Petrochemical characteristics and geotechnical properties of crystalline rocks in the archean-proterozoic terrain of Ijero-Ekiti, southwestern Nigeria

Petrokemijske značilnosti in geotehnične lastnosti kristaliničnih kamnin v arhajsko-proterozojskem kompleksu Ijero-Ekiti v jugozahodni Nigeriji

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Abstract: The Precambrian basement rocks around Ijero Ekiti, southwestern Nigeria were investigated with a view to elucidating its compositional features and geotechnical characteristics that may be related to industrial application. As part of the study approach, geological appraisal of the study area through systematic mapping was undertaken. Six samples each of the nine basement rocks were analysed for major elements using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) technique from Activation Laboratories, Ontario Canada and physical tests were conducted in Trevi Foundations, Lagos.

The systematic mapping of the study area revealed rocks comprising of the migmatite gneiss complex, quartzite, mafic-ultramafic assemblage and schistose rocks with paucity of granite and pegmatite forming steeply dipping intrusions into the older rock sequences. Petrographic examination indicates quartz, albite, biotite, hornblende, olivine, pyroxene and biotite as the common mineral constituents occurring in the basement rocks. Furthermore, from analytical result, SiO_2, Al_2O_3 and Fe_2O_3 accounts for a substantial percentage of the oxides in the rocks. However, calc gneiss has appreciably high CaO (15.15 %) and MgO (13.49 %) values. TiO_2 and P_2O_5 are less than 0.1 % and 0.3 % respectively in all the rocks. Result of physical tests including specific gravity range between 2.54 g/cm^3 and 2.85 g/cm^3;

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compressive strength 32.4–84.50 N/mm^2; wet density 2.01–2.30 g/cm^3; water absorption capacity 0.02–0.24 %; porosity 0.01–0.58 % and pH 6.7–7.3. Industrial assessments using the evaluated physical properties indicate that the gneisses, quartzite, epidiorite and granite of the area are suitable for construction purposes.

Izvleček: Kamnine predkambrijske podlage z območja Ijero Ekiti v jugozahodni Nigeriji smo raziskali z namenom opredeliti njihovo sestavo in geotehnične lastnosti v luči njihove gospodarske uporabnosti. Del raziskave je obsegal sistematično geološko kartiranje študijskega ozemlja. Nadalje so bile v šestih vzorcih od vsake glavne kamnine podlage določene glavne kemične prvine z induktivno vezano plazemsko atomsko emisijsko spektrometrijo (ICP- AES) v Activation Laboratories v Ontariu v Kanadi, medtem ko so opravili fizikalne preiskave v laboratoriju organizacije Trevi Foundations v Lagosu v Nigeriji.

Geološko kartiranje območja je razkrilo kamnine kompleksa migmatitnega gnajsa, kvarcit, mafično-ultramafično združbo in skrilave kamnine z redkimi granitnimi in pegmatitnimi intruzijami, strmo vtisnjenimi v starejših kamninskih skladovnicah. S petrografsko raziskavo so bili ugotovljeni kremen, albit, biotit, rogovačo, olivin, piroksen in biotit kot poglavitni minerali v kamninah podlage. Analizni rezultati kažejo, da tvorijo glavni delež oksidov v kamninah SiO_2, Al_2O_3 and Fe_2O_3. Izjema je kalcitni gnajs, ki vsebuje visoke deleže CaO (15,15 %) in MgO (13,49 %). Vsebnosti TiO_2 in P_2O_5 sta v vseh preiskovanih kamninah manjši od 0,1 % oziroma 0,3 %. Rezultati fizikalnih preizkusov so naslednji: prostorninska masa 2,54–2,85 g/cm^3, tlačna trdnost 32,4–84,50 N/mm^2, gostota v vlažnem stanju 2,01–2,30 g/cm^3, vpojnost vode 0,02–0,24 %, poroznost 0,01–0,58 % in pH 6,7–7,3. Iz ugotovljenih fizikalnih lastnosti sledi, da so gnajsi, kvarcit, epidiorit in granit s tega območja primerni za uporabo v gradbeništvu.

Key words: Archean-proterozoic, geotechnical characteristics, basement rocks, compressive strength

Ključne besede: arhaik-proterozoik, geotehnične lastnosti, kamnine podlage, tlačna trdnost

Introduction

Rugged relief characterized by prominent inselbergs is a common feature of many parts of Nigeria and in particular Ekiti State in the southwestern part of the country. These rocks, apart from not generating revenue from tourism, have not been fully exploited for other major economic purposes considering the available enormous quantity that occur in the area. Underutilization of these rocks may be attributable to insufficient geological information on the assessment of their properties on the one hand and shallow knowledge of what they could be used for on the other hand. These crystalline rocks could serve as raw material in most construction industries and as such contribute tremendously to the socio-economic development of the study area. This investigation is therefore aimed at evaluating the compositional features and physical characteristics of Ekiti crystalline rocks vis-à-vis their industrial application.

Regional Geological Setting

Nigeria lies within the Pan-African mobile belt specifically between the Congo craton to the southeast and West African craton to the west (Figure 1). Geology of Nigeria is made of sedimentary and crystalline rocks in almost equal proportions. The sedimentary rock sequences occupy the marginal and intracontinental basins and belong to the Cretaceous-Recent age spectrum and lie unconformably on the basement complex rocks.

The rocks constituting the basement complex (Figure 2), despite disagreements on lithological delineations, are loosely categorized into three major groups: the migmatite-gneiss complex, the schist belts and the Pan-African Granites (Elueze, 2000). The migmatite gneiss complex 2.0–3.0 Ga; (Rahaman et al., 1988, Dada & Briqueu, 1998) is the oldest and most abundant rock type in the basement and is a product of several tectonothermal events that have brought rocks of various origins together. In addition, the schist belts, comprise low-grade metasediments and metabasic rocks that crop out in a series of distinctly N-S trending synformal troughs infolded into the crystalline migmatite-gneiss complex. They are about the best-studied group of rocks in Nigeria (Russ, 1957, Truswell & Cope, 1963) because of the mineralization such as gold, Banded Iron Formation (BIF), tin, tantalum, niobium and marble, associated with them (Oyinloye, 2006). These rocks show distinctive petrological, structural and metallogenic features (Okunlola, 2005). The schist belts in southwestern Nigeria include Iseyin-Oyan, Egbe-Isanlu, Ife-Ilesha and Igarra schist belts (Rahaman, 1976; Odeyemi, 1977; Annor et al 1996). Others are the Lokoja-Jakura, Toro-Gadabuike belts (Muotoh et al 1988, Okunlola, 2001). The geochemistry of these rocks confirms their sedimentary nature but that of associated mafic and ultrabasic rocks has generated much controversy. The Older Granites display the most pervasive tectonic fabric symbolizing igneous reactivation attributable to the Pan-African events (Oyawoye, 1964). The Older Granites in all cases include rocks of a wide range of compositions, structures and textures. The Older Granite is typically a fine-medium grained to coarse porphyritic rock whose composition range from tonalite through granodiorite to granite and syenite. The lithological framework, deformation and metamorphism of the basement rocks are established in the works of Mccurry (1976), Ajibade (1976, 1980), Odeyemi (1988), Rahaman (1976, 1988), Egbuniwe (1982) and Elueze (1981). The geology of Ijero-Ekiti area has been reported in literature as part of the basement complex of southwestern Nigeria by Mccurry (1976), Tuner (1983), Rahaman et al, (1988). This area is an Archaean-Early Proterozoic terrain Grant (1970).

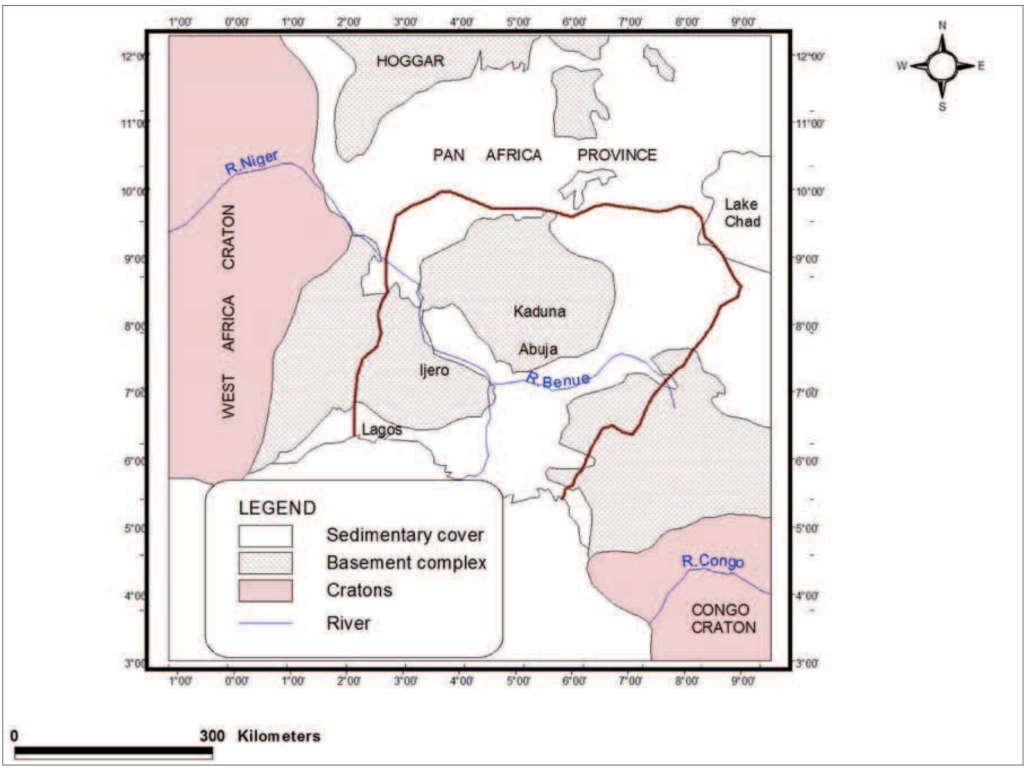

Figure 1. Map showing Nigeria within the Pan-African province between Congo and West African cratons (Ajibade et al, 1988)

Lithological relationship

Geological appraisal through systematic mapping reveals that there are nine main lithologic units in Ijero area. They are: migmatite-gneiss, biotite-gneiss, calc-gneiss, quartzite, epidiorite, biotite schist, amphibole schist, granite, and pegmatite (Figure 3). Migmatite-gneiss occurs towards the eastern part covering about two-fifth of the study area. The rock exposures occur as highly denuded hills of essentially fine textures with closely spaced alternating bands of leucocratic and melanocratic minerals. Outcrops of biotite-gneiss occur towards the west.

They are characteristically low lying, fine textured, and conspicuously foliated with abundance of platy biotite minerals sandwiched into zones that are markedly distinguishable from the light-coloured quartzo-feldspartic portions. In some areas, the foliations become so indistinct that the bands are lost leaving various indiscernible streaks of light and dark minerals. Calc-gneiss has grey to greenish colour with weakly developed foliations.

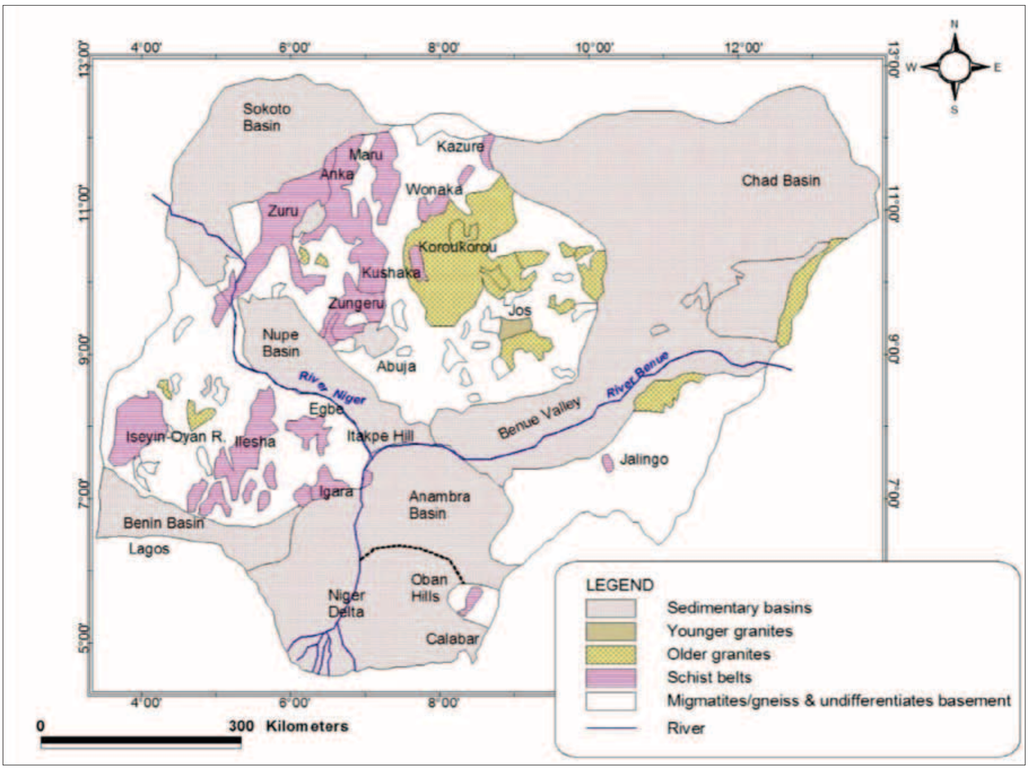

Figure 2. Generalized Geological Map of Nigeria showing the Basement Complex Rocks, Schist Belts, the Younger Granites and the Sedimentary Basins. (Black, 1980)

It is devoid of quartz vein intrusions and is restricted in occurrence only to a narrow strip in the eastern part of Ijero town. Quartzite occurs as ridge of steeply dipping, massively bedded, fine-medium grained bodies or an environment characterized by the abundance of quartz rubbles. Outcrops of epidiorite (a dense fine grained, dark coloured rock) are poorly exposed and are restricted to the southern part of the study area biotite schist and amphibole schist occurs toward the central part of the area and are bordered in the west and east by biotite-gneiss and migmatite-gneiss respectively (Figure 3). They are highly succeptible to weathering and remarkably display a North-South foliation trend with poorly exposed outcrops occupying lowlands adjourning quartzite ridges, gneisses and granite pegmatites. Granite occurs as minor intrusive bodies while the pegmatite occur as distinct dykes of variable dimensions that is, veins and veinlets within the gneissic bodies with few cases of occurrence in batholitic masses.

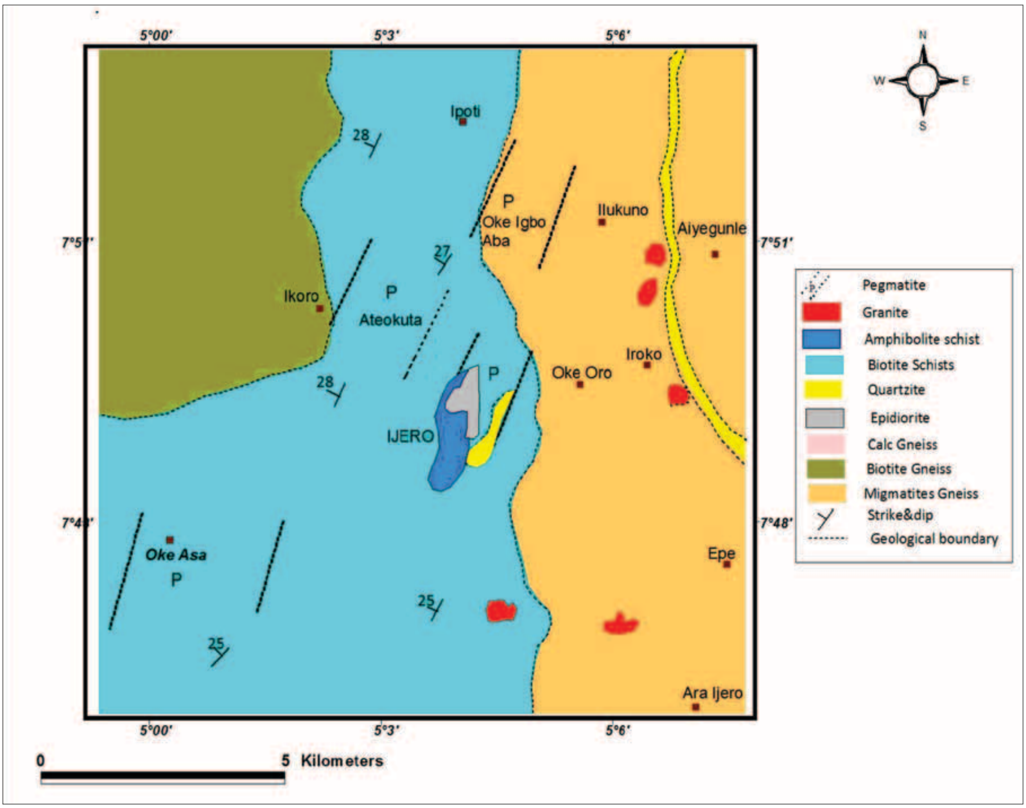

Figure 3. Geological map of Ijero Ekiti area (OKUNLOLA & AKINOLA, 2010)

Materials and Methods

The study involves systematic geological mapping and samples were collected by standard geological techniques during which thin section study of each rock unit collected were undertaken. Caution was taken to ensure that the samples were fresh, unweathered and uncontaminated. Subsequently, for geochemical investigations, collected samples were dried at 60 °C, crushed, pulverized and sieved using sieve size 0.075 mm. 0.2 g samples aliquot was weighed into a graphite crucible and mixed with 1.5 g of $LiBO_2/LiB_4O_7$. The sample charged was heated in a muffle furnace for 30 min at 980 °C. The cooled bead was dissolved in 100 m/L of 5 % HNO_3 (ACS grade nitric acid) in de-mineralized water. An aliquot of the solution was poured into a propylene test tube. Calibration standard and verification standard were included in the samples sequence. Samples solution was aspirated into an ICP Mass Spectrometer (Perkin-Elmer Elan 9000) for the determination of the major oxides at the Activation Laboratories in Ontario Canada. In addition, physical test were carried out on the basement rocks to determine their industrial characterization. The tests conducted include specific gravity (SG), compressive strength (CS), wet density (WD), water absorption capacity (WAC) and porosity (P, %) following the American Society for Testing and Materials 1985, D2487-83 procedures while pH determinations were carried out using a multiparameter portable meter (model Testr-35). Bulk porosity determination is the measure of the quantity of water which a rock will absorb when immersed in water and is measured by, the difference between the dry weight of the sample and the weight after soaking expressed as percentage of the dry weight. Compresssive strength is determined by statically loading a cylinder of rock to fracture, the load being applied across the upper and the lower faces of the sample.

Petrography

Petrographic examinations indicate that migmatite-gneiss contains feldspar, quartz, muscovite and biotite. The biotite content is low and mineral alignment is less pronounced. Other essential components include ferromagnesian minerals like hornblende. Quartz and feldspars alone constitute up to 70 % of the rock in thin section. Feldspar is second to quartz in abundance while ferromagnesian and opaque minerals such as garnet and magnetite constitute the coloured minerals (Figure 4). The mineral constituents of biotite gneiss are similar to those of the migmatite-gneiss except that they appeared stretched and elongated such that the longer axis appears in the same direction. A larger percentage of the biotite occurs in groundmass and mineral outlines are well defined.

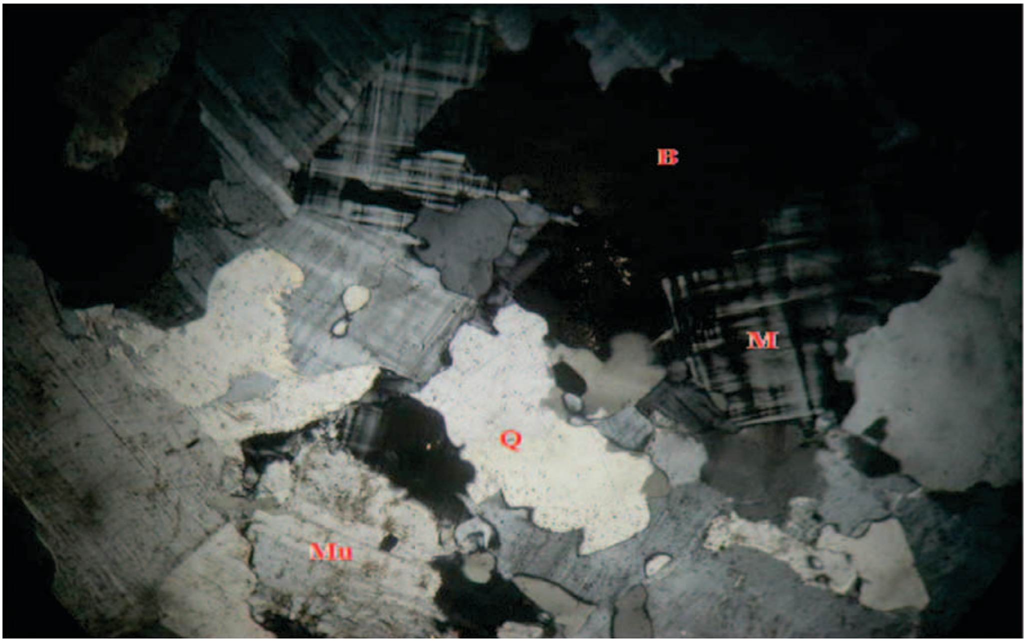

Figure 4. Photomicrograph of migmatite gneiss in transmited light showing cross-hatched twinned microcline (M), large plates of biotite (B), fine grained quartz crystals (Q) and muscovite (Mu)

Calc-gneiss is mainly composed of calcite, quartz with muscovite. Most of the minerals show evidence of strain and are altered. Calcite, quartz and muscovite are the dominant minerals accounting for 90 % of the modal composition. Ferromagnesian minerals like olivine, pyroxene and hornblende dominate the modal composition of epidiorite (Figure 5). Quartz, muscovite, hornblende and accessory opaque minerals dominate the composition of biotite schist. Quartz occurs as small, colourless and sometimes cloudy xenomorphic crystals. Accessory zircon occurs as short idiomorphic crystals while the opaque minerals are few but existing as scattered euhedral grains (Figure 6). Biotite occurs in dominant amounts and forms the major groundmass minerals. In quartzite, quartz occurs as granoblastic and unaltered euhedral crystals with well-defined outlines. It exhibits weak birefringence, low relief with wavy extinction. However, some of the quartz grains appear cloudy.Muscovite form supporting minerals as they occupy intergranular spaces of interlocking quartz crystals and sometimes occur as colourless elongated plates. In granite, the feldspars are large, well-formed crystals of albite while quartz occurs as irregular masses of colourless and unaltered grains.

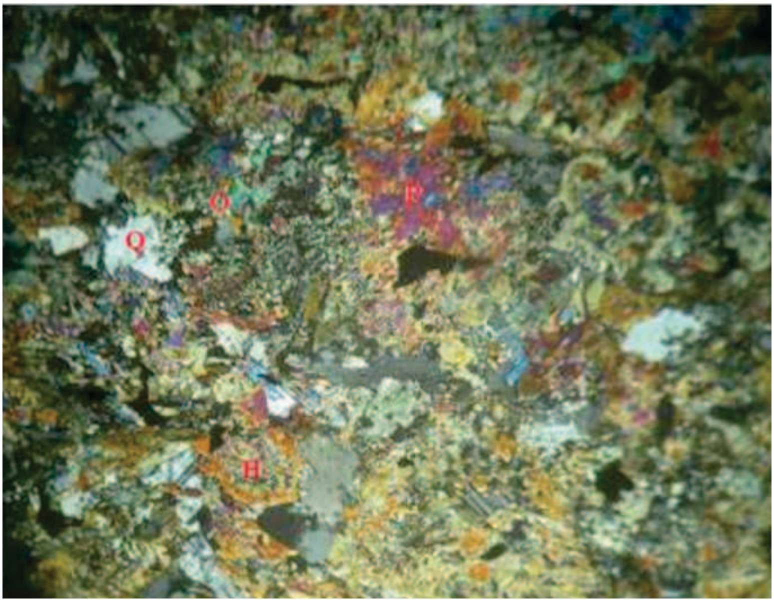

Figure 5. Photomicrograph of fine grained epidiorite in transmitted light showing dominance of ferromagnesian minerals, olivine (O), Pyroxene (P), Quartz (Q) and Hornblende (H)

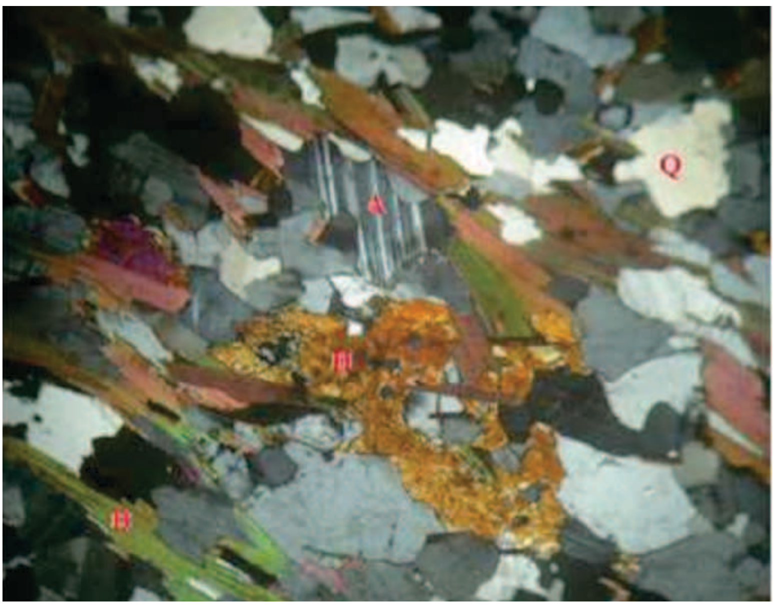

Figure 6. Photomicrograph of fine-grained biotite schist in transmitted light showing euhedral quartz (Q), albite (A), hornblende (H), and platy biotite (B).

In pegmatite, the feldspars exist as porphyries of microcline with its characteristic strong cross hatched twining and strong to weak micro perthitic intergrowth. Tourmaline crystals exhibit long needle-like prismatic shapes with acicular habit (Figure 7).

Modal analysis (Table 1) shows that quartz is adequately represented in most of the basement rocks with quartzite, granite, gneisses and pegmatite showing larger percentages while epidiorite, amphibole schist and calc-gneiss record substantially low values. Plagioclase is well represented in granite, pegmatite and the gneisses but with low representation in the schistose rocks. Biotite is another mineral that cut across most of the basement rocks. However, highest percentages are recorded in biotite schist and biotite gneiss while calc-gneiss does not show any trace of the mineral at all. As regards amphibole schist, hornblende has the highest percentage while it is of an average value in epidiorite. Olivine and pyroxene are only represented in epidiorite while tourmaline and lepidolite are present only in pegmatite.

RESULTS AND DISCUSSION

Geochemical features

Geochemical result (Table 2) shows that average SiO_2 content of all the basement rocks are high and range from lowest value in epidiorite (55.72 %) to highest value in granite (73.61 %). The gneisses have average SiO_2 similar to those found around Ilesha area (ELUEZE, 1981). Alumina content ranges from lowest in calc-gneiss (9.23 %) to higher values in amphibole schist (15.62 %) and highest in biotite schist (18.03 %). The mean Al_2O_3 content of the schistose rock around Ijero is generally higher than similar rocks encountered around Ibadan (OKUNLOLA et al, 2009)

Mean Fe_2O_3 content of Epidiorite (11.16 %)) and biotite schist (8.53) are comparable. These values are higher than biotite gneiss (7.02 %) and pegmatite (6.49 %). Low mean MnO value is common to all the basement rocks except quartzite (2.18 %) which records the highest, and this value is higher than calc-gneiss (1.64 %). All other basement rocks have average MnO values that are less than 0.6 %, for instance, epidiorite and biotite schist both record 0.08 %. Mean MgO content of Calc-gneiss (13.49 %) is slightly lower than epidiorite (14.80 %). Other rocks, amphibole schist (6.25 %), biotite gneiss (3.08 %), biotite schist (8.94 %), quartzite (1.00 %) have low mean values while the remaining basement rocks record lower values. Average CaO values of migmatite gneiss (2.51 %), biotite gneiss (2.14 %) and amphibole schist (2.04 %) are comparable. However, these

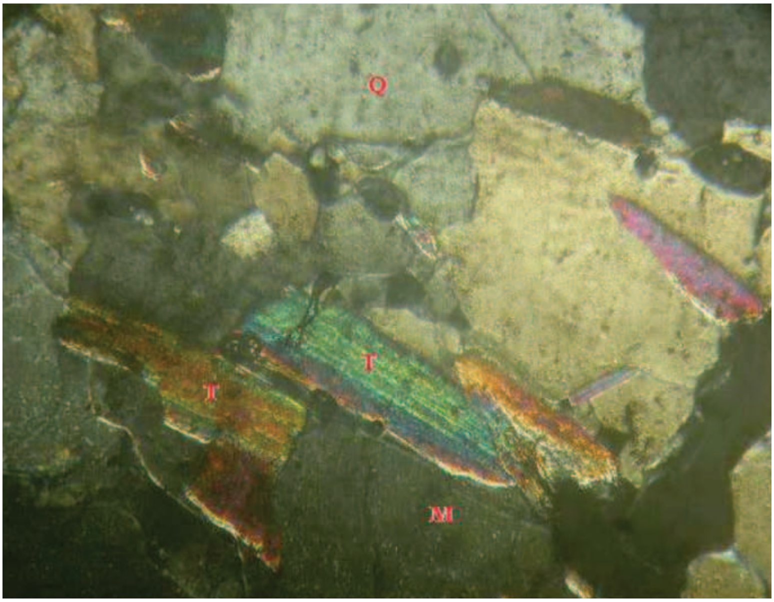

Figure 7. Photomicrograph of pegmatite in transmitted light showing tourmaline crystals (T), Quartz (Q) and muscovite (M).

Table 1. Modal composition of the basement rocks in Ijero-Ekiti area (%)

Minerals	***MG**	***BG**	***CG**	***QZ**	***EP**	***BS**	***AS**	***GR**	****PG**
Quartz	48	42	25	56	17	34	18	46	37
Plagioclase	22	18				4	10	35	12
Microcline							12		7
Calcite			36						
Muscovite			32	29	11				26
Biotite	23	32		10	13	58	15	5	8
Hornblende	4	6			18	4	32	6	1
Olivine					17				
Pyroxene					21			5	
Tourmaline									8
Epidote			6		4		3		
Lepidolite									4
Opaque	3	3		5	2		9	2	
Others							1	1	

MG (Migmatite gneiss), BG (Biotite gneiss), CG (Calc-gneiss), QZ (Quartzite), EP (Epidiorite), BS (Biotite schist), AS (Amphibole schist), GR (Granite), PG (Pegmatite); * Average of 6 samples, ** Average of 5 samples values are lower than quartzite (6.54 %), epidiorite (4.04 %), and calc-gneiss (15.15 %). Mean Na_2O value of migmatite gneiss (3.32 %) and biotite gneiss (3.00 %) are comparable. These values are higher than epidiorite (1.97 %) and pegmatite (2.38 %). While calc gneiss (1.08 %), quartzite (1.21 %) and amphibole schist (1.34 %) are within similar range. Average potash content of pegmatite (6.77 %) is higher than the comparable value for migmatite gneiss (4.18 %) and biotite schist (4.08 %) while lower mean values are recorded for biotite gneiss (3.86 %), quartzite (1.96 %) and amphibole schist (1.70 %). Other oxides, TiO_2 and P_2O_5 do not follow any discernible pattern and their values are generally less than 0.5 % in all the basement rocks. Loss on Ignition values are generally low and fall between 1.07 % in pegmatite and 5.27 % in biotite schist.

Physical and mechanical features

The result of the physical tests (Table 3) shows that amphibole schist has the lowest specific gravity value of 2.54 g/cm^3 while biotite gneiss has the higher value of 2.85 g/cm^3. Compressive strength values fall within a wide range with amphibole schist having the least value (32.4 N/mm^2) and Granite the highest value (84.5 N/mm^2). Lowest wet density was obtained for amphibole schist (2.01 g/cm^3) and highest for migmatite gneiss (2.31 g/cm^3), Water Absorption capacity values are generally low and quartzite records the lowest (0.04 %) while amphibole schist (0.28 %) records the highest. Biotite gneiss and quartzite record the lowest bulk porosity value of 0.01 % while the highest value (0.58 %) was in biotite schist. The pH values range generally between 6.7 and 7.4 with the least and highest value in migmatite gneiss/granite and biotite schist respectively.

Industrial assessment

Physical tests on the basement rocks are to ascertain their usefulness as building materials. Building stones denote pieces of rock that may undergo cutting, sawing, shaping and sometimes polishing and still be useful for construction purpose. The main requirements for building stones are strength, durability, workability, and availability. To be useful for construction purpose, a minimum compressive strength of 36 N/mm^2 (367.2 kg/cm^2) is required (ASTM, 1970). Many of the Basement rock including migmatite gneisses, biotite gneiss, calc gneiss, quartzite and granite meets the above specification (Table 3).

However, the schistose rocks have lower compressive strengths due to their fissility. Although, pegmatite meets the minimum strength requirement for use as building stone, its large-sized particles are a disadvantage. Migmatite and biotite gneiss are highly meta-

Table 2. Chemical composition of the Basement rocks of Ijero-Ekiti

Oxide in %	*MG	*BG	*CG	*QZ	*EP	*BS	*AS	*GR	**PG
SiO_2	68.42	65.63	53.40	74.86	55.72	54.22	57.07	73.61	67.46
Al_2O_3	15.13	15.49	9.23	6.25	9.01	18.03	15.62	15.43	13.90
Fe_2O_3	3.47	4.02	2.77	3.04	11.16	8.53	9.83	2.37	6.49
MnO	0.25	0.21	1.64	2.18	0.08	0.08	0.56	0.10	0.42
MgO	0.33	3.08	13.49	1.00	14.80	8.94	6.25	0.08	0.03
CaO	2.51	2.14	15.15	6.54	4.04	0.15	2.04	0.96	1.11
Na_2O	3.32	3.00	1.08	1.21	1.97	0.57	1.34	1.77	2.38
K_2O	4.18	3.86	1.45	1.96	0.93	4.08	1.70	3.21	6.77
TiO_2	0.08	0.07	0.09	0.03	0.06	0.03	0.05	0.03	0.01
P_2O_5	0.05	0.02	0.01	0.01	0.02	0.01	0.01	0.14	0.26
LOI	2.24	2.47	1.60	2.62	2.20	5.27	5.23	2.30	1.07
Total	99.98	99.99	99.91	99.70	99.99	100	99.70	100.00	99.83

MG (Migmatite gneiss), BG (Biotite gneiss), CG (Calc-gneiss), QZ (Quartzite), EP (Epidiorite), BS (Biotite schist), AS (Amphibole schist), GR (Granite), PG (Pegmatite); * Average of 6 samples, ** Average of 5 samples

Table 3. Physical properties of the major basement rocks around Ijero-Ekiti

Rock name	SG/ g cm^{-3}	CS/ (N/mm^2)	WD/ (g/cm^3)	WAC/ %	P/(%)	pH
Migmatite Gneiss	2.72	63.1	2.31	0.13	0.03	6.7
Biotite Gneiss	2.85	56.1	2.23	0.09	0.01	6.9
Calc-Gneiss	2.72	43.9	2.17	0.16	0.03	6.9
Quartzite	2.65	61.8	2.29	0.04	0.01	7.0
Epidiorite	2.75	72.0	2.24	0.10	0.03	7.3
Biotite Schist	2.69	35.3	2.01	0.24	0.58	7.4
Amphibole schist	2.54	32.4	2.04	0.28	0.41	7.1
Granite	2.70	84.5	2.11	0.02	0.02	6.7
Pegmatite	2.71	46.0	2.06	0.13	0.05	6.8

SG: Specific gravity, CS: Compressive strength, WD: Wet density, WAC: Water absorption capacity, P: Bulk porosity and pH: Acidity.

morphosed banded rocks that contains beautifully coloured alternating bands of light and dark colours. The outcrops of these rocks are particularly common around Ilukuno, Oke-Oro, Iroko and Ayegunle area and towards the southern part of Ara-Ijero and Epe. These outcrops could serve as raw materials for building applications such as as gneiss is used to decorate the outside of buildings, making of floor tiles and counters, aggregate in concrete mixing etc.

A quarry site is located along Epe road where a gneissic outcrop serves as a source of stone aggregate for more than three decades. Local sources indicate that most of the roads in the area were built with products from this stone mill. The major quartzite ridge of the area has been quarried locally to produce materials for foundation works and cement mixing for concrete slabs.

CONCLUSION

Ijero-Ekiti is within the Basement Complex terrain of southwestern Nigeria and underlain by gneisses, quartzite, epidiorite, schists, granite and pegmatite. The granite and pegmatite form steeply dipping intrusions into older rock sequences. Most of the basement rocks are rich in quartz, feldspars, biotite and hornblende. Calc-gneiss is enriched in calcite and epidiorite has high percentage of ferromagnessian minerals including hornblende, biotite, and pyroxene. The mineralogical variations also reflect in the chemical composition of the rocks for instance, calc gneiss has high percentage of CaO and MgO whereas the gneisses, quartzite, granite and pegmatite are highly siliceous. Physical properties of the basement rocks indicate that they possess average specific gravities, moderate wet densities, high compressive strengths, and low porosities. A slightly acidic to mildly basic pH characterizes the rocks and they are comparable to similar rocks found elsewhere within the basement complex. Economic evaluation indicates that the gneisses, quartzite, epidiorite and the granite have compressive strength values within the limits required for use as foundation material and building stones.

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