasedimentary rocks melted sufficiently to undergo magma flow, but did not experience a significant melt-residuum separation, mesocratic diatexites were formed. The mesocratic diatexites goes into the magma separation and further give rise to melanocratic diatexites on one hand and leucocratic diatexites on the other hand.

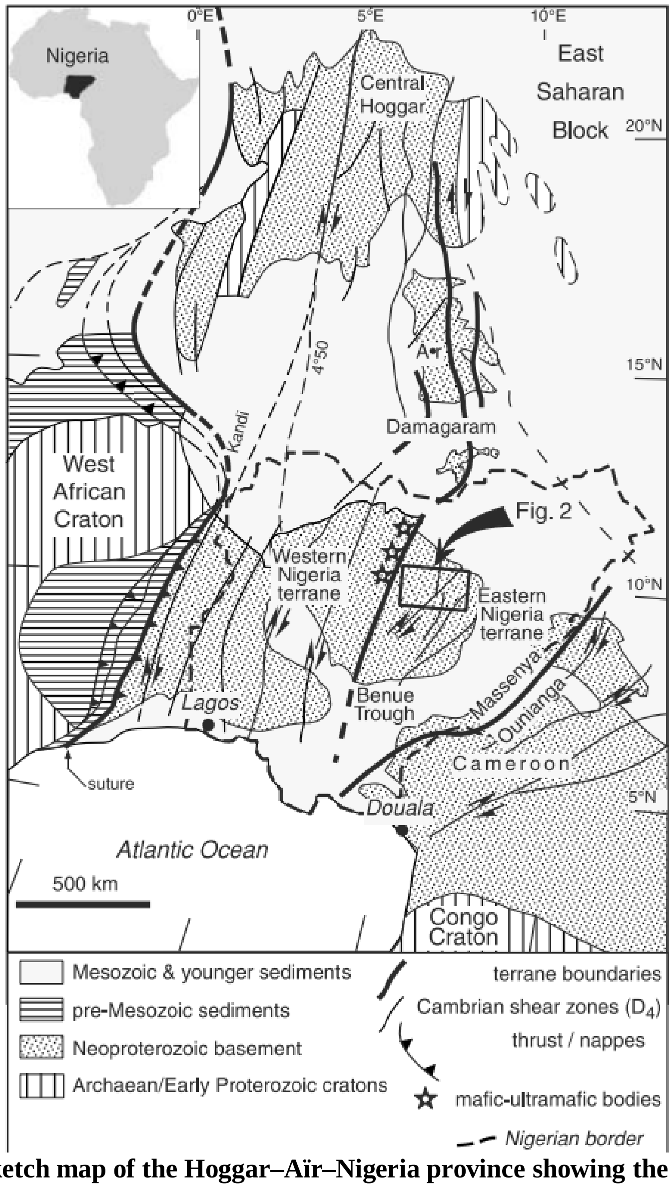

Figure 2: Geological sketch map of the Hoggar–Aïr–Nigeria province showing the Neoproterozoic Trans-Saharan belt resulting from terrane amalgamation between the cratons of West Africa and Congo and the East Saharan block. (Ferre, 2006)

III. Methodology

XRF method of geochemical analysis was used. The XRF is a method for measuring the thickness of coatings and for analyzing materials and can be used for the qualitative and quantitative determination of the elemental composition of a material sample. (Van Grieken (2013)). The samples are firstly crushed, to break down aggregates using a jaw crusher or any other suitable tool for size reduction. The particles are then air-dried in a clean place, then major and trace elements (including REEs) were determined by X-ray Fluorescence. For XRF measurements, a sample has to be additionally pulverized, homogenized and pressed into pellet with or without a binder. Usually chromatographic cellulose, boric acid or starch are used as a binder in a proportion 1:10 by weight (in some cases a liquid binder might be used). For the emission—transmission method usually a 150 or 200 mg pellet is prepared (25 mm diameter).

IV. Results

The geochemical data for ten representative rock samples from the Zongor 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. Using the results of the whole rock analysis for major and trace elements from XRF, the major elemental composition is used to classify the migmatites. For compositional variation of the migmatities, the Harker plots is used to show the relationship of silica content of the rocks with major oxides. Cross Iddings Pirsson and Washington (CIPW) and granite mesonorm are used for classifying the rocks with respect to their mafic mineral content while feldspar triangular diagram is used for classifying the feldspars into their appropriate groups. Frost et al., 2001 plot of tectonic discrimination is used for describing the tectonic history of the rocks. Trace elements are analyzed using spider plots.

4.1 Major Elements

Representative XRF from the ten rock samples of metatexite and diatexites of the Zongor area are given in Table 1. The metatexite and diatexites show variation in geochemical composition. These differences in geochemical characteristics are plotted using Harkers variation diagram. CIPW, granite mesonorm and tectonic discrimination plots are also generated for further classification.

Table 1: Major element (Wt.%) and Trace elements composition (ppm)

Oxides/Elements	A	B	C	D	E1	E2	F	G	H	I
SiO_2	52.00	76.80	76.40	77.70	77.50	75.80	78.40	74.70	78.00	78.70
CaO	2.80	1.00	3.83	0.46	0.50	3.05	3.80	3.02	0.84	0.40
MgO	6.00	0.46	1.00	0.21	0.08	0.78	0.39	0.70	0.26	0.06
SO_3	0.20	0.043	0.034	0.03	0.040	0.16	0.084	0.11	0.062	0.014
K_2O	0.40	3.00	1.80	3.00	5.00	0.63	0.53	1.00	3.00	5.00
Na_2O	0.12	1.06	0.77	1.69	2.00	0.48	0.40	0.51	1.40	1.34
TiO_2	2.32	0.80	1.12	0.43	0.14	1.09	1.03	1.21	1.10	0.26
MnO	0.20	0.067	0.06	0.058	0.03	0.10	0.070	0.095	0.066	0.023
P_2O_5	0.06	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe_2O_3	13.40	1.06	1.01	0.43	0.12	2.36	1.17	2.09	1.52	0.34
Al_2O_3	17.20	13.01	13.10	13.24	12.81	13.23	12.64	14.30	12.06	11.66
LOI	7.42	1.01	0.80	1.24	0.70	1.42	0.89	1.32	0.78	0.60
V	310.46	210.30	492.00	50.40	12.10	390.60	370.14	430.00	80.80	0.24
Cr	406.00	181.00	244.31	90.00	8.62	120.00	110.00	110.24	16.01	<0.01
Cu	590.00	250.11	390.00	200.40	190.10	250.00	240.86	260.34	260.00	27.60
Sr	1946.60	2060.00	2590.12	1500.00	1280.00	1420.00	2330.00	1900.00	890.00	1020.00
Zr	6480.00	606.30	1000.00	468.20	60.00	630.30	700.00	770.00	1540.00	140.00
Ba	<0.01	5000.00	700.22	2500.00	600.00	10.00	2000.00	100.00	2100.00	1700.00
Zn	330.44	93.00	151.01	83.30	16.00	360.21	140.00	190.00	80.50	8.44
Ce	<0.01	1.12	0.04	<0.01	8.40	0.01	2.00	<0.01	<0.01	1.40
Pb	<0.01	330.00	330.14	80.11	180.00	71.01	330.00	181.84	360.00	190.00
Ga	<0.01	13.10	18.00	8.10	7.20	15.00	11.06	0.08	10.00	1.60
As	<0.01	0.24	<0.01	0.94	0.94	<0.01	<0.01	<0.01	4.00	0.83
Y	<0.01	2.46	<0.01	1.10	1.70	0.02	<0.01	0.020	0.19	0.70
Rb	100.06	149.62	145.00	176.00	162.00	149.40	137.00	151.21	165.60	168.60
Nb	<0.01	<0.01	<0.01	6.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	0.24	3.06	<0.01	<0.01	1.10

Ta	<0.01	<0.01	<0.01	3.501	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
W	0.161	<0.01	<0.01	0.84	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hf	54.604	21.00	41.06	23.10	5.34	32.00	41.06	40.00	68.26	20.18
Sn	0.401	<0.01	0.44	<0.01	<0.01	0.28	0.60	0.62	<0.01	<0.01
Sb	1.106	<0.01	1.50	<0.01	<0.01	1.40	1.48	1.60	<0.01	<0.01
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bi	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sc	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni	70.606	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mo	<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	<0.01	<0.01	<0.01	2.70	<0.01	<0.01	<0.01

4.1.1 Classification

CIPW norm calculation classifies individual mineral content of the rocks corresponding to metatexite, melanocratic diatexite, mesocratic diatexite and leucocratic diatexite. The results of the classification are given in Table 2.

Table 2: CIPW-norm Classification

Rock Types	**Meta-texite**	**Melanocratic Diatexite**			**Mesocratic Diatexite**			**Leucocratic Diatexite**		
Samples	**A**	**C**	**E2**	**G**	**B**	**F**	**H**	**D**	**E1**	**I**
Orthoclase	0.000	1.612	1.169	3.476	16.122	7.548	16.409	16.923	29.246	29.232
Albite	1.016	3.522	4.066	4.320	8.978	6.388	11.858	14.314	16.940	11.350
Anorthite	6.101	18.997	15.128	14.979	4.960	6.848	4.166	2.282	2.480	1.984
Quartz	37.585	45.828	54.067	50.439	57.001	56.910	56.564	64.390	65.640	61.895
Apatite	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hematite	13.400	1.010	2.360	2.090	1.060	1.170	1.520	0.430	0.120	0.340
Ilmenite	2.204	1.064	1.036	1.149	0.760	0.978	1.045	0.408	0.133	0.247
Biotite	6.176	4.341	3.657	3.449	2.281	2.200	1.789	1.149	0.441	0.435
Amphibole	28.408	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corundum	13.40	2.915	6.207	6.882	6.201	4.492	4.981	6.374	3.200	3.321
Sum	97.264	99.090	97.520	97.625	97.257	98.430	98.246	97.218	98.180	97.783

4.1.2 Harker's Variation Plot

Harker variation diagram (Figure 3) gives a relationship between silica and the major elements of the rock samples and portrays the degree of magma diversification within a wide range. The metatexite has the lowest content of SiO_2 constituting about 52% but shows the hightest content of ferromagnesian with MgO and FeO constituting 6% and 13% respectively. The diatexites show high silica content with a range of 75% to 79% from the melanocratic diatexite to the leucocratic diatexites (Figure 3). The melanocratic diatexite displays an increase in calcium oxide with increasing silica content. While the leucocratic diatexite show increase silica content with a corresponding decrease in calcium oxide, the mesocratic diatexites show a fair increase in calcium oxide with a corresponding increase in silica content.

The variation of magnesium oxide and iron oxide with silica for all the diatexites shows an even trend with low content of MgO and CaO corresponding to high silca content. In all the rock samples, there is a negative correlation between aluminium oxide Al_2O_3 and silica SiO_2. In the metatexite, with increase in aluminium oxide, there is a correspoding decrease in silica, while the reverse is the case for the diatexites.

Leucocratic diatexites shows the lowest concentration of titanium oxide while the metatexite displays high titanium content. Potassium oxide is seen occuring in relatively similar amount i.e. between 0.5% to 1.5% in the metatexite and melanocratic diatexite. A higher concentration from above 2.5% to 5% is notable for the leucocratic and mesocratic diatexites.

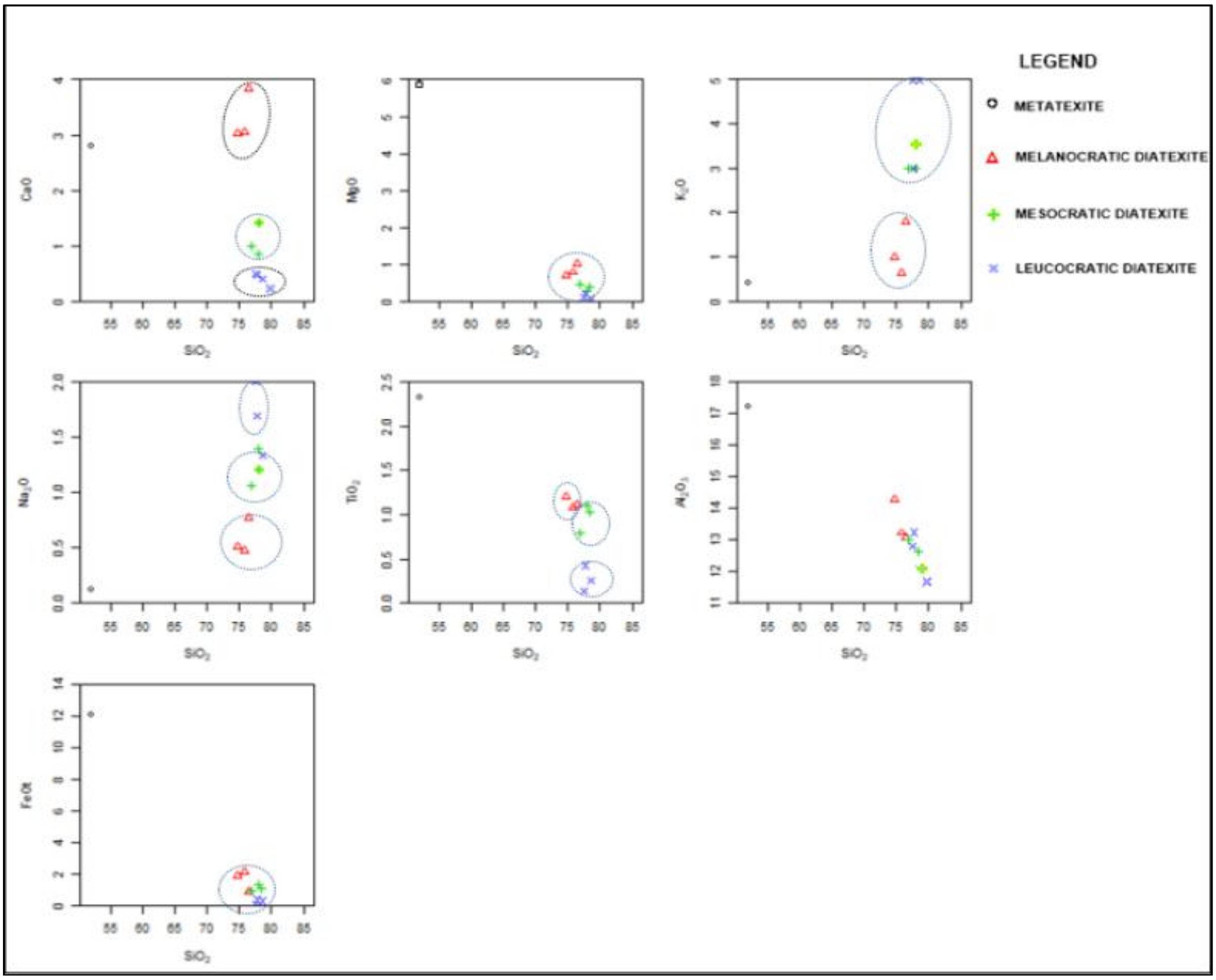

Figure 3: Harker's variation plots of Silica versus major elements

4.1.3 Feldspar Plots

Feldspar plot is used to show the distribution and proportion of sodic, alkali and calcic feldpsar present in a rock sample. The plot (Figure 4) shows the leucocratic and mesocratic diatetxites represented by samples D, E1 and I and samplws B, F and H respectively, as been rich in alkali feldpsar and sodic plagioclases relative to calcic feldspars. The alkali feldspar represents a about 70% of the feldspars in these rocks. The metatexite and the melanocratic diatexites represented by sample A and samples C, E2 and G respectively, on the other hand show a higher content in calcic plagioclase (about 80%) relative to alkali and sodic endmembers. In the metatexite, plagioclase occurs as anorthite, while in the melanocratic diatexite, it occurs as bytownite.

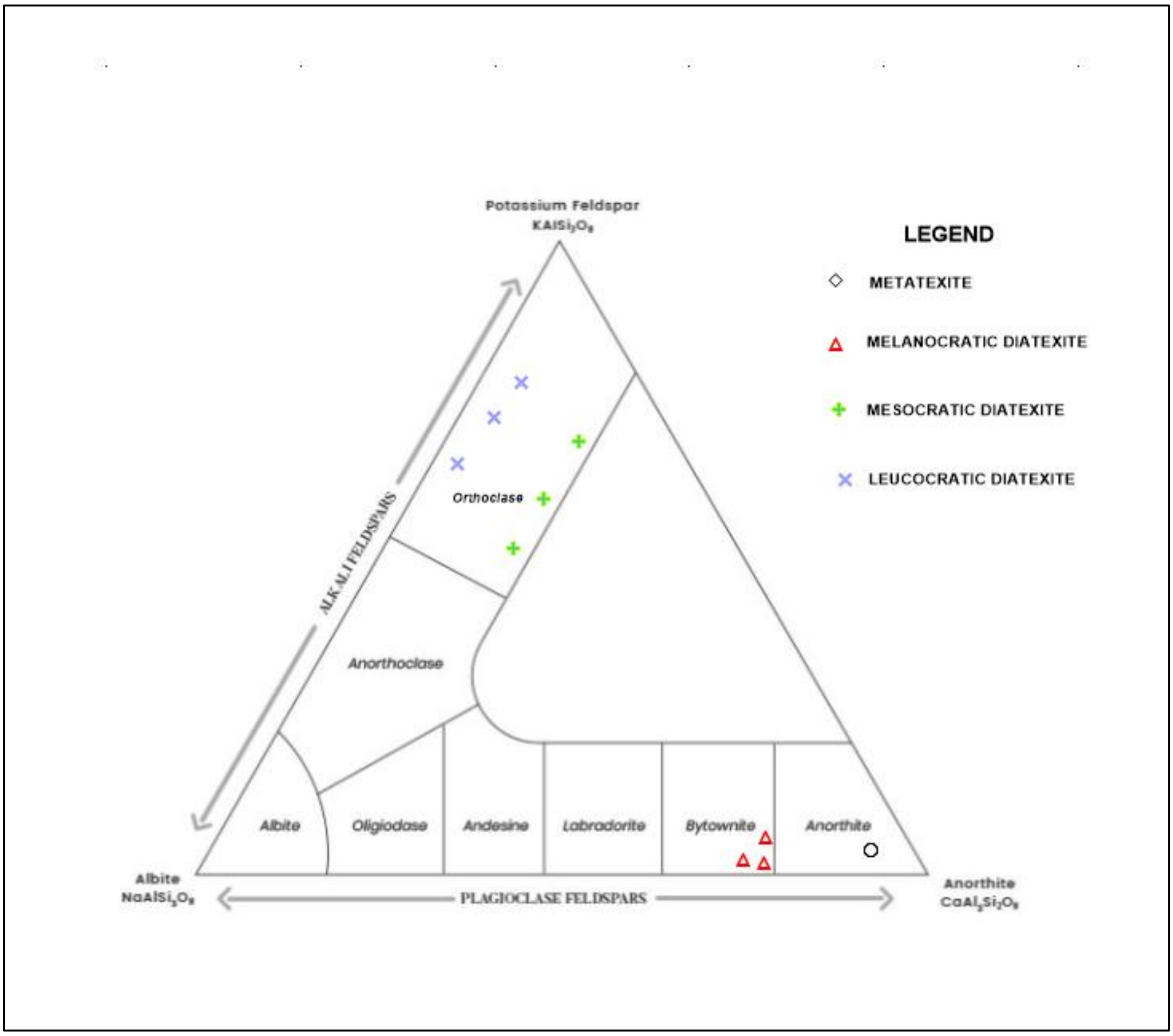

Figure 4: Feldspar Triangular Plot

4.1.4 Tectonic Significance

The geochemical data from the metatexites and diatexites were plotted on various major tectonic discrimination diagrams which are typically used for distinguishing Mid Oceanic Ridge Basalt (MORB) and Island Arc Tholeiite (IAT). In the TiO_2-MnO-P_2O_5 ternary tectonic diagram (Figure 5) all the diatexite sample plot in the field of calc-alkaline series while the metatexite fall in the tholeiite series. In Frost et al plot of tectonic discrimination, FeOt/ (FeOt – MgO) show all the studied samples as having magnesian signature (Figure 6). The Na_2O+K_2O – CaO plot, Figure 6 show the diatexites to fall within the calcic portion with an increase from about -4 to 0 in melanocratic diatexite to about 0 to 4 in mesocratic and leucocratic diatexite. The diatexites show a corresponding increase in silica content ranging from about 75% to 80%. The metatexite plots in the field of calc alkaline with a corresponding low amount of silica.

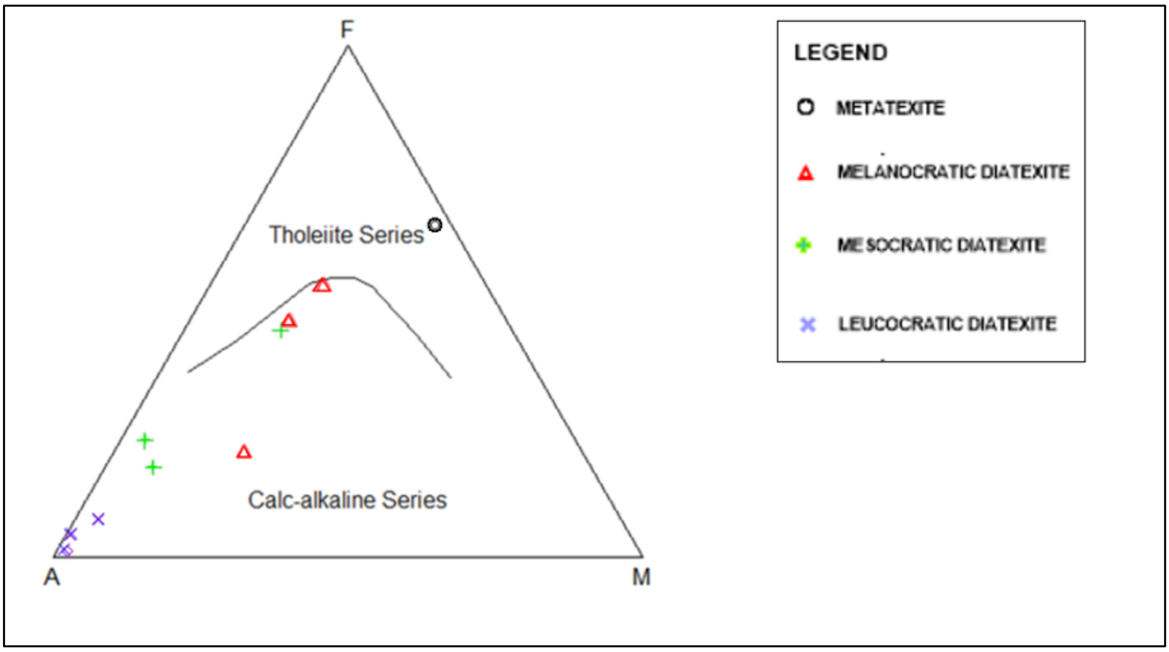

Figure 5: AFM Plot (after Irvine and Baragar 1971)

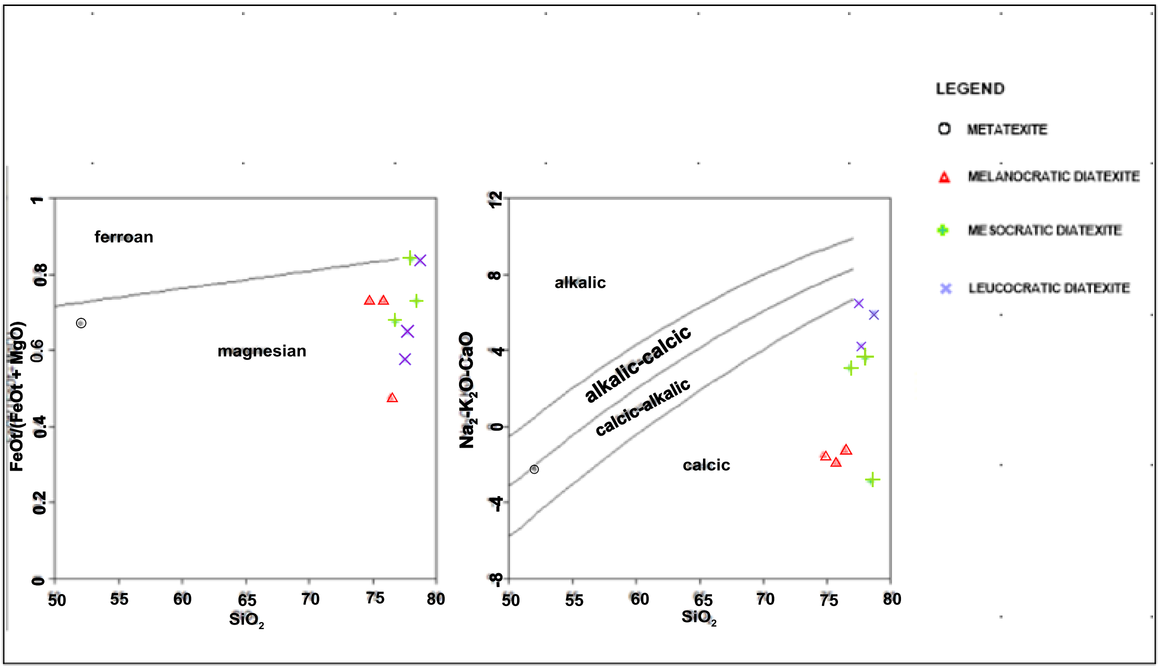

Figure 6: Tectonic Discrimination plot (Frost et al. 2001)

4.2 Trace Elements

Trace elements are analyzed using spider plots. The spider plots show the variation of trace elements in relation to compatibility in the rocks. The spider plots (Figure 7) are normalized to the composition of the average upper crust after Taylor and McLennan, 1985. The spider plot for the metatexite shows an overall trend different from the general trend given by the diatexite migmatites.

Trace element concentration of the metatexite include high nickel and high chromium (70.606 and 406.00 ppm respectively). The diatexites on the other hand show a corresponding low amount of nickel and chromium with a range of about less than 0.01 for nickel and between <0.01 to 181.00 ppm for chromium. Taylor and McLennan normalized upper continental crust plot of the metatexite show a somewhat enrichment in LILE (Rb, K, Ta) and depletion in HFSE (Ba, Nb, Y). The diatexites on the other hand, show a relatively high HFSE content (Se, Zr, Ba) and a highly variable LILE content. The slight change in composition indicate that the migmatites are cogenetic and a mantle source protolith. The input of volcanic rocks causes a divergence in the quantity of trace elements.

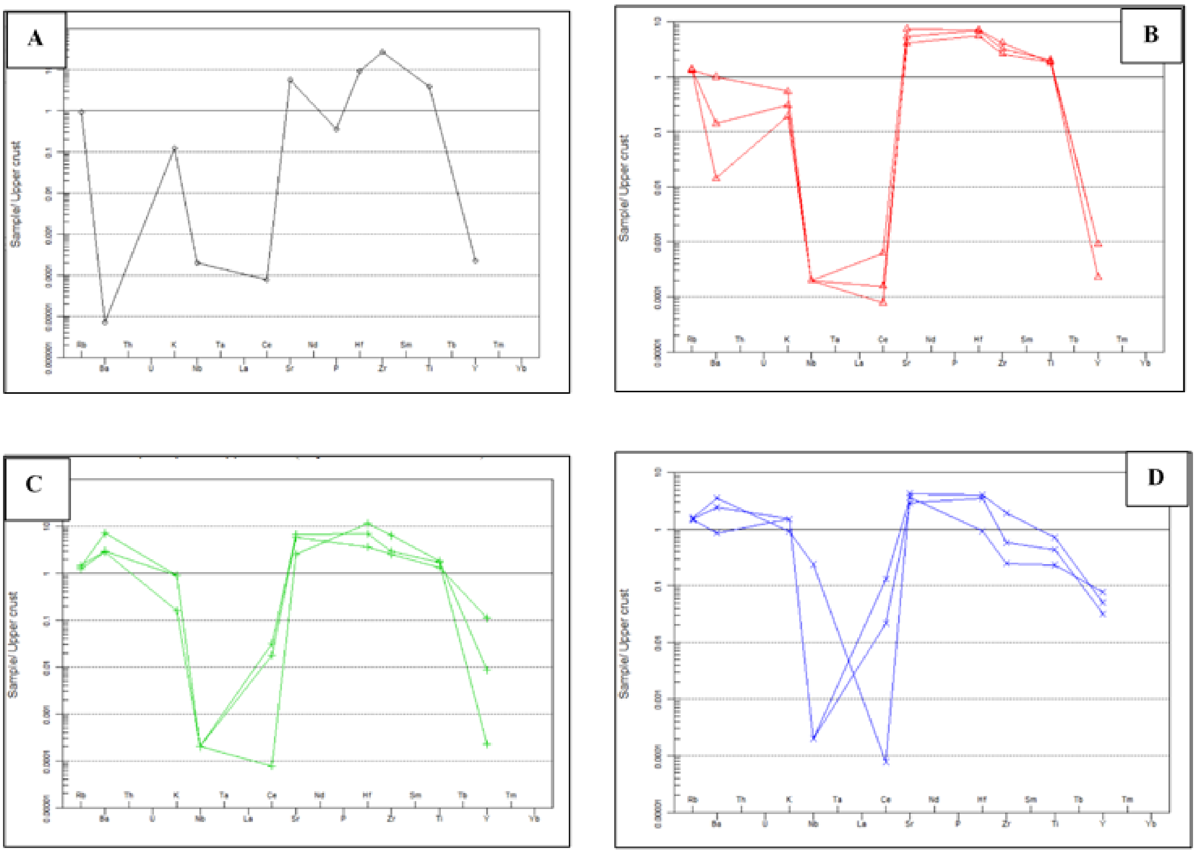

Figure 7: Spider plot (Taylor and McLennan, 1985) A: Metatexite B: Melanocratic Diatexite C: Mesocratic Diatexite D: Leucocratic Diatexite

4.3 Loss on Ignition (LOI)

Loss-On-Ignition (LOI) used in the whole rock analysis is the measurement of total volatiles usually added to the other oxides to get total up to 100 ± 1%. The LOI of the metatexite is high about 7% relative to that of the diatexite between the ranges of 0.6% to 1.42%. When high, volatiles reduce the viscosity of the magma. This suggests that volatiles act as fluxing agents which inhibits the nucleation of schists.

V. Discussion

The major and trace element components of representative rock units from the Zongor area have been used to evaluate the geochemical attributes and to constrain the nature and petrogenetic trends of the migmatites in the study area. The Harker variation plot was employed to display the trend for expected magma generation. However, due to the limited size of the study area and the scarcity of data, the variation trends are not very conclusive. K_2O and Na_2O exhibit a positive correlation with SiO_2 in the leucocratic and mesocratic diatexites. This relation between K_2O/Na_2O and SiO_2 is in accordance with crystallization of K-feldspar and gradual potash enrichment with progressive differentiation. (O'Connor, 1965). No discernible trend is shown by CaO when plotted against SiO_2 except in the melanocratic diatexites and metatexite showing high content of CaO depicting a calcic rich character of these migmatites. There is negative correlation between MgO and SiO_2 in all rock samples. While the metatexite show high MgO content with a corresponding low silica, the reverse is the case for the diatexites. The high K-character of the leucocratic and mesocratic diatexites corresponds with their high Al_2O_3 content (>10%) and is reinforced by marked abundance of potash feldspars (Lidgeois et al., 1998). The peraluminous property of the diatexites implies high development of k-feldspar with continuous fractional crystallization as the system is cooling and temperature is dropping (Frost and Frost, 1997). CIPW normative composition and granite mesonorms have been calculated for the migmatites (Table 2). The calculation classifies individual mineral content of the rocks corresponding to metatexite, melanocratic diatexite, mesocratic diatexite and leucocratic diatexite. Metatexites and melanocratic diatexites show high concentrations of ferromagnesians including amphiboles, biotite and hematite. They also show abundance in plagioclase relative to the mesocratic and leucocratic diatexites. AFM ternary plot (Figure. 5) (Irvine and Baragar, 1971), shows the diatexite samples belong to the calc-alkaline series and thus differ from the metatexite belonging to the tholeitic series. The migmatites in the study area are characterized as magnesians based on tectonic discrimination plot of Frost et al, 2002 (Figure 6). The magnesian character of the rocks suggests lack of iron-enrichment and relatively oxidizing trends due to early crystallization of magnetite (Frost et al., 2001). Trace element data (Table 1) obtained for the migmatites suggest that these rocks are characterized by strong fractionation of the LREE to HREE as displayed by the high Ce/Ba ratio. Spider plots (Figure 7) normalized to the composition of the average upper crust (Taylor and McLennan, 1985) for incompatible trace elements depicts that the metatexite are somewhat enriched in LILE and show a depletion in HFSE. High Rb/La, Ba/La of trace element composition which is observed in metatexite and is indicative of enriched mantle basalts. (Matthias, 2006). Partial melting of a rock of mafic composition i.e., basalts can serve as the petrogenesis of a mafic parent magma for the metatexite. There is a general trend for spider plots of the diatexite which differs slightly from the trend for the metatexite. In general, variation patterns of trace elements like Ba, Sr have been effectively used for evaluating fractional crystallization processes in granitic magma (Mittlefehldt and Miller, 1983; Mackenzie et al., 1988). The wide range between the compatible elements of leucocratic and mesocratic migmatites can the attributed to the dominance of alkali feldspars during fractional crystallization of the melt and further suggests role of fractional crystallization of K-feldspar in the migmatites. The geochemical variations observed for the migmatites are in consonance with the idea of fractional crystallization playing a dominant role in their petrogenetic evolution. Distinct geochemical aspects including high SiO_2 (75% to 79%) together with high K, and high Al_2O_3 suggest the derivation of diatexites from mantle source materials.

VI. Conclusion

The geochemistry of the migmatites in the Zongor area have been studied. The different suites of migmatite in the Zongor area is a consequence of partial melting resulting from high grade regional metamorphism. The in-turn results in different morphologies that are generated at different stages of partial melting. The presence of orthopyroxene and plagioclase of anorthite composition in the rocks are evidence for high grade regional granulite facies metamorphism. A metasedimentary rock (pellitic schist) is suggested as the protolith for the migmatites as reflected from the peraluminous nature of the rocks. From the geochemistry, the predominantly magnesian, calc-alkalic and strongly peraluminous characteristics of the rocks in this study suggest a close affinity to relatively hydrous, oxidizing melts and source regions, which are common in subduction-related settings.

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