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Geology and Petrogenesis of Stromatic, Schlieren and Nebulitic Migmatites around Miri and Wuntin Dada Areas of Bauchi, Bauchi State – Nigeria

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***Abstract**: Morphological, petrological and geochemical variations are used to discern the formation of different types of migmatites and their associated charnockitic rocks which are derived from metasedimentary origin. The study area lies within Bauchi sheet 149 NE. Morphological/field description shows a variation in textural and structural features from metatexite to diatexite to (nebulitic) charnockitic rocks that are dark in colouration due to high quantity of mafic minerals derived from its protolith. The diatexite shows variation from melanocratic to leucocratic containing changes in mineralogy and textures. The charnockite exhibits magmatic foliation which makes it to be metamorphic. Petrographically, the rock mainly composed orthopyroxene, silliminite, quartz, plagioclase, k-feldspar, biotite, muscovite and shows metamorphic imprints in microscopic scale such as undulous extinction in quartz, obliteration in albite twinning. The studied plagioclase are essentially Na-rich, characterized by low to moderate anorthite content. The metatexites are more calcic and range from anorthite to bytownite, while the diatexites range from bytownite to labradorite and the charnockite ranges from andersine to oligoclase respectively. Chemically, variation diagrams show negative correlation between MgO, CaO, TiO2, FeO2 and Al2O3 with SiO2 but positive correlation with Na2O, K2O indicating the normal magma crystallization trends. The positive correlation is due to the mobility of Na2O and K2O during metamorphism. This shows a mildly metaaluminous to strongly peraluminous indicating I-Type to S-Type granites signatures. From the analyzed pyroxene composition, the charnockites are magnesian augite while the metatexites are predominantly ferro-augite with exception of one which falls in the magnesian-augite rich and diatexites are magnesian with exception of one which is ferro-augite. The mineralogical composition of the investigated garnets display a moderate variations as shown, diatexites, charnockites fall within the grassular garnets with the exception of one metatexite which falls within the pyrope garnet and two other charnockites. The charnockitic magama derived from the melanocratic diatexite is from melt-residuum separation then through fractional crystallization.*

***Keywords**: metasedimentary, migmatite, charnockite, plagioclase, garnet, pyroxene*

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I. Introduction

The geology of the area around Miri and Wuntin Dada is characterized by metamorphic and plutonic rocks of Neoproterozoic of the North eastern Nigeria. The study area is located in the north-eastern part of Bauchi sheet and lies between latitudes 10^0 17' 30" and 10^0 20' 00" N and longitudes 9^0 45' 00" and 9^0 50' 00" E covering approximately 40.5 km² (Figure 1) on a scale of 1:50,000 of quarter degree sheet 149 Bauchi NE, mostly make up of basement rocks of Bauchite and granitic rocks. Some of the rocks within the study area are characterized by intensive deformation with some characterized by partial deformation. These characteristic features of the rocks around Miri and Wuntin Dada necessitated this study in order to understand the general geology of the 2 areas, thereby adding to the current understanding of the geology of the Neoproterozoic belt of North-Eastern Nigeria. Miri and Wuntin Dada have appreciable relief and are characterized by high and low level outcrops. Most of the outcrops are conically shaped and have height ranges of 605 to 740 m above sea level. The drainage pattern is dendritic (tree like) and the small streams in the area are controlled by the outcrops (structurally controlled, Figure 2).

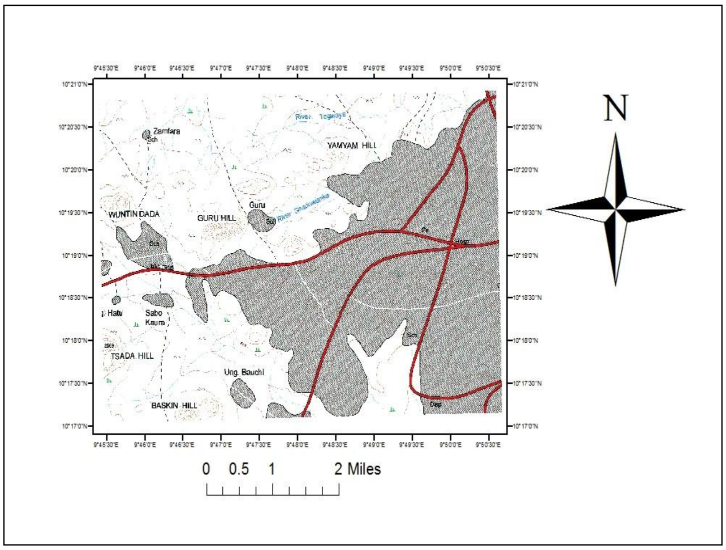

Figure 1. Location Map of the Study Area

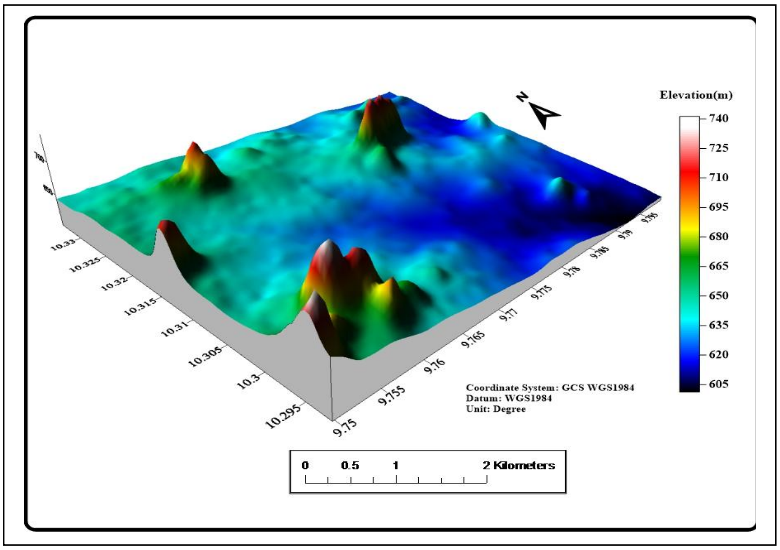

Figure 2. Relief map of the study area in 3D image

II. The Geology of Bauchi Area

The first review of works done on the rocks in the Precambrian Basement Complex of Nigeria was carried out by Oyawoye[1]. The author succeeded in subdividing the Basement Complex rocks into three major groups which he described as (a) the older metasediments, consisting of calc-silicate rocks, arkosic quartzite and high grade schists which are present as lensoid relicts in regional gneisses or as paleosomes of the migmatites. He considered this group as the oldest rocks of the Basement Complex. (b) the gneisses, migmatites and the older granites. In this group, the author recognized two major types of gneisses which include: the biotite gneiss and the banded gneiss. He also grouped the migmatites into two types, namely; the lit-par-lit gneiss and the migmatitic gneiss. In the lit-par-lit gneiss, according to the author, the paleosome (a granulite or high grade schist of the ancient metasediment) occurs with quartz-feldspar veins and dykes in parallel orientation. In the migmatitic gneiss, the metasome is also quartz-microcline veins but the paleosome, which is biotite or banded gneiss, is dissected into irregular blocks. On the basis of petrography, Oyawoye[1] suggested that the gneisses and migmatites originated through silica-potash metasomatism. For the 'Older Granites', the author used field and petrographic evidence to suggest that they probably have a metasomatic origin and associated them with three other types of rocks namely; the coarse-grained, greenish fayalite-bearing rocks, pyroxene-quartz-diorite and pyroxene-amphibole syenite. The very coarse-grained Fayalite-bearing rocks, otherwise called the Bauchites were first described from Bauchi town in Nigeria[2]. At Toro along Jos road, Oyawoye[3] reported the presence of the pyroxene-quartz-diorite within the Basement Complex, typified by the blue-black 'charnockitic'quartz-diorite while he described the pyroxene-amphibole-syenite (a typically purplish rock) as zoned intrusion at Shaki, southwestern Nigeria[4]. (c) The younger metasediments, to which he ascribed Paleozoic age[1].

The Bauchi area is underlain by migmatite-gneiss which is the oldest rock in the Nigerian Basement Complex[5]. The relationship of the present rocks can be defined in that the effect of metamorphism of the gneiss that resulted into schist and was later intruded by older granites (Bauchite). The heat from this intrusion led to a metamorphism that formed the later gneiss showing a polycyclic cycle of metamorphism[6]. However according to Oyawoye[1] who said much work has not been done in the area as quoted "I share the reluctance of modern petrologists to propose new variety names for rocks". The result of works on the migmatite gneiss in the Bauchi area shows their nature to be that of agmatite[7]. Agmatites are of sporadic and rather limited occurrence and the isotope count in them shows 618 Ma[8]. The early Gneiss and other ultramafic rock are cut into irregular blocks by the granitic component. In areas around Bauchi where they are well developed they show dikyonitic structure[3,7].

In a discussion on the Bauchite-Biotite Hornblende Granite transition by Oyawoye[2] he suggested that the charnockitic rocks (Bauchite) are formed under local pyroxene-hornfels facies conditions in regions of amphibolites facies metamorphism[1]. These conditions may be induced either by a reduction in pressure with the concomitant rise in temperature and/or by the introduction of hydrothermal fluids. It is also conceivable as suggested by some field evidence that such areas represent minor intrusions of rocks of charnockitic affinity which because of low PH_{20} have managed to retain their premetamorphic high temperature low PH_{20} mineral assemblages[9]. Bauchite happens to be part of the Eastern Nigeria's terrane which according to Ferre et al.[10], has U and W (isotopes) deposits[11]. It is implaced in metamorphic rocks which are a part of those in Northern Nigeria which consist mainly of granite, high-grade gneisses and migmatites which are cut by large Pan-African monzo-granite plutons[12].

Bauchite is a part of the Neoproterozoic belt (Pan African) of Northern Nigeria where there is a distribution of metamorphic facies[13]. High grade metasedimentary rocks reached granulite facies condition and survived as large lenses and pendants interlayered within anatexites and migmatitic granites as seen in the Toro area of Northern Nigeria. Mineral assemblages in both rock types could be used to determine magmatic and metamorphic thermobarometric conditions and it was shown to be of the barrovian type metamorphism (medium temperature) by Ferre and Caby[14]. The Neoproterozoic Trans-Saharan Belt in which the study area falls within was suggested to be formed between 700 Ma and 580 Ma by accretion of terranes between the converging West African Craton, the Congo Craton and East Saharan Block, which was probably a Craton until 700 Ma[15] when it was widely and largely reactivated, except in few areas. Extensive sampling of metasedimentary gneisses of the Bauchi area (Jos-Bauchi transect) has revealed several occurrences of granulite facies rocks. Finally, Ferre and Caby[14] stated that the metamorphic rocks of Northern Nigeria are consist mainly of monotonous granite–high-grade gneisses and migmatites cut by large Pan-African monzo-granite plutons.

III. Materials and Methods

For the purpose of this study, topographic map was used to conduct the desk study from which the coordinates of the study area were extracted. During the course of the fieldwork, samples were collected using the geologic hammer to obtain fresh samples of important rocks, also photographs of the outcrops were taken. The methods employed in the course of the work can be broadly divided into two, which are Field Methods and the Laboratory Methods. For the field method, various approaches were employed to acquire data, take samples and also interpret in the field. They include direction, bearing and position using compass and GPS. In the laboratory, the study was carried out in two parts, namely: petrographic and geochemical analyses. Thin sections for the petrographic studies were prepared at the Thin section Laboratory of the Department of Applied Geology ATBU Bauchi. Optical petrographic microscopes were used for the petrographic studies. Photomicrographs were taken by the combined use of the petrographic microscope and phone camera. Furthermore, the geochemical analyses were carried out by the National Geoscience Laboratory, Kaduna of Nigerian Geological Survey Agency from which relevant geochemical plots were generated using software (GCDkit and Petrograph). The results of the fieldwork, petrographic and geochemical studies were refined, presented, interpreted and discussed below.

IV. Results

There are basically 3 rock types in the study area (Figure 3).

1. Metatexite
2. Diatexite
   a. Melanocratic Diatexite
   b. Mesocratic Diatexite
   c. Leucocratic Diatexite
3. Nebulite (Charnockite)

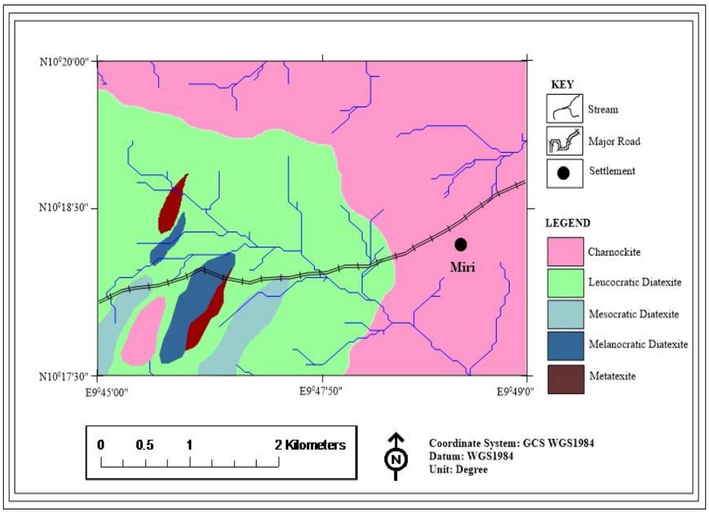

Figure 3. Geologic map of the study area

Field Relationship/Morphological Description and Petrography
Metatexite
This rock shows stromatic band of felsic composition (Figure 4a1). It mostly occurs as patch within rock body (Figure 4a1) and is nearly similar to the mineral assemblages of the protolith (Figure 4a2). The percentage of ferromagnesian is dominant in the rock (Figure 4b1,2).

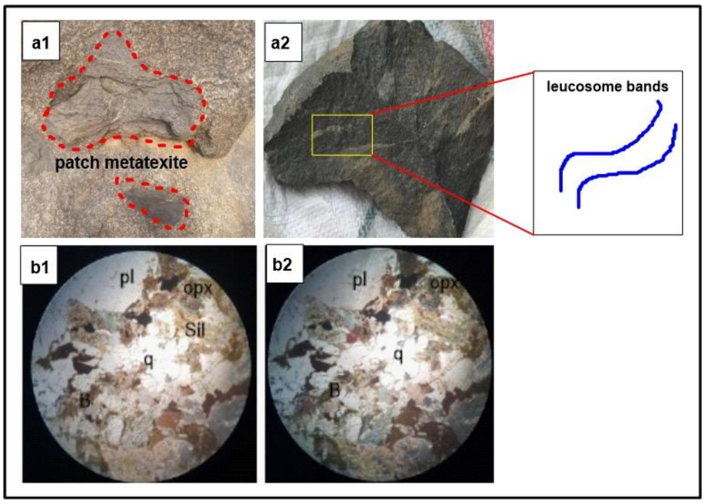

Figure 4. General characteristics of Metatexite. a1. Field photo of studied metatexite, a2. Hand description, b1,2. Photomicrograph of metatexite on plane & cross polarized lights. (Pl = plagioclase, Q = quartz, Sil = sillimanite, Opx = orthopyroxene)

Petrography Description of the Metatexite
The petrographic analysis of the metatexite shows that the rock mainly composed orthopyroxone¸ sillimanite, quartz and plagioclare (Figure 4b1,2). Under plane polarized light the minerals show low relief, yellowish to brown in color and are subhedral in form (Figure 4b1). Under cross polarized light they show undulous extinction in quartz, obliteration in albite twinning, sillimanite shows fibrous appearance (Figure 4b2).
Diatexite
These rocks show granitic appearance and its pre-migmatisation structure are destroyed. Its melt fraction is large. The diatexite in the study area shows a considerable range in morphology. Due to the systematic mineralogical and textural variations within the diatexite, it is classified into 3-subdivisions (Figures 5, 6 & 7).
Melanocratic Diatexite
This rock shows high percentage of ferromagnesian mineral especially biotite and it occurs as a patch within adjacent rock (Figure 5a).

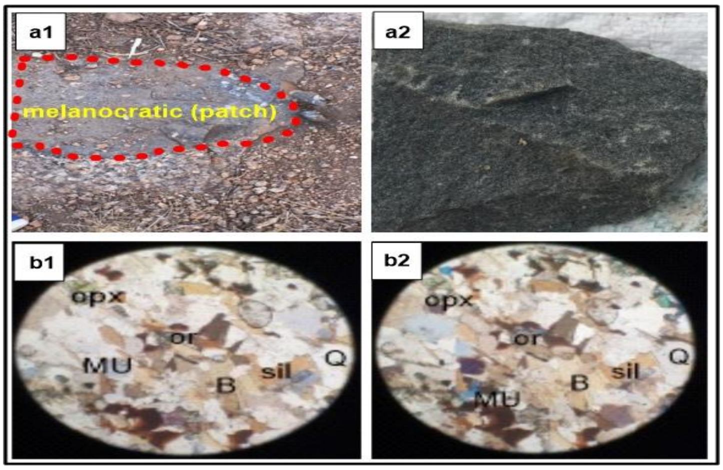

Figure 5. General appearance of Melanocratic Diatexite in studies. a1. Field view, a2. Hand description, b1,2. Photomicrograph in plane & cross polarized lights. (Or = orthoclase, Q = quartz, Sil = sillimanite, Opx = orthopyroxene, B = biotite, Mu = muscovite)

Mesocratic Diatexite

This rock shows almost equal percent of ferromagnesian and felsic minerals and it consists of raft of paleosome (Figure 6a).

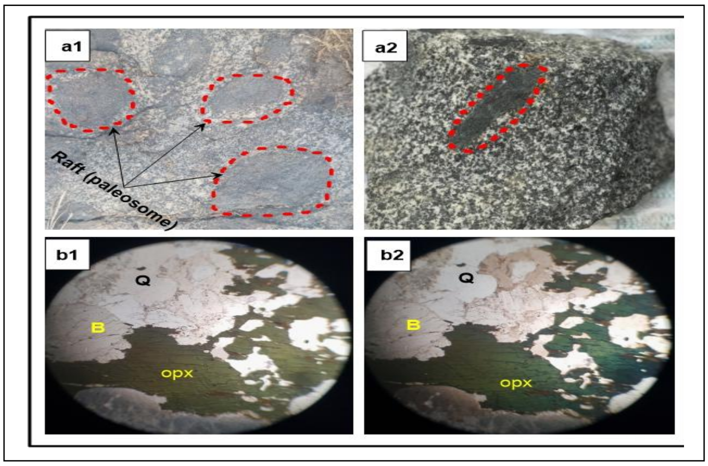

Figure 6. General appearance of Mesocratic Diatexite in the study area. a1. Field view, a2. Hand description b1,2. Photomicrograph in plane & cross polarized light. (Q = quartz, Opx = orthopyroxene, B = biotite)

Leucocratic Diatexite

This rock is coarse in texture and it is well defined by igneous textural appearance (Figure 7a). It consists of melanosome and leucosome band called the neosome and patch palesome (Figure 7a1). It contains more K-feldspar than the other type of diatexite (Figures 5 & 6) in the study area with less ferromagnesian mineral.

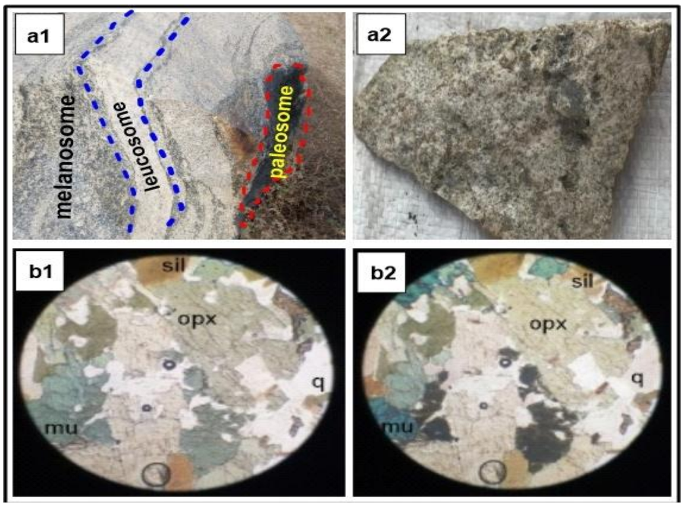

Figure 7. General Characteristics of Leucocratic Diatexite. a1. Field View. a2. Hand Description b1.Photomicrograph in plane & cross polarized lights. (Q = quartz, Sil = sillimanite, Opx = orthopyroxene, B = biotite, Mu = muscovite)

General Petrographic Description of the Diatexite

The minerals show medium to no relief, subhedral and light to brownish colouration under PPL (Figures 5, 6, 7b1). Quartz shows wavy extinction (Figures 5, 6, 7b2). Light coloured minerals show no pleochorism under PPL (Figures 5, 6, 7b1) most of the biotite show incline extinction angle.

Nebulite (Charnockite)

Charnockite occurs mostly closer to the diatexite. It shows brownish to grey coloration. It composed mainly quartz & K-Feldspar & contains biotite (Figure 8a2). It foliated which makes it to exhibit structure of the protolith (Figure 8a1). The foliation concludes that it is metamorphic in nature.

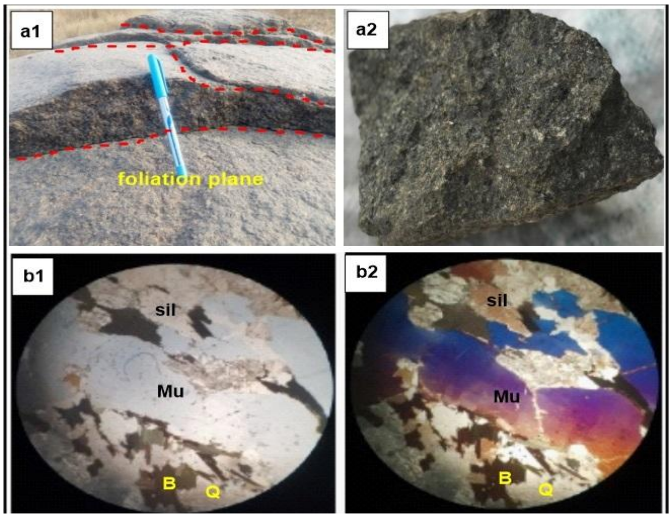

Figure 8. General factors of studied Charnockite. a1. Field view showing foliation plane. a2. Hand specimen b1,2. Photomicrograph in plane & cross polarized light. (Q = quartz, B = biotite, Mu = muscovite, Sil = sillimanite)

Petrographic Description of the Charnockite

The minerals show high to medium relief, with no pleochron under PPL (Figure 8b1). There is presence of greenish-brownish coloured mineral which indicate orthopyroxene – nuclear under XPL (Figure 8b2).

Geochemistry

A total of fifteen representative samples were analysed for whole rock geochemical analyses using X-Ray Fluorescence (X.R.F). This includes one representative sample each of the metatexite, diatexite, nebulite (charnockite) and basalt. The results of the analyses are represented in Table 1.

Major Oxides Characteristics

Harker variation diagram between SiO_2 and major oxides were prepared in order to understand the trends of major oxides and to evaluate their mobility during partial melting and differentiation in their composition e.g

Fe2O3 (0.2-8.06 wt %), CaO (0.3-7.6 wt %), MgO (0.03-3.34wt %), T_1O_2 (0.12-4.07wt %), K_2O (0.68-3.34wt %), Na_2O (0.36-1.73wt %), Al_2O_2 (7.42-16.32wt %).

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

I.D	AM2	G	AM4	AM3	E1	E2	E3	AM1
petrology	metatexite	metatexite	melanocratic	melanocratic	mesocratic	mesocratic	leucocratic	leucocratic
Major oxides (wt %)								
SiO2	56.1	60.21	62	62.62	64.4	65.8	68.9	73.2
CaO	6.4	4.2	7.6	2.5	4.81	4.71	3.4	3.01
MgO	2	3.34	2.4	1	1.93	1	1.01	0.48
SO3	1	0.24	0.12	0.62	0.41	0.048	0.042	0.13
K2O	0.7	0.68	2	1.23	3.34	3	2.02	1
Na2O	1.32	0.7	1.01	1.7	1.7	1.6	0.73	1.02
TiO2	3.21	4.07	2.5	2.81	2.37	3.78	1.5	2.5
MnO	0.25	0.49	0.39	0.4	0.46	0.35	0.083	0.28
P2O5	0.42	0.04	ND	0.03	0.07	ND	ND	0.03
Fe2O3	8.06	2.88	4	9.4	4.33	4	4.74	3
Al2O3	15	16.32	14.73	14.2	14.38	14.11	14.08	13.33
LOI	4.6	5.46	2.06	3.2	3.11	2.1	2.42	1.64
Trace elements (ppm)								
V	410.06	284.6	540	400	75	10.21	20.64	50.14
Cr	260	46	620.12	320.62	16.61	4	10.06	100
Cu	220	570	390.13	420	620	620	280	380
Sr	2490	531	3740.6	1700.6	4200	3470	1630	2820
Zr	1021	860.01	2200	2100	6970	7170	1500	3000.12
Ba	12.4	280.48	900.42	2800	6300	6600	3300	2600.7
Zn	270	630.11	487	750	760.34	780.81	170.24	510.21
Ce	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.4	<0.01
Pb	12	6.86	16.21	113	<0.01	130.2	380	940
Ga	<0.01	0.9	4.9	2.6	10.06	0.05	11	11.4
As	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Y	1.9	<0.01	0.284	1.94	7.6	0.52	<0.01	0.72
Rb	9.1	156	19.24	112	115	126	137.25	112.2
Nb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	52
Hg	0.3	1	4	<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	40.4
W	<0..01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	7.76
Hf	50.6	43	40.63	46.2	48.7	34.3	37.46	42.06
Sn	1.2	1.64	1.43	<0.01	1.24	0.42	<0.01	14.24
Sb	2.1	3.8	3.3	<0.01	2.1	1.6	<0.01	12
Se	<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
Sc	<0.01	<0.01	<0.01	<0.01	<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
Ge	7	0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

***ND = Not Detected**

Table 1 cont'd. Whole rock geochemical data for major, minor and trace elements

I.D	D	I	J	F	H	C	B
petrology	charnnockite	charnnockite	charnnockite	charnnockite	G -granitoid	charnnockite	Basalt
Major oxides (wt %)							
SiO_2	80	81.1	81.3	82.06	83.8	85.4	66
CaO	1.02	0.41	0.5	0.32	0.3	1.13	7.7
MgO	0.73	0.24	0.27	0.08	0.03	0.84	5.6
SO_3	0.016	0..026	0.021	0.012	0.014	0.013	0.73
K_2O	5	3.04	2.89	4	5	0.4	ND
Na_2O	1.36	1.3	1.46	1.22	1.4	0.36	ND

TiO_2	0.75	0.62	0.54	0.4	0.12	1.03	0.678
MnO	0.056	0.036	0.036	0.072	0.031	0.09	0.208
P_2O_5	ND	ND	ND	ND	ND	ND	ND
Fe_2O_3	0.46	0.43	0.5	0.2	0.26	1.53	1.5
Al_2O_3	8.6	11.6	11.54	11	9	7.42	12.34
LOI	0.61	0.73	0.71	0.64	0.58	0.7	5.12
Trace elements (ppm)							
V	7	3	0.84	6.62	<0.01	8	130.3
Cr	1.67	0.06	<0.01	2.06	<0.01	2.13	83.24
Cu	250	210	220	300	29	140.34	120
Sr	2490.26	1440	1630	1810.3	500	777	1760
Zr	1300.2	580	590	190	119	910	290.44
Ba	3300	1900	2100	1500	950	690	14
Zn	30.24	179.11	85.24	16.2	10.46	110.03	140.36
Ce	5.8	0.73	3	7.15	<0.01	0.72	<0.01
Pb	147	60.06	100	200	150	280	23.18
Ga	18	0.8	0.4	13	0.67	14.8	<0.01
As	0.84	0.089	0.07	2.36	0.9	1.01	<0.01
Y	1.2	0.97	0.8	2.2	1.1	1.1	<0.01
Rb	166.2	156	166.8	112	138	121.36	<0.01
Nb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	1	0.6
Ta	<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
Hf	21.23	36.3	24.16	21.18	28.46	30.93	18.24
Sn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Se	<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
Sc	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ge	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.6

***ND = Not Detected**

Variation Diagram

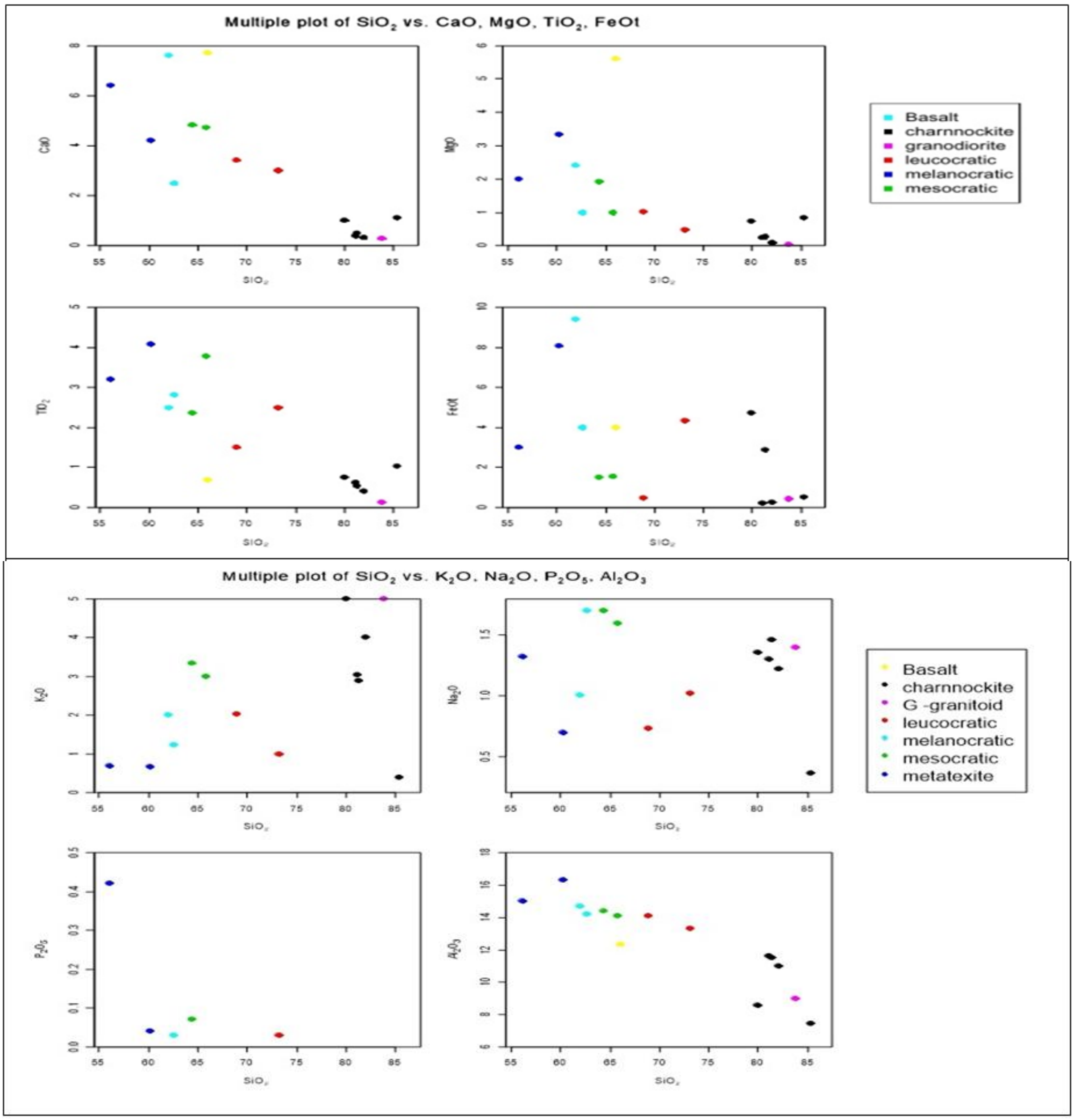

Figure 9. SiO_2 Vs Major oxides (wt %) variation diagram

The variation diagram (Figure 9) shows negative correlation between MgO, CaO, TiO_2, FeO2, and Al_2O3 with SiO_2 and positive between Na_2O, K_2O with SiO_2 indicating the normal magma crystallization trends. The positive correlation is due to mobility of Na_2O & K_2O during metamorphism.

The metatexites which are samples Am4 & G show high percentage of ferromagnesian elements which are MgO, CaO, TiO_2, Fe_2O_3 and Al_2O_3 while diatexites which are samples Am4, Am3, Am4, E1, E2 & E3 and charnockite which are samples D, I, J, F & C show low percentage of those elements but rich in K_2O and Na_2O.

Mineral Chemistry

The composition and structural formula has been determined to understand the mineral composition of the rock in the study area. Mineral formula have been calculated with normalization excel software using atom per formula unit.

Feldspar

Feldspar minerals are aluminium silicates whose crystalline structure is composed of an infinite network of SiO_2 and AlO_4 tetrahedral. The chemical formula of feldspar is MT_4O_8 where T represents Al & Si & M is Na and/or K for $AlSi_3O_8$ & Ca or Ba for $Al_2Si_2O_8$.

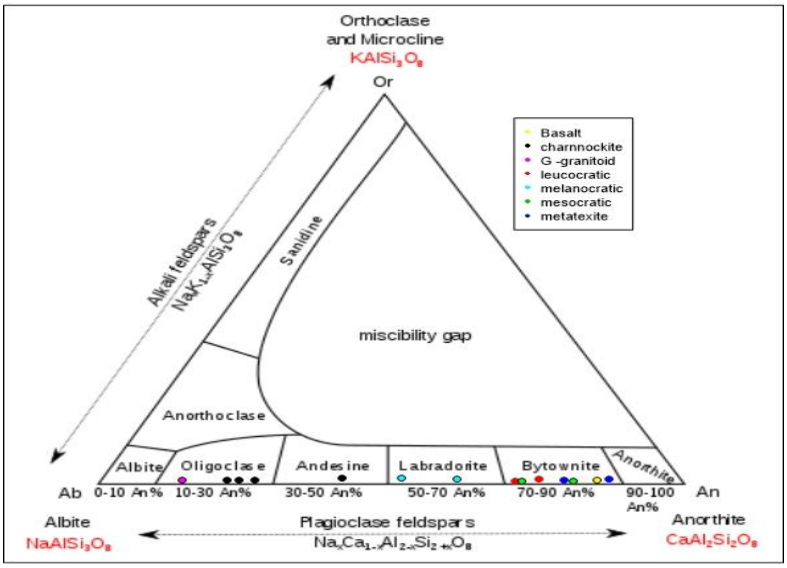

Figure 10. Feldspar triangular diagram showing representative samples plot

The studied plagioclase are essentially sodium rich, characterized by low to moderate anorthite content. The metatexite (Am2 & G) are more calcic and ranges from anorthite to bytownite (Figure 10), diatexite (samples E3, AM1, E1, E2, AM4 & AM3) ranges from bytownite to labradorite and the charnockite (samples D, I, J, F & C) ranges from andesine to oligoclase respectively. The compositional attributes of feldspars can help to determine the degree of fractionation of the magma and the relationships among different migmatites[16].

Pyroxene

These are group of important rock-forming inosilicate minerals found in many metamorphic rocks. It has a general formula $XY(SiAl)_2O_6$ where X = Ca, Na, Fe_2 or Mg and more rarely Zn, Mn, or Li and Y = ions of smaller size such as Cr, Al, Fe_3 Mg. Pyroxenes that crystallize in the monoclinic system are known as clinopyroxene and those that crystallize in orthorhombic system are known as orthopyroxene.

From the analysed composition, the charnockite (samples D, I, J, F and C) are magnesian augite while the metatexite (samples AM2 & G) are predominantly ferro-augite with exception of one which falls in the magnesian-augite rich. diatexite (samples D, I, J, & C) are magnesian with exception of sample (F) which is ferro-augite (Figure 11).

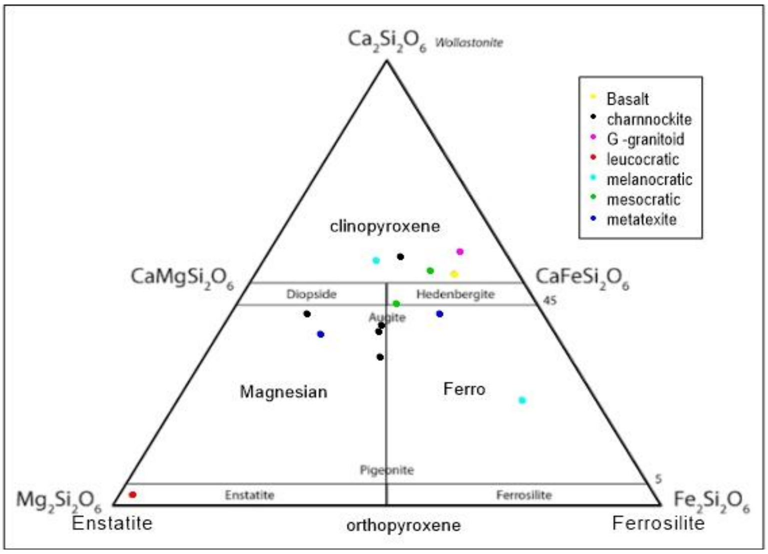

Figure 11. pyroxene triangular diagram showing representative samples plot

Garnet

This the general name of a group of mineral, with standard formula $X^{2+}{}_3 Y Si_3O_{12}$ mainly with X=Ca, Fe, Mn, or Mg and Y = Al, Cr or Fe . The common garnet end members are Pyrope ($Mg_3Al_2Si_3O_{12}$), Almandine

($Fe^{2+}{}_3Al_2Si_3O_{12}$) Spessartine ($Mn_3Al_2Si_3O_{12}$), Grossular ($Ca_3Al_2Si_3O_{12}$), Andradite ($Ca_3Fe^2{}_2SiO_{12}$) and Olvarovite ($Ca_3Cr_3Si_3O_{12}$).

The mineralogical composition of the investigated garnets displays a moderate variation as shown in Figure 12. The metatexite (sample Am2), diatexite (samples E3, Am1, E1, E2, Am4 & Am3), nebulite (charnockite (samples D, I & J) and granodiorite (sample H)) falls within the grossular garnet with the exception of one metatexite (sample G) which falls within the pyrope garnet and two other charnockites (samples F & C) and the basalt too.

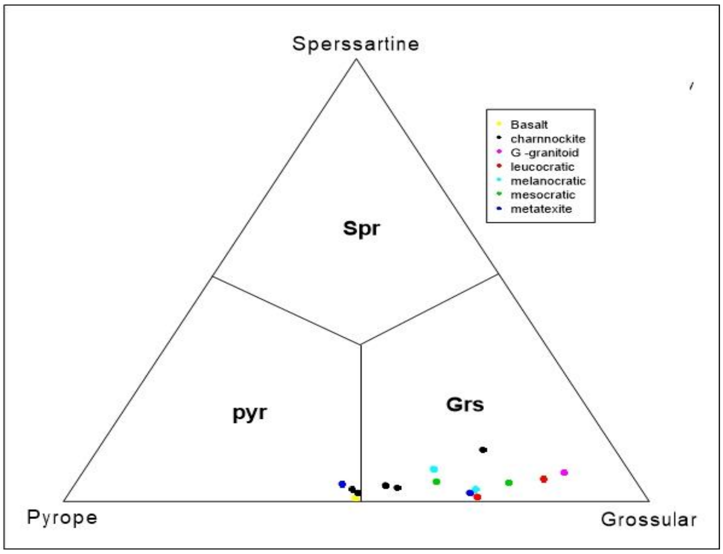

Figure 12. Garnet triangular diagram showing representative samples plot

V. Discussion of the Results

Field, petrographic and geochemical studies are the basic criteria for elucidating the petrogenesis of rocks. This section discussed the morphological, petrographic and geochemical features of the rocks under study.

Field Relationship/morphological description

Based on field relationship, the rocks in the study areas are found to be intrusive. The transitional contact relationships between the various rocks suggest that the lithologic unit had been formed by the same process. The rocks in the study areas show changes in their textural appearance from relatively fine to coarse in texture. There is a gradational change from metatexite to nebulitic rocks[17,18]. This causes heterogeneity in their appearance. The contact between different morphological characteristics of the changes from metatexite to leucocratic diatexite with different structural features with metatexite shows stromatic bands of felsic materials (Figure 4) while the diatexite shows raft of the protolith (Figures 4, 5 & 6). The charnockites (nebulite) in the areas show magmatic foliation (Figure 7) which suggests that they are metamorphic rock retaining the structure of the partially melted rock (protolith) which supported the work of Frost and Frost[19] & that charnockites are metarmorphic.

Petrographic studies

The petrographic studies conclude that the samples from different rock units are accompanied with major minerals of feldspar, quartz and biotite (Figures 4-8), with minor constituents of accessory minerals. The presence of undulous extinction in quartz and obliteration of twinning in feldspar conclude that they were subjected to high pressure and temperature conditions. Petrographic study reveals that the modal composition of ferromagnesian mineral (biotite) and plagioclase decreases from the less felsic to more felsic end of the spectrum in the rock suites in the area. This suggests that partial melting and crystallization dominated by fractionation of plagioclase and biotite have played a significant role in the evolution of the rocks. The decrease in the concentration of FeOt, MgO Al2O3 and CaO with increasing acidity (SiO2) supports the earlier observation. Abundant index metamorphic minerals were observed, e.g clinopyroxene, orthopyroxene, sillimanite (Figures 4-7).

Geochemistry

The geochemical data show that the rocks in the study areas have silica content ranging from (62-85.4 wt %; Table 1) and also show variable range in concentrate of major, minor and trace elements. In Harker variation diagram (Figure 9) for most of the sample: the ferromagnesian element decreases with increasing SiO_2, this is because they take part in ferromagnesian minerals in the initial stage of partial melting adding the process of crystallization so their concentration decreases with increasing SiO_2. The SiO_2 has negative concentration with Al_2O_3, CaO but a positive correlation with Na_2O. The K2O positive correlation with SiO_2 (Figure 9) indicates fractional crystallization – the last stage of partial melting and the beginning of magma crystallization. This trend is identical to calc-alkaline suits[20]. The ASI vs SiO plot shows an erratic increase of silica values. This increase may indicate assimilation of metasedimentary source rock[21] or assimilation and fractional crystallization of a genetically related igneous source with involvement of sedimentary country rock[22]. The available data indicate that the rocks in the areas were derived from partial melting of metasedimentary crustal protolith having ASI>1 and abundant & fractional crystallization of igneous source with significant involvement of sedimentary rock having ASI<1.

Geochemical classification of the studied rock samples shows different consistent chemical affinity. The TAS diagram of Middlemost[23], shows the metatexite & diatexite having granodiorite chemical composition while the nebulite (charnockite) having granitic composition. This is consistent with petrographic results. On the SiO2-K2O plot of Peccerillo & Taylor[24] the rocks show ranges from the tholeiitic to high k-calcalkaline series which indicates potassium rich nature, supported by petrographic studies with modal proportions of k-feldspar. According to the indexes of Frost[25] the rocks show both magnesian and ferroan signature in the Fe index and showing similar trend in MALI having calcic nature and metaluminous to peraluminous. This is due to the nature of assimilation of both metasedimentary crustal signature & igneous source signature. The tectonic discrimination diagram of Pearce *et al.*[26] and Harris et al.[27] indicates that the geotectonic environment of the formation of the rock is syn-collisional + volcanic arc and support the Himalayan type collision which result in the formation of the rocks in the study area during the Pan- Africa orogeny.

VI. Conclusion

From the morphological/field relation, petrography & geochemistry, it can be concluded that the study areas consist of different types of migmatite based on their morphological characteristics as metatexites, diatexites and nebulite (charnockite). The boundary between them is transitional, marked by changes in structural appearance. Charnockites in the area exhibit magmatic foliation which concludes that they are metamorphic. Petrographic studies revealed that quartz; microline, plagioclase and biotite constitute the major minerals present in the rocks, while apatite and zircon are the most dominant accessory minerals. The groundmass of the rock samples is mainly composed of plagioclase, quartz, K-feldspar, biotite and index granulite facies mineral (sillimanite, orthopyroxene). Normative minerals include: zircon, apatite, rutile, magnetite, illminite. Geochemical studies have shown that the migmatites are peraluminous and have calc-alkaline affinity. TiO2 vs SiO2 discrimination plot reveals that the rocks are paragneiss (derived from metasedimentary source). The high SiO_2 (Na_2O + K_2O) and Al_2O_3, MgO, Fe_2O_3 & CaO low concentration imply that the primary magma was derived from partial melting that involves lower crust. The compositional trends of the rocks indicate a decrease in Al_2O_3, Fe_2O_6, MgO, CaO, TiO_2 with increasing SiO_2 which might be due to the fractionation of plagioclase or biotite or crustal contamination of magma during partial melting. The constructed discrimination diagrams together with the geochemical characteristics of high K-calcalkaline affinity, their I-type & S-type character with strongly peraluminous (>1.0) to low metaluminous (<1.0) signify a magmatic tectonic of volcanic arc & syn-collisional granitoid.

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