

Engineering geological Characterization of Basement Rocks for Construction Aggregates: A Case Study of Kajuru Area Kaduna, Nigeria.

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Abstract

The microstructure, mineralogical composition and analysis of chemical constituent of rock samples were evaluated as part of the research on the quality and suitability of rocks in Kajuru, Kaduna State, Nigeria as sources of aggregate for construction. Advanced Spaceborne Thermal Emission and Reflection (ASTER) Global Digital Elevation Model (GDEM) in Global mapper software was used to visualize three dimensional perspectives (3D) of the study area and quantities of major oxides present in Rock samples were determined using x-ray florescence machine called X-supreme 8000. The microstructural characteristics of rocks such as mineralogy, structure, textural and distributions of minerals in the matrix were studied using a petrographic microscope. The rock predominantly consists of porphyritic granites and gneisses with minor quartz vein and quartzofeldpathic pegmatite intrusions. The high silica contents are confirmed from microscopic studies that elucidated the prevalent mineral specie to be felsic component - quartz and feldspar with interlocking grain boundary. The studies revealed mica, microcrack and fracture in some of the rock type which will invariably affect their engineering performance. It is therefore recommended that physicomechanical evaluation be carried out on the rock aggregates to establish the strength of aggregate and the link between physicomechanical properties and geological characteristics of the rock.

Keywords: Basement rocks; microstructure; mineralogical composition; petrography

1. Introduction

The mapped area covers an area of about 36km^2 and is bounded by longitudes 10^o 18' 00" N to 10^o 21'30" N and latitudes 7^o 53' 00" to 7^o 56' 00". It lies within the Nigerian basement (Fig. 1) which is characterised by synclinorial belts of low grade metasediments downfolded into high grade gneisses and migmatites, the whole intruded by batholitic granites.

The area is characterised by process of several phases of deformation, recrystallization and intrusion, the last of which is the Pan African orogeny (McCurry and Wright, 1977). Russ (1957) considered the gneissic complex to represent the oldest member of Precambrian basement in northwestern Nigeria and that it evolved by successive sedimentation, deformation, metamorphism and igneous intrusion over a vast period of history of the basement.

Granitic bodies are widespread and range in size from sub-elliptical plutons to masses of batholithic dimensions over 100 km in length. The masses may or may not be foliated and are concordant and elongated to the regional structural trend (McCurry, 1976). Other granitic rocks described according to their petrographic affinities are porphyritic granites, fine to medium grained granite, syenite, quartz syenite and fayalite quartz monzonite (bauchite) as described by Oyawoye (1972).

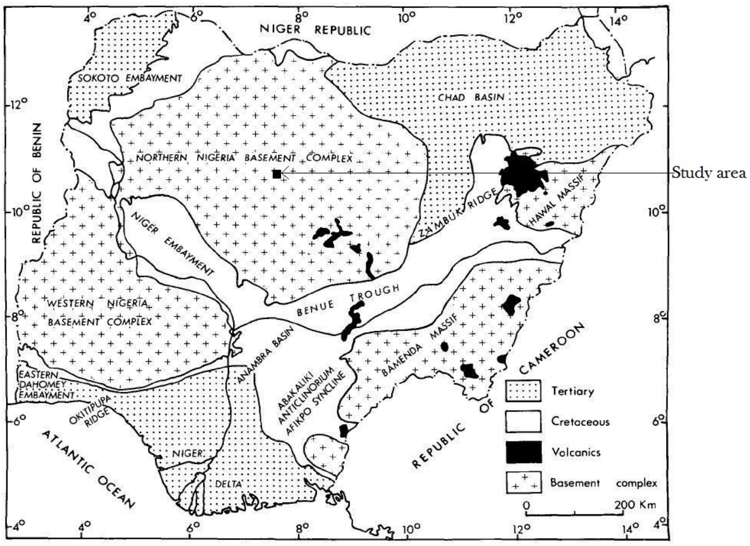


Fig. 1: Study area within the geologic Map of Nigeria (modified after Dessauvagie, 1975 in Avbovbov, 1980).

Silica-potassium metasomatism has been suggested to have affected the basement complex of Nigeria (Oyawoye, 1972). This may not be unconnected with alteration of minerals to yield new ones in events associated with dynamic metamorphism (Elueze, 1981b). The Pan African orogeny (ca 600 Ma) is established as a granite emplacement period that witnessed the intrusion of older granites into the migmatite gneiss - quartzite complex.

In present study petrographical and geochemical data from granitoids were utilized to investigate petrogenesis of the rocks.

2.0 Materials and Methods

Remote sensing study with Global Mapper 13 (ASTER GDEM Worldwide Elevation Data) was used for geomorphological interpretations. Also, structural data was extracted with GCI-Geomatical software from subsets of LandSat ETM+ (Path 153/Row 082 acquired in October, 1999).

This was followed by a two days reconnaissance field work to collect data on the major lithologies and establish boundaries of the study area. Subsequently, detailed field mapping using GPS traversing method was carried out for 5 days. The compass clinometer was used to measure trend and dips of lithologies and other structural features on outcrops. All observations at different locations are recorded in field notebook. Representative samples (rocks) for petrographic studies and geochemical analysis were taken from outcrops with sledge hammer.

Thin sections were produced with Logitech CL50 machine, studied under polarised light microscope and their photomicrographs were taken with digital camera. JMicroVision software (Appendix I) was used for point counting (modal analysis) at the Department of Geology, Ahmadu Bello University, Zaria.

Also, to obtain geochemical data, sizeable fractions were pulverized and analysed for major elements with X-ray Fluorescence machine in Multi-User Science Research Laboratory (MUSRL), Ahmadu Bello University, Zaria. Loss on Ignition (LOI) was determined by igniting a sample split then measuring the weight loss. Also, geochemical data analysis was performed using GCD toolkit.

Map of study area was scanned and uploaded into MapInfo software (MapInfo Professional 11.0). It was digitized at scale 1:25, 000.

3.0 Results and Discussion

3.1 Remote Sensing Studies

In this study an Advanced Spaceborne Thermal Emission and Reflection (ASTER) Global Digital Elevation Model (GDEM) of the mapped area (Fig. 2) was utilized for reconnaissance survey.

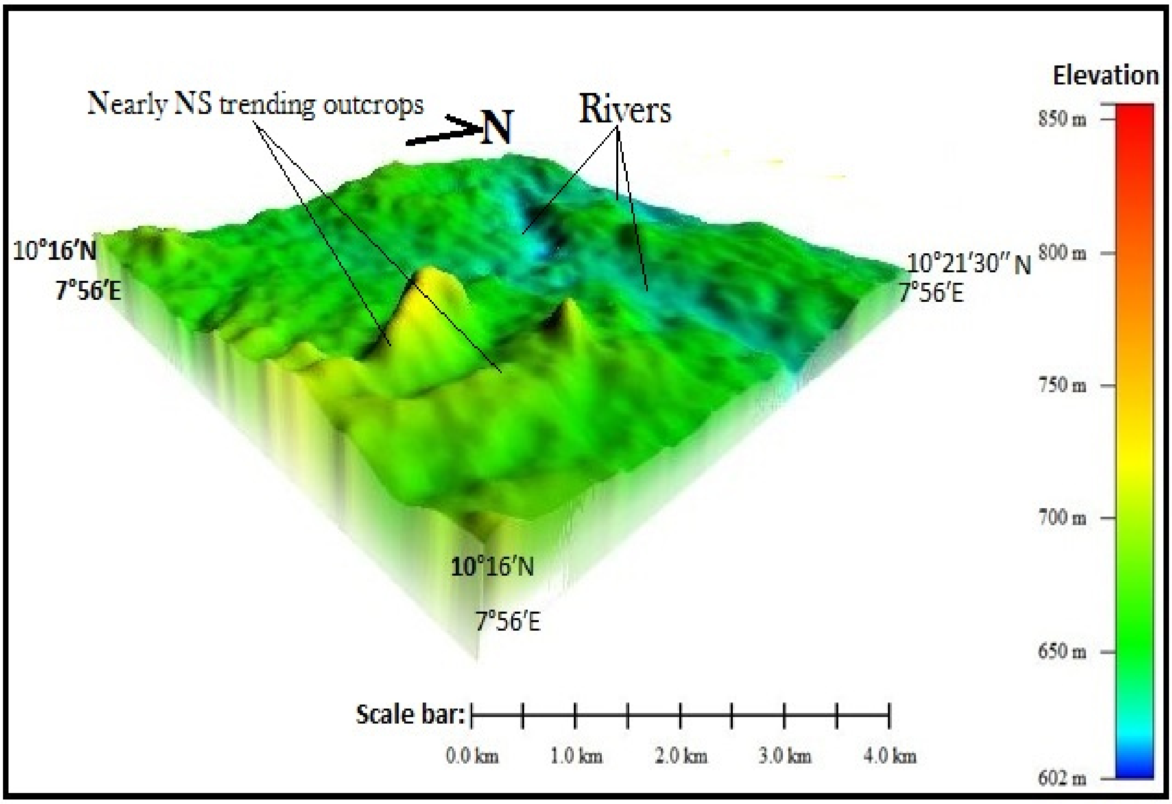


Fig. 2: ASTER GDEM 3D perspective view of the study area

The resultant image gave a 3-D perspective view of physiographic features in the study area. Atlas shader displayed topographic variations with color (Fig. 2). The highest outcrop lies at the southeastern part of the study area. Nearly NS trends are noted on these outcrops. Other smaller outcrops and features like the major rivers and their tributaries are observed.

3.2 Field Geology

The mapped area generally accessible through minor road, footpaths and cattle tracks. Northern flowing river Kaduna drains the area with dendritic drainage pattern (Fig. 3). The major rock types in the study area include the gneisses (porphyroblastic, granitic and banded gneisses), biotite granites (porphyritic and medium to coarse grained varieties) as shown in Fig. 3.

The banded gneiss mainly occurs at the western edge while porphyroblastic gneiss covers the central part and tapers into the southeastern part. The biotite granites had gradational/inferred contacts with gneisses and it predominate the north-western, north-eastern and southwestern parts. The medium to coarse grained varieties underlay areas around Kasuwa Magani (Fig. 3). The minor rocks types include quartz veins, quartzofeldspathic pegmatites. Alluvium, laterite and soil occur as superficial deposit. The minor rocks cannot be mapped on the scale of the map.

The hand specimens of porphyroblastic gneisses are mostly composed of creamy-white feldspar and quartz, together with dark minerals. The dark minerals are arranged in a streaky banding, giving the rock a gneissic texture. The granite gneiss and banded gneiss are grey in colour and fine to medium grained in texture. Mineralogically, it is composed of quartz, feldspars and biotite with foliation defined by biotite laths (Table 1).

The hand specimen the granite samples are generally light greyed, porphyritic with white coloured, foliated phenocryst of feldspars. The cut surface of hand specimen shows the typical minerals of granite. There are two varieties of feldspar: potassium feldspar is pink in colour, sodium feldspar is white. The texture consists of interlocking crystals up to 2cm across. The feldspar phenocrysts show regular blocky shapes. Mineralogically it consists of microcline, quartz, and biotite and plagioclase feldspar (Table 1).

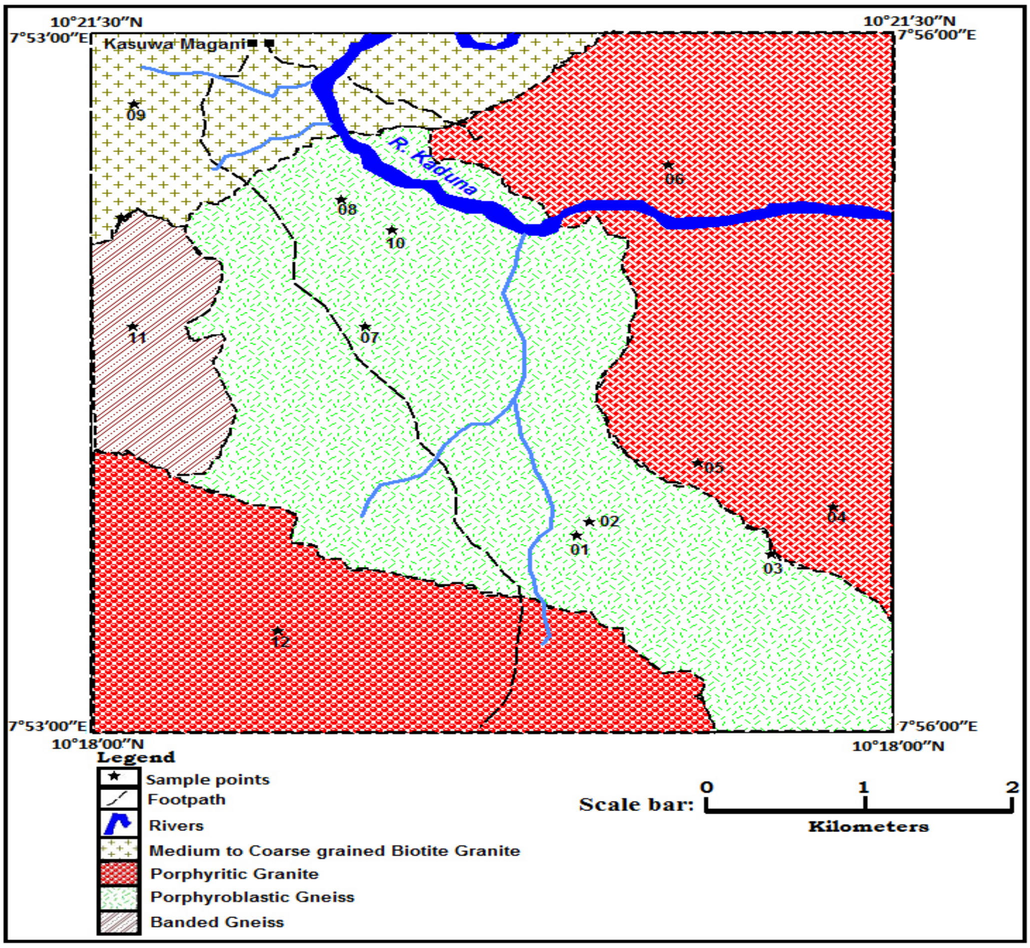


Fig. 3: Geological map showing lithologic variations in the study area

3.3 Petrographic Studies

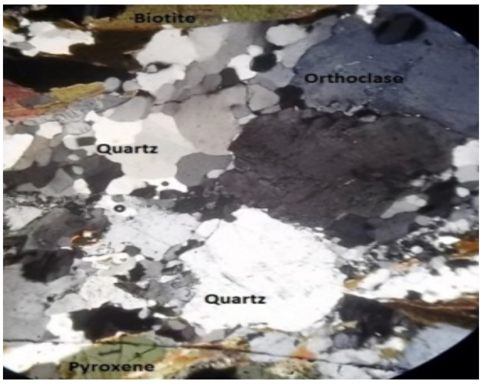
Thin sections of twelve representative samples were observed under optical polarizing microscope in both crossed and plain polarised light magnified for forty times. This was used for establishing structural and textural characteristics, minerals identification, calculation of modal composition of the minerals present and classification of rocks in the study area.

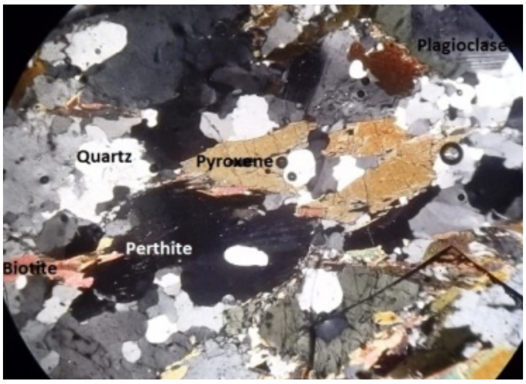
3.3.1 Granite and Gneiss Photomicrographs

Photomicrographs of the classified granite and gneiss rocks from the twelve thin sections were represented under six major rock types.

Porphyroblastic gneiss

The rock is generally medium to coarse grained with porphyroblastic minerals in places. quartz grain with interlocking grain boundary with orthoclase feldspar, Prismatic, lineated biotite with light green interference colour. Clinopyroxene with brown interference colour, Perthite (altered plagioclase) and polysynthetic twinned plagioclase feldspar.

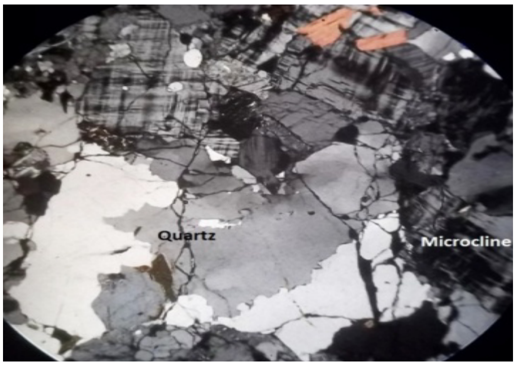


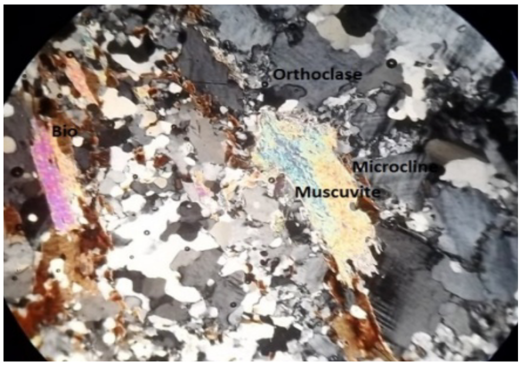


Plates I: Photomicrographs of porphyroblastic gneiss (XPL views)

Granite gneiss

The felsic minerals (quartz and feldspars) with fractures predominates, view showing microcline with characteristic cross hatch twinning pattern and grey interference colour with microcracks and fractures, also muscovite with bluish and pink interference colours.

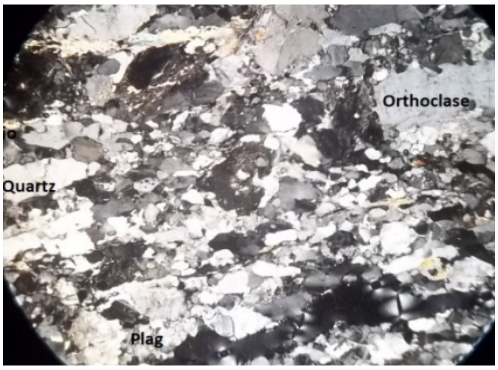


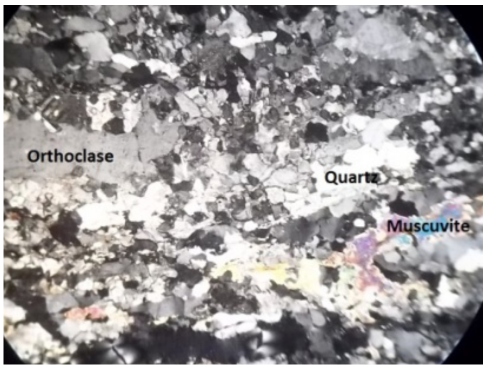


Plates II: Photomicrographs of granite gneiss (XPL views)

Banded Gneiss

Crossed polar view showing fine grained felsic grains that appear lineated and traces of mica (muscovite and biotite) with pink and blue interference colour.

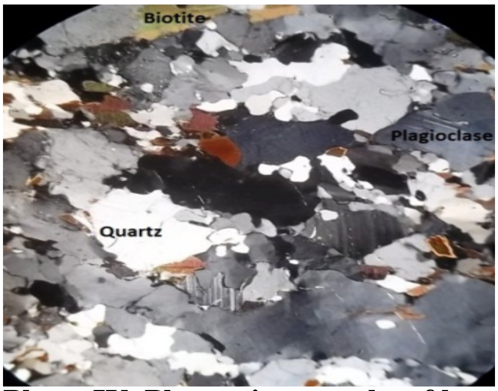


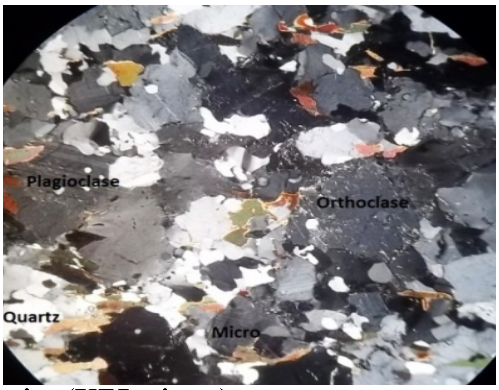


Plates III: Photomicrographs of banded gneiss (XPL views)

Leucocratic granite

It is medium grained and porphyritic in places. The hand specimen is light grey. Views showing the dominant minerals are felsic quartz, plagioclase and orthoclase feldspars.

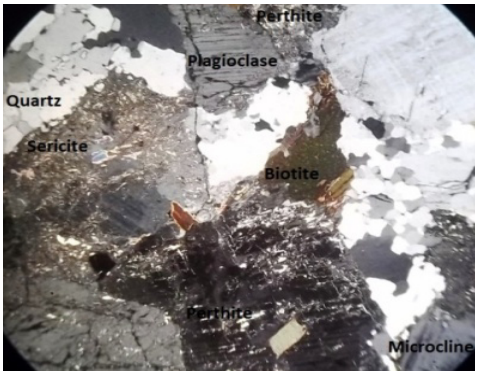


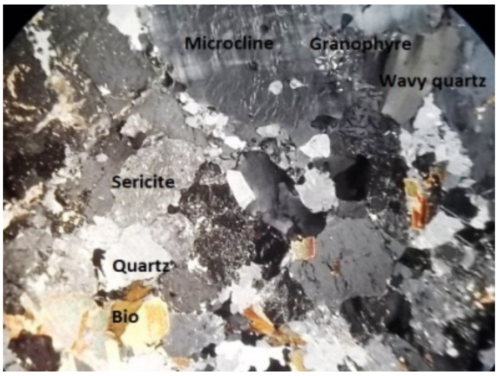


Plates IV: Photomicrographs of leucocratic granite (XPL views)

Porphyritic granite

The hand specimen had large grains (phenocrysts) that are light brown coloured, confirming slight alteration of felsic feldspars. Views are showing orthoclase feldspar phenocryst, quartz and other felsic minerals including alteration product of orthoclase feldspar (sericite) with microcracks.

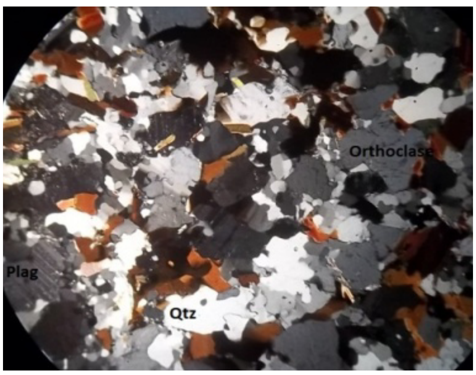


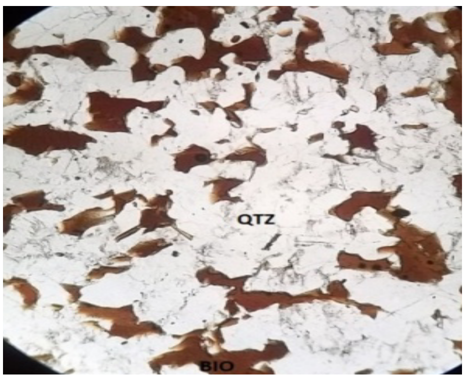


Plates V: Photomicrographs of porphyritic granite (XPL views)

Medium to coarse grained biotite granite

Generally, views show fine to medium grained crystals of quartz with wavy extinction. Grey colored orthoclase and plagioclase with Carlsbad and lamellar twinning. Other view showing the brown coloured biotite is pleicrioc from light to dark brown with pleicroic halo in places.





Plates VI: Photomicrographs of medium to caorse granite (XPL and PPL view)

Table 1: Modal composition of minerals in major lithologies in the study area

	Percentage composition (by volume)									
Lithology	Quartz	Plagioclase	Orthoclase	Microcline	Perthite	Sericite	Muscuvite	Biotite	Pyroxene	Opaque
PGn01	35	20	10	-	5	-	-	20	10	-
PGn02	40	-	15	25	10	-	-	10	-	-
GGn03	45	-	20	25	-	-	-	10	-	-
LGr04	50	10	15	10	-	-	-	15	-	-
PGr05	40	-	25	35	-	-	-	08	-	02
PGr06	30	15	10	20	-	-	<5	15	-	5
GGn07	40	-	15	20	-	-	10	15	-	-
PGn08	30	10	20	-	-	15	10	15	-	-
MGr09	35	25	15	-	-	-	-	25	-	-
PGn10	40	-	15	20	-	-	-	15	-	-
BGn11	55	-	35	-	-	-	5	5	-	-
PGr12	50	30	-	-	-	-	-	20	-	-

Where PGn = Porphyroblastic Gneiss PGr = Porphyritic Biotite Granite
LGr = Leucocratic Granite GGn = Granite Gneiss
MGr = Medium to Coarse Grained Granite BGn = Banded Gneiss

3.4 Geochemical Charaterization

The analysed rock samples are variably siliceous. The mean content of SiO2 in the gneisses (67.32) is a slightly lower than the granites (68.76). The high silica contents are confirmed from microscopic studies that elucidated the prevalent mineral specie to be felsic components i.e quartz and feldspars (microcline, orthoclase and plagioclase) with interlocking grain boundary. Essentially, the silica being higher than 66 wt% by volume are similar to silica content of basement granite and gneisses from Oban massif, southwestern Nigeria, Egesi et al., (2012).

Table 2: Major element composition in the gneisses

Analyte wt%	PGn 1	PGn 2	GGn 1	GGn 2	PGn 3	PGn 4	BGn	Range	Mean	STD
SiO2	69.51	65.21	65.73	65.44	64.55	68.90	71.91	64.55-71.91	67.32	2.78
Al2O3	16.84	15.73	16.34	15.07	15.05	16.11	15.17	15.05-16.84	15.76	0.70
Fe2O3	2.68	5.76	6.11	6.54	7.04	3.74	2.61	2.61-7.04	4.94	1.87
CaO	3.37	3.97	2.29	3.56	3.81	2.41	2.93	2.29-3.97	3.19	0.66
MgO	0.54	1.39	0.54	1.77	1.79	0.78	0.49	0.49-1.79	1.04	0.59
K2O	3.16	3.34	4.91	3.42	3.69	4.40	3.45	3.16-4.91	3.77	0.64
Na2O	2.95	2.43	2.42	1.97	1.66	2.32	2.47	1.66-2.95	2.32	0.41
P2O5	0.05	0.36	0.08	0.34	0.44	0.20	0.12	0.05-0.44	0.23	0.15
TiO2	0.47	1.28	1.05	1.35	1.45	0.63	0.39	0.39-1.45	0.95	0.44
Cr2O3	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00-0.01	0.00	0.00
Mn2O3	0.05	0.10	0.14	0.12	0.12	0.08	0.05	0.05-0.14	0.09	0.03
ZnO	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00-0.01	0.01	0.00
LOI	0.43	0.42	0.37	0.40	0.40	0.42	0.42	0.37-0.42	0.41	0.01

Where: PGn = Porphyroblastic Gneiss, GGn = Granite Gneiss, BGn = Banded Gneiss

Table 3: Major element composition in the granites

Analyte (wt%)	LGr	PGr 1	PGr 2	MGr	PGr 3	Range	Mean	STD
SiO_2	69.00	72.31	66.08	66.37	69.55	66.08-72.31	68.76	2.45
Al2O3	15.15	15.58	15.09	14.91	15.69	14.91-15.69	15.29	0.33
Fe2O3	4.69	2.74	5.96	5.20	4.02	2.74-5.96	4.52	1.22
CaO	1.92	0.95	3.44	3.45	2.39	0.95-3.45	2.43	1.06
MgO	1.05	0.66	1.44	1.57	1.11	0.66-1.57	1.17	0.36
K2O	4.35	4.88	3.95	3.23	3.47	3.23-4.88	3.98	0.67
Na2O	2.11	1.82	1.88	1.95	2.11	1.82-2.11	1.97	0.13
P2O5	0.25	0.14	0.36	0.34	0.31	0.14-0.36	0.28	0.09
TiO2	0.92	0.46	1.24	1.25	0.83	0.46-1.25	0.94	0.33
Cr2O3	0.00	0.00	0.01	0.01	0.01	0.00-0.01	0.00	0.00
Mn2O3	0.10	0.04	0.10	0.10	0.06	0.04-0.10	0.08	0.03
ZnO	0.01	0.01	0.01	0.01	0.01	0.01-0.01	0.01	0.00
LOI	0.02	0.02	0.03	0.03	0.02	0.02-0.03	0.02	0.01

Where: LGr = Leucocratic Granite, PGr = Porphyritic Granite, MGr = Medium to Coarse Grained granite

3.4.1 Harker diagram

In the gneisses, strong negative correlation is noted in plot of SiO_2 against TiO_2, MgO, P_2O_5, Fe_2O_3t, and Mn_2O_3 according to Harker diagram. Na_2O shows a small data spread and positive correlation, whereas K_2O exhibits significant data scatter without correlation (Fig. 4A).

Also, moderate to strong negative correlation occur within SiO_2 and other major oxides except K_2O that is positive (Fig. 4B).

Strong negative correlation between SiO_2 and Fe_2O_3 and SiO_2 and MgO in the gneisses suggests pyroxene and hornblende fractionation in protolith (Okonkwo and Folorunsho, 2013). Variations in correlation of the oxides indicate that the samples are not co-genetic.

The alkali metals (Na and K) are often highly mobile elements during metamorphism and weathering (e.g., Pearce *et al*., 1975) but Na_2O vs SiO_2 and K_2O vs SiO_2 diagrams show significant data scatter with lack of correlation for K_2O, low positive for Na_2O (Fig.4). This indicates that these major elements undergo varying mobility during metamorphism confirming low to medium grade for the gneisses (greenschist to lower amphibolite facies).

Moderate to strong negative correlation between SiO_2 and other major oxide is shows that the granites are co-genetic.

4.0 Conclusion

Remote sensing studies with ASTER GDEM aided 3-D perspective view of physiographic/topography features in the study area. Field studies shows that the main lithology in the area include the granite gneiss (banded, augen and porphyroblastic) and granite (porphyritic and medium to coarse grained) while quartz vein, micro granite dyke and quartzofeldspathic pegmatites constitute minor rock types.

The petrographic analysis reveals the major minerals in the granite and gneisses include quartz, feldspar (plagioclase, microcline, orthoclase and perthite) which are felsic in nature, while the trace mineral is mica (biotite, muscovite with opaque, ± pyroxene as accessories). Mica being a flaky and unstable mineral reduces the strength of concrete. The grain sizes colour, shapes and arrangement also help in mineral identification. The microcrack and fracture present in some of the rock type is a deformation that results from the effect of overburden pressure on the plutonic rocks.

The analysed rock samples are variably siliceous. The mean content of SiO_2 in the gneisses (67.32) is a slightly lower than the granites (68.76).Discrimination diagrams from geochemical analysis shows that the gneisses undergo varying mobility during metamorphism confirming low to medium grade for the gneisses (greenschist to lower amphibolite facies). Also, striking negative correlation between SiO2 and other major oxides shows they are co-genetic and exhibit almost the same weathering properties. The gneisses are of igneous parentage except granite gneiss that may be sedimentary.

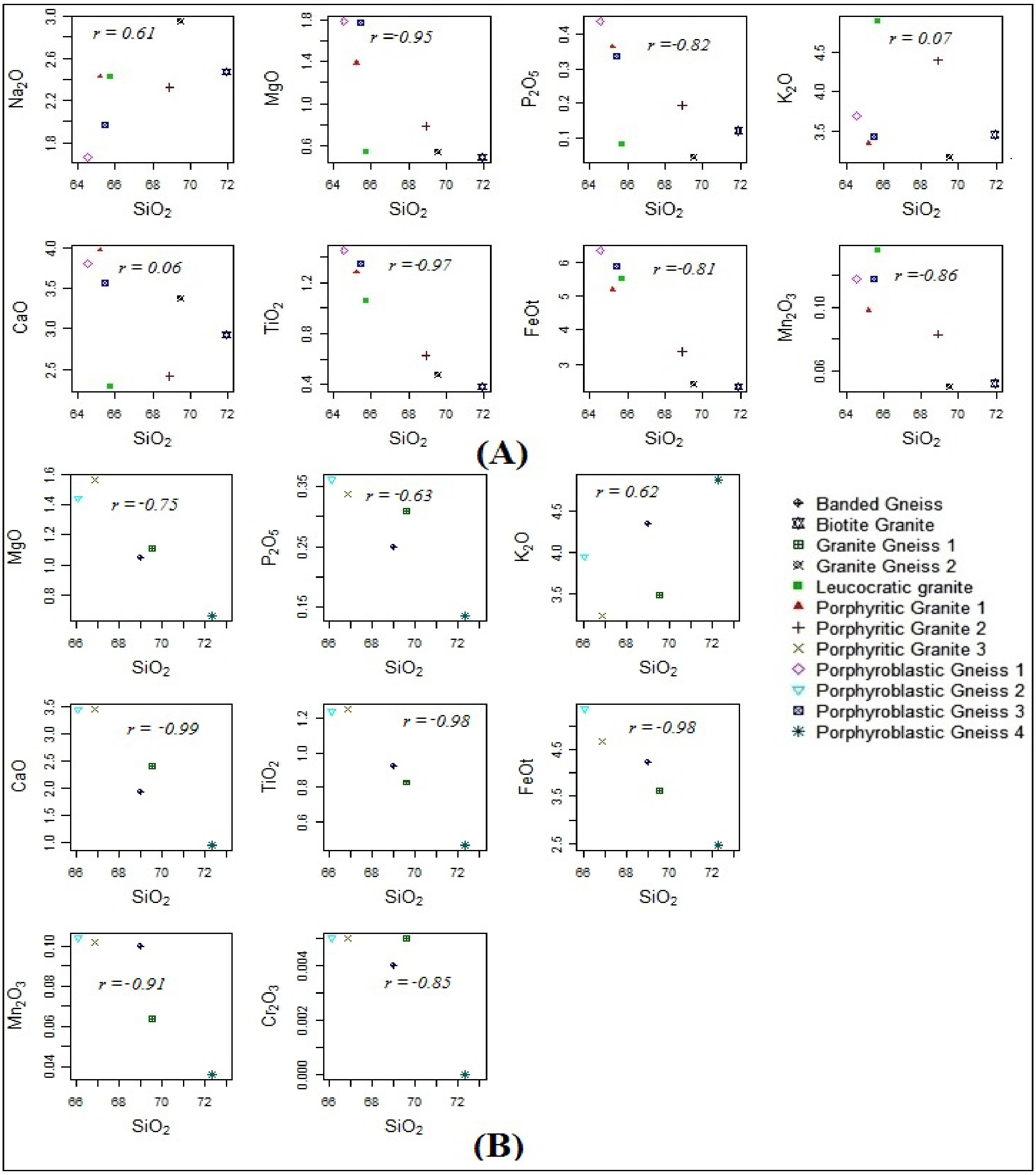


Fig. 4: Binary variation plots of SiO_2 with the other major oxides in gneisses (A) and granites (B)

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