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The Petrochemistry and Origin of Precambrian Gneisses around Madaka and Kwana-Bala Area, North Central Nigeria

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Abstract

This paper discusses the petrochemistry and origin of gneisses within basement complex of Nigeria around Madaka and Kwana-Bala area. The lithological units of rocks from Madaka and Kwana-Bala area comprises of gneisses (migmatitic, banded, granitic), kyanite-sillimanite schist, semi-pelitic schist, amphibolites, talcose rock, quartzite, phyllite, granodiorite, fine-medium-grained granites and porphyritic granite. Seven samples of gneisses were analyzed for major element oxides using (ICM-MS). The gneisses are often variable in colour which depending on the nature and proportion of the feldspar and the ferromagnesian minerals. The variation in textures of these rocks from study area is due to varying size and amount of the K-feldspar porphyroblasts couple with varying degree of foliation. In thin section, the characteristics granoblastic textures were observed in migmatitic and granitic gneisses. The mineral compositions of the gneisses rocks are variable, the common minerals assemblage includes: migmatitic gneiss quartz + plagioclase +microcline +biotite + chlorite +garnet, banded gneiss: quartz + plagioclase+ muscovite +biotite+sphene +chlorite+ garnet and granitic gneiss contain quartz +plagioclase+microcline + muscovite+ biotite + chlorite +garnet + opaque minerals. The gneisses of the study area are product of reworked rocks during the Pan-African with a positive DF values, this suggests igneous sources for the protoliths of these rocks in the study area. The chemistry of the gneissic rock also show a variable proportion of Na_2O and K_2O with alkali-calcic affinity, which suggests, a closed system behaviour during metamorphism on one hand, and possibly a co-magmatic origin of the igneous protolith on the other hand.
Keywords: Magmatic, Metamorphism, Petrochemistry, Precambrian, Protoliths, Tegina.

1. Introduction

The migmatite–gneiss of Nigeria basement complex is generally considered as the sensu stricto and it is the most widespread of the component units in the Precambrian basement [1-3], Figure 1. [4] revealed two generation of migmatitic-gneiss of different ages in the Northwestern basement blocks of Nigeria: The early migmatite type are differentiated in the field from the Pan-African Migmatite by complex fold structures with several generation and types of leucosomes which include granitic, aplitic and pegmatitic units, the Pan-African Migmatite show simple structures which include alternating schistose and tonalitic, granitic or pegmatitic layers. Ajibade, *et al.* [4], Observed that the relationship between the gneisses and the granitic gneiss suggests a common deformational episode. Oversby [5] Observed that the deformation and migmatitic processes that affected the basement tend to have dragged rocks of different lithologies, ages, and origin in parallelism such that differentiating these basement rocks into periodic episodal granitic additions becomes a problems. Geochronology of the gneiss complex from various parts of the Nigeria indicates that the rock has gone through at least four major tectonothermal events namely, the Liberian (2,700Ma, Oversby [5] Eburnean (2000Ma, Grant [6], Kibarian (1,100Ma. Grant, *et al.* [7] and Pan-African 600Ma [8, 9].

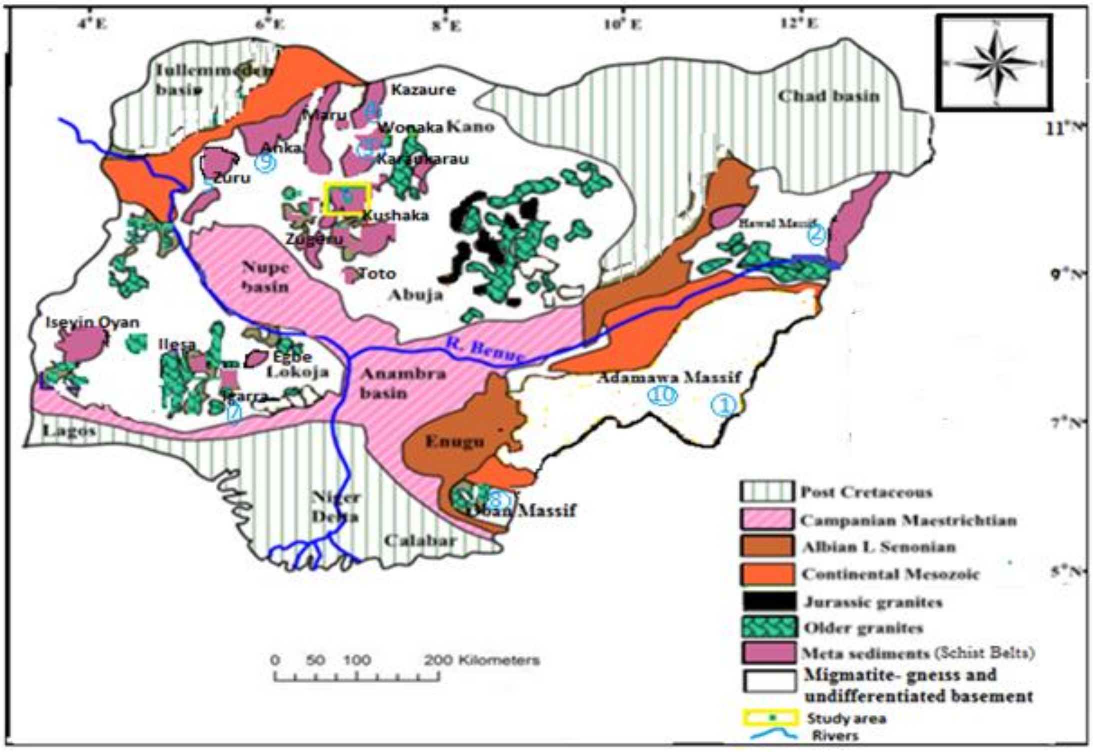


Figure-1. The geological map of Nigeria basement complex and other units of rocks [3].

Other reasonable age determinations are those by Rahaman [10], Dada [11], Oyinloye [12]. Previous works from Madaka and Kwana-Bala area includes petrographic descriptions of rocks [13-20]. The most comprehensive study of any mineral group was done for the talc and amphiboles, their compositions were variables in Tegina area [15, 16, 19]. The geochemistry of rocks identified by Truswell and Cope [14] in Niger and Zaria provinces, have been studied [21-27]. Other works from Madaka and Kwana-Bala area includes the tectonic evolution of granites, amphibolites, and talcose rocks [6, 7, 15, 19]. This paper is therefore intended to discuss the petrochemistry of the gneisses, particularly in relation to their petro-tectonic significance in the Madaka and Kwana-Bala area Figure 2.

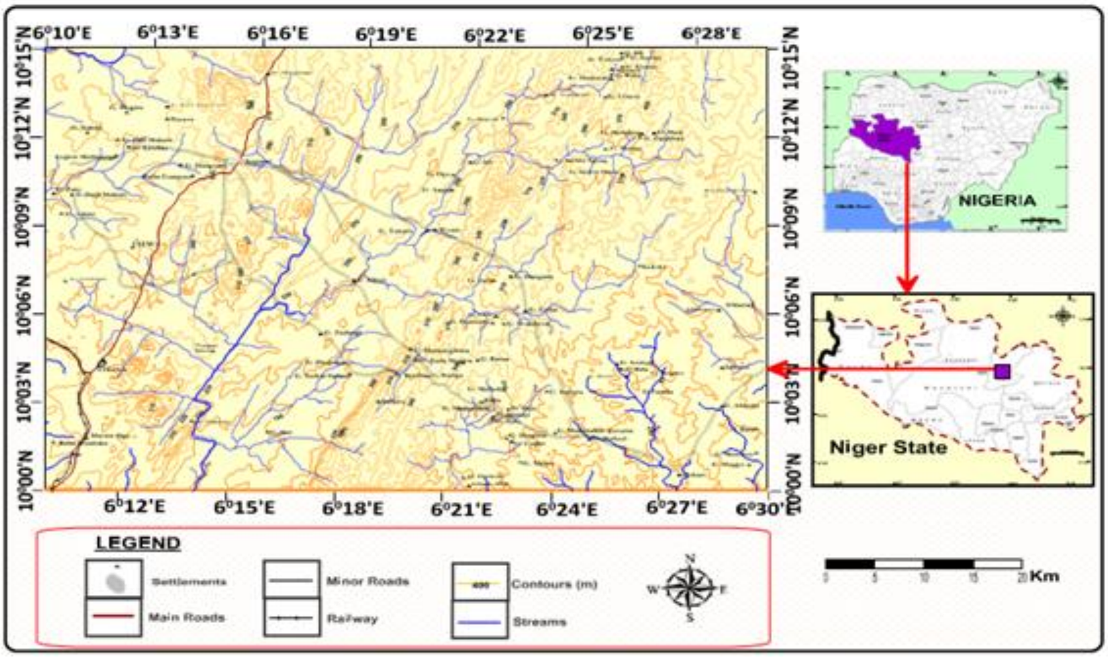


Figure-2. The location and accessibility map of the Madaka and Kwana–Bala area

2. Materials and Methods

Seven (7) Fresh samples of gneisses were taken during the field work from Madaka and Kwana–Bala area with the aid of sledge hammer and chisel. The lithological units of rocks from Madaka and Kwana–Bala area were observed, described based on their mode of occurrence, macroscopic characteristics, structural patterns and field relation with adjacent rocks. Hand specimens were described based on the following macroscopic characteristics of the rocks. Samples taken from the field were prepared as thin section. The photomicrographs of obtained from thin sections of gneisses were produced in the petrographic Laboratory of Geology, Faculty of Sciences, Ahmadu Bello University, Zaria, Nigeria. Seven (7) selected samples of gneisses were analyzed for major element oxides at Activation Laboratories Limited (ACTLAB), analytical Laboratory Ancaster, Ontario, Canada.

3. Results

3.1. Field Description and Petrography of the Gneisses

The basement rocks from Madaka and Kwana–Bala parts of Tegina Sheet 142 comprise of gneisses of varying proportion (migmatitic, bande and granitic), the metasediments includes kyanite-sillimanite schist, semi-pelitic schist, amphibolites, talcose rock, quartzite, and phyllite and granitic rocks consists of porphyritic granites, fine-medium-grained and granodiorite, Figure 3. The migmatitic gneisses around Gidian Zudangi and Gidan Biyaboki areas are cut by pegmatitic veins and have ptygmatitic characteristic (Plate Ia). It is banded with leucocratic layer persistently thicker than the melanocratic layer. The migmatitic gneiss around Supana area were characterized with a variable development of veins and discontinuous streaks or augen of leucocratic layer most of which are parallel to the prevailing foliation (Plate Ib).

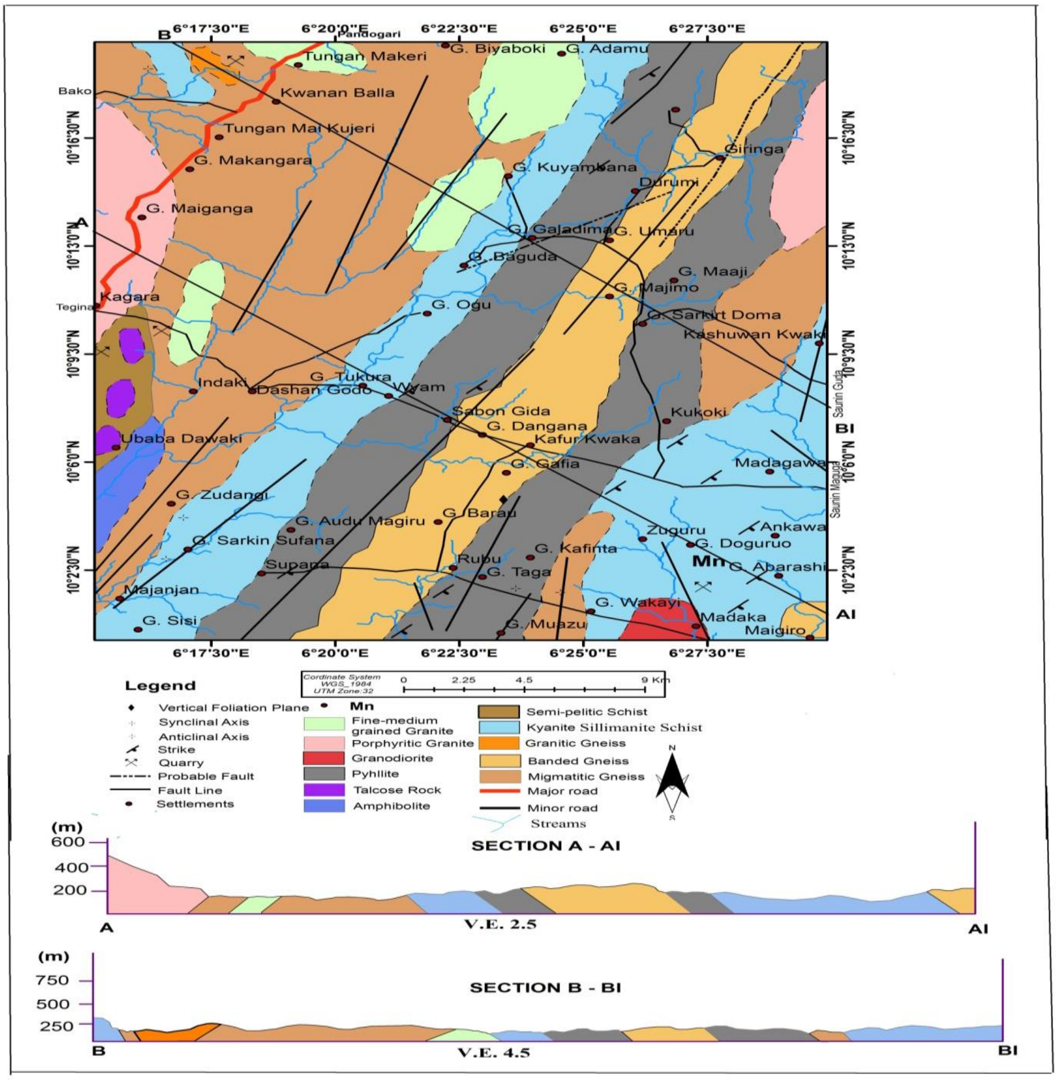
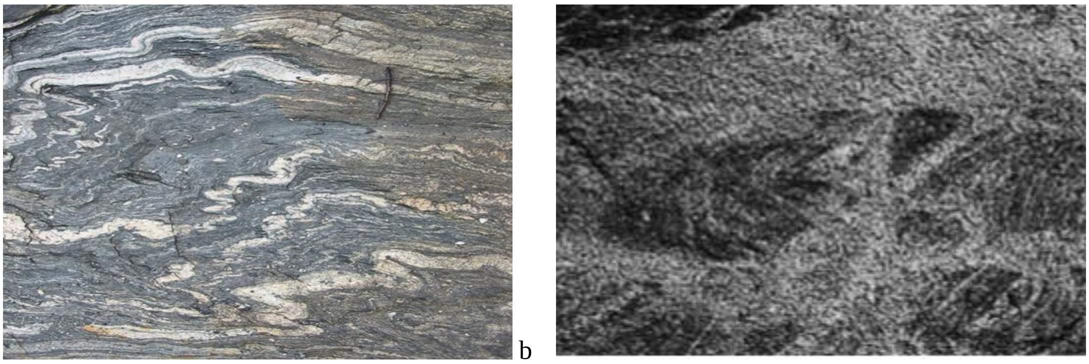


Figure-3. The geological map of the Madaka and Kwana-Bala area

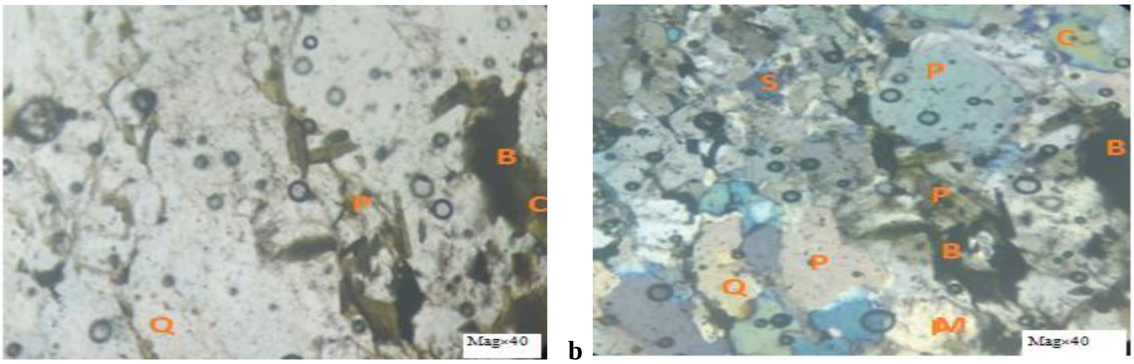
Migmatitic gneiss around Kwaioki portrayed diktyonitic features (Plate Ia). Within migmatitic rock, layering is not conspicuous, the composition of quartz and plagioclase with minor amounts of biotite formed irregular, ovate or lenticular in shape. The biotites within this rock were surrounded by leucosome contents. The leucosome veins of the migmatitic gneiss fill shear, and locally tensile, fractures between enclaves of this rock Plate Ib. They are medium to coarse grained with the banding ranges from well banded to discontinuous in some outcrops. The northwestern and southwestern part occurs as banded, granular in nature and consists of the paleosome and neosome regions (Plate Ia). The plaeosome region (the gneissic) is the metamorphic host rock while the neosome consists of light grey medium grained granitic components which were introduced into the pre–existing parent rock that is the plaeosome (Plate Ib). Generally, the degree of migmatization increases in the vicinity of the principal granite and granitic gneiss masses.



a b

Plate I Outcrops of migmatitic gneisses: (a) in form of low-lying along the northwestern part around Gidan Biyaboki with ptygmatitic fold (Lat 10° 11′ 47″ N and Long 6° 21′ 23″ E),(B) showing diktyonitic features with enclaves surrounded by veins around Kwaioki area (Lat 10° 12′ 02″ N and Long 6° 29′ 18″ E).

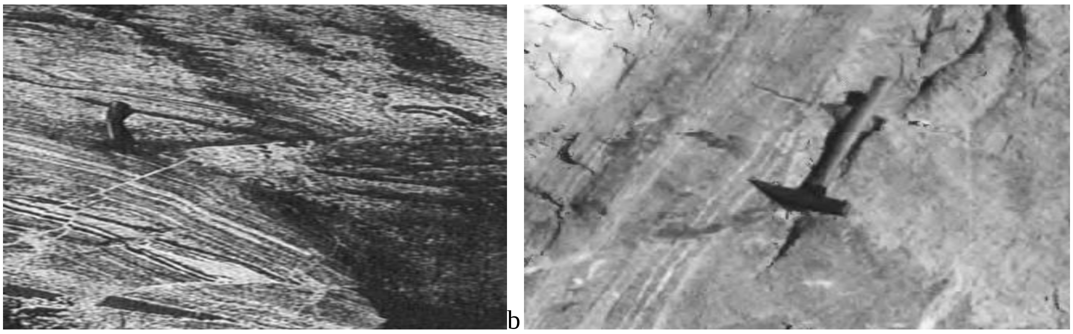
The mafic minerals of the migmatitic gneiss (quartz and feldspar) from Madaka and Kwana-Bala area display discontinuous thin layers, lenses which were interleaved with layers rich in biotite as shown in (Plate IIb). The migmatitic gneiss of Madaka and Kwana-Bala area shows eudral to anheral aggregates of dark and light minerals. The dark mineral is the biotite while the microcline, plagioclase and quartz are the light coloured minerals. The biotite minerals occurs along the cleavage, margins of the plagioclase and as separate flakes. The biotite within the migmatitic gneiss tends to be distributed evenly and is oriented nearly parallel to the layering of the foliation planes. The quartz is colourless with low relief and had anhedral form. The quartz grains in this rock have irregular to lobate shapes and as a replacement toward the other minerals, the increasing alteration of the quartz within this rock unit became coarser, more irregular, and somewhat more abundant. The quantity of chlorite varies widely biotite occurred as light to deep brown felted mass due to Fe-rich materials with chlorite (Plate IIa-b). Plagioclase exists as tabular crystals. The migmatitic gneiss contain quartz 29%, plagioclase 18%, microcline 19%, biotite 24%, chlorite 4%, garnet 2% and opaque constitutes about 3% of the rock.



a **b**

Plate V: The photomicrograph of migmatitic gneiss from Madaka and Kwana-Bala area under (a) plane polarized light (PPL) a mesosome region with the foliation defined by crystals, and annealed texture of unstrained quartz (b) crossed polarized light (XPL). Note contrast with a contrast in crystals shape between quartz (q) and feldspar (P)=Plagioclase (B)=Biotite, (Q)= quartz, M= Microcline C=Chlorite.

The banded gneiss in the study area occurs mostly as hills in the northwestern parts of the study area extending up to 300m around Gidan Sisi up to Gidan Usman. The banded gneiss occur as hilly and low lying outcrops, where they form contact with the schists. Contacts are generally gradational but sharp contacts are commonly characterized with pretectonic dykes, pegmatite dyke and veins (Plates IIIa-b). The rock is dark to grey in colour. Individual bands of the banded gneisses vary greatly in thickness from a few milimetres to tens of centimetres Plate (IIIa). Texurally, it is fine to medium grained. Foliation within the bands, defined by aligned biotite and quartz, are almost always parallel to the banding. The proportion of neosome to paleosome varies in banded gneiss outcrop around Gidian Barau. Quartz, biotite and plagioclase contents of the paleosome also vary within wide limits. These variations are probably related to an original stratification. Paleosome is usually fine to medium grained, while the neosome is medium grained.



a b

Plate III: Photographs of banded gneisses around (a) Gidan Sisi showing the extension of pretectonic dykes (Lat 10° 5′47″ N and Long 6° 16′23″ E), (b) Dutumi cut through by pegmatite dyke (Lat 10° 5′ 31″ N and Long 6° 17′ 41″E),

The biotite contents in the banded gneisses occurs as pleochroic yellow-brown tabular aggregates. The quartz in the banded gneiss occurs as interstitial aggregates and as fine irregular grains characterized with micrographic intergrowths at the margin. The feldspar (plagioclase) shows a deformed polysynthetic twinning free from zoning suggesting post crystal deformation in this rock (Plate IVb). The replacement of the plagioclase by sericite is also observed. The muscovite mineral occurs as coarse-grained, the mineral aggregates shows euhedral to subhedral in the banded gneiss. The mineral assemblage of the banded gneiss consists of quartz 17%, plagioclase 23%, muscovite 5%, biotite 43%, sphene 3%, chlorite 3%, garnet 3%, and opaque 3%.

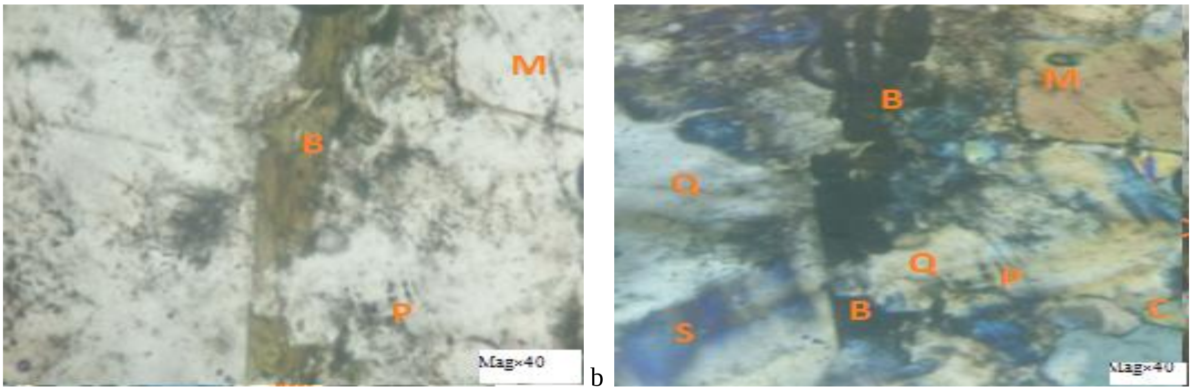


Plate IV: The photomicrograph of banded gneiss from Madaka and Kwana-Bala area under (a) plane polarized light (PPL) with brown coloured biotite (b) crossed polarized light (XPL) showing biotiteand plagioclase feldspar with deformed twin lamellea. B= Biotite, Q= Quartz, P= Plagioclase, M=M uscovite, C=Chlorite.

The granitic gneiss is a highly foliated rock that is well-developed towards the Kwana-Bala border to the east and Godo to the west. In the east of Makeri the rock covers an extensive area and rise into an oval shaped hill. Texurally, it is medium–grained, pale grey to white in colour. The granitic gneiss has a clear and sharp contact with the surrounding migmatitic gneiss (Plate Va). Structural features like faults and veins were mapped on the outcrop (Plate Vb).

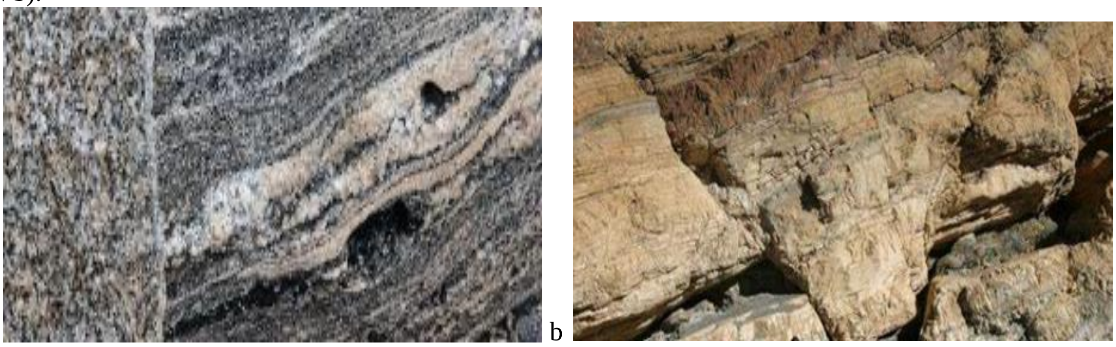


Plate V: (a) The contact of granitic gneiss and migmatitic gneiss along Muazu-Wakayi road (Lat 11° 4' 46" N and Long 6° 19' 26" E), (b) fault and veins on the granitic gneiss along Godo road east of Supana (Latitude 10° 7' 22" N and Longitude 6° 22' 17" E).

The biotite occurs as flakes, fine to medium grained subhedral crystal. It is the most dominant mineral next to plagioclase in the rock. The biotite within the granitic gneiss occurred in two forms. One as light to deep brown felted mass of iron rich biotite without a well-defined crystal outline and the other as distinct green to pink grains (PlateVIb). Quartz occurs in the form of large aggregate and lenses and generally have contacts with fragments of plagioclase. The plagioclase generally occurs as grey and platy crystals. Microcline crystals of varying sizes and shapes are common in the rock. The crystals show cross-hatch twinning. Accessory minerals include muscovite and garnet. The mineral assemblage of the granitic gneiss consists of quartz 30%, plagioclase 25%, microcline 10%, hornblende 5%, muscovite 3%, biotite 17%, chlorite 5%, garnet 3% and opaque 2%.

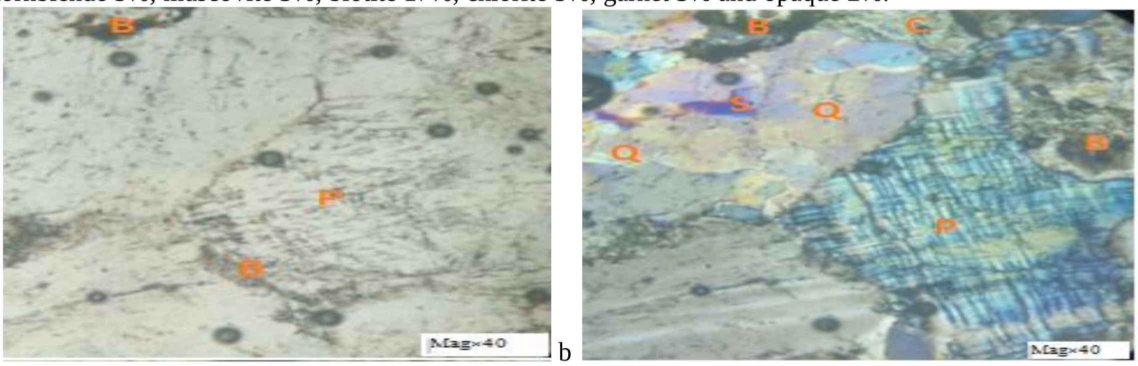


Plate VI: The photomicrograph of granitic gneiss from Madaka and Kwana-Bala area under (a) plane polarized light (PPL) with folation plane alighed with biotite (b) crossed polarized light (XPL) B= Biotite, Q= Quartz, P= Plagioclase, H=hornblende, C= Chlorite, S=sphene.

3.2. Geochemistry

The major, **t**race and rare earth elements in gneisses from Madaka and Kwana-Bala areas were characterized using discrimants plots for quantitative comparison and genetic interpretation.

The major elements composition of the gneisses from Madaka and Kwaana-Bala area area indicates SiO_2 values of the gneisses range from 63.77- 69.9 wt%, average 65.66, Al_2O_3 ranges from 3.17- 6.88 wt%, average 15.9, $Fe_2O_{3(T)}$ ranges from 13.46-17.3 wt%, average 4.84, CaO ranges from 2.15-3.64 wt%, average 3.01, Na_2O ranges from 2.66-9.38 wt%, average 5.68 and L.O.I ranges from 2.57-4.0 wt%, average 2.68. In addition, the concentration of MnO, MgO, K_2O, TiO_2, P_2O_5 in the gneisses varies from 0.03-0.82 wt%, 0.011-0.822 wt%, 0.23-0.91 wt%, 0.01-0.75 wt%, 0.01-0.79 wt% respectively. The banded gneiss contains low P_2O_5 (0.01-0.04 wt%) compared to (0.34-0.68 wt%, 0.71-0.79 wt%) in granitic gneiss and migmatitic gneiss respectively. To determine the protolith of gneisses based on the amount of quartz and feldspatic composition, if the MgO< 6%, and SiO_2< 90% [28] with discriminant function (DF). Shaw [28], assigned positive and negative DF values to igneous and sedimentary rocks respectively using this general formular**:** Discriminant Function $=10.44-0.21SiO_2 - 0.32Fe_2O_3T-0.98MgO+0.55CaO+1.46Na_2O+0.54K_2O$. Table (2) presents the DF of the gneisses obtained in the study area. The binary diagrams of Al_2O_3 versus MgO, after [29] (Figure 4) The variation diagram FeO/MgO versus FeO/MgO of the gneiss plots within high pressure metamorphism (Figure 5).

Table-1. Major elements composition and some ratios of gneisses in the study area (values in wt%)

	Granitic gneiss	Granitic gneiss	Granitic gneiss	Banded gneiss	Banded gneiss	Migmatitic gneiss	Migmatitic gneiss		Ran	- ge	
Code	S_{25}	S_{26}	S_{27}	S_{28}	S_{29}	S_{30}	S_{31}	Total	Min	Max	Average
Oxides											
SiO_2	63.77	65.19	65.01	67.65	69.90	64.21	63.92	459.65	63.77	69.9	65.66
Al_2O_3	15.90	17.30	17.11	14.41	13.46	16.63	16.98	111.79	13.46	17.3	15.9
$Fe_2O_{(T)}$	4.10	3.41	3.17	4.84	5.22	6.21	6.88	33.83	3.17	6.88	4.84
MnO	0.41	0.82	0.73	0.07	0.03	0.58	0.71	3.35	0.03	0.82	0.48
MgO	0.01	0.09	0.011	0.18	0.11	0.8	0.822	2.02	0.011	0.82	0.29
CaO	3.19	3.22	2.15	3.64	2.33	3.34	3.2	21.07	2.15	3.64	3.01
Na_2O	9.38	6.11	7.40	5.99	5.11	2.66	3.11	39.76	2.66	9.38	5.68
K_2O	0.77	0.91	0.55	0.89	0.23	0.67	0.85	4.87	0.23	0.91	0.67
TiO_2	0.01	0.27	0.09	0.01	0.27	0.11	0.75	1.51	0.01	0.75	0.22
P_2O_5	0.34	0.68	0.71	0.01	0.04	0.79	0.71	3.28	0.01	0.79	0.47
L.O.I	2.12	2.0	3.07	2.67	3.30	4.0	1.57	18.73	1.57	4.00	2.68
Total	100 .0	100 .0	100.0	100.4	100.0	100 .0	100.0	100.36	100.0	100.4	100.1
FeO	3.69	3.07	2.85	4.35	4.69	5.58	6.19	4.35	2.81	6.19	4.35
FeO/MnO	9.00	3.74	3.90	62.1	157.3	9.62	8.72	254.38	3.74	157.3	36.34
FeO/MgO	369.0	34.11	385.0	24.17	42.64	6.98	7.75	769.65	6.98	369.0	109.95

Table-2. Discrimant function (DF) of the gneisses in the study area

Rock units	Discrimant function (DF) of the gneisses
Granitic gneiss S_{25}	11.59
Granitic gneiss S_{26}	7.88
Granitic gneiss S_{27}	7.76
Banded gneiss S_{28}	8.05
Banded gneiss S_{29}	4.81
Migmatitic gneiss S_{30}	0.27
Migmatitic gneiss S_{31}	0.77

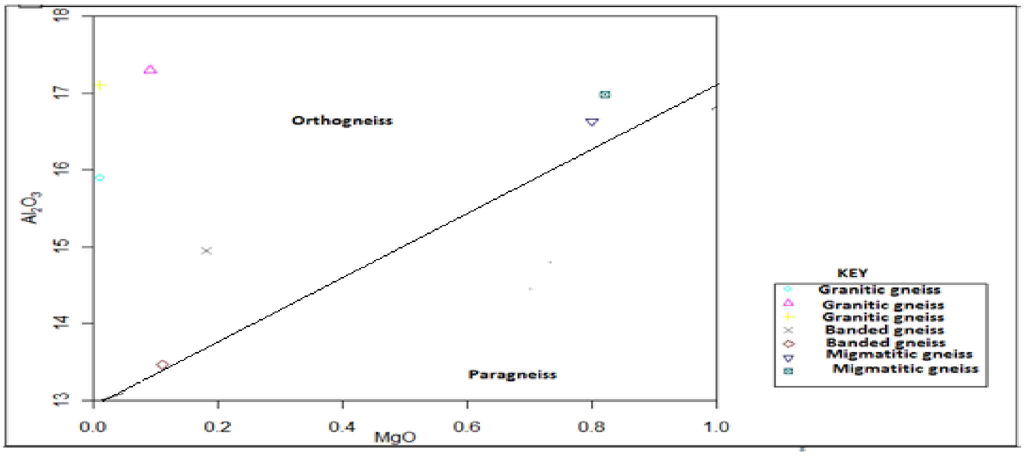


Figure-4. Bivariate Al_20_3 versus MgO discrimination diagrams (after [29] with line that separate paragneiss from orthogneiss for gneisses in the study area

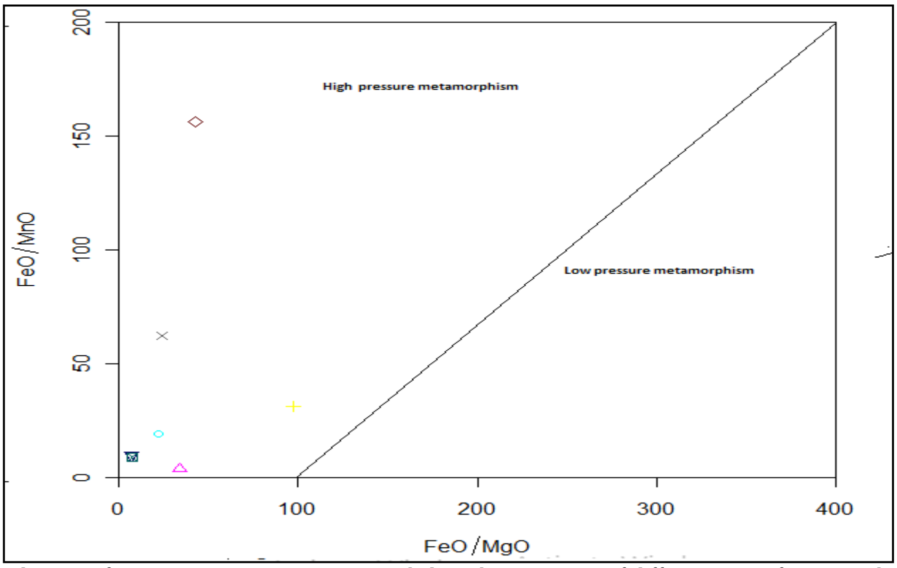


Figure-5. The binary diagram of FeO/MgO versus FeO/MnO in whole rock–comparison of different types of metamorphism (after [30]. Same key as in Figure 4)

4. Discussion

The gneisses (migmatitic gneiss, banded gneiss, granitic gneiss) of Madaka and Kwana-Bala area lies within the North central Nigerian Basement Complex. The rocks units within the study area comprise of the gneisses, metasediments and the granitoids (granodiorite, fine-medium-grained granites and porphyritic granite) as shown on the geological map of Madaka and Kwana-Bala area (Figure 4) with the exception of the minor rocks (the pegmatite and quartzite). The assemblages of these rocks show metamorphic imprints in the study area, indicative of various degree of deformation the rocks have suffered. The mineral composition of the gneisses in the study area is variable, the common assemblage being quartz + plagioclase +hornblende+ biotite and accessories like sphene and iron-a reflection of high amphibolites facies conditions during the D_1 tectono-metamorphic episode. The crystallization of the major rock forming minerals in the gneisses, particularly in K-feldspar + plagioclase +biotite ± muscovite controlled the assemblage. The occurrence of muscovite between plagioclase feldspar and quartz within the gneisses from Madaka and Kwana-Bala area, suggesting their late crystallization. The melting of the protolith of the gneisses occurred under hydrous conditions as indicated by the presence of hydrous minerals like biotite.

Field evidence from mineralogical descriptions of gneisses from Madaka and Kwana-Bala area indicates that the study area is a typical metamorphic zone where each rock units represents a state in the cycle of metamorphic change. The origin of the gneisses in Madaka and Kwana-Bala area has to be studied in terms of the general metamorphism that prevailed there and beyond. The gneisses are normally regarded as products of either injection of leucocratic, usually low-temperature and therefore more mobile, felsic minerals into pre-existing older bodies, or the segregation of such leucrocratic components into separates bands that finally confer the lit-par-lit nature. In a regional metamorphic terranes, all these and more may take place which support the evolution models of the northern Nigerian Basement Complex by Ajibade [22], Ajibade and Wright [31]. The experiment of Winkler [32] suggests a closed-system derivation of gneiss (neosome) from clayey or smecitic family subjected to higher temperature of about 700^0C at over 2 kb. In an open system, ingress by metasomatising fluids would progressively produce variants of metamorphites. Beginning with the lower-grade variants of what is evidently a metamorphic continuum. The assemblages of mineral, plagioclase-hornblende-biotite-garnet indicate that the metamorphic conditions were the lower grades of amphibolites facies in the ranges 4-8kb and 550-750^{o}C [32]. It is importance to know if the gneisses around Madaka and Kwana-Bala area have acted as closed chemical systems or if some alterations process has changed the original chemistry of the rocks in the areas. The high concentrations of SiO_2 (63.77-69.9) in gneisses resulted from miscibility of silica contents of the rocks from Madaka and Kwana-Bala area (Table 1). The composition of CaO, NaO, K_2O, P_2O_5 and TiO_2 are strikingly lower to oxides of SiO_2, Al_2O_3 and Fe_2O_3 in the gneisses (Table 1). The lower values of these oxides were attributed to chemical reactions under oxidizing conditions of the source rocks in the Madaka and Kwana–Bala area. The gneisses from Madaka and Kwana-Bala area are product of reworking of the rocks during the Pan-African events as observed with the high contents of Na_2O and K_2O, predominantly of alkali-calcic affinity in nature, which can be compared and related to rocks of Archaean migmatite gneisses [15, 24]. In line with Shaw [28] Table (2), the DF values of the gneissic rocks from Madaka and Kwana-Bala area including granitic gneiss (7.88-11.59), banded gneiss banded gneiss (4.81-8.05), migmatitic gneiss (0.27-0.77) are positive. Essentially, this suggests igneous sources for the gneisses in the area.

The binary plot of Al_2O_3 versus MgO diagram after [29] (Figure 4), shows that the gneisses falls in the orthogneiss field with one banded gneiss slightly lying in paragneiss field. The diagram FeO/MgO versus FeO/MgO after [30]. Figure 5 of the gneisses in the area plots within high pressure metamorphism [30, 31].

The origin of the gneisses from Madaka and Kwana-Bala area.

The migmatitic gneiss from Madaka and Kwana-Bala area was a product of partial melting of the gneissic rock, leading to mineral segregation into mafic and felsic minerals in response to intense high grade metamorphism. They are presumed to be the oldest rock in the study area (Plate Ia-b). The banded gneiss from Madaka and Kwana-Bala area were form as a result of metamorphism of pelitic materials accumulated as older supracrustals. The banded gneiss from Madaka and Kwana-Bala area is characterized by alternation of mafic and felsic layers (Plate IIa-b) and the granitic gneiss from Madaka and Kwana-Bala area, composed of biotite, K-feldspars, quartz minerals, occurs in close association with the migmatitic gneiss. This suggests that the migmatitic rocks in the area were also intruded by granitic bodies probably during the early Kibaran event and were later metamorphosed together with the older supracrustals. This is evident also by cataclastic deformation which produced multiple features found in granitic gneiss. The veins occurring within the granitic gneiss are believed to have occurred as a result of syn deformational process during the last orogenic episode because it is concordant with the trend of the foliation (Plate IIIa-b). The gneisses of the study area are product of reworked rocks formed at the Pan-African event with a positive DF values, this suggests igneous sources for the protoliths of these rocks in the study area. This process was aided by partial melting of the protoliths.

5. Conclusion

Petrographic evidence of gneisses from Madaka and Kwana-Bala area show that, the Pan-African reworking of rocks led to re-crystallization of the minerals within the migmatite–gneiss complex (migmatitic, banded and granitic gneisses), with the lithology of rocks within the study area displaying variation of metamorphism facies (medium to upper amphibolites) in the area. The geochemistry data shows that the gneisses in the study area exhibit a high degree of geochemical variability in the major element oxides. The chemistry of the gneisses show a variable proportion of Na_2O and K_2O with alkali-calcic affinity, which suggest a closed system event during metamorphism of gneissic rocks on one hand and possibly a co-magmatic origin of the igneous protolith on the other hand.

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