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GEOLOGY ANDGEOCHEMISTRY OF MALALI-KWARU BASEMENT ROCKS IN KADUNA, NORTH WESTERN NIGERIA: INSIGTHS INTO THEIR ORIGIN AND METAMORPHISM

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ABSTRACT

Geological and geochemical studies of Malali-Kwarubasement rocks covering an area of 85 km^2 were carried out in order to classify and shed more light on their protolith and nature of metamorphism. The Geology of the rocks in Malali-Kwaru and environs show that the area is underlain by migmatite, biotite gneiss, banded gneiss, and porphyritic granite. Porphyritic granite dominates the NE and NW part of the study area, followed by the biotite gneiss in the central to SW part of the study area, migmatite were found in the south and NW part of the study area, while banded gneiss is located at the SW part of the study area. Six representative samples were subjected to petrography and XRF geochemical analysis. The rocks are characterized by a wide range of SiO_2 having tholeiitic to calc-alkaline affinity, metaluminous to weakly peralkaline compositions, similar to rocks found in island arcs. Results of this study indicates that the Malali-Kwaru area, is underlain by a low to medium grade (greenschist facies to lower amphibolite facies) metamorphic rocks of basic to intermediate protolith. These rocks, which are thought to be Paleoproterozoic in age was later intruded by the Pan African porphyritic granite.

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1 Introduction

The area of study is part of the northern Nigeria basement terrain, represents segment of the Neoproterozoic belt of Northern Nigeria comprising suites of migmatites, whose chemical make-up and transformation is poorly established (Ferre and Caby, 2006). The area lies within the geographical coordinates, northing's 10°30´00" to 10°35´00" and easting's 7°25´00" to 7°30´00"on the Nigerian Topographical Map Sheet Kaduna S.E sheet 123, around Malali-Kwaru area of Kaduna state. It coversa total area of about 85 km^2 comprising localities such as Tudun Wada, Kabala Doki, Gabasawa, UnguwanRimi, Malali, Kurmi Mashi, and Kawo. The study area is accessible through a network of major roads and footpaths. The topographical relief is relatively flat, having an elevation of 600-650 meters in most parts of the study area. It is over 650 meters above mean sea level in some places, and below 500 meters in places that slope downward towards the river. Sampling of basement rocks within the area reveals occurrence of

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migmatite, biotite gneiss, banded gneiss, and porphyritic granite. This study is therefore, aimed at identifying and classifying the different rock units within the study area and to shed lights on their original protolith and nature of metamorphism.

2 Regional geology

The Nigerian Basement Complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons (Gireiet al, 2020, Black, 1980). The Nigerian basement terrain was affected by the Pan-African orogeny (600 Ma) and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006Girei et al, 2020). The Nigerian Pan African Basement Complex has been divided into two contrasting terranes namely the western and the eastern terranes (e.g., Ferreet al. 1997, Girei et al, 2020, Ahmed et al, 2021). The western terrain corresponds to an area west of Jos Plateau and composed of Archaean tonalites– trondhjemite–granodiorites suites which are largely overlain by the N–S trending supracrustal metasediments (e.g., McCurry 1976; Turner 1983). By contrast, the eastern terrane which corresponds to an area east of Jos Plateau is composed of high-grade metamorphic rocks comprising gneisses, migmatites, and metapelites (Ajibade et al. 1979; Ferre´ et al. 1996, 2002). Metamorphism in this region has reached upper amphibolite and granulite facies condition in places (Girei et al, 2020, Ferre´ and Caby 2007). Both the western and the eastern terranes are intruded by Neoproterozoic granitoids generally known as Older Granites to distinguish them from the Mesozoic anorogenic alkaline granitoids also known as Younger Granites.

3 Local Geology and petrography

3.1 Local Geology

The study area is situated in north-western part of Nigeria, which is bordered by byIgabi L.G. to the north, Soba L.G to the east, Chikun and Kaduna South L.G. to the south and BirninGwari L.G. to the west. The area is underlain by migmatite, biotite gneiss, banded gneiss, and porphyritic granite (Fig 2). Porphyritic granite dominates NE and NW part of the study area, followed by the biotite gneiss in the central to the SW part of the study area, migmatite were found in the south and NW part of the study area, while banded gneiss is located at SW part of the study area.

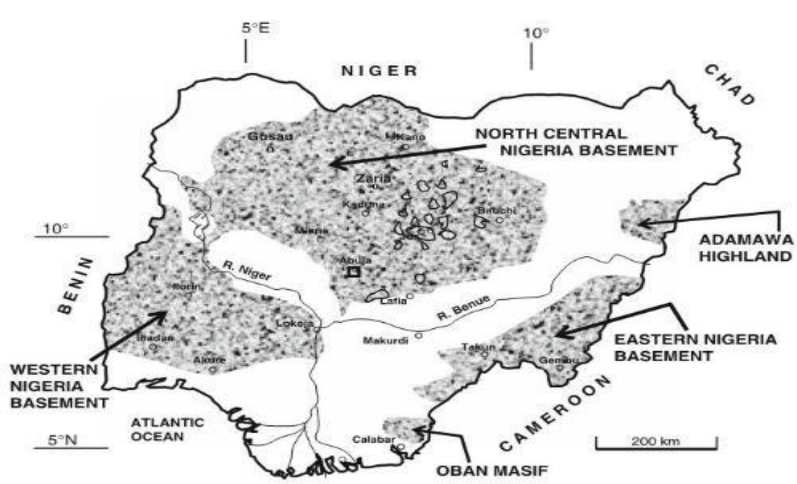

Fig 1. Geological map of Nigeria showing the Basement Complex, the Younger Granites and the Sedimentary Basins(After Murat, 1972).

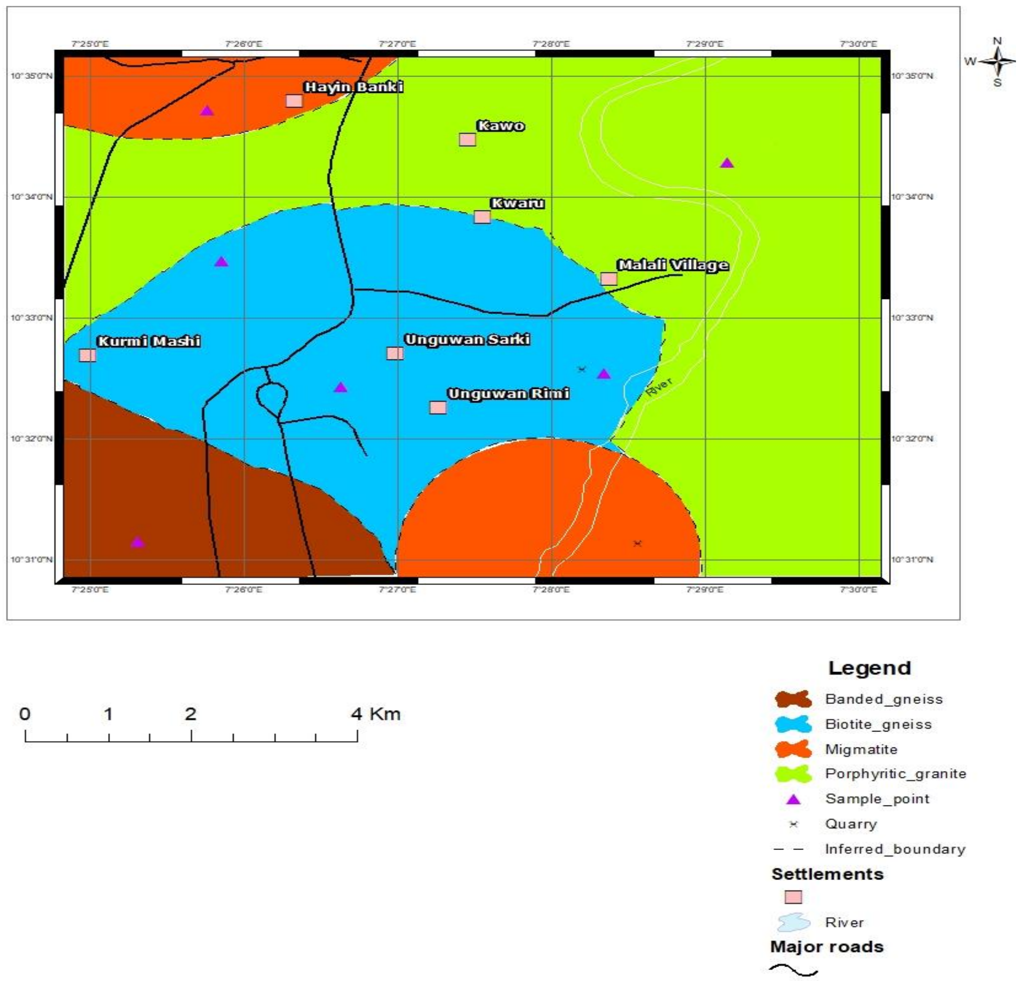

Fig 2. Geological map of the study area

3.1.1 migmatite

The occurrence of migmatite occur mainly in the south and northwestern part of the study area, it shows a clear banding of mafic minerals, and mineral grains vary in grain size from medium to coarse grained (Fig. 3a). There are numerous quartz veins on the rocks. Petrographic studies indicate that the rock is made up of microcline about (49 %), biotite (27%), quartz 13.6% muscovite (4%), and other accessory minerals that range in colour from greenish grey to dark (5.6%) (Fig. 4a). The microcline is a dominant mineral, it shows cross hatched twinning, on top of it is quartz, which is characteristically anhedral, colorless, and high relief, biotite has tones of brown crystal in colour under both plane polarizedlight (PPL) and crossedpolarizedlight (XPL), it shows a preferred orientation.

3.1.2 Biotite gneiss

Biotite gneiss are exposed around Nnankada road and Rabah road. Two sample are analysed in Nnankada road and one in Rabah. Using hand lens, the dominant minerals are quartz, biotite, feldspars and the veins are also striking in east west (EW) direction (Fig. 3b-c). The dominant mineral assemblages found in the biotite gneiss include, quartz (40%-45%), biotite (27%-31.2%), plagioclase (12%-13.6%) and accessory mineral (9%-15.2%), the quarts occur as anhedral, and colorless, plagioclase occur as subhedral crystal with low relief and carlsbad twinning (Fig. 4b and 4d). This sample is characterized by presence of mafic minerals in both XPL and PPL, exhibiting mesocratic features. Quartz occurs as colourless and white crystal in PPL and XPL respectively. The shape of the crystal is generally irregular with no cleavage and pleochorism, its generally medium to fine grained.

3.1.3 Banded gneiss

Banded gneiss the Banded gneiss are exposed around Kabala Doki, the texture of this rock type consists of medium grain (Fig. 3e). The dominant minerals observed in hand specimen are quartz, biotite, and feldspar. There was no clear evidence of sharp boundary between the porphyritic granite and the banded gneiss. The boundary was inferred. Mineralogically, the rock is made up of quartz (63.1%), microcline (18.65%) and biotite (18.25%, Fig. 4e). The rock is having cleavage that is the ability of a rock to split on a planer face, the rock is leucocratic and also the grains size ranges from medium to coarse grain.

3.1.4 Porphyritic granite

Porphyritic granite is exposed around Baju street Katsina road, the rock is light in colour in hand specimen and the texture of the rock is medium to coarse grained also the structures found on the outcrop is joint (Fig. 3f). Mineralogically, the rock is made up of quartz (48.8%), microcline (29.2%), plagioclase (11.6%), muscovite (4.8%), and accessory mineral (5.6%) (Fig. 4f). The microcline which is potassium rich shows cross hatched twinning. The quartz, which is light in color, shows a preferred orientation with the grain sizes ranging from medium to coarse.

Table 1. Major elements composition of granitoid in the studied samples in percentages (Wt.%).

Sample no	MS1	MS2	MS3	MS4	MS5	M6	
Element	Migmatite	Biotite gneiss	Biotite gneiss	Biotite gneiss	Banded gneiss	Porphyritic granite	Average
SiO_2	64.699	46.494	54.771	68.57	69.836	59.873	60.70717
Al_2O_3	13.828	12.001	15.541	14.002	14.625	14.396	14.0655
Fe_2O_3	6.843	6.193	12.541	3.395	2.371	2.786	5.688167
CaO	2.587	2.046	7.207	2.304	2.389	2.036	3.094833
Na_2O	0	25.563	0	0	0	12.966	6.4215
K_2O	8.821	5.912	5.787	10.059	8.962	6.683	7.704
MnO	0.1	0.119	0.155	0.036	0.033	0.058	0.0835
P_2O_5	0	0.135	0.325	0	0	0	0.076667
CuO	0.043	0.02	0.049	0.038	0.32	0.028	0.083
ZrO_2	0.083	0.016	0.089	0.036	0.013	0.037	0.045667
TiO	0.707	0.015	2.018	0.35	0.226	0.238	0.592333
Total	88.89	98.514	98.483	98.79	98.742	98.742	97.02683

Fig. 3. Field photographs showing: a) migmatite, b) biotite gneiss, c) biotite gneiss, d) biotite gneiss, e) banded gneiss, and f) porphyritic granite.

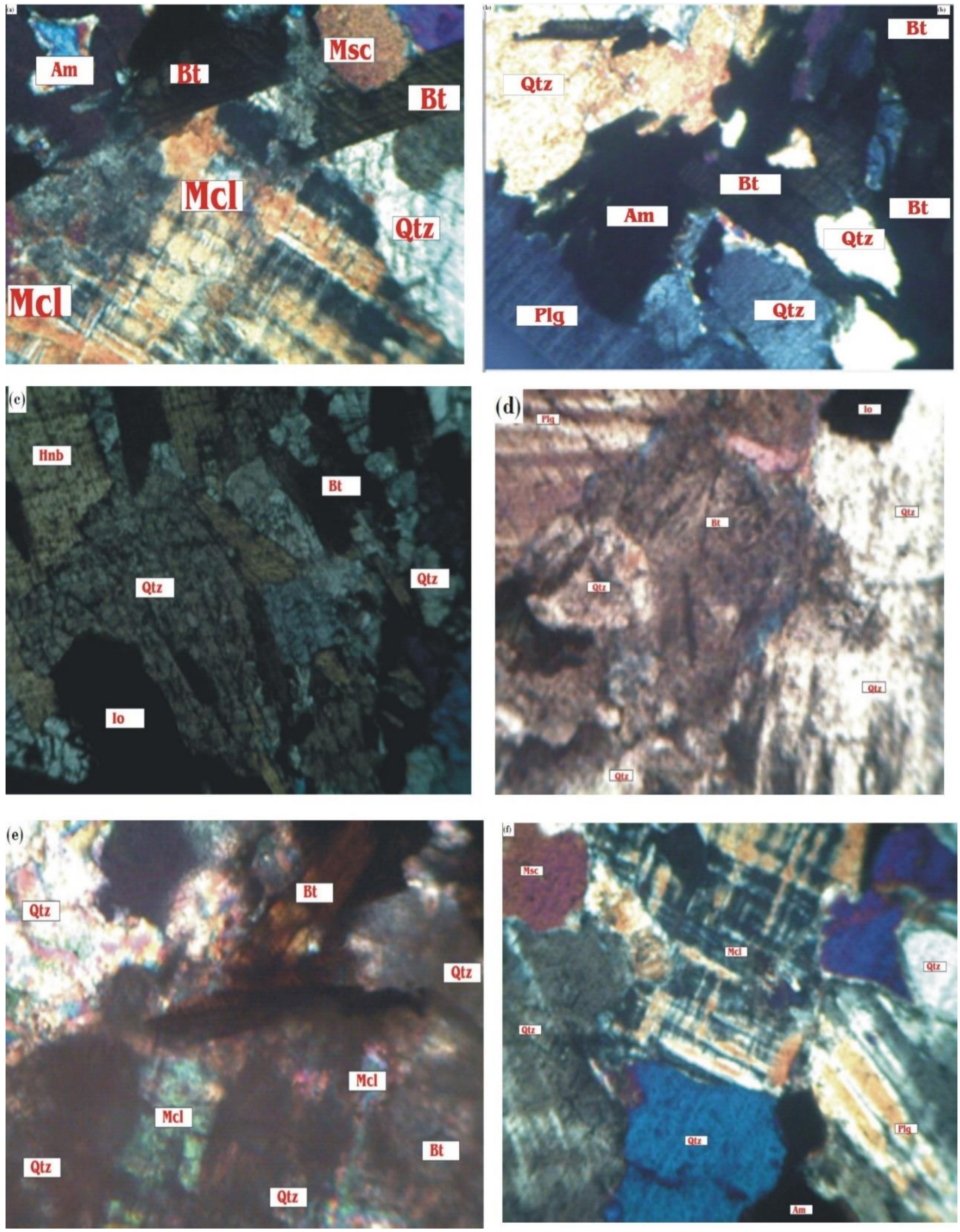

Fig. 4 Photomicrographs of a) migmatite, b) biotite gneiss, c) biotite gneiss, d) biotite gneiss, e) banded gneiss, and f) porphyritic granite. Note: all photomicrographs were taken under cross-polarized light (XPL). Qtz = quartz; Plg = plagioclase, Bt = Biotite, Mcl = Microcline, Am = Accessory mineral, Msc = Muscovite Io = Ion oxide, Hnb=Honblande

4. Sample handling and analysis

Fresh six (6) representative samples of mappable lithologic units were pulverized to fusible fineness in a tungsten carbide mill at the National steel raw material exploration agency the samples were, approximately 100-200 mesh, and then about 5g of each sample was weighed into 32 mm sample cups with a polypropylene X-ray film of 4μm thickness and were hydraulically pressed. Sample heights were measured in millimetres and sample cups were capped. The EDXRF analysis was performed using a Rigaku NEX DE EDXRF spectrometer equipped with a fifteen-place sample changer, with spin function using slow and steady spinning mode.EDXRF measurements were carried out under helium (He) atmosphere using a palladium (Pd) X-ray tube at a voltage of 60 kV and current of 10μA, with 10 mm beam spot size, and silicon (Si) drift detector comprised of Peltier electronic circuit cooling system. Standardless calibration was employed using Fundamental Parameters (FP) methods software (Rigaku RPF-SQX) to allow for elemental quantification of completely unknown. The software can automatically estimate elemental concentration and provide appropriate corrections. Rigaku NEX DE EDXRF spectrometric analysis can be employed to measure a wide range of elements with varied atomic numbers, from sodium (11) through uranium (92), while providing elemental detection limits from low parts-per-million (ppm) to high weight percent (%wt). The analytical uncertainties were generally within 0.1-1% (RSD).

Table 2. Trace elements composition of granitoid in the studied samples (in ppm)

Sample no	MS1	MS2	MS3	MS4	MS5	MS6	
Elements	Migmatite	Biotite gneiss	Biotite gneiss	Biotite gneiss	Banded gneiss	Porphyritic granite	Average
Sn	69.809	11.8	0	18.924	10.646	6.778	19.6595
Nb	25.677	51.059	12.063	21.062	21.345	26.912	26.353
V	12.279	24.281	33.111	12.448	14.072	10.409	17.76667
Ti	269.399	412.45	682.11	171.302	113.993	145.218	299.0787
Zr	132.994	39.329	100.335	84.769	34.031	114.335	84.29883
Sr	67.555	56.349	318.957	77.152	83.644	71.499	112.526
Rb	143.56	244.403	102.763	168.91	162.576	202.756	170.828
Cu	75.664	55.267	62.024	97.704	89.005	93.486	78.85833
Ta	25.847	7.065	11.443	14.624	18.806	9.89	14.6125
Ag	4.469	1.811	2.737	3.642	5.723	4.759	3.856833
Cr	48.724	39.882	33.407	57.579	60.954	66.036	51.097
Ni	0	0	3.168	1.732	11.481	2.507	3.148
Co	52.052	70.575	69.003	33.821	22.919	27.999	46.0615
Zn	24.842	46.853	39.224	17.368	10.805	16.57	25.94367
Ba	18.877	0	34.489	41.869	18.304	11.986	20.92083
Mo	5.199	4.126	3.192	6.189	9.259	5.314	5.5465
W	1.806	0.627	0.751	0	4.248	0.218	1.275
T_{Zr}(^{O}C)	374.6	155.1	359.7	348.1	323.7	287.3	369.7

5. Major oxides and trace elements geochemistry

The chemical compositions of the rocks from the study area are presented in Tables 1 and 2. Silica (SiO_2) contents range from 46.494 to 69.836 wt.% in the granitoids with the lowest content of SiO_2 (46.494–54.771 wt.%.) recorded in the biotite gneiss while the highest content (69.836 wt.%) is recorded in the banded gneiss. Most of the oxides show decrease in their content with increasing silica (Fig. 5). This indicates the removal of the high temperature minerals and plagioclase in the course of crystallization although the increase in the SiO_2 may indicate more fractionation.

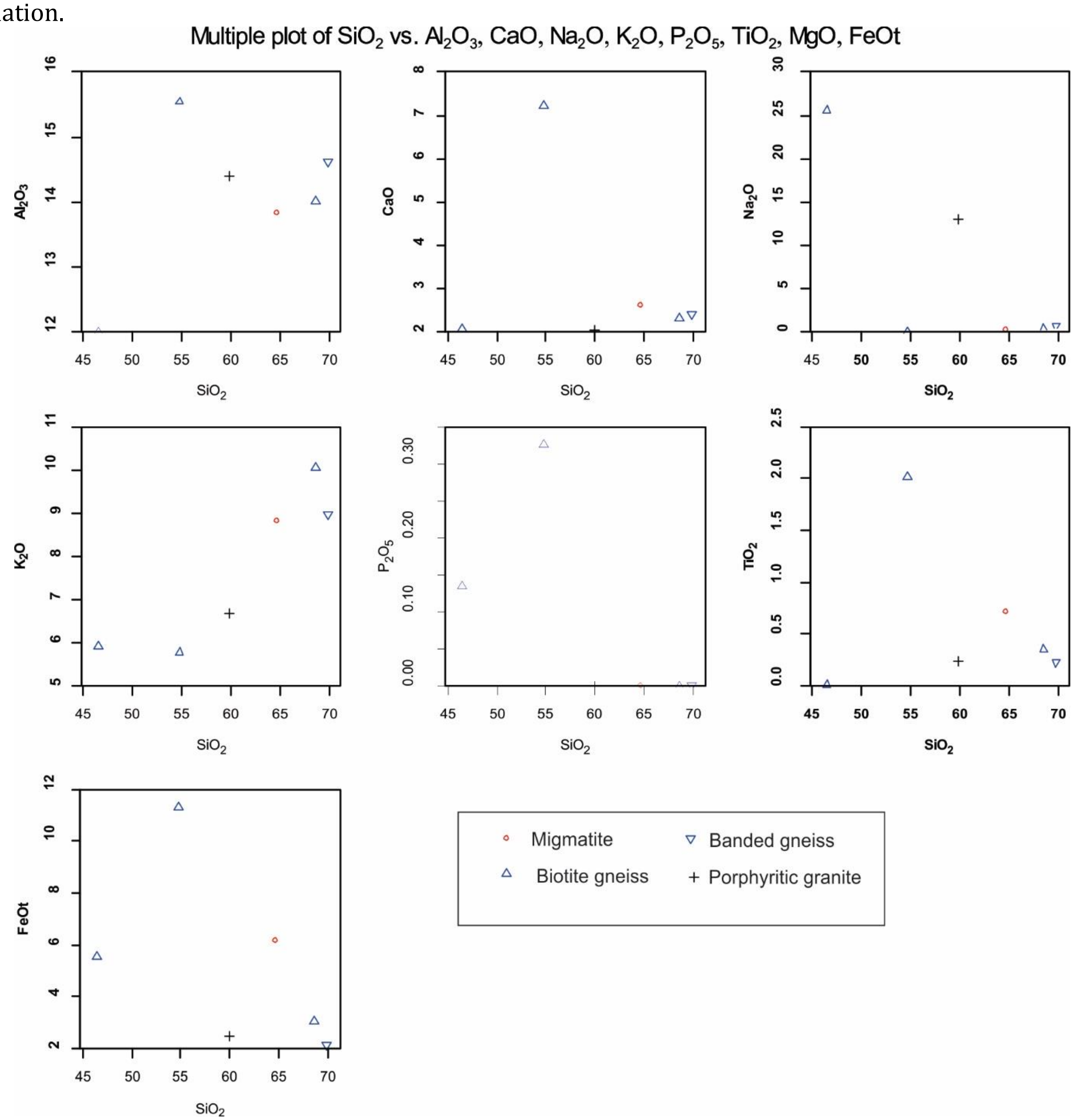

Fig 5: Harker plot of some major elements against SiO_2

The major oxides composition of the granitoids plotted on Harker diagram using SiO_2 as an index of differentiation shows that soda (Na_2O), P_2O_5, CaO, TiO_2, and FeOt behave as compatible components, each of these oxides decreases as SiO_2 increases and generally defined consistent linear trends (Fig. 5). According to Hassanenand Haraz (1996) such linear trends can be attributed to either hybridization or fractionation. Potash (K_2O) and Al_2O_3on the other hand show somewhat opposite behavior, increasing with increase in SiO_2.

6. Origin

Due to possible error in Na2O values, many discrimination plots were not used in achieving the aim of this study. Hence, field relationship, petrography, and some geochemical characteristics are the basic criteria utilized in achieving the aim of this study. TheK_2O versus SiO_2discrimination plot (Fig. 6) showsthat all the rocks in the study area are of shoshonite series [After Peccerillo and Taylor (1976)], The term 'shoshonite magma series' refers to a K-rich rock association with both calc-alkaline and alkaline affinities that has been considered separately as a rock series (Morrison 1980). Basalt and basaltic andesites are the most common typesof shoshonitic rocks. Other shoshonite types include traychy-andesites (Armienti et al., 1983). The SiO_2 constituents of the rocks, which range from 46wt.%-69wt.% (Table 1), indicates that the protolith of the metamorphic rocks were from basic and intermediaterocks. This is in consonance with the composition of shoshonitic rocks as described by the aforementioned workers.

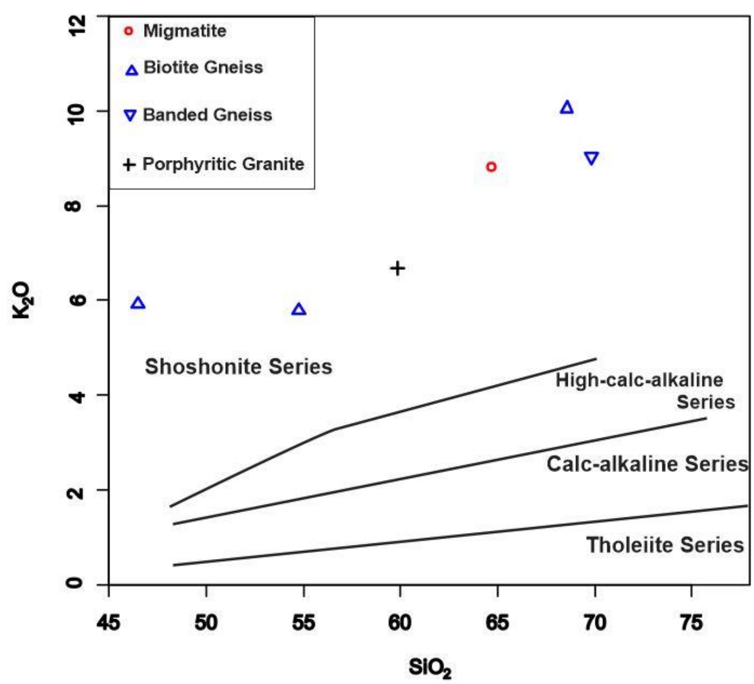

Fig. 6 K_2O versus SiO_2 (after Peccerillo and Taylor 1976)

Stability ranges of index minerals are important in the assessment of temperature and pressure of metamorphism and in establishing metamorphic facies. The intensity of metamorphism is mainly related to the pressure and temperature conditions prevailing during rock transformation (Bucher, 2005).Zircon is an important accessory mineral, found in a wide range of igneous, sedimentary and metamorphic rocks (Sepidbar et al, 2018; Siégel et al., 2017). Ti-in zircon thermometry and zircon saturation temperatures (TZr) are useful techniques in petrology as a way of constraining magmatic zircon crystallization temperatures in igneous (e.g., Sepidbar et al, 2018) and high-grade metamorphic rocks (e.g., Sepidbar et al, 2018; Liu et al., 2015). The zircon content of the granitoids in the study area is low to moderate concentration (34-132 ppm). Using the bulk-rock composition and the zircon saturation thermometry model of Watson and Harrison (1983), the calculated zircon saturation temperatures (TZr)of the Malali-Kwaru granitoids after Janousek et al, (2006) range from 155^{o}C-375^{o}C with an average of 369.7^{o}C (Table 2).

Metamorphic rocks formed within the P-T range of 2-9 kb and 250-450 ^{o}C can be regarded as low-grade metamorphic rocks. Mafic volcanic rocks metamorphosed under these conditions contain green minerals like chlorite and epidote, hence the name Greenschist Facies. Rock samples in Malali-Kwaruarea contains such greenish minerals reported as accessory minerals. On the other hand, rocks metamorphosed within the P-T range of 2-9 kb and 450-700 ^{o}C are regarded as medium grade metamorphic rocks, while those metamorphosed within temperatures >700 OC and pressures ranging from 4-10 kb are the highest grade.

Based on the geochemical results and inferred protolith of the studied rocks in area, coupled with the zircon saturation temperature of the rocks (155 ^{0}C - 375^{0}C; Table 2), the metamorphic rocks can be regarded as a low grade (<450^{0}C) greenschist facies metamorphic rock. In general, the idea of metamorphic facies is based on the fact that, at a given temperature and pressure, a unique group of minerals are produced with a fixed constituent. For example, an outcrop composed of plagioclase and hornblende can be regarded as an amphibolite facies (Bucher, 2005; UgwuonahandObiora, 2011). Therefore, the obvious presence of hornblende and plagioclase in some of the samples in the study area indicates that they probably belong to the amphibolite facies. The preponderance of fine and medium grained rocks in the study area is in consonance with the regular grain size for low to medium grade metamorphism respectively.

Based on field relationship, the migmatite and biotite gneiss might be the oldest rock comparable to the older Precambrian unit of the basement complex of Nigeria (Alagbe, 1979), whereas the porphyritic granite is the youngest and was probably emplaced during the Pan African Orogeny. Results of this study indicates that the Malali-Kwaru area, is underlain by Paleoproterozoic low-grade (greenschist facies) to medium grade (amphibolite facies) metamorphic rocks of basic to intermediate protolith that was intruded by Pan African porphyritic granite.

6. Conclusion

The geological and geochemical studies of the basement complex rocks in Malali-Kwaru area have been studied and from the results, it is concluded that the rocks belong to the northwestern basement complex rocks of Nigeria. Correlation between the petrographic study, field relationship records and the geochemical results give a good match and shows that the rocks are majorly metamorphic in origin. The tectonic imprints on the major and minor rocks shows signatures of the Pan-African Orogeny. Finally, our findings indicate that the Malali-Kwaru area, is underlain by Paleoproterozoic basement rocks that are thought to be low-medium grade (greenschist to lower amphibolite facies) metamorphic rocks of basic to intermediate protolith, which was intruded by Pan African porphyritic granite. Minor intrusions such as the quartzo-feldspathic veins imprinted on these rocks are indication of events which marked the termination of the Pan-African Orogeny. Further geochemical, structural and isotopic studies is recommended to support this concept.

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