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Petrography and Geochemical Reconstruction of Provenance and Melt Extract Estimation of Migmatites around Dungulbi Area of Bauchi State

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***Abstract**: The study area is situated in Bauchi within the north-central Basement complex of Nigeria. It lies within latitudes $N10^0$ $15^{'}$ $00^{''}$ to $N10^0$ $18^{'}$ $00^{''}$ and longitudes $E9^0$ $55^{'}$ $00^{''}$ to $E9^0$ $59^{'}$ $00^{''}$ and covers an area of about 38.52 km^2part of quarter degrees sheet 149 Bauchi N.E. This work presents multidisciplinary data of migmatites in order to ascertain its different subdivisions. The field observations and petrology unravel 3 morphological units of migmatite: (1) Metatexite (2) Diatexite (Leuco-, Meso- and melanocratic) and (3) nebulite. This result favours a melting process; the presence of neosome suggests a high rheological contrast between the neosome and the surrounding rocks. The rocks consist of Biotite, Quartz, Plagioclase, Garnet, Orthopyroxene, Sillimanite, and Muscovite all displaying metamorphic signatures with minor accessory minerals which include Zircon, Ilmenite, Apatite, Hematite and Rutile. The proportion of neosome varies between 20 to 50% and it is segregated into leucosome and melanosome.The study also reveals a proportion melt generated of around 30% by metatexites and greater than 40% by the Diatexite. The major and trace elements compositions of the migmatites are consistent of being chemical form; biotite break down and partial melting of metapelitic association without igneous intrusion. The rocks are calc-alkaline, displaying S-type affinities and appear to be formed in a compressional regime or continental arc tectonic settings and are characterized by high SiO_2,high Alkali concentrationsshowing a predominance of K_2O over Na_2O. The negative correlation of SiO_2 with Al_2O_3, Fe_2O_3, CaO_2, MgO, and positive correlation with K_2O and Na_2O even though some are erratic indicate the features of silicate melt derived from partial melting of metasedimentary source. The thermobarometric estimation based on major oxides mineral studies indicates temperature of 640 – 1080^0C and pressure of 3 – 5Kbar respectively for the formation of the migmatites. The peraluminous (>1.0) nature of these rocksalso strongly point towards a metasedimentary source. This evidence thus points toward all the migmatites being formed by a process of crustal anatexis largely controlled by source composition rather than solely genetic process. This is in keep with recent studies that have also challenged the widely accepted model that migmatite should be studied morphologically and raised questions about the origin of migmatites worldwide.*

***Keywords**: migmatites, metasedimentary, melt, thermobarometry, crustal anatexis, biotite, quartz, pyroxene*

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I. Introduction

Metatexites represent small to moderate degrees of partial melting, in which a pervasive melt fraction does not develop throughout the rock[1,2]. They can be divided into two main parts, the 'palaeosome' and the 'neosome'[3]. The paleosome is described as the parent rock of a migmatite and neosome as the newly formed part of a migmatite. The neosome is divided into the dark 'melanosome' and the light plutonic 'leucosome'. Migmatites are subdivided into metatexites and diatexites[4]. Where migmatitic banding is present, the rock is called a metatexite, where the banding is disrupted due to higher melt volumes, it is called diatexite. In contrast to metatexites, diatexites having compositions similar to granite plutons, represent high degrees of partial melting, and contain variable amounts of restite; pre-migmatization structures are destroyed and homogenization and coarsening of the textures occurred. Sawyer[5] provides genetically based definitions and a system of nomenclature with which it will be possible to describe and map migmatites effectively and to understand how combinations of factors and processes produce a bewildering morphological diversity. The process of migmatization is generally accompanied by prograde reactions that either produces a water-rich vapour phase (subsolidus migmatites[6]) or melt (anatectic migmatites[7]). Kriegsman[8] proposed that anatecticmigmatites commonly show prograde and retrograde reactions between minerals and melt. Felsic migmatites may be generated by melt infiltration from an external source into bandedorthogneiss during deformation.

This research dealt with the geology, petrography and whole rock chemistry of the migmatites subdivisions around Natsiraand Dungulbiof Bauchiin order to characterize the main compositional differences and to elucidate their tectonic settings and to provide a petrogenetic link adding to the existing literatures. The area which is part of quarter degrees sheet 149 Bauchi N.E. lies within latitudes N10^{0} 15$^{'}$ 00$^{''}$ to N10^{0} 18$^{'}$ 00$^{''}$ and longitudes E9^{0} 55$^{'}$ 00$^{''}$ to E9^{0} 59$^{'}$ 00$^{''}$ and covers an area of about 38.52 km^2. It is accessible through a major road linking Bauchi to Gombe and numerous footpaths. Ithas an average elevation of 560m above sea level (Figure 1).

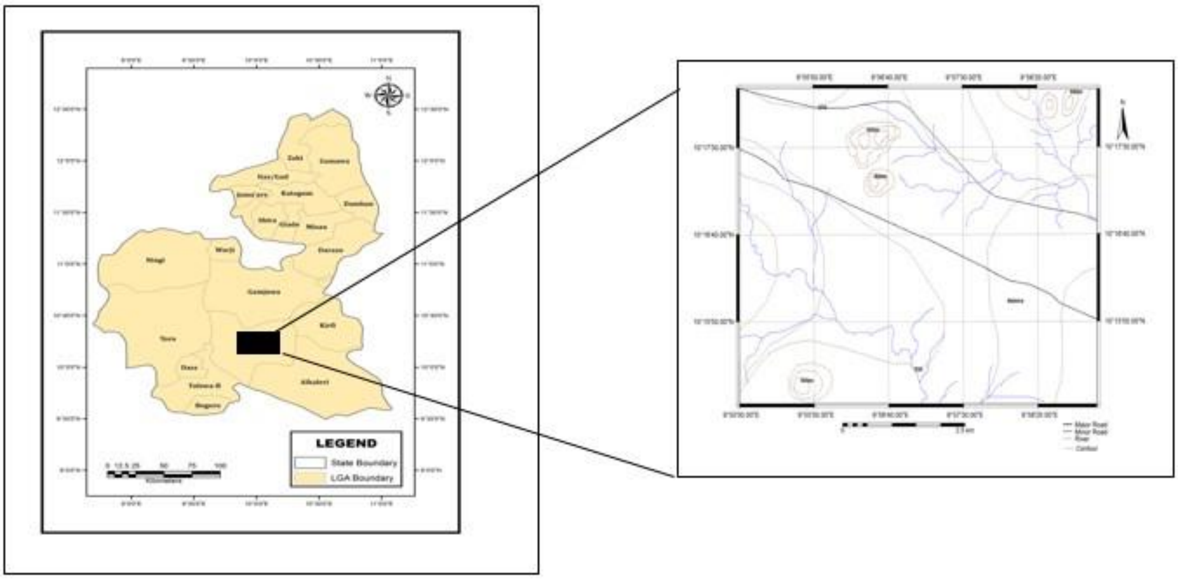


Figure 1: Geographical map of Bauchi State showing the study area

II. Geological Framework

The study area falls within the Neoproterozoic Trans-Saharan Belt and the Migmatisation has been dated to 500±100Ma[9]. It was suggested to be formed from the converging West African Craton, the Congo Craton and East Saharan Block, which was probably a Craton until 700Ma when it was widely and largely reactivated, except in few areas. Its rocks are mainly metamorphic consisting of monotonous granite-highgrade gneisses and migmatites cut by large Pan-African monzogranite plutons and their mineral assemblages were used to determine magmatic and metamorphic thermobarometric conditions and it was shown to be of the Barrovian type metamorphism (medium temperature) based on the result of works by Ferre and Caby[10].The use of U-Pb zircon isotopes to determine the ages of the syn-kinematic to late kinematic plutons suggests that most of the outcrops found in the study area irrespective of the compositions are 638±3ma and 585±7ma[11,12]. The close relationships between the regional tectono-metamorphic evolution of gneisses, regional anatexis and emplacement of syn-kinematic plutons from the monzodioritecharnockite association within the study area strongly suggest that the area underwent a monocyclic metamorphic history[13]. For example, the above statement is in agreement with a model age of 1.8Ga obtained in Tilden Fulani migmatiticmetasedimentary rocks. Hence it further establishes that the source of the metasedimentary rocks is younger than Late Palaeoproterozoic and strengthens the case for a single monocyclic Pan-African evolution. Furthermore, Bauchite happens to be a part of the Neoprotorozoic belt of North Central Nigeria basement where there is a distribution of metamorphic facies[14,15]. High grade metasedimentary rocks reached granulite facies condition and survived as large lenses and pendants interlayered within anatexites and migmatitic granites as noted in Toro area of Northern Nigeria. Thus, extensive sampling of metasedimentary gneisses of the Bauchi area has revealed several occurrences of granulite facies rocks within high temperature amphibolite facies rocks and anatexites[10].

III. Methodology

The area was studied using two methods, these are;

1. The field work/field mapping
2. The laboratory method (petrographic, mineralogical and geochemical studies)

Field Methods

The desk study was conducted with the aid of a topographic map from which the coordinates of the study area were extracted and the area calculated. Fresh samples were taken with the aid of a geologic hammer during the field mapping and locations of each samples extracted from the GPS were recorded in the field notebook. Samples were grouped based on physical characteristics (macroscopic study) and representative samples from each group were selected.

Laboratory Methods

The laboratory method was required in order to confirm the inferred results from the field work through petrographic study and geochemicalanalysis.

a. Petrographic/Microscopic study: this involves the detailed analysis of minerals by optical mineralogy in thin section. Using the optical microscope, the samples are viewed under plane and crossed polarized lights (PPL) and (XPL) respectively. The properties observed under PPL are colour, pleochroism, relief, cleavages, shape and alterations while those observed under XPL are birefringence, interference colour, extinction angles, isotropism, twinning, zoning, interference figures and dispersion.

b. Geochemical analysis**:** whole rock geochemistry involves analyzing for major, minor and trace elements which is used for geochemical characterization of the rocks. A part of each representative sample was used for the Energy Dispersive X-Ray Fluorescence (EDXRF) analytical technique conducted at National Geoscience Research Laboratories (NGRL), Kaduna state of the Nigerian Geological Survey Agency (NGSA).

IV. Results

The field relationship, morphological description, petrography and the geochemistry of the rocksreveals basically 3 rock types in the study area (Figure 2).

1. Metatexite

a.BandedOrthogneiss

b. SromaticMetatexite

2. Diatexite

a. Melanocraticdiatexite

b. Mesocratic Diatexite

c. Leucocratic Diatexite

3. Nebulite

Field Relationship, Morphology and Petrography

Metatexite

Metatexites are migmatites that preserve coherent, pre-partial melting structures in the palaeosome and residuum.Figure 3(A1) shows patch metatexite according to the divisions of 2nd order metatexite by Sawyer[16]. This texture is seen when melting occurs at discrete sites to form small, scattered patches of non-foliated in-situ neosome. The neosome are generally round or oval in shape and are characteristic of the incipient stages of partial melting Figure 3(A2). As the melt fraction increases, the neosome grows and the patches can coalesce to form irregular, lobed shapes.

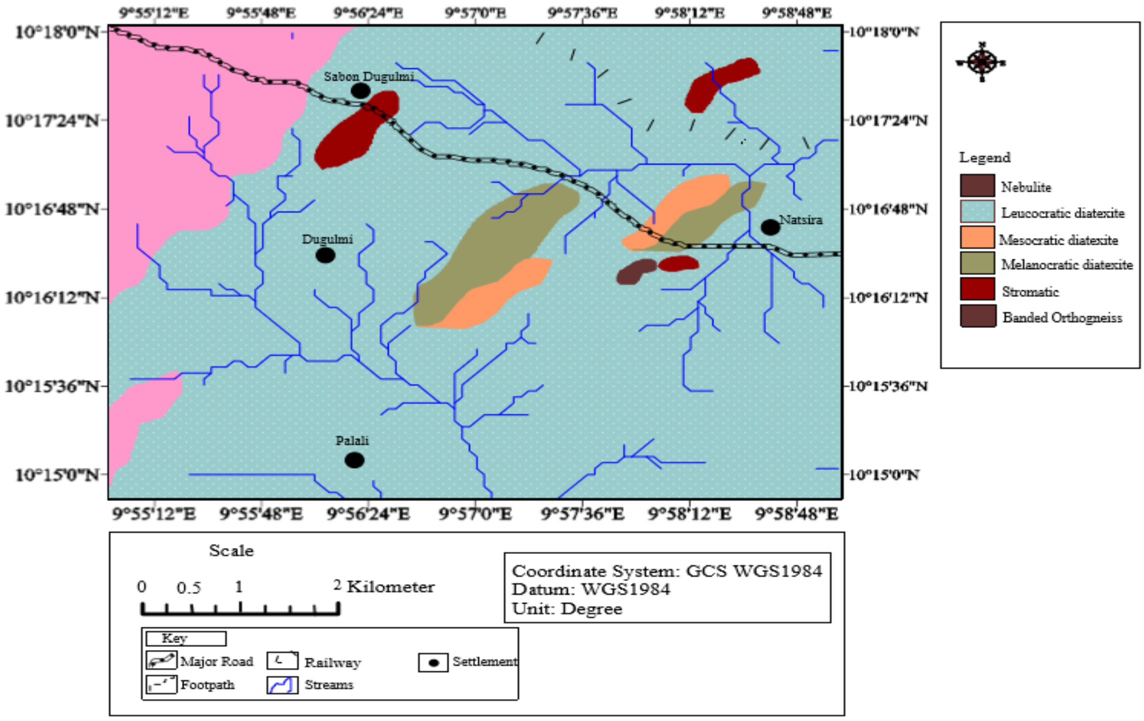


Figure 2: Geologic Map of the Study Area

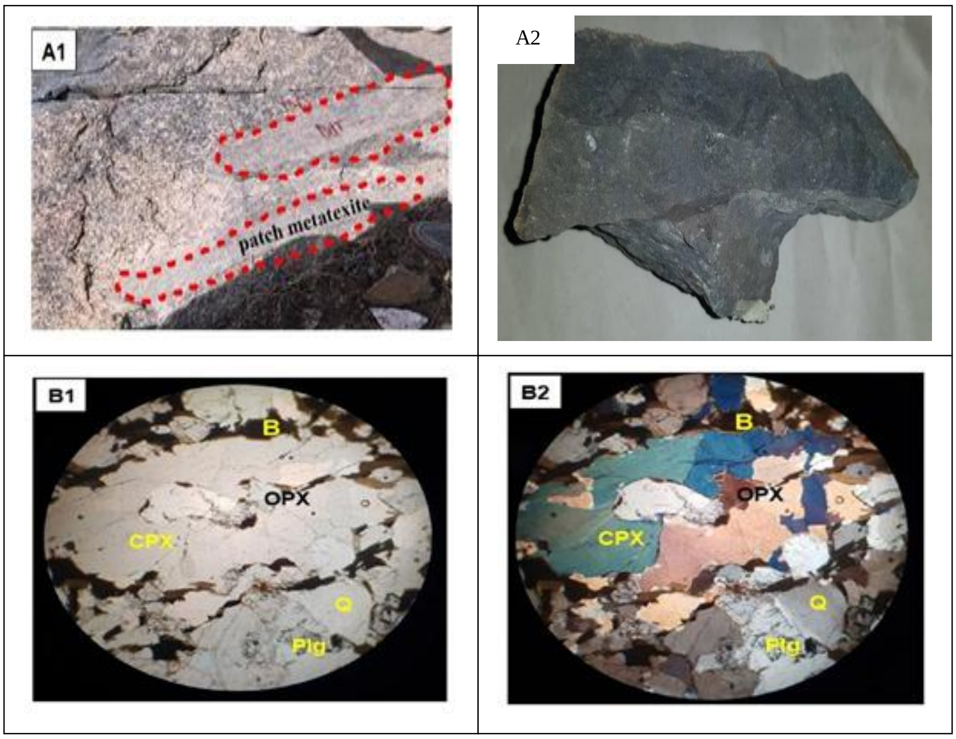


Figure 3: A1= field photograph of metatexite, A2= hand sample of metatexite, B1= photomicrograph of metatexiteunder PPL and B2= under XPL×10. CPX= clinopyroxene, B= biotite, OPX= orthopyroxene, Plg= plagioclase and Q= quartz.

Melanocraticdiatexite

The transition from a metatexite to a diatexite is largely based on two factors; the proportion of melt in the rock and degree of strain that the rock mass is subjected to. Amigmatite in which the pre-migmatization structures are destroyed and a homogenization and coarsening of the texture occurs is called a diatexite[4]. These diatexites are further grouped based on the quantity of their dark colored minerals. Melanocraticdiatexite has the highest quantity of dark colored minerals. Figure 4(A1) shows melanosome which is the darker coloured part of the neosome in a migmatite. Itis rich in dark minerals such as biotiteFigure 4(B1,2).

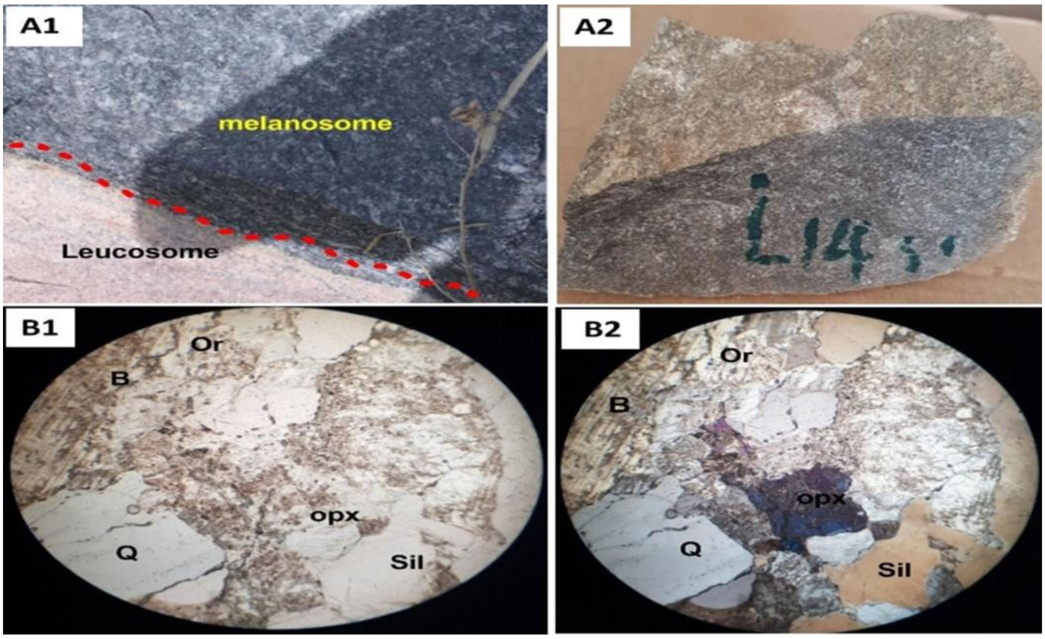


Figure 4:A1= field photograph of melanocraticdiatexite, A2= hand sample of melanocraticdiatexite, B1= photomicrograph of melanocraticdiatexiteunder PPL and B2= under XPL×10. Or= orthoclase, B= biotite, OPX= orthopyroxene, Q= quartz and Sil= sillimanite.

The melanosome is the solid, residual fraction (i.e. residuum) left after some, or all, of the melt fraction has been extracted. Microstructure such as mrymekite intergrowth (appendix) indicating partial melting may be present. A leucosome patch can also be seen on Figure 4(A1) which leucosome is the lighter-coloured part of the neosome in a migmatite, consisting predominantly of feldspar and quartz. The leucosome is derived from segregated partial melt and it may contain microstructures that indicate crystallisation from a melt or magma. The leucosome may not necessarily have the composition of an anatectic melt, as fractional crystallisation and separation of the fractionated melt may have occurred.

Mesocratic diatexite

A mesocratic diatexite has a moderate amount of dark minerals. Figure 5(A1) shows patches of a nebulite which is a type of mixed rock whose fabric is characterized by indistinct, streaky in homogeneities and in which no sharp distinction can be made between the component parts of the fabric. Nebulitediatexitemigmatites have neosome that is diffuse and difficult to differentiate from the palaeosome. This happens when patch metatexitemigmatites reach higher melt fractions in the absence of any external strain.

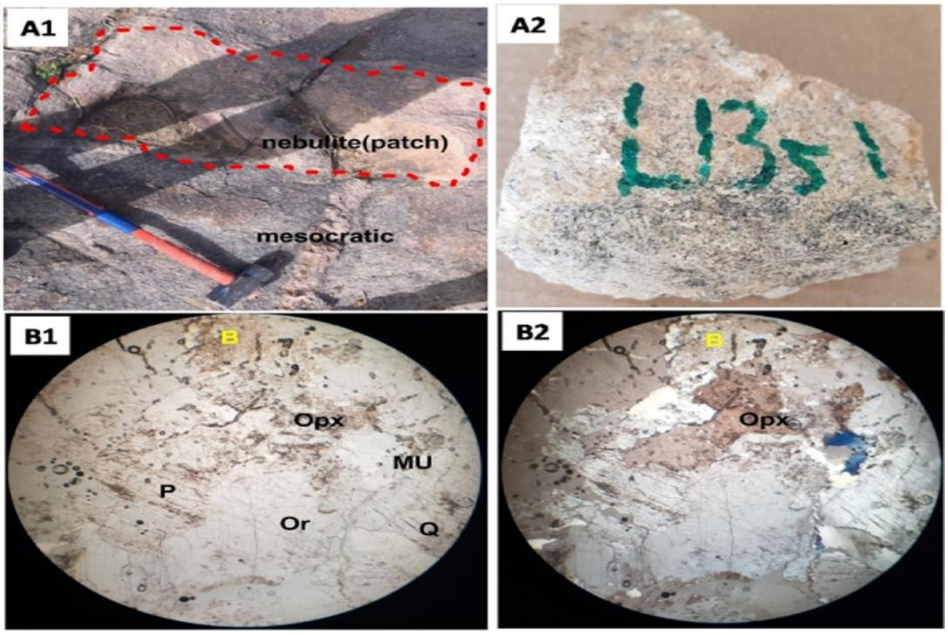
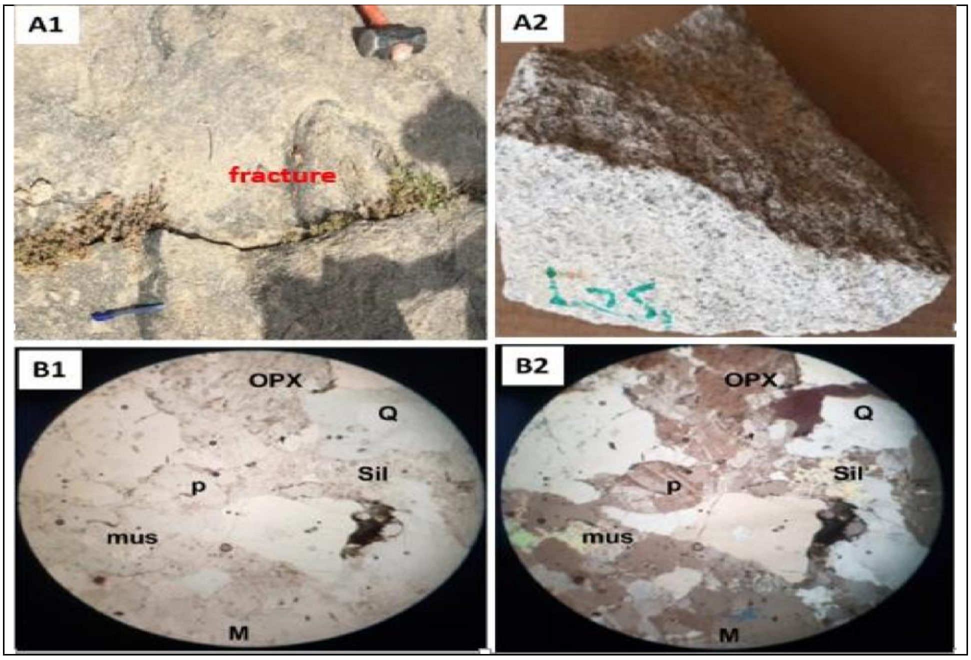


Figure 5: A1= field photograph of mesocratic diatexite, A2= hand sample of mesocratic diatexite, B1= photomicrograph of mesocratic diatexiteunder PPL and B2= under XPL ×10. Or= orthoclase, B= biotite, OPX=orthopyroxene, Q= quartz and MU= muscovite, P= plagioclase.

Leucocratic diatexite

A leucocratic diatexite has a low quantity of dark minerals and are homogenous. Figure 6(A1) shows a fracture which is any kind of seperation or break in a rock formation, this can occur due to stress.

Figure 6: A1= field photograph of leucocratic diatexite, A2= hand sample of leucocratic diatexite, B1=



photomicrograph of leucocratic diatexiteunder PPL and B2= under XPL ×10. M= microcline, OPX= orthopyroxene, Q= quartz and Mu= muscovite, P= plagioclase, Sil= sillimanite.

Nebulite

A type of mixed rock whose fabric is characterized by indistinct, streaky inhomogeneities and in which no sharp distinction can be made between the component parts of the fabric is termed **Nebulite.** Figure 7(A1) shows nebulitic part and melanosome.

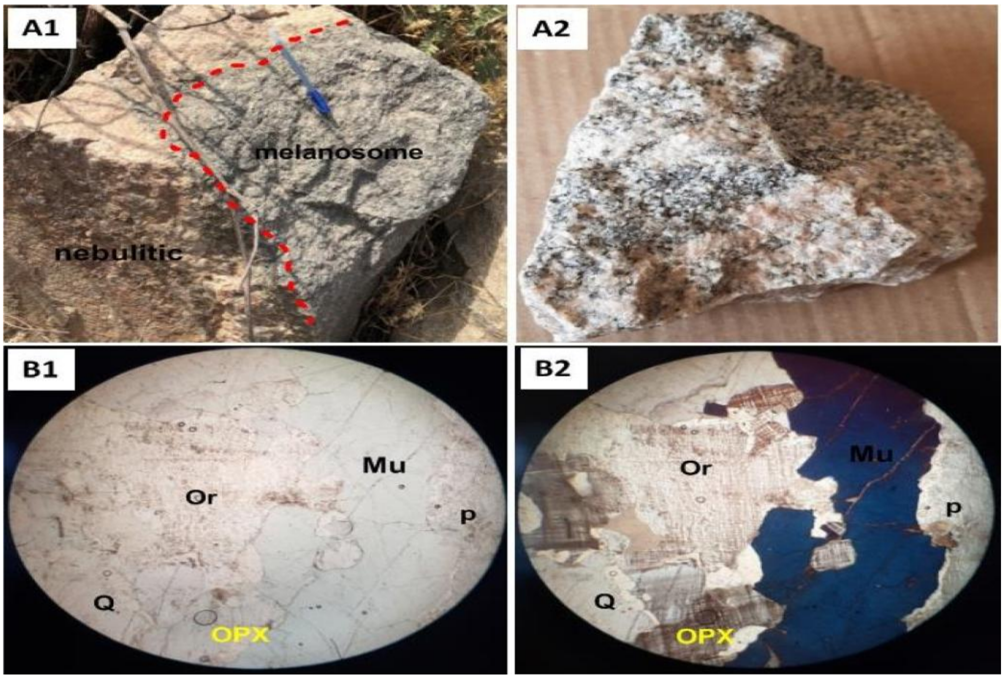


Figure 7:A1= field photograph of nebulite, A2= hand sample of nebulite, B1= photomicrograph of nebuliteunder PPL and B2= under XPL ×10. Or= orthoclase, OPX= orthopyroxene, Q= quartz and Mu= muscovite, P= plagioclase.

Geochemistry

Chemical analyses of whole-rock major, minor and trace elements were carried out at the National Geosciences Research Laboratory (NGRL), Kaduna. Fourteen representative samples were used for the analysis,the results of the major oxides and trace elements are presented in Table 1. SiO_2 abundance ranges from 70.50 to 85.00%, Na_2O from 0.60 to 2.0%, K_2O from 1.0 to 7.11%, Fe_2O_3 abundance ranges from 0.06 to 4.0%, MgO from 0.06 to 0.76%, TiO_2 from 0.03 to 1.14%, CaO from 0.30 to 2.45% and Al_2O_3 from 8.12 to 15.00%. Out of the fourteen representative samples 5 rock groups were depicted, these are 1 metatexite (sample L14SI), 5 melanocraticdiatexite (sample L4S3, L14S2, L13S1, L16S2 and L11S1), 4 mesocratic diatexite (sample L2S1, L15S2, L8 and L5S2), 2 leucocratic diatexite (sample L11S2 and L12S1) and 2 nebulite(L4S2 and L14S2a).

Major Oxides Variations

These are variation diagrams in which the concentrations of an element or oxide are plotted (on the vertical axis) against those of SiO_2 (on the horizontal axis) for a rock suite. Major elements make up to 99% of most igneous rock compositions. The major element variations in igneous rocks are consistent with the minerals that are present and the order in which they crystallized. Out of the 7 major oxides, CaO, MgO, TiO_2 and FeO and Al_2O_3 shows a negative correlation with SiO_2 that is, as the system is cooling the oxides are depreciating while SiO_2 is appreciating while K_2O and Na_2O shows a positive correlation with SiO_2 **(**Figures8a and b).

Table 1: Whole rock geochemical data for major, minor and trace elements

Major Oxides (wt%)	L2S1	L4S2	L4S3	L5S2	L8	L11S1	L11S2	L12S1	L13S1	L14S1	L14S2a	L14S2	L15S2	L16S2
SiO_2	81.90	83.20	73.70	82.40	81.20	85.00	74.00	84.60	78.40	70.50	83.00	78.40	80.00	78.40
CaO	1.41	0.50	0.81	0.70	0.98	0.42	0.52	0.30	ND	2.45	ND	2.02	0.46	1.00
MgO	0.24	0.06	0.20	0.21	0.09	0.08	0.06	0.06	ND	0.65	ND	0.76	0.54	0.28
SO_3	0.024	0.016	0.043	0.020	0.022	0.030	0.040	0.024	0.042	0.12	0.020	0.036	0.036	0.040
K_2O	3.01	1.01	3.50	3.00	3.00	2.60	6.20	3.00	5.00	1.00	7.11	1.06	3.00	2.14
Na_2O	1.02	2.00	2.00	1.62	1.02	0.80	1.80	1.04	1.60	0.86	0.60	0.78	0.80	0.74
TiO_2	0.26	0.08	0.87	0.44	0.35	0.16	0.41	0.15	0.13	2.21	0.03	1.14	0.25	1.05
MnO	0.071	0.04	0.097	0.019	0.097	0.017	0.035	0.030	0.052	0.19	0.076	0.13	0.041	0.034
P_2O_5	ND	ND	ND	ND	ND	ND	0.01	ND	ND	0.03	ND	ND	ND	ND
Fe_2O_3	0.25	0.07	1.50	0.204	0.20	0.18	0.20	0.24	0.10	4.00	0.06	2.00	0.56	2.00
Al_2O_3	10.06	12.30	14.06	10.00	10.98	8.12	14.10	9.14	13.00	15.00	9.04	12.06	12.26	12.00
LOI	0.62	0.52	1.62	0.64	0.80	0.60	1.40	0.70	1.01	2.00	0.58	1.02	0.80	1.03

Trace Elements (ppm)														
V	2.06	201.30	100.20	140.00	70.63	60.20	46.00	60.12	54.10	390.12	16.00	240.64	60.00	200.16
Cr	1.00	98.69	91.23	170.41	74.00	46.00	18.76	26.06	46.00	90.60	12.02	146.00	20.60	70.00
Cu	220.00	280.00	270.00	240.00	740.30	190.06	250.00	200.00	240.11	340.00	220.00	270.00	220.12	280.11
Sr	300.60	310.00	670.21	330.11	3150.00	950.16	1500.70	690.00	1670.00	1690.00	390.00	1850.00	911.00	3080.00
Zr	330.00	400.00	1790.00	530.00	1500.00	750.10	390.00	220.00	50.46	1200.00	120.40	1000.00	420.00	930.00
Ba	4000.00	16.77	2200.00	100.24	2800.00	400.00	1700.00	16.00	3600.00	1000.00	600.00	60.00	120.00	3100.00
Zn	78.46	80.10	190.11	150.22	400.00	80.00	40.14	40.00	21.20	460.00	16.24	140.00	136.00	160.00
Ce	4.70	8.30	1.80	3.08	1.00	0.93	<0.01	0.050	0.20	2.00	5.30	5.20	0.02	1.25
Pb	<0.01	200.66	250.00	98.76	180.91	94.60	240.00	290.00	280.00	<0.01	270.00	280.60	<0.01	20.16
Ga	0.86	18.00	<0.01	1.30	1.30	0.85	1.20	0.68	0.64	<0.01	0.20	1.00	1.02	1.20
As	0.13	5.05	<0.01	0.70	2.14	0.81	0.15	0.60	0.80	<0.01	0.40	0.40	0.12	0.70
Y	1.30	0.80	2.70	1.00	4.40	0.80	1.70	0.96	6.00	1.74	0.60	0.90	1.20	0.80
Rb	102.00	75.40	72.00	70.00	130.00	53.00	113.00	163.90	85.70	100.12	170.00	161.00	174.07	162.00
Nb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	<0.01	<0.01	<0.01	0.28	2.06	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ta	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
W	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hf	46.32	30.85	36.00	36.60	<0.01	40.23	21.20	<0.01	7.00	41.00	30.06	46.12	26.67	310.00
Sn	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	<0.01	<0.01	<0.01	<0.01	0.53	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Se	1.10	<0.01	<0.01	<0.01	<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	0.50	<0.01	0.31	<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	16.00	240.64	60.00	200.16
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	12.02	146.00	20.60	70.00

***ND = Not Detected**

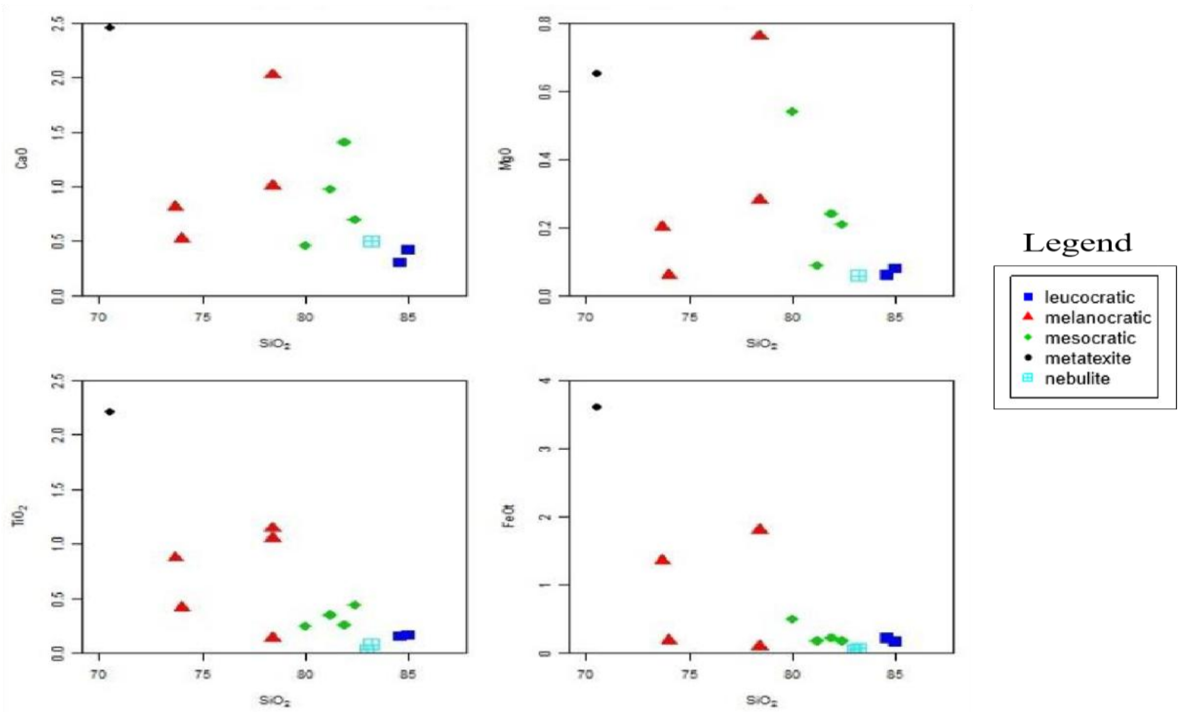


Figure 8a: Harker plots of selected major oxides (CaO, MgO, TiO2 and FeO)

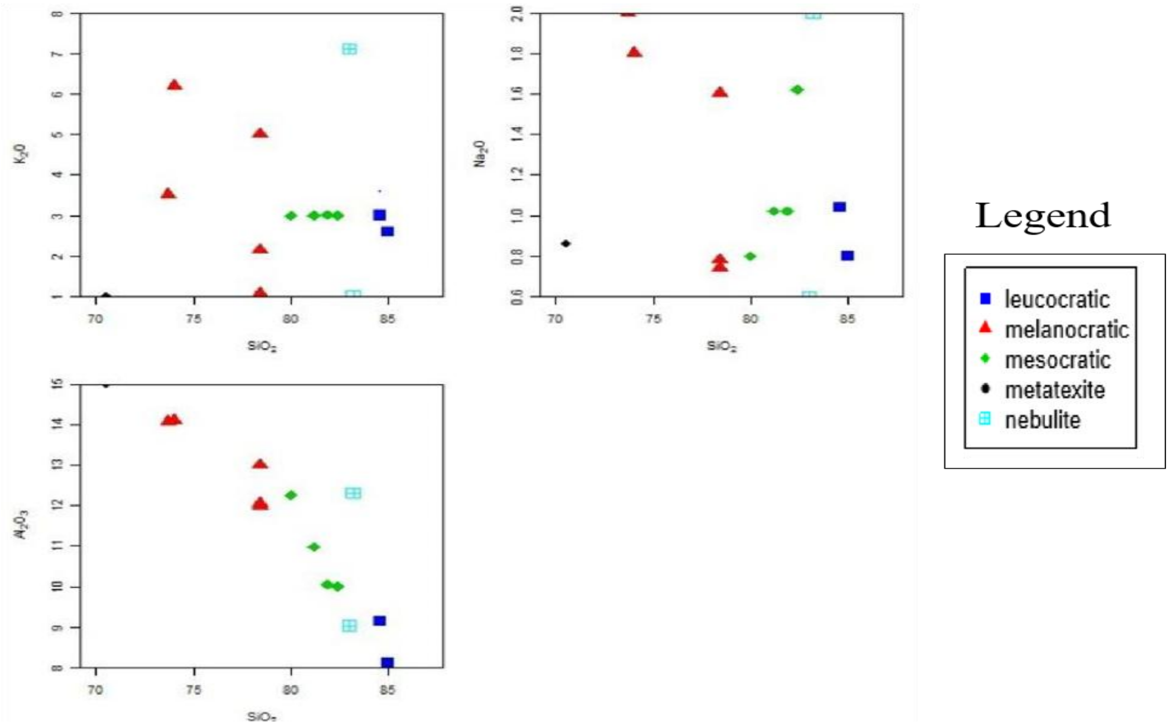


Figure 8b: Harker plots of selected major oxides (K2O, Na2O and Al2O3)

Geochemical Reconstruction of Provenance and Melt Extract Estimation
Provenance Reconstruction

Major elements geochemistry was applied to reconstruct the source of melt (provenance) of the different morphological division of migmatite in the study. The change in chemical and mineralogical heteraogeneity in the rock is due to the source implication,

The plot of Chappell & White[17](Figure 9) based on elemental chemical ratio of Na2O/Al2O3 Vs Al2O3 reveals that the provenence of the rock morphology reflect the meta-sedimentary source which was confirmed by plot of Mg Vs SiO2[18](Figure 10) in which majority of the morphologies fall on pure crustal partial melt with the exception of one each of meso- and melanocraticdiatexite and nebulite.

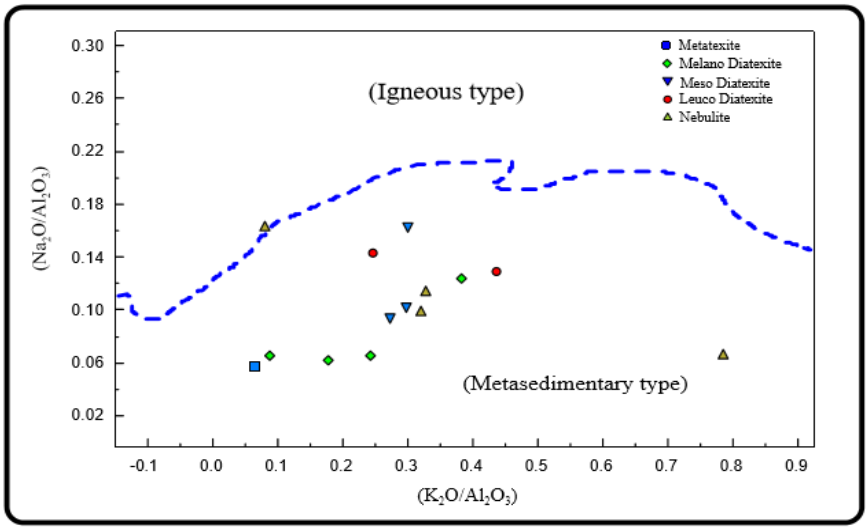


Figure 9: Source discrimination plot of Na2O/Al2O3 Vs Al2O3[17]

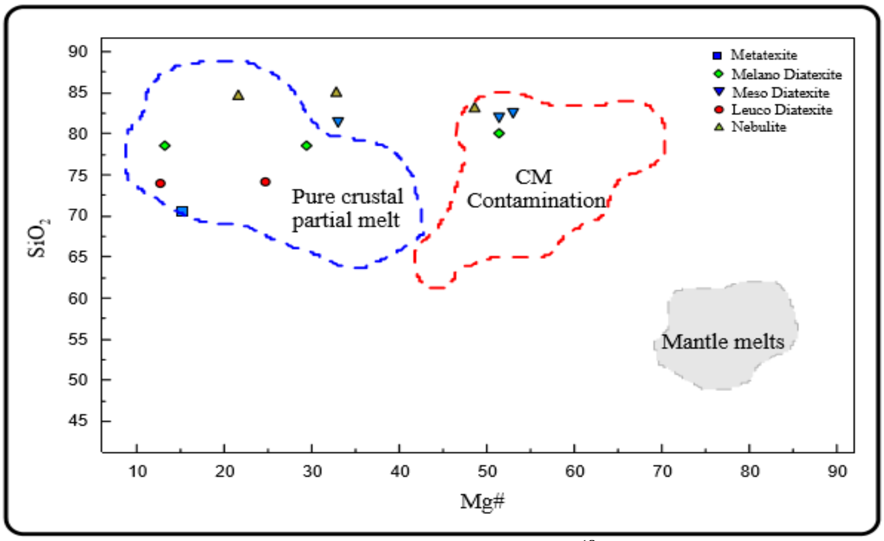


Figure 10: Plot of Mg Vs SiO2[18]

Melt Fraction Generation

The transition between the different subdivisions of migmatite is generally a function of melt fraction and the amount of syn-anatectic strain[19]. The proportion of melt that corresponds to breakdown of the structural framework of the rock and the transition from metatexite todiatexiteare different to quantify. More realistic mode determine the transition from a metatexite to diatexite based on melt fraction of (0.16 – 0.6) in which metatexite has rheological critical melt percentage of 20 ± 10 volume and diatexite greater than 30%. From the plot of Sylvester[19] (Figure 11) source discrimination diagram shows the percentage of melt generation, metatexite found in domain less than 30% melt and the diatexite are in domain greater than 30% melt.

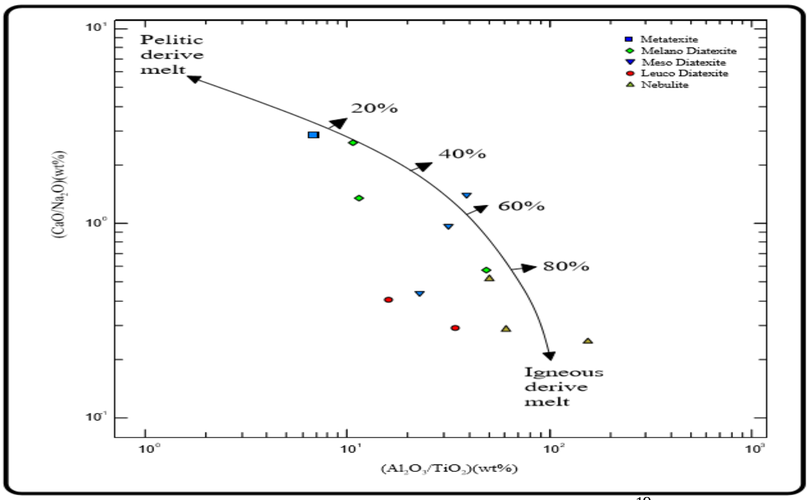


Figure 11: Melt generation discrimination diagram[19]

Temperature and Pressure Estimate

Metarmorphic pressure and temperature estimation in Granulite facies environment is inferred using the mineral assemblages. The diagram of Qz-Ab or Norm by Tuttle & Bowen[20](Figure 12) was used as geothermometer to estimate the temperature at which the different divisions of migmatite in the study area formed. From the plot, the temperature ranges from 800^0c - 1080^0c which suggests that the migmatite morphologies in the studies were formed under high temperature with an inferred pressure of 8 – 11Kbar for rocks that formed under such certain temperature condition.

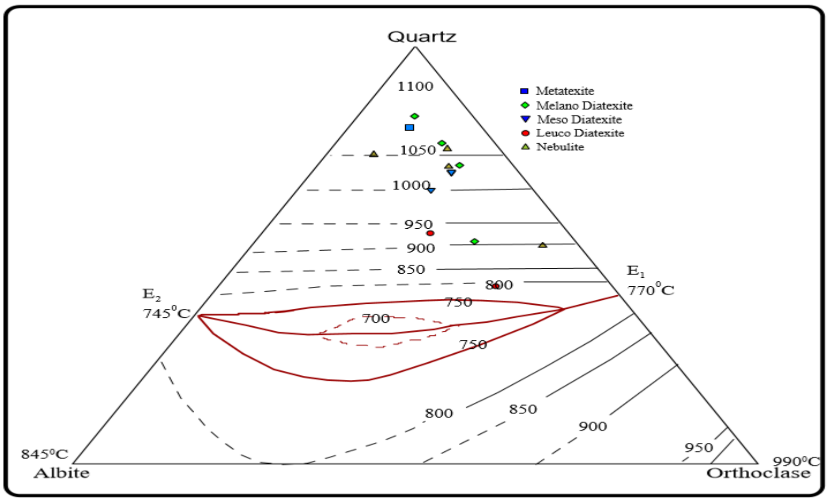


Figure 12: Geothermometer diagram of Qz-Ab or Norm[20]

V. Discussions

From the Field Relationship, Morphology and Petrography, five representative rock groups were identified within the study area, these are: metatexites, melanocraticdiatexites, mesocratic diatexites, leucocratic diatexites and nebulites. The metatexites constitutes orthopyroxene, quartz, clinopyroxene, biotite and plagioclase as major minerals. The diatexites are composed of orthopyroxene, quartz, orthoclase, plagioclase, biotite, muscovite and sillimanite. The nebulites are made up of orthopyroxene, quartz, plagioclase, orthoclase and muscovite(Figures 3-7B1,2).

The **Quartz** is the most abundant mineral in the study area. It occurs as interstitial, subhedral to anhedral medium crystals. They are frequently dusted with iron oxides and clay minerals especially along their peripheries. Quartz crystals exhibit undulose extinction and are highly cracked, indicating that they were subjected to high stresses (Figures 3-7B1,2). The cracks are usually filled with iron oxides and muscovite. Small quartz crystals are sometimes found as fracture fillings.

Plagioclase feldspar occurs as subhedral to euhedral tabular crystals. They generally show polysynthetic twinning. Some plagioclase crystals are cracked or show at least glide twinning indicating high tectonics (Figure 7B1,2). The cracks are usually filled with iron oxides and quartz. **Orthoclase Perthites**occur as subhedral crystals. They are mainly of string and flame like types (Figures5and 7B1,2). Orthoclase perthite rarely shows clear simple twinning. They are often cracked or have signs of weak brecciation and fine granulation along their rims. The cracks are filled with iron oxides and muscovite.

Biotiteis found as small to medium irregular and elongated flakes showing preferred orientation. They occupy the interstitial position between the other minerals. Sometimes, they show green color in plane polarized light, because of their strong alteration to chlorite (Figure 4B1,2). **Muscovite** occurs as small to medium irregular flakes and/or filling the cracks or replacing feldspars.

Both **Clinopyroxene**and **Orthopyroxene** exhibits grey to pale green under the microscope. They are pleochroic with parallel extinction. Their presence indicates granulite facie terrain. Their association exists at low-intermediate pressure. With increase in pressure, orthopyroxene reacts with plagioclase to produce garnet. The occurrence of brownish high relief **Sillimanite** (Figure 6B1,2) with parallel extinction and cleavage indicates that we are dealing with granulite metamorphic terrain.

From the results of Harker Diagram (Figures 8a and 8b), CaO, MgO, TiO_2 and FeO and Al_2O_3 show a negative correlation with SiO_2, that is, as the system is cooling the oxides are depreciating while SiO_2 is appreciating. K_2O and Na_2O show a positive correlation with SiO_2 suggesting commencement of plagioclase fractionation or magmatic differentiation trends. On a primitive upper mantle normalized spider diagram, the samples exhibit strong negative Nb, Ta, Ce, Ti and Y anomalies with the exception of Ce, Ti and Y. The high SiO_2, (Na_2O + K_2O), and Al_2O_3, low MgO, Fe_2O_3, and CaO concentrations imply that the primary magma was derived from partial melting of the lower crust[21].

Chappell and White[17] distinguished S-type and I-type granites using different chemical parameters. I-types have relatively high sodium, Na_2O greater than 3.2%, in felsic varieties, decreasing to more than 2.2% in mafic types. S-types have relatively low sodium, Na_2O normally less than 3.2% in rocks with approximately 5% K_2O, decreasing to less than 2.2% in rocks with approximately 2% K_2O. Based on these findings, the rocks of the area can be said to be of S-Type because the average Na_2O is 1.1 while that of K_2O is 3.1.

Petrogenetic Model

The migmatites show a genetic relationship from metatexite to diatexite locally preserving metamorphic textures and shows a change in melt fraction generation and are interpreted to have a metasedimentaryprotoliths which have undergone metamorphism and deformation (Figure 13).

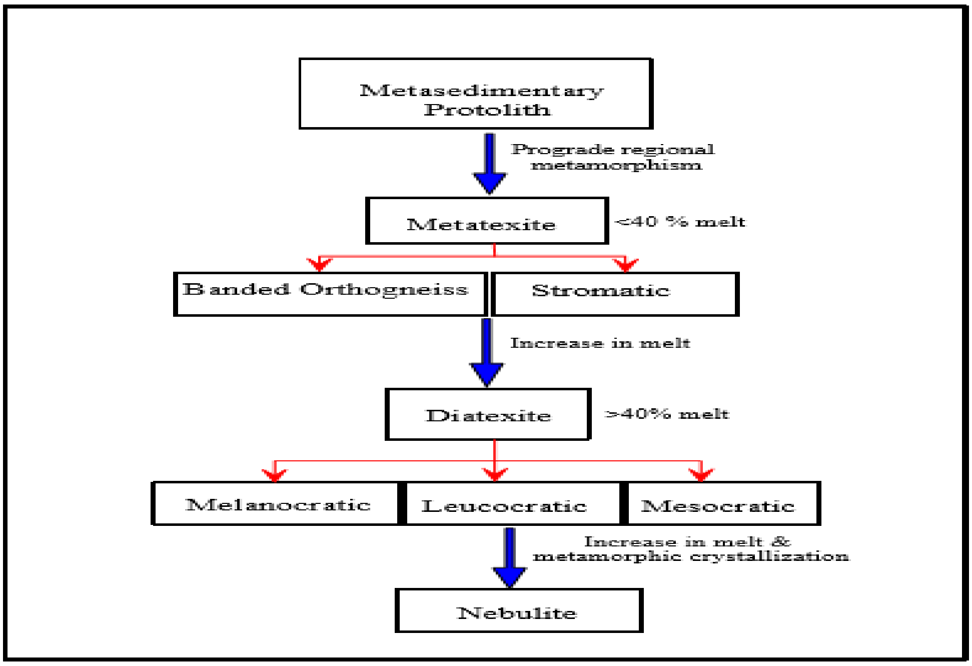


Figure 13: A flow chart summarizing the proposed conceptual model for the origin migmatites in the study area

VI. Conclusion

We can hereby conclude that the study area is composed of metatexites, melanocratic, mesocratic, and leucocratic diatexites and nebulites. The rock units constituteorthopyroxene, quartz, clinopyroxene, biotite and plagioclase as major minerals. The area is geochemically 'magnesian', 'peraluminous' and 'calcic' having originated from crustal materials as S-type granites. Due to the temperature ranges from 800^0c - 1080^0c the migmatite morphologies in this study are found under high temperature with an inferred pressure of 8 – 11Kbar for rock that formed under such temperature conditions. These characteristics are typical of granulite facie terrain.

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