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RESEARCH ARTICLE

GEOCHEMICAL AND PETROGRAPHIC EVIDENCE OF BARROVIAN FACIES METAMORPHISM IN THE ISEYIN-OYAN-IBADAN SCHIST BELT, SOUTHWESTERN NIGERIA: IMPLICATIONS FOR PALEOPROTEROZOIC CRUSTAL EVOLUTION

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ABSTRACT

The Iseyin-Ibadan Schist Belt in southwest Nigeria, part of the Nigerian Basement Complex, displays Barrovian-type metamorphism typical of the Dalradian Supergroup of the Scottish Highlands. This study investigated the metamorphic basement south of this schist belt where a Dalradian metamorphism was first reported. Mineralogical composition and geochemical characteristics of the quartz mica schist and muscovite garnet schist within this belt were studied. Field mapping, petrographic analysis, and whole-rock geochemistry revealed a greenschist to amphibolite facies metamorphic grade, evidenced by assemblages such as phengite-bearing muscovite, biotite, and almandine garnet. The compositional differences between the schist units are subtle but the mineralogy was significantly striking, particularly in muscovite and garnet concentrations. Average Al_2O_3/TiO_2 value (41.30) suggested a granitic source for the metasediments. Geochemical signatures, major oxides, suggest a mixed provenance and moderate weathering intensity.

KEYWORDS

Metamorphism, petrographic analysis, amphibolite facies, Geochemical

1. INTRODUCTION

A Dalradian regional metamorphism with progressive grading towards the south of Iseyin was first described by Rahaman (1979) and since then no mention on this has been made. The Dalradian facies series, which was described from the north of the Grampian Highland Boundary around the Great Glen faults in Scotland, represent sequence of predominantly clastic metasedimentary rocks, with some volcanic units formed during the mid-Neoproterozoic (ca. 800 Ma) to early-Ordovician (Rahaman, 1970). This Super-group sequence, its basement and younger volcanics were deformed and metamorphosed to varying degrees during the Early Palaeozoic (510 Ma) Caledonian Orogeny (Harte and Hudson, 1979; Stephenson et al., 2013). The structural and metamorphic geology of the region has made it a reference study for over a century (Anderton, 1985).

Barrovian facies metamorphism was initially described from the Dalradian sequence from the fault bounded Grampian highlands. This sequence experienced deformation and metamorphism during Early Proterozoic Caledonian orogeny (490 – 390 Ma) which saw the collision of several continents (Laurentia, Baltica and Avalonia), the formation of mountain ranges across northern parts of Europe and eastern North America and closure of Iapetus sea. Based on the foregoing, the southwestern part of Nigeria in which this study area is situated shares similarities as a collision environment, formation of quartzite mountain ranges and an arguable closure of an ancient sea (Rahaman et al., 1988; Oyinloye, 1998; Caby and Boesse, 2001; Kroner et al., 2001). The Oyan-Iseyin-Ibadan, part of the Basement of Complex of southwest Nigeria forming a part of the Supracrustal cover that infolded into the migmatite gneiss complex and suffered its last series of deformation, metamorphism, uplift and magmatism during the Pan African orogeny (Neo-Proterozoic deformation, 650 +/- 150Ma), shares similarities with the Dalradian (now Barrovian) facies series.

The basement complex of Nigeria is a mosaic of crustal blocks formed from crustal relics of island arcs and older continental crust (Wright et al., 1985; Ajibade and Wright, 1989). Schistose rocks are members of this complex and together with the migmatite gneiss-quartzite hold records of crustal reactivation, magmatism and metamorphism during the Precambrian Eon. Schist belts (Igarra-Kabba, Oyan-Iseyin-Ibadan, Ife-Ilesha-Apomu, Ijero-Ekiti belt, and the Igarra belt, Anka-Zungeru) in Nigeria are restricted to the western part of Nigeria and are aligned, predominantly, in the N-S trend depicting a structural style characteristic of the Pan African orogeny (Dada, 2008). The schist belts which are mineralised are characterised by faulted blocks with fault traces that coincides with the Hoggar Afar region. The southwest of Nigeria lies between contrasting lithologies marked by north-south shear zones (Raghane shear zone) with the Hoggar province to the north, the Braziliano-Borborema province to the south, West African craton to the west, and Congo craton to the east. Contrasting lithologies and a continent-continent geodynamic setting may be attributable to the varied mineralogical and geochemical compositions, structural complexities, and evolution of these late Proterozoic supracrustals that are intricately infolded into the migmatite gneiss - quartzite complex (Dada, 2008).

Mineralised schist belts serve as hosts to tourmaline, spodumene, beryl, aquamarine, agate, tantalite, gold, and lepidolite. Rocks constituting these schist belts are varied in composition as they are in mineralisation and

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texture. They have been metamorphosed generally in the greenschist to amphibolite facies typical of Barrovian facies during the Pan-African orogeny (Oyinloye, 1988; Akinlalu et al., 2021). Rocks within these schist belts have varied sources ranging from ensimatic volcano-sedimentary to reworked ensialic supracrustals hence their diverse compositions and are coalesced together at several suture zones (Ajibade and Wright, 1989). The dominant rocks constituting these schist belts are amphibolites, quartzite/quartz-mica schist, mica schist, and calc-silicates. These rocks are formed from older rocks and are laid as supracrustal sequences over the basal migmatite gneiss complex. The migmatite and the supracrustal were deformed, metamorphosed, and intruded by granitoid plutons, forming the Late Proterozoic cover (Fitches et al., 1985).

Rocks within the Iseyin-Ibadan schist belt are quartz- and quartz-mica-garnet, amphibole-rich schistose units occurring in close association with amphibolites, late Pan African granitoids, and pegmatites. These units are infolded within the late Archean – Early Paleozoic migmatite gneiss. Mineralogical studies identified the presence of pyrope-almandine garnet in the quartz mica schist found at Iwere Ile, west of Iseyin, indicating an amphibolite facies. Based on geochemical evidence obtained from amphibolites, the geodynamic setting of the Ilesha schist belt was determined to be tensional tectonic and rifting (Elueze, 1981; Olade and Elueze, 1979). Because of the petrogenetic significance of amphibolites, they are extensively investigated, though they typically occur in the field as small lensoid to oval rock units within the schist belts. Quartz mica schist with garnet metamorphic zones has not received nearly as much attention as the migmatite gneiss. This schistose rock unit belong to the slightly metamorphosed group (Rahaman, 1988) previously grouped as the Younger metasediment (Oyawoye, 1964, 1972; McCurry, 1988; Elueze, 1988). The metasediments have, arguably, been described as unconformable units over the migmatite gneiss complex with common structural complexities. They are more prevalent, texturally more complex, and frequently linked with faulting, folding (synclinorial keels), and shearing within the gneisses and migmatites (Oyawoye, 1972; McCurry, 1988).

Based on facies assemblage, zoning of Dalradian type from green schist to almandine amphibolite facies has been suggested from the Iseyin area (Rahaman, 1970). This article aims to explore the genesis and evolution of quartz mica schist and quartz muscovite garnet zones in the Ibadan-Iseyin Schist Belt, shedding light on their mineralogical characteristics, metamorphic conditions, and the broader tectonic implications for the Proterozoic crustal development of the region. By combining petrographic, geochemical, and structural data, this work contributes to a fuller understanding of the geodynamic processes that have defined part of the evolution of the eastern end of the West African Craton.

2. Geological Setting

The gneiss complex is the dominant lithology in the area and was differentiated into biotite granite gneiss, granodioritic gneiss and biotite hornblende gneiss. Quartzite exposures were observed as localised ridges and were found within the biotite hornblende gneiss and quartz schist. The dominant schistose rock in the study was identified as quartz mica schist within which is a minor schistose unit with muscovite-garnet composition. This schist association makes up a subordinate lithology to the main gneiss complex and exposures were found east and southwest of the area.

2.1 Gneiss-Quartzite complex

The gneiss-quartzite complex of this study is a part of the migmatite gneiss–quartzite complex that covers about 50% of the total land area covered by the crystalline basement complex of Nigeria. The composition of this undifferentiated migmatite complex is mainly tonalite-trondhjemite-granodiorite (TTG), migmatitic and granitic gneisses (Jones and Hockey, 1964; Rahaman, 1988; Oluyide et al., 1998; Afolabi et al., 2019). Quartz, biotite, alkali feldspar (microcline and orthoclase), plagioclase, and sometimes hornblende have been reported as the main mineral phases (Rahaman, 1988; Oluyide et al., 1998; Lawal et al., 2017; Afolabi et al., 2019; Akinola and Obasi, 2020). Hand specimen observations showed the presence of quartz, biotite, alkali feldspar, and hornblende as the main minerals. These minerals differentiated the gneiss into biotite granite gneiss, granodioritic gneiss, and biotite hornblende gneiss. The dominant type is the biotite hornblende gneiss, the biotite granite gneiss occurred as the minor migmatite variety, and outcrops were found as enclaves within the biotite hornblende gneiss, while granodioritic gneiss is localised in the south of the study.

2.2 Quartz mica Schist

The quartz schist was found in close association with the muscovite garnet schist in the south eastern part and inter-banded with the gneisses in the north-east and south-western part of the study area (Figure. 1). They occur as low-lying rocks trending N-S with moderately dipping schistose planes. The quartz schist is fine to medium grained and darker in colour than the hosted quartz muscovite schist. There are dominant amount of quartz lens phenocryst showing development of quartz ribbons on some of the outcrops (Figure. 2). Microfolds as well as concordant quartzofeldsparthic veins were observed on some of the quartz schist. At the boundary of quartz-schist with other lithological unit, the mica minerals occurred as sparsely aligned grains within the quartzo-feldspartic minerals.

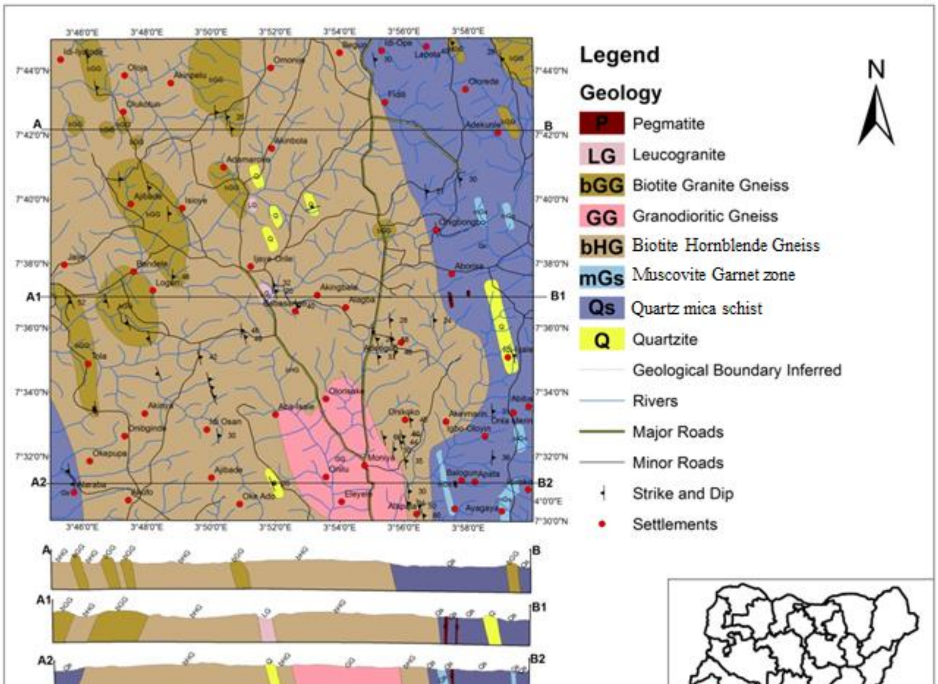

Figure 1: Geological map of the study area. Inset is the study area within Nigeria.

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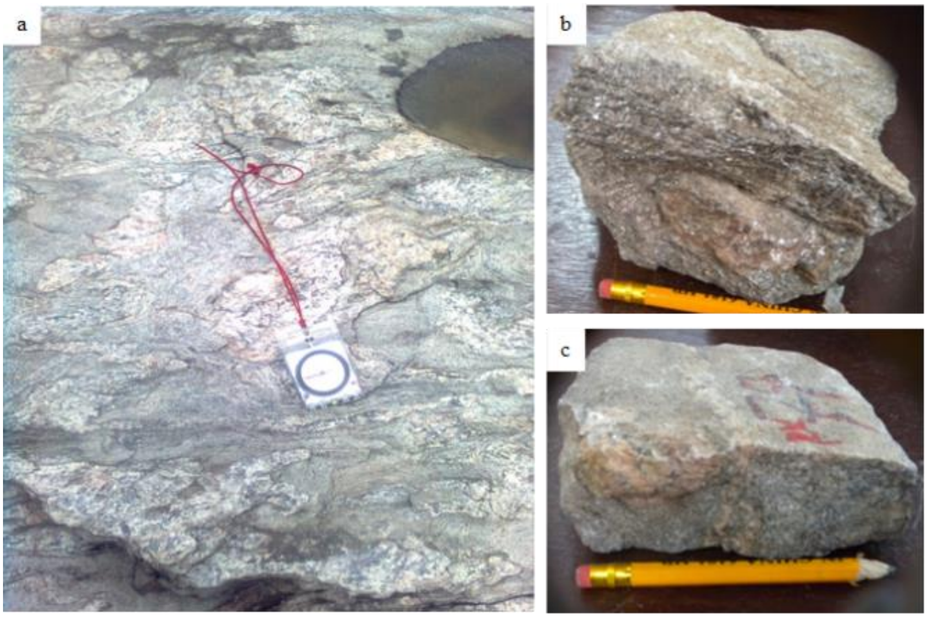

Figure 2: (a) Low lying quartz schist outcrop. (b) Sample with numerous muscovite flakes. c) Alkali feldspar (pencil length is 7cm in long) grain forming a porphyroblastic texture with the finer groundmass.

2.3 Muscovite Garnet Zone

The muscovite garnet zone was found occurring within the quartz schist east of the study area. They outcropped as small hilly topographic highs within the low-lying terrain formed by the host, the quartz schist. The muscovite garnet schist generally trend in the N-S direction with moderately dipping foliation planes. The muscovite garnet schist is coarser in grains than the quartz schist and is more leucocratic due to the relative abundance of muscovite over the host quartz schist. Hand specimen observations revealed high percentage of quartz, larger and numerous crystals of muscovite, feldspars and garnet (Figure. 3).

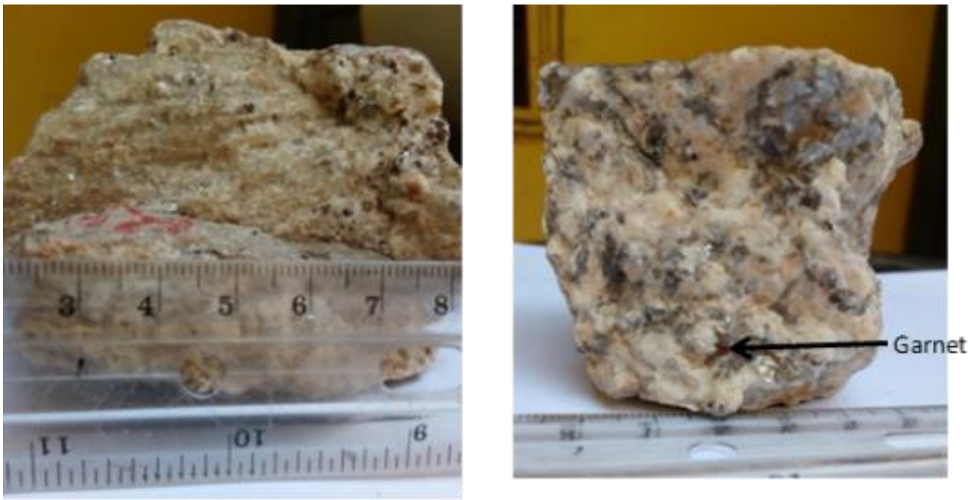

Figure 3: Hand specimen samples revealing quartz, pink alkali feldspar, muscovite and garnet.

3. Materials and Methods

The geological field mapping exercise conducted by traversing the area involved detailed observation of outcrops, structural features (such as foliations, lineation, folds, etc.), field relationship of the rocks, measurements of trends and orientations of rock units were undertaken and fresh representative samples were obtained. Thin section preparations were made from representative rock samples collected from the study area for petrographical study at the thin-section laboratory of the Department of Geology, University of Ibadan. Representative schistose rock samples were pulverised prior to Whole-Rock geochemical analysis conducted at the Bureau Veritas Minerals (BVM) Pty Ltd, Canada using Inductively Coupled Plasma-Mass Spectrometry. To ensure the reliability, accuracy and reproducibility of the data generated, reference materials, blanks and duplicates were analysed with the samples.

4. Results

4.1 Mineralogy and Petrography

4.1.1 Quartz schist

In transmitted light, the quartz schist contained quartz (35-55%), albite plagioclase feldspar (10-25%), microcline (2-15%), muscovite (2-25%), biotite (8-20%), hornblende (2-8%), chlorite (2-5%), orthoclase feldspars (2-8%), opaque mineral (2-4%), and accessory apatite (Table 1). Numerous platy muscovite and biotite minerals strongly defined numerous foliation bands (Figure. 4). Some of the muscovite flakes display kink crystals (Figure. 4a). At the right end of this kinked muscovite crystal (Figure. 4a). In figure 4a the muscovite (labelled) appears greenish suggesting phengite composition. The presence of phengite is indicative of low temperature and high pressure (Velde, 1965). Because these observations, kinking and phengite compositions, were not seen as a common phenomenon, hence, a low temperature to medium strain metamorphism is inferred. Quartz grains appear as subgrains and share embayed to lobate interphase grain boundaries with biotite, muscovite, and feldspar grains. The subgrains display lobate to dentate grain boundaries. These grain boundaries point to a thermodynamic non-equilibrium, presumably due to late-stage deformation, whereas the quartz might have suffered grain boundary migration due to stress during regional metamorphism (Spry, 1974; Vernon, 2018). Biotite grains are mottled and range in colour from brown to green (Figure. 4b). In some biotite it is observed that chlorite grains are pseudomorphosed on them (Figure. 4c). This process of chloritisation may be linked with albitisation of plagioclase (Figure. 4d). They argued for an increased volume in neighbouring crystals in an Al-rich mineral system (Parneix et al., 1985). Large crystals of plagioclase (Figure. 4d) were observed in close association with smaller grains of biotite.

4.1.2 Muscovite garnet schist

The modal composition reveals: quartz (30-45%), orthoclase feldspar (12-18%), muscovite (16-20%), biotite (6-10%), albite plagioclase (5-8%) and significant amount of garnet (8-12%). Chlorite (4-5%) and opaque mineral (1-2%) were observed in accessory amounts (Table 1). Muscovite flakes occur as large lenticular grains and as fine grains smeared at the grain boundary of plagioclase feldspar and muscovite. High proportion of muscovite may be due to the close association of the muscovite garnet schist with the quartz-schist in the eastern corner of the area.

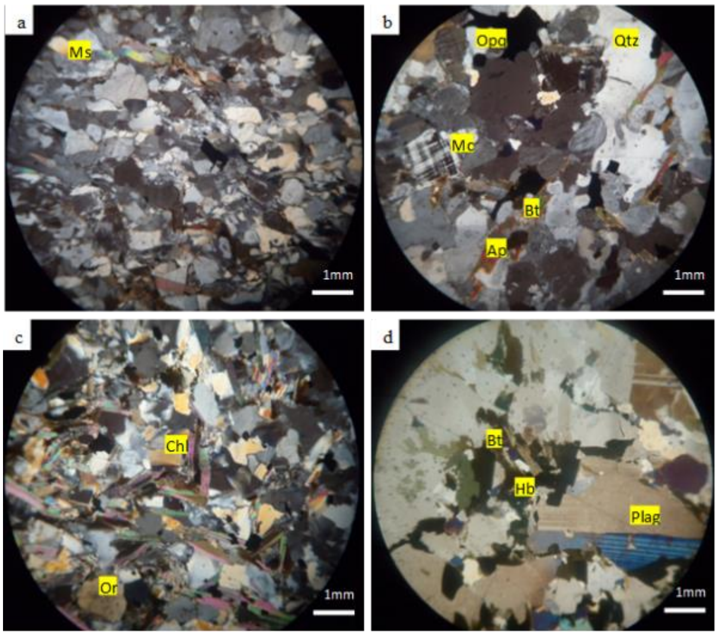

Figure 4: Mineralogical composition of the quartz mica schist showed abundance of quartz (Qtz), micas (Muscovite, Ms, and biotite, Bt), chlorite (Chl), plagioclase (Plag), hornblende (Hb), orthoclase (Or). Other accessory minerals include apatite (Ap) and opaque minerals (Opq). The muscovite displayed kinking (a) from slip in lattice structure resulting from possible regional shearing.

Table 1: Modal composition of Quartz (volume percentage).

	Quartz Schist								Muscovite Garnet Zone		
Sample No/Mineral	QMS1	QMS2	QMS3	QMS4	QMS5	QMS6	QMS7	QMS8	MS1	MS2	MS3
Quartz	38	45	45	45	55	40	40	43	40	30	45
Albite Plagioclase	20	18	10	10	15	15	25	20	5	8	6
Microcline	-	-	-	15	2	-	2	4	-	-	-
Chlorite	5	3	2	3	5	5	4	3	5	4	-
Muscovite	5	10	25	8	2	10	7	6	16	20	20
Biotite	18	12	11	10	15	20	8	10	10	8	6
Orthoclase Feldspar	8	5	3	2	4	8	5	4	15	18	12
Hornblende	3	3	-	-	2	2	7	8	-	-	-
Apatite	-	-	-	3	-	-	-	-	-	-	-
Opaque	3	4	4	4	-	-	2	2	1	2	1

Biotite flakes sometime showed alteration to chlorite and display pleochroism from brown to dark brown colour. Isotropic garnet crystals occur as fine grains and not very conspicuous in the thin section as in the hand specimen.

4.2 Geochemistry of the mica schist

Geochemical analysis was run on nine representative samples; six samples were obtained from the quartz mica schist and three samples from the muscovite garnet schist. Table 2 contains result of the major oxides in weight percentage (wt. %). Concentrations of the trace elements and rare earth elements, in parts per million (ppm), are presented in Table 3.

Average silica (SiO_2) value (68.89 wt. %) for the quartz mica schist ranged from 63.15 to 73.38 wt. % and was close to the average silica value obtained for the muscovite garnet schist (69.61 wt. %). Silica values for the muscovite garnet schist ranged from 68.54 to 70.40 wt. %. Average alumina values for the quartz mica schist (15.15 wt. %) was slightly higher than that observed for the muscovite garnet schist (14.75 wt. %). Alumina values for the quartz mica schist ranged more widely (13.01 – 17.84 wt. %; Standard Deviation, 1.77%) than values observed for the muscovite garnet zone (14.59 – 14.96 wt. %; Standard Deviation, 0.15). Ferric oxide (Fe_2O_3) concentrations in the quartz mica schist ranged from 1.60 to 6.01 wt. % while concentrations of Fe_2O_3 for the muscovite garnet schist ranged from 1.76 to 3.90 wt. %. The average concentration and standard deviation values, 3.00 wt. % and 1.72 (quartz mica schist) and 2.63 wt. % and 0.92 (muscovite garnet schist), are close but the range is larger (Table 3) for the quartz mica schist than for the muscovite garnet schist.

Concentrations of magnesia (MgO), lime (CaO), Soda (Na_2O) and potash (K_2O) did not vary significantly within the schist. Magnesia and lime values for the quartz mica schist ranged from 0.41 – 1.89 wt. % and 1.22 – 4.75 wt. %, respectively, while the same oxides for the muscovite garnet schist ranged, respectively, from 0.51 – 1.92 and 1.53 – 4.80 wt. %. Average value of MgO for the quartz mica schist (0.86 wt. %) was slightly lower than the average magnesia value for the muscovite garnet schist (0.99 wt. %). The average lime values were however closer (quartz mica schist, 2.47 wt. %; muscovite garnet schist, 2.64 wt. %). The average Na_2O values showed similar closeness in values between the petrologically varied schist (3.82 wt. % for the quartz mica schist and 3.95 wt. % for the muscovite garnet schist). The average potash value observed for the quartz mica schist was marginally lower (3.09 wt. %) than that observed for the muscovite garnet schist (3.65 wt. %). Average TiO_2 values were observed to be the same. The Loss on Ignition (LOI) values ranged from 1.6 to 2.8 accounting for moderate abundance of H2O rich minerals.

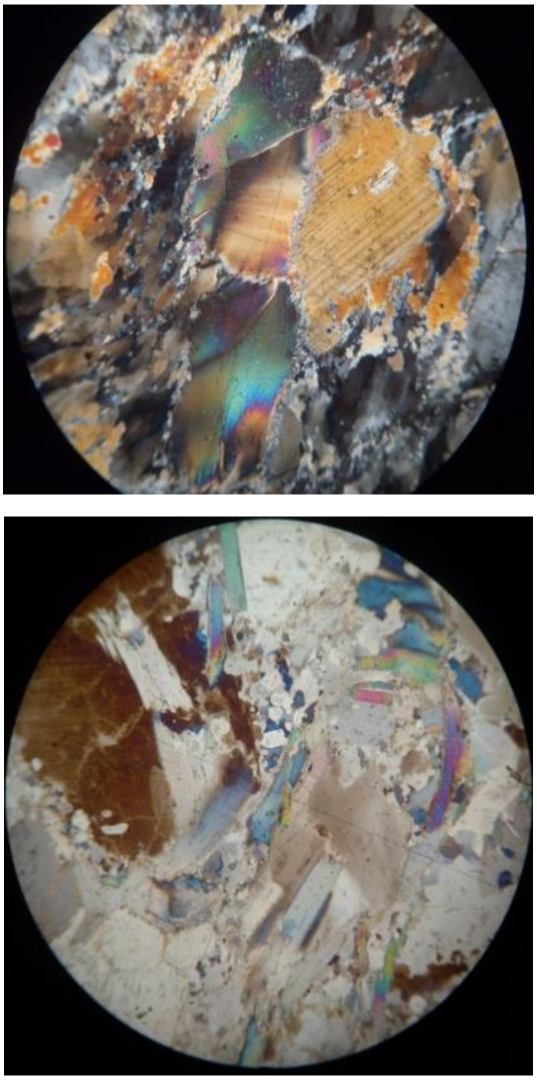

Figure 5: Mineralogical composition of muscovite garnet zone

Table 2: Major oxide composition (wt. %) for the Schist.

Sample No / Major Oxide(wt%)	Quartz Mica Schist							Muscovite garnet Schist			
	QS1	QS2	QS3	QS4	QS5	QS6	Av.	GS1	GS2	GS3	Av.
SiO_2	73.33	69.67	69.86	63.15	63.95	73.38	68.89	70.4	69.89	68.54	69.61
TiO_2	0.53	0.23	0.36	0.57	0.5	0.49	0.45	0.3	0.3	0.3	0.38
Al_2O_3	13.03	15.19	15.09	16.75	17.84	13.01	15.15	14.96	14.71	14.59	14.75
Fe_2O_3	1.89	1.6	1.81	6.01	4.73	1.98	3.00	1.76	2.24	3.9	2.63
MnO	0.02	0.02	0.02	0.13	0.11	0.02	0.05	0.02	0.02	0.12	0.05
MgO	0.41	0.51	0.53	1.89	1.43	0.41	0.86	0.53	0.51	0.54	0.99
CaO	1.26	1.61	1.57	4.75	4.39	1.22	2.47	1.53	1.58	4.8	2.64
Na_2O	3.31	4.66	3.65	3.74	4.23	3.3	3.82	3.71	4.43	3.41	3.95
K_2O	3.01	4.12	4.92	1.73	1.79	2.98	3.09	4.85	3.69	2.42	3.65
P_2O_5	0.12	0.13	0.09	0.35	0.32	0.12	0.19	0.08	0.1	0.05	0.08
Cr_2O_3	0.004	0.003	0.003	0.001	0.001	0.005	0.00	0.002	0.005	0.005	0.00
Loi	2.8	2	1.8	0.7	0.6	2.8	1.78	1.6	2.2	1.2	1.90
Sum	99.84	99.84	99.84	99.7	99.89	99.83	99.82	99.85	99.81	99.88	99.89

5. Discussion

5.1 Lithology, Provenance and Weathering implications

The mineralogical compositions of both schistose rocks were similar and dominated by quartz and mica. However, abundance of muscovite and the presence of garnet in the muscovite garnet zone were observed in the muscovite garnet schist over the quartz mica schist. Staurolite, described in some occurrences of the mica schist from Ibadan, was not observed in any of the samples obtained during this study. Jones and Hockey (1964), from their observations in some biotite schist from Ibadan, suggested that the presence of lenticular quartz could be responsible for the absence of staurolite. This mineralogical composition agrees with a greenschist to amphibolite facies for the schist of the study.

The concentrations of SiO_2 for the quartz mica- and muscovite garnet-schist samples were slightly lower than values obtained from most of the quartz schist rocks from the Nigeria metasedimentary belts but are higher

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than the Igbeti quartz schist (Akinola et al. 2014), Post Archean Australian shale and North American Shale Composite (Table 3) (Gromet et al., 1984; Taylor and McLennan, 1985; Okonkwo, 2005; Okunlola et al. 2009). Similarly, Al_2O_3, CaO, K_2O and Na_2O contents of the quartz schist were comparably similar to Igbeti Quartz schist but significantly higher than those reported from Ibadan, Jebba area and Okemesi (Okonkwo, 2005; Okunlola *et al.*, 2009, Table 3). Between the two schists, slightly elevated values were observed in the magnesia, lime and the alkalis contents for the muscovite garnet schistose rocks.

Variation diagrams of A-CNK vs A/NK and SiO_2 vs TiO_2 (Figs. 6a and b, respectively) established peraluminous precursors of igneous and sedimentary origins (Shand, 1948; Tarney, 1977). The plots of log(SiO_2/Al_2O_3) vs log(Na_2O/K_2O) and log(SiO_2/Al_2O_3) vs log(Fe_2O_3/K_2O) (Herron, 1988) showed that the schistose rocks were metamorphosed from a dominantly wacke, fine grained sediment (Figure. 6c and d).

The Mica schist within the Oyan-Iseyin-Ibadan schist belt has been described as the core lithologic unit within the Ibadan syncline and are susceptible to weathering but no evidence for intense weathering has been suggested (Jones and Hockey, 1964). Occurrences of lenticular quartz, garnet and staurolite and possibly tourmalinisation of the mica schist through the intrusive actions of

Table 3: Comparison of averages of major oxide compositions with schistose rocks from some parts of the western half of Nigeria.

	This Study		(Jebba)	Okemesi	Igbeti	PAAS	NASC
Sample location/	Av. Quartz	Av. Muscovite	Quartz mica	Quartz mica	Quartz mica	Post Archean Australian Shale	North American Shale composite
Sample location/	Av. Quartz	Av. Muscovite	Quartz mica	Quartz mica	Quartz mica	Post Archean Australian Shale	North American Shale composite
Average Major Oxide compositions (wt%)	mica Schist	Garnet schist	Schist (Okonkwo, 2005)	Schist (Okunlola, et.al., 2009)	Schist (Akinola, et.al., 2014)	(Taylor and McLennan, 1985)	(Gromet et al., 1984)
SiO_2	68.89	69.61	75.33	84.38	63.4	62.80	64.80
TiO_2	0.45	0.38	0.42	0.23	0.3	1.00	0.70
Al_2O_3	15.15	14.75	12.46	8.15	14.23	18.90	16.90
Fe_2O_3	3.00	2.63	3.67	1.2	6.58	6.50	5.66*
MnO	0.05	0.05	0.03	0.01	0.05	0.11	0.06
MgO	0.86	0.99	1.43	0.59	1.85	2.20	2.86
CaO	2.47	2.64	0.32	0.19	3.43	1.30	3.63
Na_2O	3.82	3.95	1.41	0.5	2.18	1.20	1.14
K_2O	3.09	3.65	3.46	2.85	3.5	3.70	3.97
P_2O_5	0.19	0.08	0.13	0.14	-	0.16	0.13
Cr_2O_3	0.00	0.00	-	-	-	-	-
Loi	1.78	1.90	-	-	-		
Sum	99.82	99.89	98.66	98.24	95.52	-	-

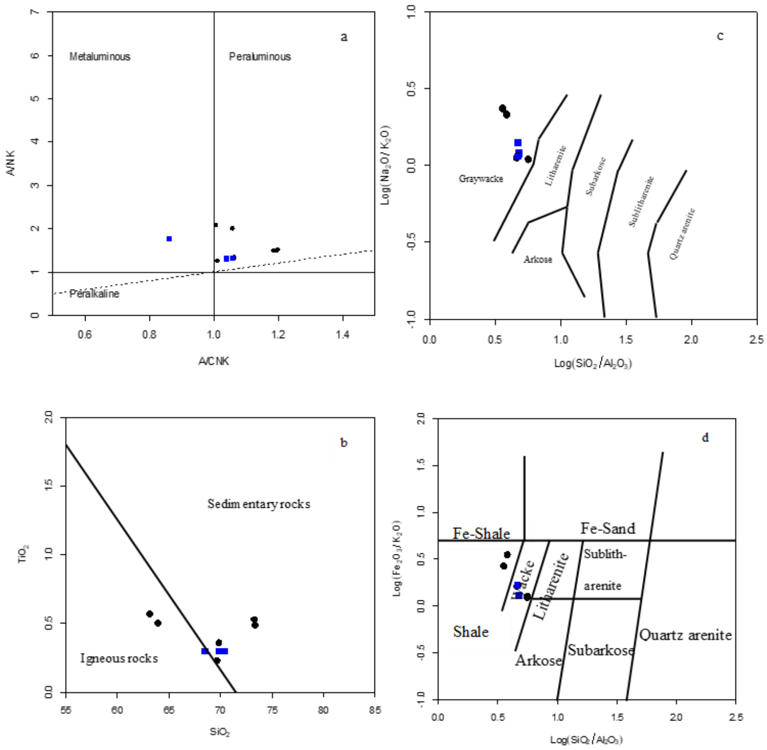

Figure 6: a) Plot of A/CNK vs A/NK (Shand, 1948) described the schist as dominantly peraluminous. b) Tarney's (1977) plot of SiO_2 vs TiO_2 revealed igneous and sedimentary precursors for the mica schist. c and d) Plots of log(SiO_2/Al_2O_3) vs log(Na_2O/K_2O) and log(SiO_2/Al_2O_3) vs log(Fe_2O_3/K_2O) (adapted after Herron, 1988), respectively, suggest that freshly weathered feldspar-rich sediment of fine to medium grain formed the constituent of the metasediment's precursor.

pegmatitic bodies were largely responsible for the resistance to weathering (Jones and Hockey, 1964). The degree of weathering of the mica schist (quartz mica schist and the enclosed zone of muscovite garnet schist) of the study was investigated using Chemical Index of Alteration (CIA) and Plagioclase Index of Alteration (PIA). These indices were calculated based on the molar proportions of their major oxides. The CIA was calculated using Nesbit and Young (1982) formular (eq. 1) while the PIA (Fedo et al., 1995) was calculated using equation 2. Values obtained for the CIA (av. 51.79) and the PIA (av. 52.53) were low.

$$CIA = [Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100 \text{ (Nesbit and Young, 1982)} \quad (1)$$

where CaO represents the CaO in silicate fraction only and calculated using (CaO* = mole CaO-[10/3×mole P_2O_5]).*

$$PIA = [(Al_2O_3 - K_2O)/(Al_2O_3 + CaO + Na_2O - K_2O) * 100] \text{ (Fedo et al., 1995)} \quad (2)$$

The tectonic setting during the sedimentary processes bears on the compositional maturity of sediments. Low CIA (46.4 – 55.1) and PIA (45.7 – 57.1) values obtained for this study implied fresh rock to low degree of weathering and indicated tectonically active setting of the parent rock (Price and Velbel, 2003; Qiugen et al., 2005). Figure 7 showed a granitic to granodioritic protolith for the schist of the study. Also, the samples did not follow the weathering trend indicated in the Nesbit and Young's (1988) diagram suggesting low degree of feldspar weathering.

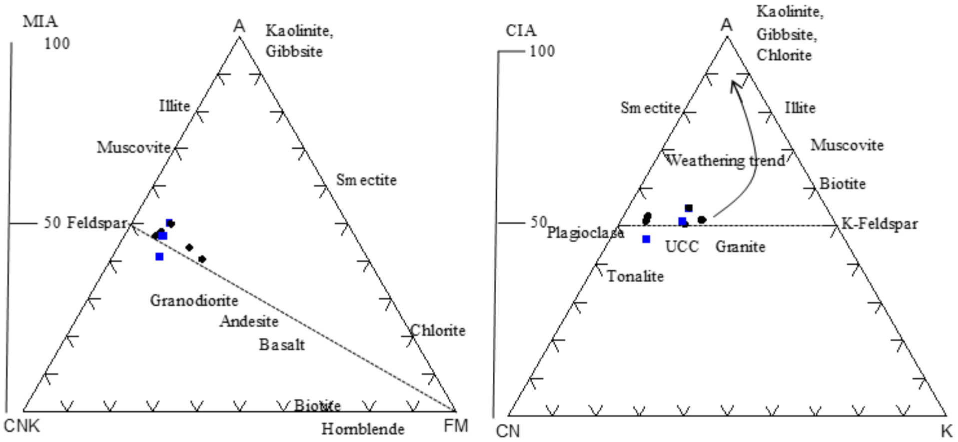

Figure 7: Plots of A-CNK-FM and A-CN-K (after Nesbitt and Young, 1989) showed that the metasediments are derived from granite-granodiorite source-protolith under mild weathering processes.

5.2 Metamorphism

The KFMASH ($K_2O–FeO–MgO–Al_2O_3–SiO_2–H_2O$) system and the mineralogical composition suggest a low-Al pelite and granite origins for the schistose rocks of the study (Figure. 8). The relatively low Al content in the bulk compositions of the quartz mica (av. 15.15 wt. %) and the muscovite garnet (av. 14.75 wt. %) schists suppresses the stability fields of Al-saturated minerals, such as staurolite or kyanite, thus shifting the reaction boundaries within the KFMASH diagram. This allows for garnet growth over a broader range of P–T conditions without the simultaneous stabilisation of Al-rich index minerals within localised metamorphic zones as observed in the field (Figure. 1). The absence of staurolite, kyanite and sillimanite and presence of biotite and garnet suggests that the grade of metamorphism is mid-grade judging from the Barrovian facies assemblage (chlorite-biotite-garnet-staurolite-kyanite-sillimanite) described by Tilley (1925).

The studied quartz-mica and muscovite-garnet schists shares the defining characteristics of a low-Al pelite. Petrographic analysis confirms the presence of abundant quartz and muscovite, with garnet forming porphyroblasts within a fine-grained mica-rich matrix (Figure. 3), with minor biotite present. The garnet mineral-in in the muscovite garnet assemblage suggests medium grade metamorphic conditions (c.a. 500–600°C and 5–7 kbar). The garnet crystals (Figure. 3) might have grown from a mineral reaction involving chlorite and muscovite (phengitic), without crossing into the stability field of Al-saturated phases (Figure. 8).

5.3 Source and Tectonic setting

Sediments derived from mafic rocks have Al_2O_3/TiO_2 values less than 14 while those showing Al_2O_3/TiO_2 values ranging between 19 and 28 could be derived from a source with average andesitic to rhyodacitic (and/or granodioritic to tonalitic) composition. With Al_2O_3/TiO_2 values from this study ranging from 24.58 to 66.04 (av. 41.30), we suggest a granitic source for the metasediments. The older granites that predominate during the Proterozoic are inferred as the main source components for the sediments that formed these schistose rocks.

Bhatia (1983) observed progressive depletion in Fe_2O_3 + MgO, TiO_2, Al_2O_3/SiO_2 from oceanic island arc to continental island arc to active continental margins to passive margins while K_2O/Na_2O and $Al_2O_3/(CaO + Na_2O)$ increased. K_2O/Na_2O (0.42 – 1.35) values of the study showed consistency with Bhatia's (1983) values for continental island arc (0.4 – 0.8) and active continental margin (1). His observation on Fe_2O_3 + MgO variation across these tectonic settings argues for continental island arc and active continental margins for the environment of emplacement of this schistose rock.

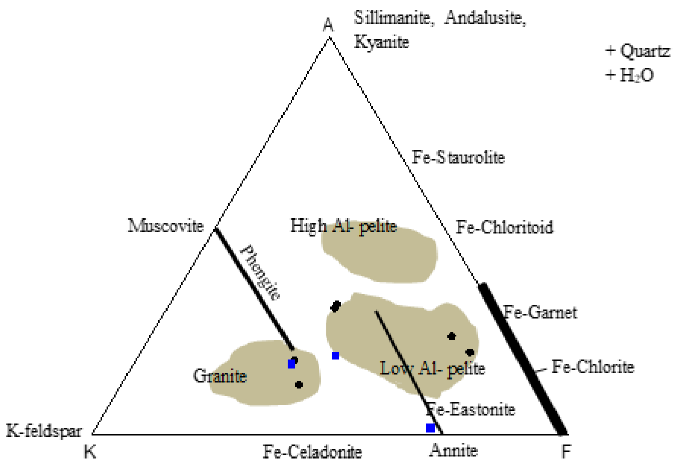

Figure 8: An AKF (Al_2O_3-MgO-$FeO_{(tot)}$-K_2O) subset of the KFMASH shows the plotting of the samples within and around the granite and low Al-pelite fields. The formula for calculating the AKF is $A = 1/2AlO_{3/2} - 1/2KO_{1/2}$; $K = KO_{1/2}$ and $F = FeO_{(tot)}$ (Spear, 1993).

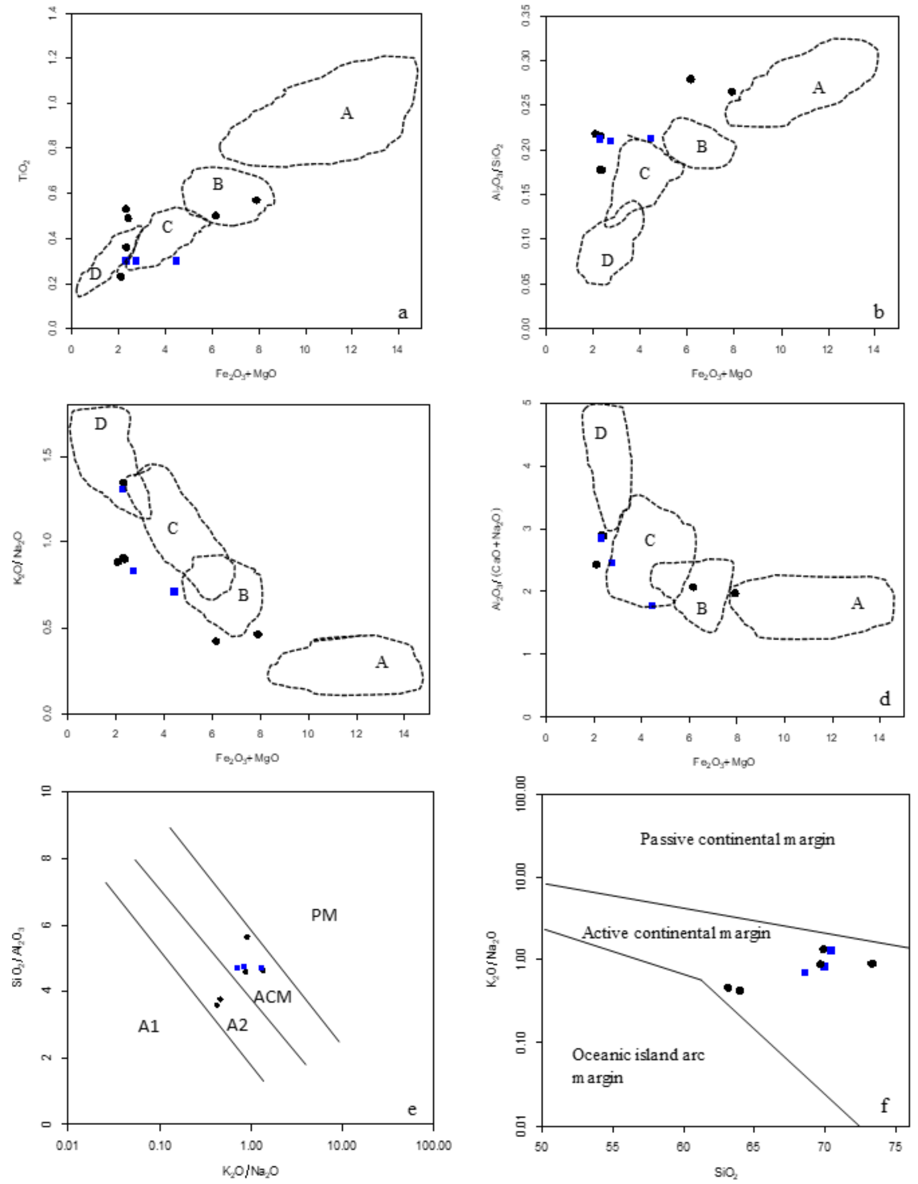

Figure 9: a – d) Plots of Fe_2O_3 + MgO vs TiO_2, Al_2O_3/SiO_2, K_2O/Na_2O, and $Al_2O_3/(CaO+Na_2O)$ (after Bhatia, 1983) showed samples plotting in and around active continental margin, continental island arc margin fields indicating felsic protolith as source rocks (Dotted lines in figures a to d represent fields of sandstones depicting tectonic settings: A-Oceanic island arc; B-Continental island arc; C-Active continental margin and D-Passive margins); e) Plot adopted after Maynard et al. (1982) showed that most of the samples fell within the active continental margin and evolved arc setting-felsic plutonic detritus fields (A1 - arc setting-basaltic and andesitic detritus; A2 - evolved arc setting-felsic plutonic detritus. ACM - active continental margin; PM - passive margin); f) Plot of SiO_2 vs K_2O/Na_2O (adapted after Roser and Korsch, 1986) revealed active continental margin as the dominant environment of emplacement for the schist.

6. Conclusion

On the bases of field relationship and lithological association, the schist outcropped as an inter-banded unit within the gneisses which were identified as biotite granite gneiss, granodioritic gneiss, and biotite hornblende gneiss. The schist is dominantly quartz mica rich with enclaves rich in muscovite and garnet which are mapped, altogether, as muscovite garnet zone.

The quartz mica schist comprised of quartz + plagioclase feldspar + biotite + muscovite + microcline + k-feldspar + hornblende ± chlorite while the muscovite garnet schist is comprised of quartz + plagioclase feldspar + muscovite + garnet ± biotite ± chlorite. These mineral assemblages described a metamorphism in the greenschist facies that graded locally into amphibolite facies.

Major oxide geochemistry revealed pelitic source rocks which were derived from freshly weathered granite and possibly immature metasediments. The AKF diagram suggests that the progenitor is low Al-pelite which was emplaced in a mixed environment but predominantly active continental margin.

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