

Geochemistry and Petrogenetic Features of Metasediments in Northern Part of Kushaka and Birnin Gwari Schist Belts NW Nigeria

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Abstract

The Kushaka and Birnin Gwari metasediments and associated banded iron formations constitute important lithological units within the Precambrian Basement Complex. They were studied to evaluate their compositional characteristics and petrogenesis in order to contribute further to the understanding of the geodynamic evolution of Nigeria's Schist belts. The Kushaka metasediments comprise quartzite, graphite and sulphur bearing staurolite-muscovite quartz schist interbedded with Banded Iron Formations (BIFs) while the Birnin Gwari schist comprise staurolite-biotite quartz schists with lithic (angular to rounded clastic quartz, schistose, volcanic and quartzo-feldspathic) sandstones. These schists are associated with fissile and ferruginous quartzite, banded and granitic gneisses, basalts and amphibolites. Petrographic work revealed varying proportions of quartz, staurolite, biotite and muscovite with subordinate iron-oxide minerals. Geochemically the metasediments in the Kushaka are enriched in SiO₂ (61.23 to 65.99 wt %) with elevated values of Al₂O₃ (16.53 – 20.93 wt %), Ba, V, W, La, Nb, Nd, Rb, Th and Zr; while the Birnin Gwari schists, even though enriched in SiO₂ (63.03 to 65.13 wt %), has moderately elevated Al₂O₃ (15.4 – 15.16 wt %) values but is depleted these trace elements. Field and geochemical characterization of the Kushaka metasediments suggests peraluminous, tholeiite and calc-alkaline character; arkosic and shale-greywacke sedimentary protoliths derived from quartzose sedimentary and granite-quartz monzonite provenance. Calculated ICV values of 0.52 - 0.99 and occurrences of graphite and sulphur in the Kushaka metasediment suggests shallow stable shelf-type sediment of carbonate and iron formations in a reducing environment with matured sedimentary protolith. The Birnin Gwari metasediments on the other hand have a peraluminous and calc-alkaline character, inherited from shale-greywacke and quartzose sedimentary protoliths derived from granodioritic and granite-quartz monzonite provenance. ICV values of 1.12 – 1.18 and angular and volcanic clasts suggest rapid subsidence of basin during genesis and / or tectonic instability in the surrounding environment with immature sedimentary protolith. This is an indication of two contrasting environment in an arc setting with contribution from basaltic and andesitic detritus. Available geochronological data on granite and granitic gneisses have ascribed the Kushaka schist belt to Kibaran and the Birnin Gwari schist belt a Pan-African age.

Keywords: Metasediments, protolith, Kushaka, Birnin Gwari, quartzite, provenance, shale, greywacke.

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1. INTRODUCTION

The Birnin Gwari Schist belt and the underlying quartzo-feldspathic rocks of the Zungeru Formation form a single structural unit named Zungeru-Birnin Gwari Schist Belt. It is a simple N-S syncline, 150 km long, with the northern part displaced dextrally by a NE-SW transcurrent fault. It is characterized by conspicuous NNE-SSW trending ridges rising over 100m above surrounding country, comprising mainly phyllites, mica schists, with which metagreywacke, pebbly schist and metavolcanics are interlayered. The lower part (south of the study area) consists of finely banded phyllites in the west and higher grade biotite-muscovite schists in the east. They are overlain by the Durimi pebbly schist, a metamorphosed mudstone conglomerate (Turner, 1983; Ajibade et al., 2008).

The Kushaka Schist Belt is a metasedimentary succession of schist, phyllites and banded iron formations, intruded by large volumes of granitic rocks engulfing the whole formation and fragmenting it into smaller bodies separated by granites and migmatites (Grant, 1978). The main rock type is semi-pelitic biotite-muscovite schist, in other places containing garnet and staurolite. Other rock types are phyllites, metasilstone and graphitic schists. Amphibolites are locally very thick, suggesting large volcanic accumulations. Basalt extrusion has been mapped in this belt south of the Kalangai fault (Oluyede et al., 2020).

The northern part of both Kushaka and Birnin Gwari is the focus of this study; here the NE-SW Kalangai-Zungeru-Ifewara (KZI) transcurrent fault dextrally displaced the Birnin Gwari schist belt to the south while it cuts through the whole Kushaka schist belt. Both schist belts have two contrasting structural styles (Fig. 1C). Birnin Gwari metasediments are simple, monocyclic and interpreted as a sedimentary cover infolded during Pan-African event into basement complex, while the Kushaka metasediments are complex and polycyclic and believed to have occurred with the gneisses and migmatites (Grant, 1978). Both belts are of different ages, and are separated by the

Migmatite-Gneiss-Quartzite Complex. There has been no agreement on the delineation, geological nomenclature, geochemistry and geodynamic setting of this major rock unit of the Nigerian Precambrian Basement Complex (Okunlola and Okoroafor, 2009). This work is an attempt to highlight the geochemical and petrogenetic features of this part of the Kushaka and Birnin Gwari schist belts in order to gain understanding of the evolution of this major rock unit of the Precambrian basement of Nigeria.

2. REGIONAL GEOLOGICAL SETTING

The N-S trending Nigerian schist belts are over 400 km in width and over 1000 km in length, and lie in the western part of the Precambrian basement complex (an ancient shield reworked in the Pan-African). They are predominantly composed of metamorphosed pelitic to semi-pelitic rocks but each belt differs in the amount of such lithologies as conglomerates, and greywackes, quartzites, meta conglomerates, mafic to ultramafic rocks, calc silicate rocks, marble, metavolcanics and banded iron formations (BIFs). The rock associations differ from one belt to the other. The schist belts are considered to be Upper Proterozoic supracrustal rocks which have been infolded into a migmatite gneiss complex. Syntectonic to late tectonic granitoids (Older Granite) intruded both the migmatite gneiss complex and the schist belts (McCurry, 1976; Rahaman, 1988; Garba, 2002; Mucke, 2005; Danbatta 2008 b) (Fig 1).

Two types have previously been identified, the older metasediment (predominant in southwest Nigeria) and the younger (low-medium grade) metasediments (predominant in northwest Nigeria). However, it is now known that schist belts also extend eastwards of 8^o meridian (Ajibade, 1976; Emeronye, 1988; Eneh et al., 1989; Ekwueme and Shing, 1987), exhibiting distinct petrological, structural and geochemical characteristics.

Presently, schist belts have been identified namely: Iseyin-Oyan, Ife-Ilesha, Igarra and Egbe-Isanlu and Obajana in the southwest (Rahaman, 1976; Odeyemi, 1977; Elueze, 1981; Annor et al., 1995; Olobaniyi, 2003; Okunlola and Okoroafor, 2009; Adegbuyi et al., 2017). The Lokoja-Jakura, Toto-Gadabuike belts (Muotoh et al., 1988; Elueze, 1981; Okunlola, 2001); the Kushaka, Birnin Gwari, Malumfashi, Wonaka, Kazaure, Maru, Anka, and Zuru in the northwest (McCurry, 1976; Fitches et al., 1985; Turner, 1983; Danbatta, 1999; 2008b; Alaku et al., 2017) and Obudu schist belt recently highlighted in the southeast (Ekwueme & Shing, 1987; Asinya et al., 2016) (Fig. 1C). The schist belts occur as series of antiformal and synformal troughs and forming prominent strike ridges, subsequent erosion and deep weathering has led to its been poorly exposed. The belts are intercalated with relics of migmatites and gneisses and/or intruded granite which separate or lie within them.

The Nigeria's schist belt is believed to have evolved as a result of an initial continental extensional stage culminating in rift openings and sedimentation with contemporaneous magmatism in the basins. These processes were followed by basin inversion which led to the deformation of sediments (Ajibade, et.al., 1987; Elueze, 1992; Danbatta, 2008b). Most of the postulated models recognize that the belts formed in discrete basins, usually demarcated by basement uplifts, and comprise significantly distinct lithological associations. Geochemical parameters of both the metasediments and the mafic rocks are used to constrain their tectonic setting. Both ensialic and ensimatic models have been postulated (Olade and Elueze, 1979; Ajibade and Wright, 1989; Danbatta, 2008b).

3. STUDY AREA

The study area covers a total area of 2,809 square kilometers and lies in the north western part of Nigeria comprising parts of the Kushaka and Birnin Gwari schist belts. It falls within 1:100,000 Kushaka Sheet 122 and bounded by latitudes 10^o 15'' N and 11^o 00'' N and longitudes 6^o 30'' E and 7^o 00'' E (Fig. 1). The area is underlain predominantly by four main lithologies: (i) Migmatite-Gneiss-Quartzite suite represented by dioritic, granodioritic, granitic and granitic gneisses with fissile and ferruginous quartzites and banded iron formation (BIF); the schist belts represented by (ii) the Kushaka graphite and sulphur bearing staurolite, biotite and muscovite quartz schist and in places inter-banded with iron formations; iii) the Kushaka Gneiss Complex represented by extrusive basalts, staurolite and muscovite gneiss and banded iron formation (BIF) and (iv) syn- tectonic and late- orogenic biotite-hornblende syenite (BHS) and biotite-hornblende granite (BHG) in the Kushaka schist belt and biotite muscovite granite (BMG) in the Birnin Gwari schist belt area.

3. MATERIALS AND METHODS

Fifteen representatives (eight in Kushaka and seven in Birnin Gwari) metasediments samples were carefully selected and thin sections were prepared and petrographic studies of different rock types were done using a petrographic research microscope at the Department of Geology, Ahmadu Bello University, Zaria. Modal compositions of the rocks were estimated from thin section studies using the JMicrovision software of Nicholas Roduit version 1.2.7. (2002-2008). Modal analyses of the metasedimentary rocks are given in Table 1.

Seven representative samples were analysed (Table 2) comprising each mappable lithologic unit which include ferruginous quartzite, staurolite, biotite and muscovite quartz schists. About 1 kg of each sample was broken into pieces with a hammer and crushed into smaller pieces with a jaw-crusher. The samples were thereafter pulverized in a disc mill for about two minutes. Each pulverised sample was thoroughly homogenized to obtain a

representative portion. The samples were thereafter sent to laboratories for whole-rock geochemistry in the Department of Geological Sciences, University of Vienna, Austria.

Rocks were crushed and grounded to the finest powder possible in an agate (or tungsten carbide) swing mill for the whole X-ray-fluorescence analysis. Major elements were determined by the fused bead method on calcined rock powder fused with lithium tetraborate as flux to form a glass bead. Trace elements used the pressed pellet method directly on the crushed and milled rock powder mixed with polyvinyl alcohol as a binding agent. The element analyses are performed on a sequential X-Ray spectrometer PHILIPS PW2404 using a super-sharp end-window tube with a Rh-anode and a programmable 4kW generator (60kV max., 125mA max.; iso-Watt-switching), with accompanying PANalytical software.

4. RESULTS AND DISCUSSIONS

4.1 Field Occurrence and Petrography

The Kushaka metasediments comprise staurolite, biotite and muscovite quartz schists interbedded with banded iron formations (BIFs). Two varieties are recognized in the field. (i) The fine grained grey to silvery grey staurolite-muscovite types confined to the river channels in Kugu area; (ii) The yellowish to grayish type around Sabo-Layi is graphite, sulphur bearing, (minerals in hand specimen) biotite schist. Graphite is silvery grey to black colour with greasy feel and smudges the hand when touched, but may have been transformed or altered to magnetite and haematite as opaque minerals as observed under the microscope (Fig. 2 and 3).

The **staurolite-muscovite schist** in Kushaka around Kugu consists predominantly of staurolite (30%), iron-oxide (5%), quartz (30%), K-feldspar (20%) and muscovite (10%) embedded in a quartz, feldspar and muscovite matrix (Table 1). Staurolite occurs as pale brown (in plain polars and with yellow, orange, purple and blue interference colours in cross polars), euhedral six-sided elongated crystals and rounded edges with high relief from the groundmass (Fig. 2 A and B). The staurolite is also characterized by quartz inclusions and dotted with iron-ore crystals. Muscovite occurs as fibrous and acicular crystals stacked between the staurolite minerals. Iron-ore occurs as euhedral and subhedral crystal disseminations. Medium grain quartz crystals are elongated and prismatic tightly joined together with wavy extinction. Accessory mineral is magnetite.

Quartzites: Consists of greyish white fissile and reddish brown ferruginous types. The grayish white and fissile rock occur as poorly exposed low lying ridges in Nasarawa Kwona area of Kushaka schist belt. Where exposed, they are aligned in the N-S foliation direction. The ferruginous quartzite occurs as iron-formation interbedded with quartzite. They are characterized by clear microfolds, crenulation cleavages, nearly vertical dips and well defined schistosity. They are well exposed in Maganda area (Plate I). In the adjoining Kuseriki, south west of the study area, they are interlayered with phyllites.

Banded Iron Formation (BIF) is exposed as series of N – S trending ridges and as isolated hills with elevation of ≥ 600 m in Sabo-Layi, Kugu and Galadimawa area. Where they are interbedded with the schist, exposures show iron-formation occurrence with semi-pellitic schist and the iron concretions at the top. Concretionary ironstone at the top of the isolated hill is composed of cherts and iron-rich minerals which form alternating bands (Fig. 1).

Amphibolites: Amphibolites occurs as dykes in the Kungwi area, showing characteristic brittle deformation with fragmented boulders. The major one extend for over 1 km in length and >6 m in width trending N160° direction. It is a fine grained dark coloured rock with acicular quartz occurring as bands (1 – 2 mm), trending in the general N – S foliation direction. There are others of smaller length and width.

The Birnin Gwari metasediment occurs as an elongate, N-S trending metasedimentary outcrop of 430 m elevation, and as a whale back outcrop exposed along Kogi Kuseriki river channels, through Mando (Fig. 2C). It consists of staurolite and biotite quartz schists with lithic sandstone (clastic quartz, schistose, volcanic and quartzofeldspathic materials) (Fig. 2). Four types based on field occurrence have been observed:

The bluish grey fine grained rock with clast (2mm to 5cm and making up to 25% of the constituent of the rock), aligned in the foliation direction, showing flow structure. (ii) Light grey, medium grained rock with dark minerals evenly distributed, the clast making up about 40% is angular to rounded and flattened, and are poorly sorted with range of particle sizes from sand to cobbles. (iii) Dark grey colour, fine grained rock characterized by ripple marks cross bedding and cross lamination, typical of sedimentary structures. (iv) Dark fine grained with granular texture without clastic materials, close to the Mando granitic intrusion with granitic dyke occurring in the biotite and iron-rich metasediment (Plates I).

The **staurolite-biotite schist** variety in Birnin Gwari occurs as slightly foliated fine to medium grained rock dark coloured rock with clastic materials consisting of staurolite (30%), quartz (30%), K-feldspar (20%), muscovite (10%) and iron-oxide (5%). Biotite crystal is sub-hedral to anhedral and sometimes aligned with quartz and staurolite minerals (Table 1) (Fig. 3D).

4.2 Geochemistry

Whole-rock major and trace elements data of representative rock samples of the metasediments are represented in Table 2 and 3.

Major Elements

Analytical results (Table 2) indicate that SiO₂ value ranges both in the Kushaka and Birnin Gwari metasediments is 61.23 – 65.99 wt %. They are generally siliceous and falls within the limits for average schistose rocks of Nigeria (Elueze, 1979; Olobaniyi, 2002) including the Obudu schist in the southeast (Obioha and Ekwueme, 2012). Ferruginous quartzite has 62.61 wt %, chemically similar to those for the Jebba quartzite, micaceous quartzite of central Nigeria (Okonkwo, 2006) and quart-sandstones (Blatt, et. al., 1972) but less silicious compared to the Okemesi quartzite (Okunlola and Okoroafor, 2009). The banded iron formation has 50.98 wt %.

Kushaka metasediments exhibit high Al₂O₃ content with a range of 17.71 – 19.72 wt % for the staurolite-muscovite schist, high value for the ferruginous quartzites (20.93 wt %), but moderate Al₂O₃ content for the Birnin Gwari staurolite schist (15.40 – 15.16 wt %). The high Al enrichment in the Al₂O₃ reflects their composition by aluminous clay minerals and pelitic nature of the metasediments. The K₂O content (2.36 – 4.2 wt %) is higher than the Na₂O content (0.98 - 2.29 wt %). The K₂O/Na₂O reflects probable secondary addition of potassium (K-metasomatism) during metamorphism (Fedot et al., 1995).

TiO₂ content ranges from 0.74 – 1.01 wt % in Kushaka to 0.92 – 0.97 wt % in Birnin Gwari metasediments. Fe₂O₃ ranges from 4.92 – 7.96 wt % in Kushaka to 6.62 – 7.3 wt % in Birnin Gwari metasediments; with 29.22 wt % for the banded iron formation. MnO in Kushaka is 0.05 – 0.13 wt % while Birnin Gwari is 0.11 – 0.12 wt %. MgO is 0.18 – 2.97 wt % in Kushaka and 2.17 – 3.31 wt % in Birnin Gwari metasediments. CaO ranges from 0.17 – 0.84 wt % in Kushaka to 1.69 – 1.92 wt % in Birnin Gwari. Generally, TiO₂, Fe₂O₃, MnO, MgO and CaO shows moderate to high concentration in the metasediments; however values in Birnin Gwari are higher compared to Kushaka metasediments. This reflects the high content of ferromagnesian minerals in both metasediments. Variable MgO and CaO contents perhaps indicate shales and clays that are both carbonate-free as well as containing about 30 % carbonates. MgO content in excess of CaO content by < 0.6 wt % is typical of carbonate-free protolith (Ekwueme, 1985).

Trace Elements

The Kushaka metasediments has fairly high Ba with a range of 599 – 974.8 ppm, but a low range in Birnin Gwari with 27.6 – 32.2 ppm. Rb shows high concentration (116 – 153.6.8 ppm) in Kushaka compared to Birnin Gwari (13.5 – 14.4 ppm). Zr also revealed high concentration (187.3 – 212.6 ppm) in Kushaka compared to Birnin Gwari metasediments (32.7 – 41.9 ppm). The high Ba, Rb and Zr concentration in Kushaka are within the range of supracrustal rocks (Brown et al., 1979) and similar to the semi pelitic schist of Isanlu area and Ijero Ekiti metasediments (Olobaniyi, 2002; Akinola and Okunlola, 2012); The high Ba indicates K-feldspar rich source rocks in Kushaka and low Ba in Birnin Gwari indicates K-feldspar poor source rocks. The low Ba, Rb and Sr values in Birnin Gwari is similar to the Okemesi quartzites (Okunlola and Okoroafor, 2009).

The concentration of Rb especially in the Kushaka metasediments is similar to their derivation from clay and shales which is a reflection of their origin. Rb/Sr ratio of >0.4 % in Birnin Gwari metasediments is typical for pelitic metasediments (Van De Kamp, 1968). High Zr concentration is a reflection of the presence of detrital zircon in the Kushaka metasediments and lack of it in the Birnin Gwari metasediments (Elueze, 1981). Sr content is in the range of 99.2 – 127.9 ppm in the Kushaka metasediments and 134 – 557.6 ppm in the Birnin Gwari schists. Zn concentration is 32.5 – 109.1 ppm in the Kushaka metasediments and 32.7 – 41.9 ppm in the Birnin Gwari schist. Generally, Ba, V, W, La, Nb, Nd, Rb, Th and Zr are more enhanced in Kushaka metasediments than in Birnin Gwari metasediments. Enrichment of incompatible high field strength elements (HFSE) and large ion lithophile elements (LILE) in the Kushaka metasediments compared to Birnin Gwari metasediments may have been responsible for the mineralization of the earlier.

4.3 Petrogenetic Characteristics

The petrogenetic character of the rocks as established on the Na₂O/Al₂O₃ versus K₂O/Al₂O₃ plot (after Garrels and Mackenzie, 1971) (Fig. 4A) that shows that both Kushaka and Birnin Gwari metasediments plot in the sedimentary/metasedimentary field, implying that the rocks are largely of sedimentary origin, hence postulating a common origin for the protolith of the rock units. In the MgO-CaO-Al₂O₃ diagram of Leyleroup et al., 1977 (Fig. 4B) shows the entire metasediments plot outside the magmatic field also supporting the sedimentary antecedent of these rocks. These petrogenetic character of the Kushaka and Birnin Gwari metasediments is similar to those of Ilesha (Elueze, 1981), Lokoja-Jakura (Okunlola, 2003), Sepeteri (Okunlola et al., 2006), Birnin-Gwari schist (Ajibade et al., 2003), Okemesi (Okunlola and Okoroafor, 2009).

Al₂O₃ / (CaO + Na₂O + K₂O) versus Al₂O₃ / Na₂O + K₂O geochemical data of the metasediments (after Maniar and Piccoli, 1989) (Fig. 5A) are dominantly in the peraluminous field. This consistent with the molecular proportion of Al₂O₃ > (CaO + Na₂O + K₂O), thus corroborating the peraluminous character of both Kushaka and Birnin Gwari metasediments.

The (Na₂O + K₂O) – Fe₂O₃ – MgO ternary plot (Fig. 5B) (after Irvine and Baragar, 1971) discriminates the metasediment of Birnin Gwari as having a calc-alkaline affinity and Kushaka as tholeiitic and calc-alkaline. This

shows that metasediments of Birnin Gwari area have a petrogenetic character that is similar to those in Okemesi area, while Kushaka metasediment bear similarity with the Sepeteri amphibolitic schist (Okunlola et al., 2005). The composition of the metasediments (Table 2), when plotted in the ACF diagram of Winkler (1967) (Fig. 6A), shows ferruginous quartzite (KFQ1) and biotite-muscovite quartz schist (KKSc1) samples (around Sabo Layi area in the Kushaka metasediments) plot at the edge of Al-rich clay and shale and clay (1a) and shales free of carbonate (1b). Kugu biotite and staurolite-muscovite schist (KKSc 2 and KKSc 3) of Kushaka metasediment, and staurolite-biotite schists (KBGSc1 and KBGSc 2) of the Birnin Gwari metasediment both plot in the field 1b (between arrows) of Winkler (1967), indicating shales and clays containing about 30 % carbonates; no sample plots in the field 2 (Wyoming greywackes), while banded iron formation samples plot close to field 3 (basaltic and andesitic rocks) (Fig. 6A). This shows that metasediments of Kushaka and Birnin Gwari area are possibly derived from clays and shales which could have been contaminated by mantle derived rocks of basaltic composition from the Kushaka Gneiss Complex. Similarly the chemical composition of the Kushaka and Birnin Gwari metasediments plotted in the ACF diagram (after Miyashiro, 1973) (Fig. 4b) reveal a shale protolith. The data falls in the field of shale-graywackes, which suggest they originated from shale; clay and shale also shows mixed nature of these sediments. When the Kushaka and Birnin Gwari metasediments are plotted on the CaO–Na₂O–K₂O diagram (Fig. 7A), and the fields showing the compositional variations in acid to basic rocks are superimposed (Condie, 1967), Kushaka metasediments plot in the field of granite –quartz-monzonite, while Birnin Gwari metasediments plot at the edge of the field of granodiorite/ granite –quartz-monzonite indicating that their shale-arkose protoliths were derived essentially from a granitic–quartz-monzonitic source.

The Na₂O versus K₂O plot of metasediment (after Pettijohn, 1975) (Fig. 8A) further distinguish Kushaka schist into the arkosic and Birnin Gwari schist into the greywacke field. As confirmed by (Pettijohn, 1957), the average composition of shale show high abundances of Al₂O₃ and K₂O which is generally in excess of Na₂O. K₂O>Na₂O is used to indicate shale, and high proportion of K-bearing rock forming minerals such as mica, K-feldspar, illite, compared to Na-feldspar which is unstable prior to metamorphism. On the Al₂O₃–CN–K₂O plot, (Fig. 8B) the ferruginous quartzite, staurolite, biotite and muscovite quartz schists all of the Kushaka metasediment plot close to the illite fields while the staurolite and biotite quartz schist of Birnin Gwari metasediment plot close to the average shale. Banded iron formations straddle between kaolinite and smectite.

The results of the Chemical Index of Alteration (CIA) (Nesbitt & Young 1982; Okunlola, 2003) reveal values of 80.84% for ferruginous quartzite, 73.36 - 78.56 % for Kushaka metasediment, 67.13 – 70.51 % for Birnin Gwari metasediments and 89.64 % for the banded iron formation (Table 2). These values point to relatively intense chemical weathering of the source rocks.

The Index of Compositional Variability (ICV) (Cox & Lowe, 1995) measures the abundance of alumina relative to other constituents of the rock, except SiO₂. Compositionally immature pelitic rocks have high ICV, whereas mature pelitic rocks with very little non silicates or those rich in kaolinite group clay minerals possess low values (< 0.6) (Elueze & Okunlola, 2003). In the study area, Kushaka ferruginous quartzite; biotite, staurolite-muscovite quartz schist; Birnin Gwari staurolite and biotite schist and Kushaka banded iron formation shows 0.52, 0.59 – 0.99, 1.12 – 1.18 and 3.11 respectively (Table 3). The calculated ICV value for the Kushaka ferruginous quartzite (0.52) and biotite, staurolite and muscovite quartz schist (0.59 – 0.99) shows the matured nature of the sedimentary protolith prior to metamorphism; whereas calculated ICV value for the Birnin Gwari staurolite and biotite schist (1.12 – 1.18) shows the immature nature of the sedimentary protolith prior to metamorphism. Mature to moderately mature pelitic metasediments are characteristic of relatively stable cratonic environments, marked by moderate to very intense chemical weathering of first cycle material (Weaver, 1989; Bershad, 1966).

4.4 Provenance of the protolith and Tectonic Setting

Th/U ratio is also a useful parameter in determining the source characteristics of clastic sedimentary rocks (Roddaz et al., 2006). This ratio ranges between 4.25- 4.30 in present day crust, while its values of 2.6 and 3.8 have been assigned to upper and lower mantle respectively (Cullers and Podkovyrov, 2002). Higher Th/U ratios can also increase in response to oxidative weathering and/or removal of U. Nevertheless, clastic sedimentary rocks derived from the upper crust are characterized by ratio ≥ 4 , whereas ratio <4 has been related to a mantle contribution (Roddaz et al., 2006). In the Kushaka metasediments, Th/U ratios vary from 3.40 - 6.14 in the staurolite and biotite schist, and 13.75 in the ferruginous quartzite. This suggests that there have been significant proportion of the felsic rocks with mantle contribution from the source region.

The TiO₂-K₂O-P₂O₅ plot (Fig. 7B) (after Pearce et al., 1975) of the biotite muscovite and staurolite schist and ferruginous quartzite confirms continental nature of the sediments while the banded iron confirms oceanic nature of the sediment. The dual continental and oceanic field is a confirmation of the nature of the sediments which underwent metamorphism.

Roser and Korsch (1986) have shown that sandstone–mudstone suits from different tectonic settings can be distinguished on the basis of the K₂O/Na₂O and SiO₂/Al₂O₃ values and SiO₂ contents (Fig 9A). On the SiO₂/Al₂O₃ versus K₂O/Na₂O plots, all samples of the metasediment, plot in the basaltic and andesitic arc setting, except for

the Kugu staurolite and muscovite schist which plot in the evolved arc setting – plutonic detritus (Fig 9B). Thus, metasediments of the Kushaka and Birnin Gwari are of arc basaltic and andesitic setting. Basalts and amphibolites have been used as geochemical indicators of the tectonic setting in the Nigerian schist belts as of back-arc tectonic environment, near subduction zone setting (Elueze, 1992; Okunlola et al., 2006; Danbatta and Garba, 2007).

Grant (1978) obtained Rb – Sr data from Kuseriki granite emplaced across the gneissic envelope in Birnin Gwari and augen gneiss in the Sabon Gayam area of Kushaka schist belt. The Kuseriki granite with low and uniform Rb/Sr ratios, and an isochron based on four whole-rock samples and two spatially associated aplite veins gives an age of 500 ± 4 m. y., with an initial ratio of 0.7119 ± 0.0002 (Fig. 7a), ascribing Pan-African age to the Birnin Gwari schist belt. The augen gneiss have high and uniform Rb/Sr ratios, and no isochron can be based on them (Fig. 10B). Model ages for the five analysed samples are insensitive to initial $87\text{Sr}/86\text{Sr}$ ratio assumptions, and that the ratio for these rocks lies within limits 0.725 ± 0.02 , the data centroid implies that their ages lie between 730 and 650 m. y., a possibility that rocks from the schist belt was derived from pre-Pan-African rocks.

5. CONCLUSION

The Kushaka schist in the study area is composed of quartzite, ferruginous quartzite, graphite and sulphur bearing biotite quartz schist (BQS) and staurolite and muscovite quartz schist (SMQS) interbedded with Banded Iron Formations (BIFs). Birnin Gwari schist comprise staurolite-biotite and staurolite-muscovite quartz schist (SBQS) with angular to rounded clastic quartz, schistose, volcanic and quartzo-feldspathic materials (lithic sandstone).

Kushaka and Birnin Gwari metasediments are of sedimentary origin, hence a common origin for the protolith and dominantly of peraluminous character. Birnin Gwari metasediment has calc-alkaline and Kushaka has tholeiitic and calc-alkaline affinity. Their metasediments are possibly derived from clays and shales which could have been contaminated by other mantle derived rocks. Kushaka metasediment is further distinguished as arkosic while Birnin Gwari metasediment is distinguished as greywacke. Their geochemical composition revealed continental affinities with oceanic contribution and interpreted as reflecting contamination of crustal sources (Elueze, 1985). These belts are ensialic and evolved most probably in a rifted environment. Occurrences of graphite and sulphur in the Kushaka metasediment suggests shallow stable shelf-type sediment of carbonate and iron formations in a reducing environment and matured sedimentary protolith. Angular and volcanic clasts in the greywacke of Birnin Gwari metasediment suggest rapid subsidence of basin during genesis and / or tectonic instability in the surrounding environment and immatured sedimentary protolith prior to metamorphism. These are two contrasting environments in an arc setting with contribution from basaltic and andesitic detritus. This is similar to greywacke rocks of the Isanlu schist belt (Olobaniyi, 2003) and schistose rocks of Okemesi on the eastern side of the Ife-Ilesha schist belt (Okunlola and Okoroafor, 2009) where they suggests a rapidly subsiding basin accompanied contemporaneously with tectonic instability resulting in deformation and fracture in a rifted environment. The metasediments of the Kushaka and Birnin Gwari are of both continental and oceanic affinities. In terms of tectonic setting, the metasediments are of arc basaltic and andesitic setting which evolved most probably in a rifted environment.

Different ages have been assigned to the belts (Kushaka and Birnin Gwari) based on available geochronological data. Kushaka schist belt ascribed to Kibaran and Birnin Gwari schist belt ascribed to Pan-African (Grant, 1978; Turner, 1983; Ajibade, 2003).

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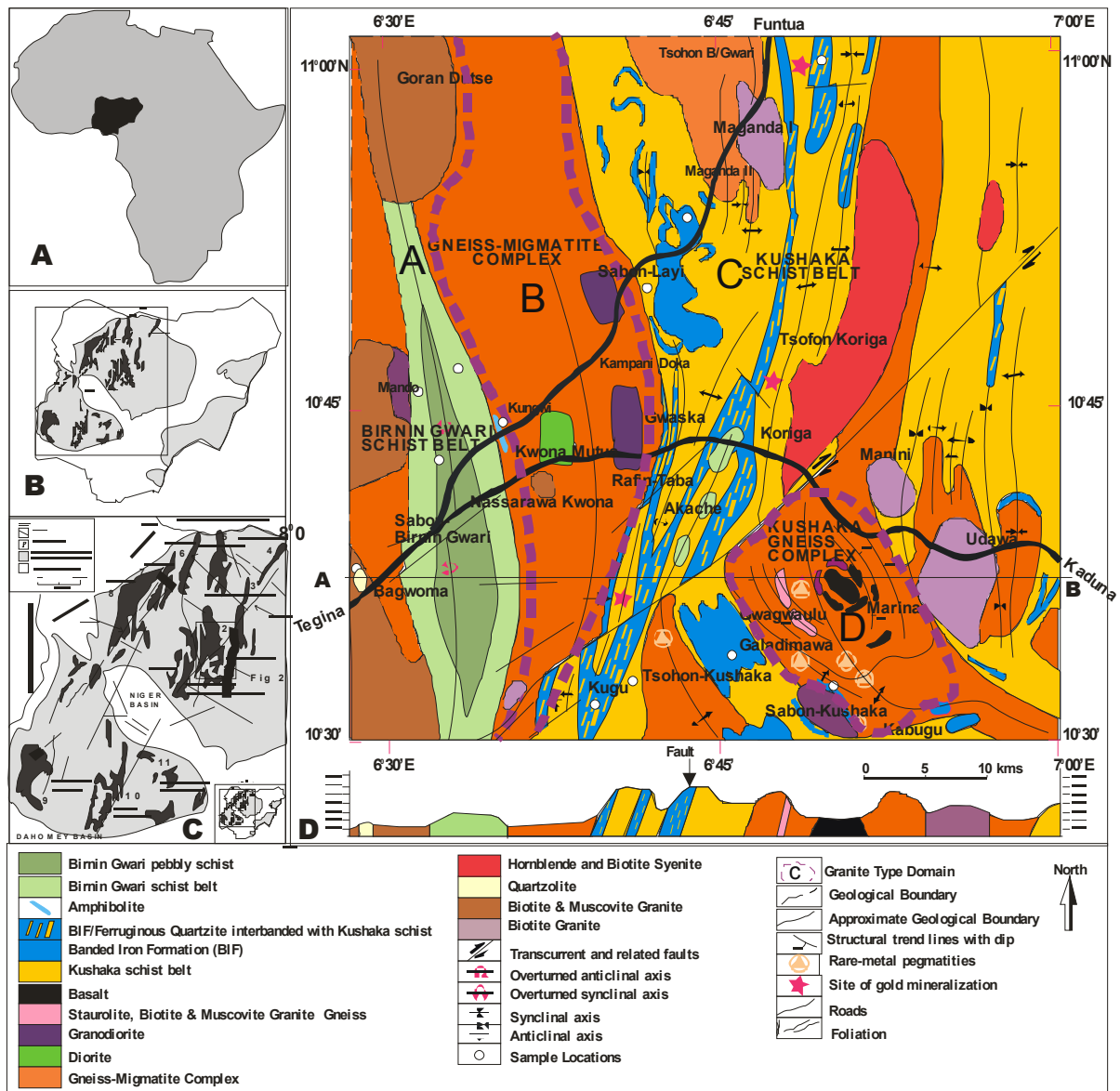


Fig. 1: Geological map of northern part of Kushaka and Birnin Gwari schist belts (Sheet 122) Modified after Truswell and Cope, (1963).

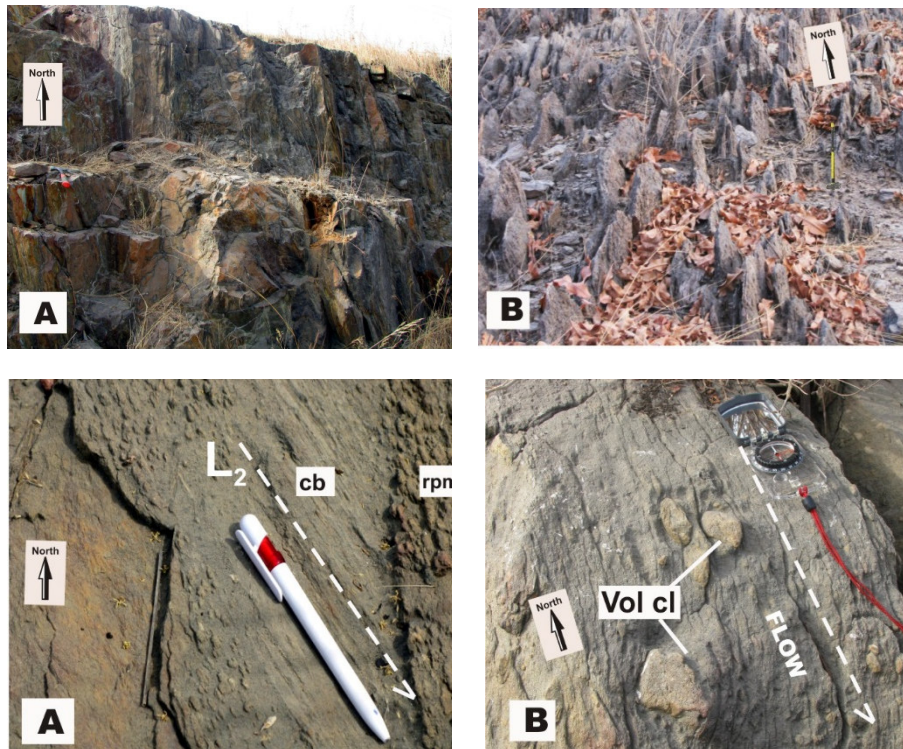


Fig. 2: Field occurrence of (A): Greyish Sabo-Layi biotite schist (N10° 49' 38" E 6° 42' 02") in Kushaka schist belt (B): Ferruginous quartzite outcrop in Maganda with vertical dips and well defined schistosity (N10° 58' 18" E 6° 47' 43"). (AB): Birnin Gwari staurolite and biotite, quartz schist with Lithic (angular to rounded clastic quartz, schistose, volcanic and quartzo-feldspathic) sandstones (N10° 42' 48" E 6° 33' 42"). cb=cross bedding; vol cl=volcanic clast; rpm=ripple marks; L₂=lineation.

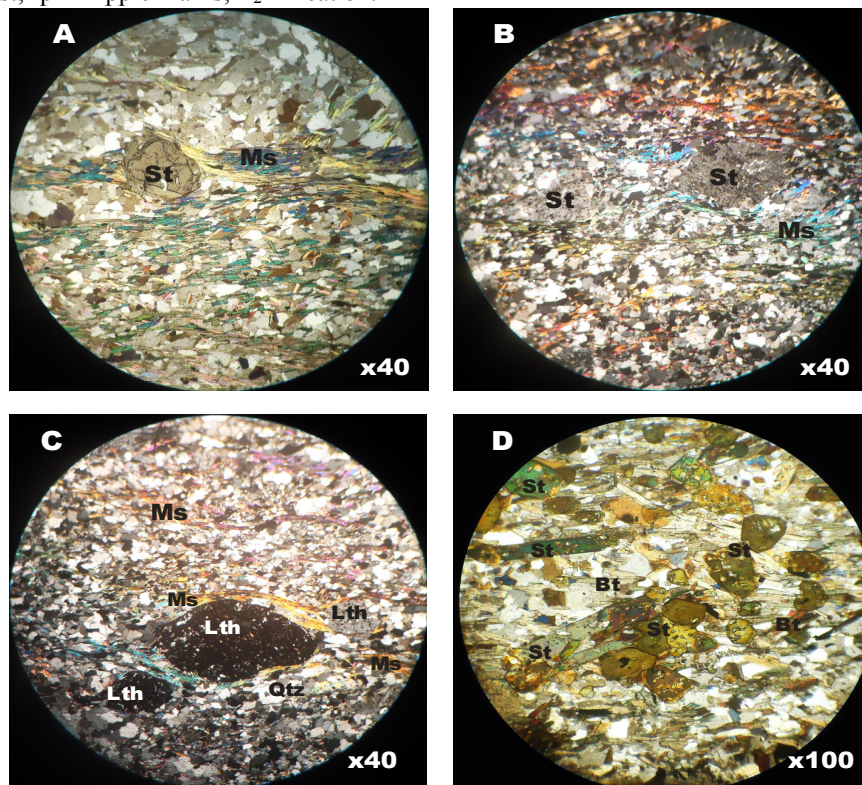


Fig. 3: Photomicrograph of (A&B): Kugu Staurolite and Muscovite Quartz Schist; in the Kushaka Schist Belt and (C): Staurolite-Muscovite Quartz Schist with lithic materials and (D): Staurolite-Biotite Quartz Schist in the Birnin Gwari Schist Belt. St=Staurolite, Ms=Muscovite, Bt=Biotite. Lth=Lithic (angular to rounded clastic quartz, schistose, volcanic and quartzo-feldspathic) sandstones.

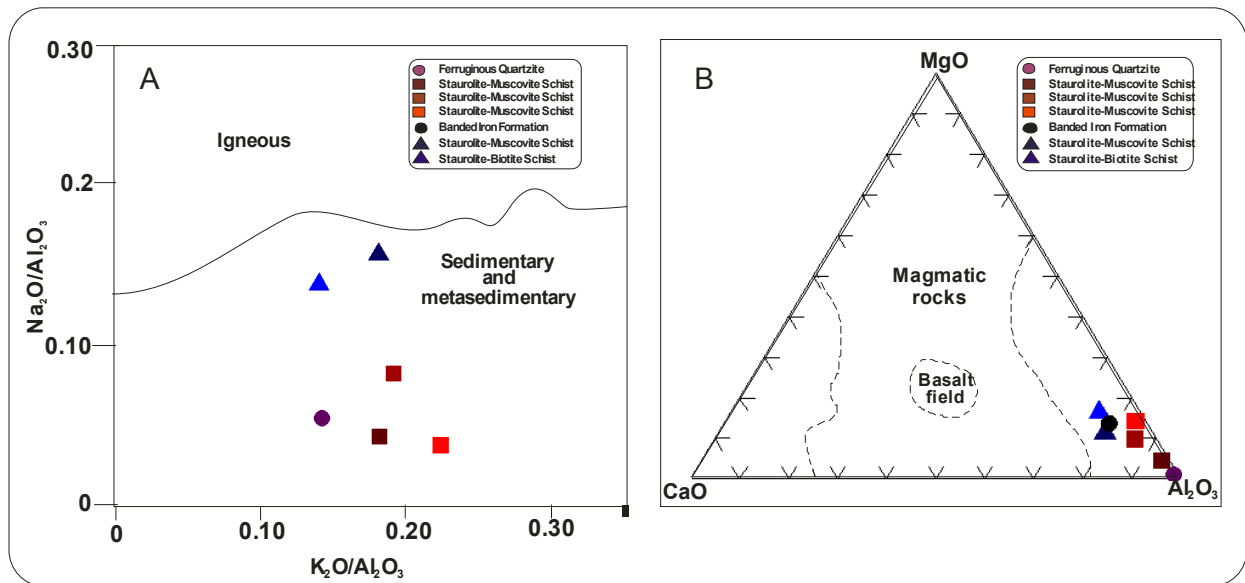


Fig. 4: (A): $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ against $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ plot (after Garrells and Mackenzie, 1971) and $\text{MgO-CaO-Al}_2\text{O}_3$ ternary plot (after Leyleroup et al., 1977) of metasediments in the study area.

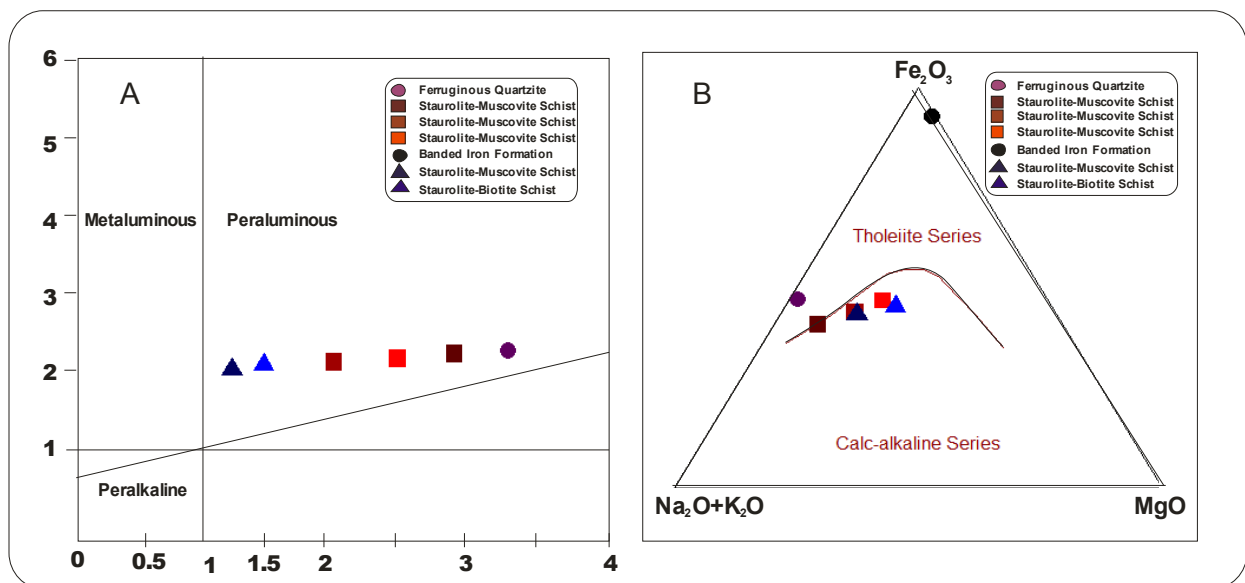


Fig.5: (A): $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ plot of dominantly Peraluminous nature of metasediments (after Maniar and Piccoli, 1989) and (B): AFM plot (after Irvine and Baragar, 1971) of metasediments in the study area.

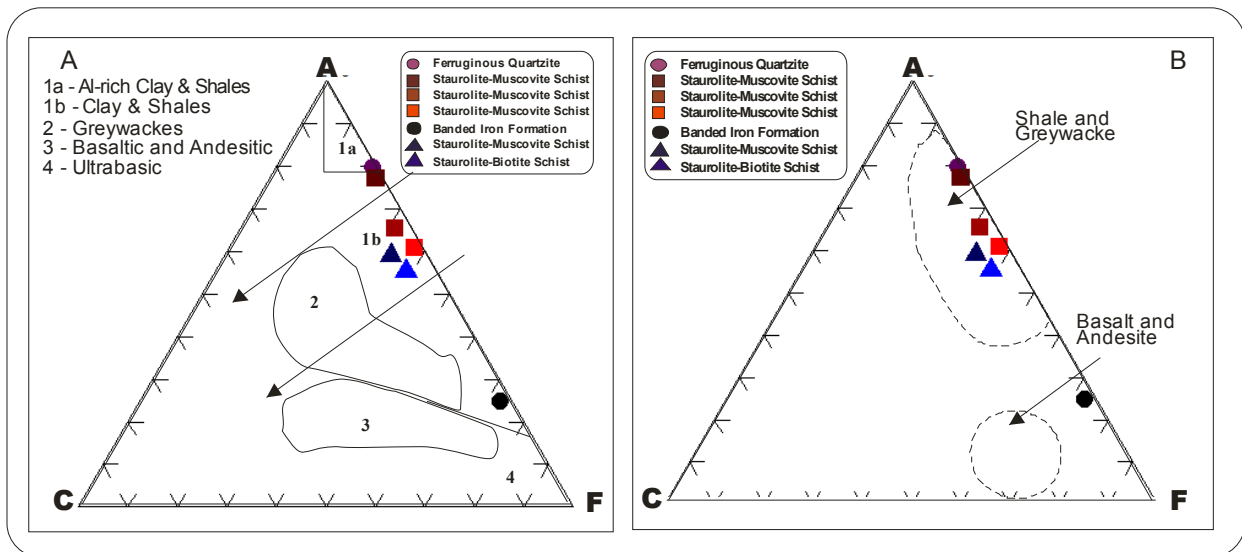


Fig.6: (A): ACF plot (after Winkler, 1967) (1a: Al-rich clays and shales; 1b: clays and shales either free of carbonate, between arrows marks containing 35-65 carbonate; 2: Greywacke; 3: basaltic and andesitic; 4: Ultrabasic) and (B): ACF plot (after Miyashiro, 1973) of metasediments in the study area.

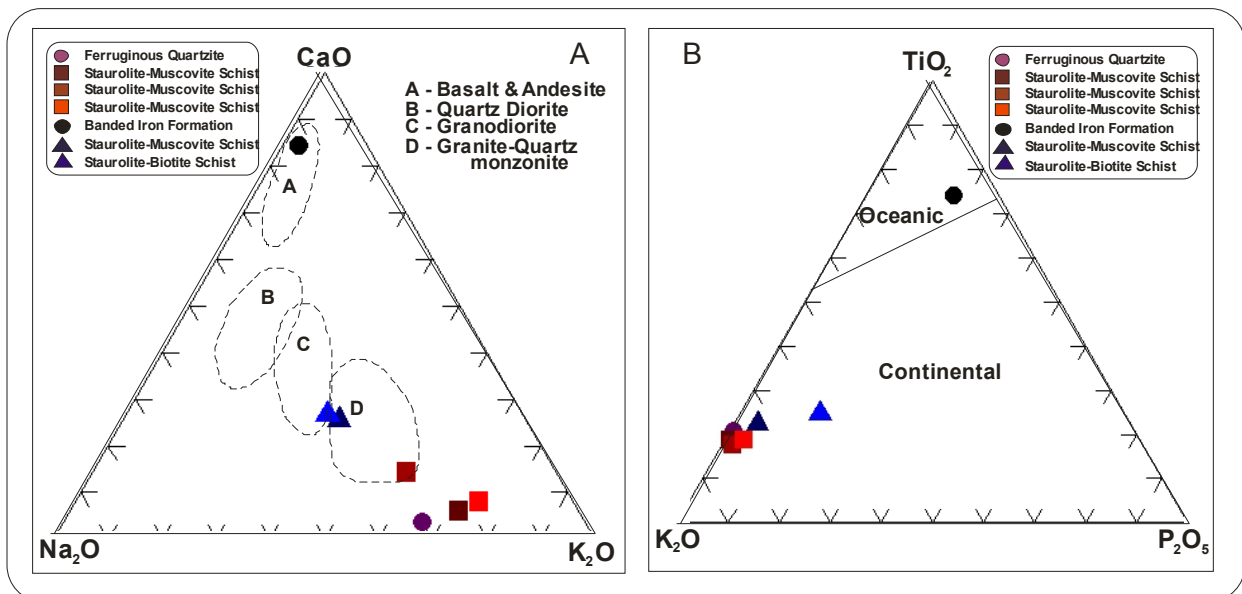


Fig. 7: (A): CaO–Na₂O–K₂O ternary diagram (after Condie, 1967) and TiO₂-K₂O-P₂O₅ ternary plot (after Pearce et al., 1975) of the metasediments in the study area.

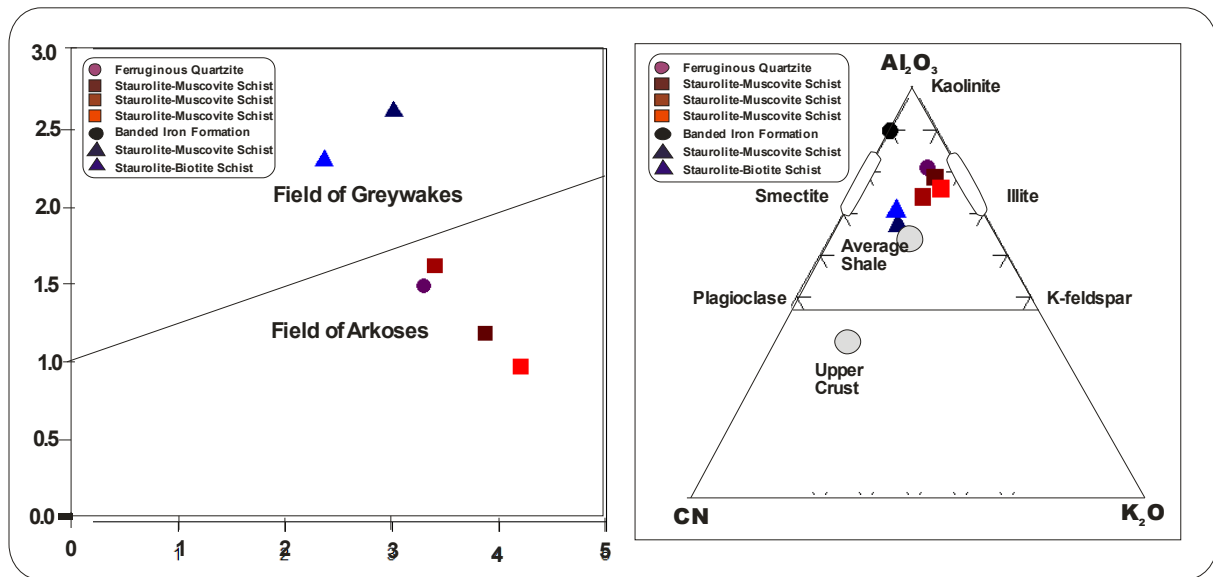


Fig. 8: (A): Na₂O versus K₂O plot of metasediment (after Pettijohn, 1975) and (B): Al₂O₃-CN-K₂O plot (after Pearce et al., 1975) in the study area.

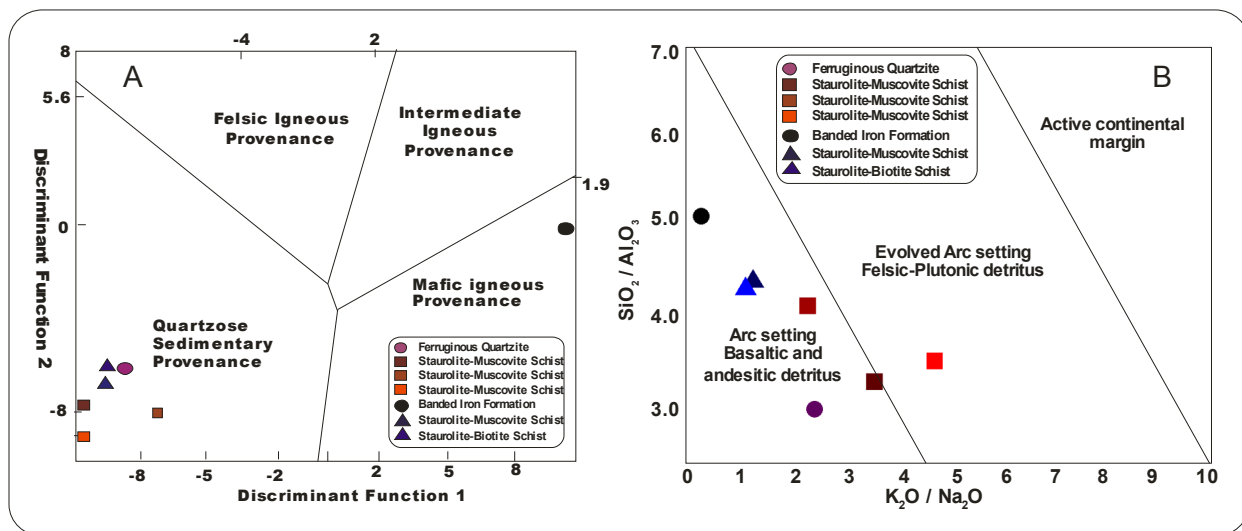


Fig. 9: (A): Discrimination Function diagram for the provenance signatures of sandstone-mudstone suite using major elements (after Roser and Korsch, 1986) and (B): SiO₂/Al₂O₃ versus K₂O/Na₂O plot of metasediments in the study area (after Roser and Korsch, 1986).

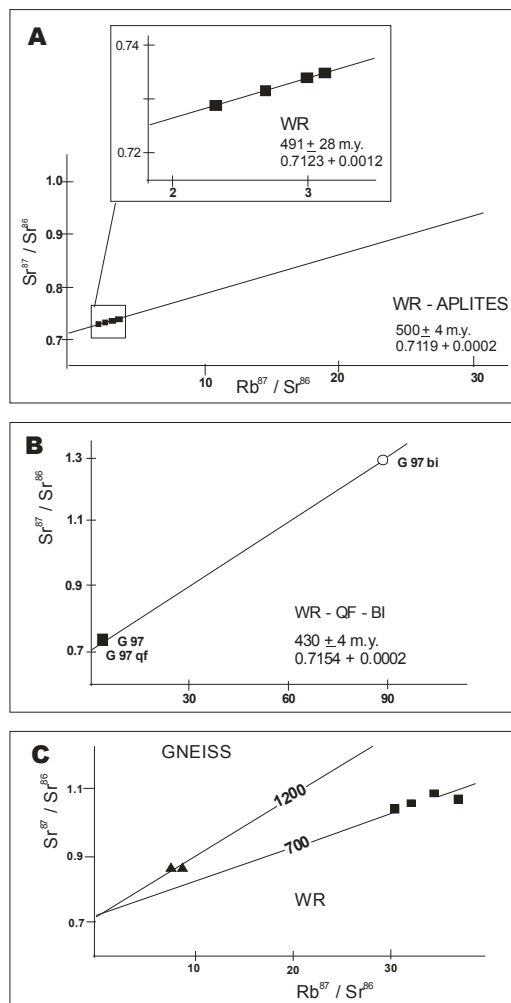


Fig. 10: Rb-Sr whole rock and mineral data (A&B) Kuseriki granite, 20 km west of Birnin Gwari; (C) Granitic augen gneiss, Sabon Gayam, Kushaka (Grant et al., 1972; Grant, 1978).

Table 1: Average Modal Composition of schists and quartzite in parts of Kushaka and Birnin Gwari Schist Belts

Mineral	KKFQ 1	KKSc 1	KKSc 2	KKSc 3	KBGSc 1	KBGSc 2
Quartz	35	30	30	30	30	20
Plagioclase	10	5	10	5		5
K-feldspar	35	20	35	25	20	30
Staurolite		30		15	30	25
Biotite	5		20			10
Muscovite		10		15	10	
Iron-oxide	10	5	5	5	5	5
Accessory	5			5	5	5
Total	100	100	100	100	100	100

Table 2: Major elements (wt %) abundance in the schists, quartzite and BIF in parts of Kushaka and Birnin Gwari Schist Belts

Sample (%)	KKFQ 1 Ferru Q/tzite	KKSc 1 Schist	KKSc 2 Schist	KKSc 3 Schist	KBGSc 1 Schist	KBGS 2 Schist	KKBIF BIF
SiO ₂	62.61	64.2	65.99	61.23	65.13	63.03	50.98
TiO ₂	0.87	0.9	0.74	1.01	0.92	0.97	0.34
Al ₂ O ₃	20.93	19.72	16.53	17.71	15.4	15.16	10.47
Fe ₂ O ₃	4.92	4.58	6	7.96	6.62	7.3	29.22
MnO	0.08	0.05	0.13	0.07	0.11	0.12	5.19
MgO	0.18	0.93	1.87	2.97	2.17	3.31	1.82
CaO	0.17	0.32	0.84	0.45	1.93	1.69	1.02
Na ₂ O	1.49	1.19	1.62	0.98	2.6	2.29	0.15
K ₂ O	3.3	3.87	3.4	4.2	3.01	2.36	0.04
P ₂ O ₅	0.03	0.05	0.09	0.2	0.19	0.62	0.08
LOI	4.11	3.78	1.98	2.73	1.25	1.03	0.18
Total	98.69	99.59	99.19	99.51	99.33	97.88	99.49

Table 3: Trace elements (ppm) abundance in the schists, quartzite and BIF in parts of Kushaka and Birnin Gwari Schist Belts

Sample	KKFQ 1	KKSc 1	KKSc 2	KKSc 3	KBGSc 1	KBGS 2	KKBIF
	Kushaka				Birnin Gwari		Kushaka
	Ferruginous Quartzite	Biotite Schist	Biotite Schist	Biotite Schist	Staurolite Schist	Staurolite Muscovite Schist	BIF
As	4.2	3.5	1	1.5	<1	<1	5.6
Ba	670.7	729.8	599	974.8	32.2	27.6	21.2
Ce	39.9	61.4	57.4	37.7	<1	6.2	10.9
Co	30.1	25.2	34	32.1	0.7	0.3	1.2
Cr	122	123.2	85.9	122.4	23.7	7.9	15.9
Cu	23.9	12.2	21.2	15.9	210.8	210.6	219.2
Ga	27.3	24.2	22.5	22.3	3.3	3.8	3.8
La	13.9	44.3	36.9	23.1	9.1	16.4	<1
Mo	0.7	0.2	0	<1	<1	<1	<1
Nb	15.2	14.9	13.4	12.1	<1	<1	<1
Nd	7.7	24.6	22.4	21.8	<1	18.7	11.5
Ni	6.5	1.5	17.8	54.7	2.1	1.8	2.1
Pb	30.3	28.1	21.3	14.3	27.5	31.1	31
Rb	150.5	163.7	153.6	116	14.4	13.5	13.2
Sc	22.2	20.7	17.1	24.9	<1	2.6	<1
Sn	5.8	7.7	6.6	7.1	27.1	35.9	35.3
Sr	111.6	99.2	127.9	108.3	557.6	134	129.1
Ta	0	0.7	0.3	<1	<1	<1	<1
Th	16.5	17.2	12.3	9.2	<1	<1	<1
U	1.2	2.8	2.6	2.7	6.4	1.1	1
V	114.7	107.8	106.1	149	0.4	<1	7.1
W	164.3	126.2	148.9	58.9	<1	<1	<1
Y	16.2	22.2	20	31.9	2.9	3.6	4
Zn	32.5	45.6	85.9	109.1	32.7	41.9	44.6
Zr	187.3	205.9	201.7	212.6	35.3	28.3	27.6
CIA	80.84	78.56	73.36	75.87	67.13	70.51	89.64
!CV	0.52	0.59	0.87	0.99	1.12	1.18	3.11