PETROGRAPHY AND GEOCHEMISTRY OF TURONIAN EZE-AKU SANDSTONE RIDGES, LOWER BENUE TROUGH, NIGERIA IMPLICATION FOR PROVENANCE AND TECTONIC SETTINGS.

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ABSTRACT

An integrated petrographic and geochemical study of the Turonian sandstone of Eze-Aku Formation exposed within the southern portion of the Benue trough, was undertaken to infer the sandstone provenance and tectonic setting of the basin. Field observations show that the sandstones, about 30m thick on average, are fairly parallel, linear, northeastsouthwest trending ridges characterized by a coarsening upward sequence. Sandstone facies recognized were bioturbated, cross-stratified and channel sandstones which suggest a shallow shelf environment, generally below wave base. Petrographic studies reveal that these sandstones contain quartz, feldspars, rock fragments and minor amounts of micas. Modal analysis framework grains suggest a subarkosic sandstone. The petrographic characteristics indicate plutonic igneous rocks as the dominant parent rock with minor contribution from metamorphic rocks. Average major elements abundance for this Turonian sandstone are SiO_2 (62.7%), TiO_2 (1.23%), Al_2O_3 (21.99%), Fe_2O_3(6.46%), MnO (0.02%), MgO (1.42%), CaO (0.63%), Na_2O (2.12%) and K_2O (1.46%). Tectonic setting discrimination diagrams based on major elements suggest a continental block provenance in a passive continental margin. As indicated by the CIA (chemical index of alteration) and CIW (chemical index of weathering) of the Eze-aku sandstone (average values of 86 and 89 respectively), their source area underwent intense weathering and recycling in a humid climatic condition. The petrography and geochemistry results are consistent with a humid climate and low-relief highlands. Thus suggesting that the sandstone source is probably from Oban and Cameroon massifs which were situated in a humid climatic setting during the Turonian times.

Keywords: Benue Trough; Eze-Aku Formation; Geochemistry; Petrography

INTRODUCTION

The Benue trough is a linear northeast-southwest trending basin, 800km long and 90km wide on the average, in eastern Nigeria. It is considered to have originated as an aulacogen on the Precambrian shield as a result of the separation of the African and American plates in early Cretaceous times (King, 1950; Olade, 1975). The sequence of events leading to the formation of the Benue trough is well documented (Grant, 1971; Burke *et. al.*, 1972; Nwachuckwu, 1972; Olade, 1975; Offodile, 1976; Wright, 1976, 1981; Petters, 1978; Benkhelil, 1989). The Benue trough is arbitrarily subdivided into Upper, Middle and Lower parts (Obaje *et. al.*, 2004). No concrete line can be drawn to demarcate the individual portions, but major localities (towns/settlements) that constitute the depocenters of the different portions have been well documented (Petters, 1978; Nwajide, 1990; Idowu and Ekweozor, 1993). The Lower Benue trough is the southernmost of the three main Cretaceous downwarps forming the Benue trough and has a lateral extent of about 250km.

The Turonian Eze-Aku Formation of the Lower Benue trough is dominated by shales (Reyment, 1965). However, in the southeastern part of the trough, there are a number of northeast-southwest trending sand bodies forming prominent sandstone ridges and are parallel to the axis of the trough (Amajor, 1987). Previous studies of the sandstones have concentrated on stratigraphy and petrography (Reyment, 1965; Banerjee, 1980; Amajor, 1987). The work of Reyment (1965) suggested that Eze-Aku sandstones were deposited in a shallow marine environment and possibly a tidal deposit (Banerjee, 1980). Amajor (1987) argued that Eze-Aku sandstone is storm-dominated, not tide-dominated based on facies analysis of the sandstone. Hoque (1977) and Amajor (1985) considered the sand bodies to be texturally and compositionally immature feldspathic arenites based on petrographic studies.

The combination of petrograpic and geochemical data of sedimentary rocks can reveal the nature, source regions, tectonic setting and paleoclimatic conditions of sedimentary basins (Dickinson and Suczek, 1979; Valloni and Mezzardi, 1984; Bhatia and Crook, 1986; McLennan *et. al.,* 1993; Armstrong-Altrin *et. al.,* 2004). The main assumption behind sandstone provenance studies is that different tectonic settings contain their own rock types, which when eroded, produce sandstones with specific compositional ranges (Dickinson and Suczek, 1979; Dickinson *et. al.,* 1983; Dickinson, 1985). The determination of tectonic setting of sandstones using the framework mineral composition (detrital modes) was first proposed by Crook (1974) and has since then undergone considerable refinement (Dickinson and Suczek, 1979; Dickinson *et al.,* 1983; Weltje, 2002; Basu, 2003).

Geochemical analysis is also a valuable tool in the study of sandstones (McLennan *et al.,* 1993). Major element discrimination diagrams (Bhatia, 1983) have been used to discriminate the tectonic setting of sedimentary basins (Krooneneberg, 1994; Zimmermann and Bahlburg, 2003; Armstrong-Altrin *et al.,* 2004), although, caution is required in their indiscriminate use (Armstrong-Altrin and Verma, 2005). In this study, we present new petrograpic and geochemical data which were utilized for reconstructing the parent rock assemblages of the Eze-Aku sandstones, their provenance and physiographic conditions of deposition.

GEOLOGICAL SETTING

In the study area, Precambrian Basement rocks, known as the Oban and Cameroon massifs, lie to the east and comprise mostly granites, granodiorites, gneisses, schist, migmatites, phylites and metaconglomerates. Quartizite intrusions are of secondary occurrence (Rahaman *et al.,* 1981).

The earliest sediments in the Benue trough were Aptian-Albian pyroclastics which consist of intraconglomerates, sandstones and shales of fluvial origin and basaltic rocks which rest unconformably on the basement rocks (Uzuakpunwa, 1974; Hoque, 1977; Olade, 1978; Ehijinwa, 1984). These formed the basal unit of the Albian- Cenomanian depositional sequence (Petters, 1978) and were overlain by sediments of Asu River group. The common practice in the area is to classify these rocks together with the overlying mid-Albian Asu River Group because they are lithologically similar (Amajor, 1990).

The mid Albian marine strata of the Asu River Group in turn unconformably overlie these basal rocks (Fig. 1). These represent sediments of the first marine transgression into the trough (Reyment, 1965). Lithologically, the Asu River Group consists of micaceous sandstones, mudstones, sandy shales and shales with sandstone and limestone lenses.

The Asu River Group is unconformably overlain by Turonian Eze-Aku Formation. This formation represents sediments of the second marine depositional cycle in the trough (Reyment, 1965; Nwachukwu, 1972; Amajor, 1985). In the study area, the unit consists essentially of northeast-southwest trending sandstone ridges which vary in thickness from 10 to 50m. The inter-ridge lows are occupied by marine shales and limestone lenses in places.

Both the Asu River Group and the Eze-Aku Formation are structurally deformed by the Santonian tectonic event. However, the Asu River Group is more intensely deformed in some places, a consequence of the mid Cenomanian deformational event (Nwachukwu, 1972; Amajor, 1985).

MATERIALS AND METHODS

The sandstone ridges outcropping in places like Abini quarry, Adim, Ugep, Ekuri, Adadama, Ibalebo, Itigidi and Imina cave (Fig. 1) were studied and described. Twenty-eight thin sections were prepared from the samples collected. These were studied under a transmitted light petrographic microscope, with an average of 900 point counts per thin section. To characterize detrital modes, a quantitative petrographic analysis was performed on thin sections after the method of Blatt (1992). Chert and polycrystalline quartz grains were plotted as rock fragment. Recalculated modal analysis data from the point-counting of the framework grains are listed in Table1. Petrographic classification was done using quartz (Q), rock fragment (RF) and feldspar (F), after Dott (1964) and Leeder (1982).

Chemical analyses (major elements) of thirty samples were performed by Inductively Coupled Plasma Mass Spectrometry technique (ICP-MS) with a detection limit of 0.01% and precision of +/- 0.1% at Acme Laboratory Limited, Vancouver, Canada. Samples were selectively digested by treatment with Aqua Regia. The samples were normally treated with the acid at 80-95^{0}C between one to three hours.

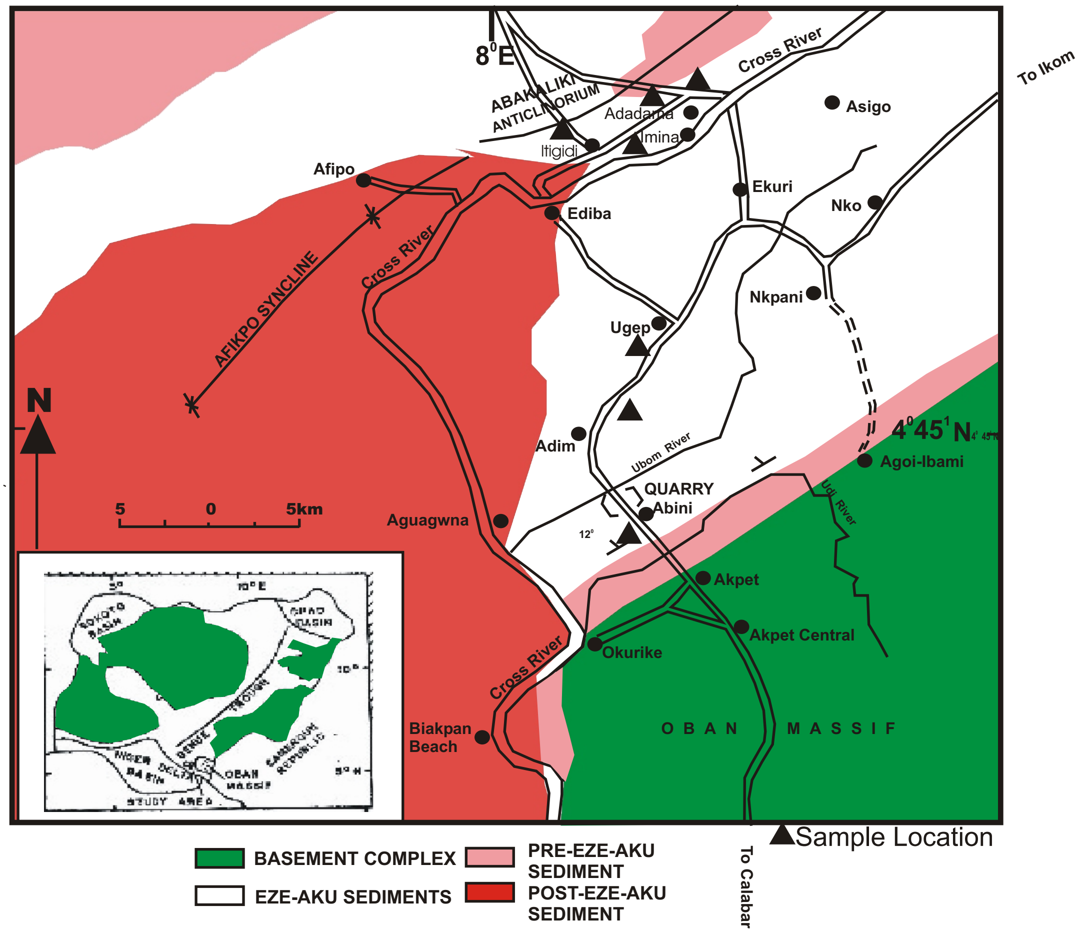


Fig 1: Sketch Of Geological Map of Parts of Southern Benue Trough Showing Study Location (Modified After Akpan and Nyong, 1987)

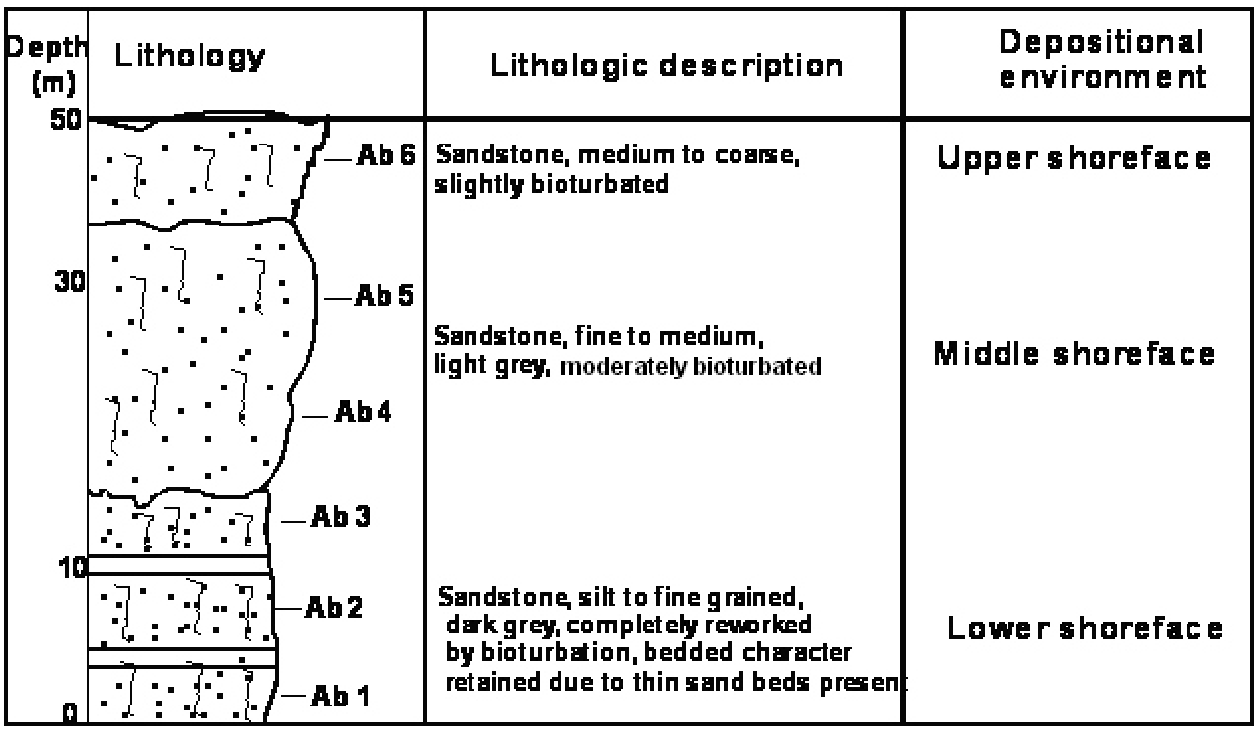


Fig. 2: Lithologic Succession of the Exposed Outcrop at Abini Quarry

RESULT AND DISCUSION

Lithostratigraphy

Based on field observations, the bulk textural character of Eze-Aku sandstone comprises a coarsening upward grain size gradient, which ranges from fine to very coarse sandstone. Cement is dominantly calcite and bioturbation is ubiquitous. Despite the textural and compositional homogeneity of these sandstone units, distinct assemblages of sedimentary structures and lithology allow subdivision into three lithlogic facies.

Facies 1: Bioturbated Sandstone

This facies re-occurs intermittently within the area of study. At Abini quarry, the degree of bioturbation is generally high and the trace fossils are preserved between and within the beds. Generally, the sandstone displays a coarsening upward sequence (Fig. 2). The section begins with fine to medium-grained, fairly sorted, burrowed, calcareous sandstone, with relict bedding and this passes into intensely burrowed calcareous sandstone that coarsens upward, with reduced bioturbation at the top. The facies also reoccurs within sandstone ridge exposed at Adadama. The trace fossils encountered include horizontal burrows, horizontal crawling trails and flat impressions. Akpan and Nyong (1987) argued that these horizontal traces represent the Cruziana ichnofacies, which is characteristic of a shallow sublittoral marine environment generally below wave base, where low bottom energy and slow rate of sedimentation enhance preservation of traces.

Facies II: Cross-stratified Sandstone

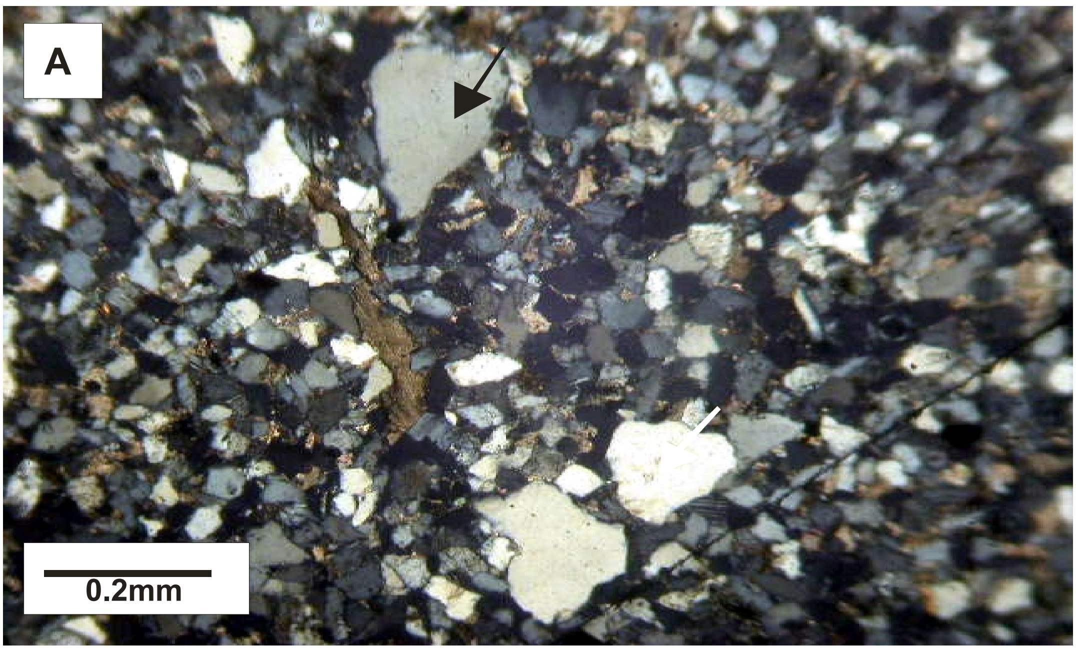
This unit consists of medium to coarse grained sandstone. It was observed at Imina cave and New bridge site through Itigidi. Medium scale, low angle planar cross-stratified set are the dominant structures. The cross stratification suggests that sand was probably shifted up ridge flanks and onto the crestal region in the form of sand-waves by tidal or storm generated currents (Swift *et. al.*, 1978). The above interpretation coupled with the lithologic and stratigraphic position of this unit in the sequence suggests deposition at shallow marine environment by relatively strong currents and fair weather processes (Stubblefield *et. al.*, 1975).

Facies III: Channel Sandstone

This unit was observed only at Ekuri beach where it has been extensively weathered. The unit comprises a 60 cm thick fining upward, coarse to fine sands. This unit at the upper part consists of ill-defined small-scale trough cross laminations. Amajor (1987), also observed such channel sandstone and based on the underlying facies; he suggested storm surge currents for the genesis of the channel sandstone facies.

Detrital Framework Components and Classification

The detrital framework grains of the Eze-Aku sandstone include quartz, feldspars, rock fragments, micas and accessory heavy minerals. Quartz is the dominating framework grain in the studied thin sections (Table 1). The percentage range of quartz is 61 to 87%. The monocrystalline and polycrystalline grains have straight to strongly-undulose extinction (Fig. 3A). However, the polycrystalline quartz has curved to sutured



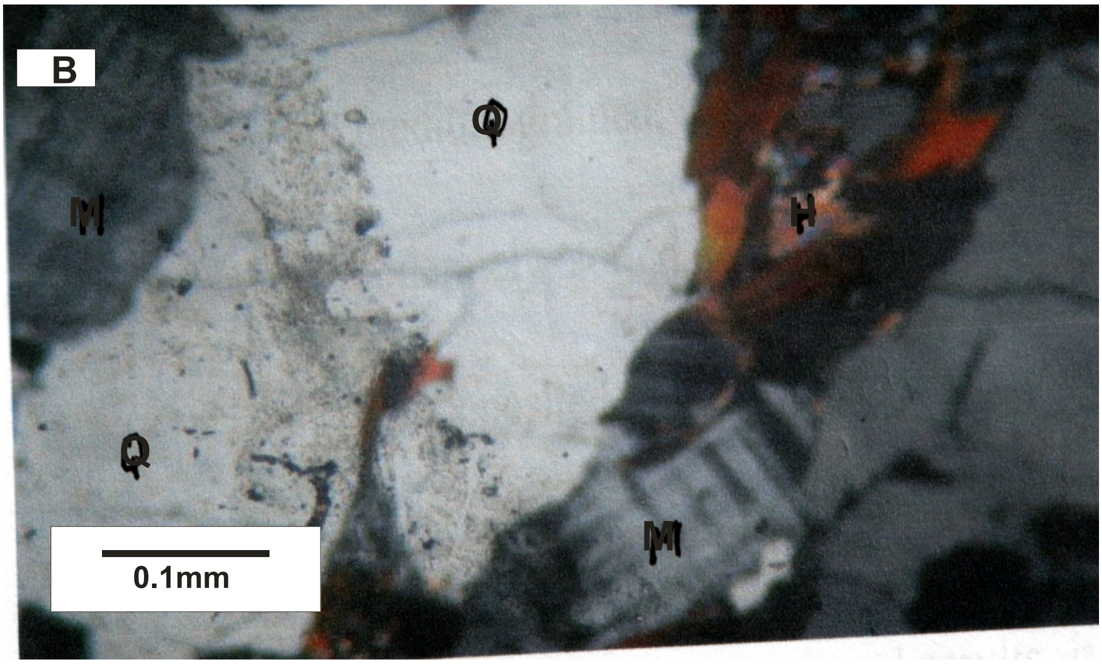


Fig. 3: A: Photomicrograph Showing Quartz Grains with Undulose Extinction (black Arrow) and Straight Extinction (white Arrow); B: Photomicrograph under a Cross Nicols Light Showing Quartz (q), Microcline Feldspar (m), and Heavy Minerals (h)

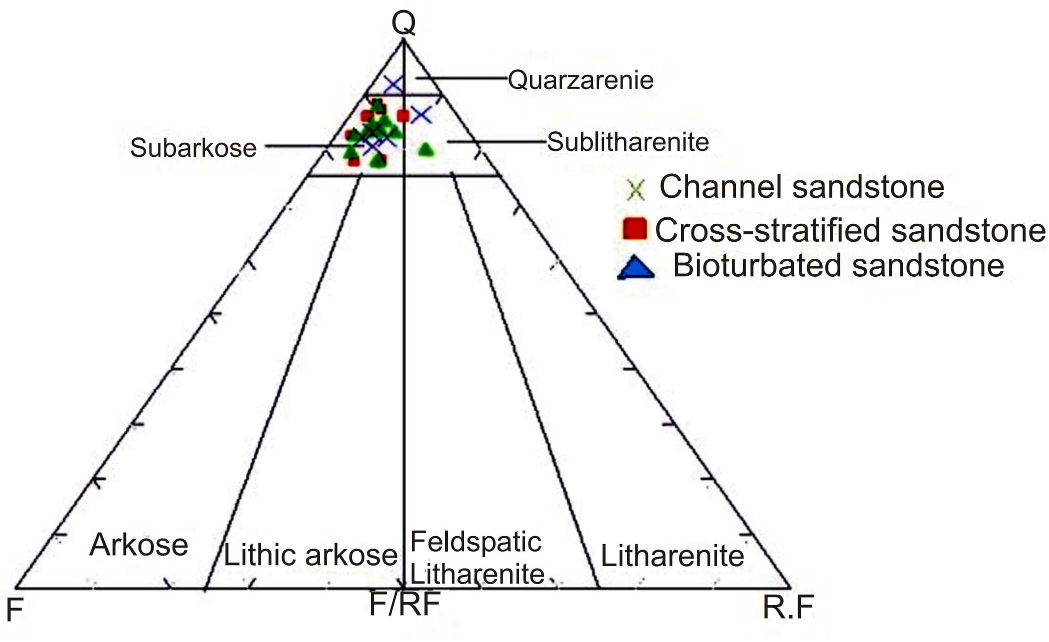


Fig. 4: QFR Triangular Classification Plot (Folk, 1974) for the Eze-Aku Sandstone Samples.

intra-grain boundaries. The quartz grains are angular to subrounded, are not morphologically elongated or flattened and do not show parallel crystallographic orientation. The ratio of monocrystalline quartz grain is higher.

Feldspar constitutes 4 to 15% of the detrital grains of the sand bodies. Microcline dominates with the characteristic grid twinning (Fig. 3B). Most of the feldspar grains were extensively altered. Occurrence of extensively weathered feldspar suggests a low source relief, short transport distance and slow sedimentation.

Rock fragments generally constitute a minor proportion of the detrital fraction. The range is from 2- 11 %. Quartz-poor lithic fragments are most abundant. Specific types are shale, carbonate and mudstone. Siltstone, igneous and metamorphic rock fragments are rare. In addition, where they occur, the minerals in the rock fragments are usually altered.

Both biotite and muscovite are present in minor amounts with biotite being more common. Here the biotite flakes usually are bent and commonly altered to chlorite. The observed non-opaque minerals are garnet, zircon and apatite.

Matrix is between 4 to 8% of the detrital fraction, and more common in very fine to fine sandstone samples. Cement constitutes a significant proportion of some of the samples ranging from 1 to 10%. Calcite, silica and iron oxide constitute the cement in order of abundance. From the high matrix content (>5%), the subangular to subrounded grains and moderately sorting, Eze-Aku sandstone is texturally submature (Folk, 1951).

From the recalculated framework composition of quartz, feldspars and rock fragments, a ternary plot (QFR) for classification of the sandstone was constructed after Folk (1974)(Fig. 4). Ninety-nine percent of the samples plotted in the subarkose field; the sandstones are therefore classified as subarkosic sandstones.

Geochemistry

Table 2 gives the abundance of the major elements analyzed. The result shows a slight variation in element composition of all the samples reflecting the homogeneity of the sediment suite and indicating constancy of provenance and sedimentary environment of the rock. Variations in the chemical composition reflect changes in the mineralogical composition of the sediment, especially in the quartz-feldspar ratio. SiO_2 abundance ranges from 57.3 69.8% with an average of 62.7%; TiO_2 ranges from 0.09 2.32%; Al_2O_3 ranges from 19.6 23.94%; Fe_2O_3 ranges from 3.8 9.8%; MnO abundance ranges from 0.01 0.57%; MgO ranges from 0.05 4.12%; CaO ranges from 0.02 to 2.45%; Na_2O ranges from 0.15 to 5.38% and K_2O ranges from 0.55 to 2.99%. In comparison with the upper continental crust (Taylor and McLennan, 1981) which provides a consistent normalizing scheme for sandstone geochemistry (Zimmermann and Bahlburg, 2003), Eze-Aku sandstone is enriched in SiO_2, TiO_2, Al_2O_3, Fe_2O_3 and deplected in K_2O, MnO, Na_2O, MgO, CaO. Mineralogical studies revealed that SiO_2 is mainly present as quartz (fine, medium and coarse grained) and Al is mainly held in the clay mineral lattice as an essential constituent.

The Pearson's correlation analysis performed on the major elements abundance shows a negative correlation of SiO_2 with Al_2O_3, K_2O and Na_2O which suggests that aluminosillicates and feldspar do not contribute much SiO_2 to the sandstone. Positive correlation of TiO_2 with SiO_2, Na_2O, K_2O and Fe_2O_3 suggests that TiO_2 content of the sandstone mainly comes from the detrital minerals and hence could be inherited from the source. The opaque (Ilmenite-$FeTiO_3$) and non-opaque (Rutile- TiO_2) are important Ti bearing minerals in the sandstone. A strong positive correlation of SiO_2 and TiO_2 at 95% confidence level further confirms the primary source for Ti. Positive correlation of Na_2O with K_2O at 95% confidence level further confirms the dominance of alkali feldspar and the negative correlation of Na_2O with CaO suggests that Ca distribution in the sandstone is not associated with feldspars.

Parent Rock Lithology

The abundance of feldspar minerals and the preponderance of these over lithic fragments in these sandstones are suggestive of a primary rather than reworked source (Pettijohn *et al.,* 1987). The absence of volcanic rock fragments and quartz containing inclusion in the samples studied indicate a non-volcanic source (Moorehouse, 1959). The presence of polycrystalline quartz that are not elongated or flattened and of nearly equant grains with sutured intercrystalline boundaries; non- undulose quartz extinction; abundant twinned feldspar and zircon favour a plutonic igneous granitoid source as the dominant source rock (Pettijohn *et al.*, 1987; Folk, 1974; Blatt *et al.*, 1980; Basu, 1985). Moreover, the presence of monocrystalline quartz with strong

Table 1: Petrographic Analysis Data

Sample No	Quartz %	Feldspar %	*R.F. %	Mica %	Matrix %	Cement %	*H.M. %
Ab/ 1	73	10	4	-	5	7	1
Ab/ 2	77	8	2	-	5	7	0.5
Ab/ 3	75	6	6	-	2	10	1
Ab/ 4	67.5	20	5	-	8	10	0.5
Ab/ 5	74	10	2	1	5	7	1
Ab/ 6	75	10	2	1	5	7	-
Ad/ 7	71	11	3	5	7	1	3
Ad/ 8	74	10	4	1	5	5	1
Ad/ 9	76	8	3	1	5	5	2
Ad/ 10	68	12	7	2	5	5	1
Ad/ 11	80.8	15	2	0.2	4	7	1
Ib/ 12	61	11	6	2	8	10	2
Ib/ 13	73	10	3	1	5	5	1
Ib/ 14	70.5	8	6	1	5	7	0.5
Ib/ 15	69	6	11	3	5	5	1
IG/ 16	67	12	2	0.5	6	10	0.5
IG/ 17	71	8	4	1	6	5	1
UG/ 18	70.5	15	3	-	5	6	0.5
UG/ 19	71	11	3	2	5	5	2
UG/ 20	71.7	10	4	1	6	5	0.3
UG/ 21	69	10	3	2	8	7	1
UG/ 22	76	8	2	1	7	5	1
Nb/ 23	72.8	11	3	1	7	5	0.2
Nb/ 24	70	12	3	1	8	5	1
Nb/ 25	70	12	5	1	6	5	1
Nb/ 26	86.5	12	4	-	5	7	0.5
Nb/ 27	69	4	2	5	10	8	2
Nb/ 28	76	4	8	1	5	5	1

*H.M. = Heavy Mineral; *R.F. = Rock Frag

Table 2: Major Elements Composition (Expressed in Percentage)

Sample No	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Fe_2O_3 + MgO	Al_2O_3/ SiO_2	K_2O/ Na_2O	Al_2O_3/ (CaO+ Na_2O)
Ab/ 1	59.4	1	19.8	9.6	0.03	1.5	0.05	5.35	2.99	11.03	0.3	0.56	3.67
Ab/ 2	57.5	-	22.8	6.2	0.03	1.4	0.75	1.28	0.69	7.58	0.4	0.54	11.23
Ab/ 3	59.4	-	23.8	3.8	0.02	1.4	0.72	1.34	0.55	5.22	0.4	0.41	11.57
Ab/ 4	67.2	1.2	20.2	5.6	0.01	0.1	0.93	1.03	1.95	5.65	0.3	1.89	10.33
Ab/ 5	59.9	0.9	22.8	8.7	0.01	2.6	1.72	2.43	2.01	11.27	0.4	0.83	5.5
Ab/ 6	59.4	-	23.8	3.8	0.02	1.4	0.72	1.34	0.55	5.22	0.4	0.41	11.57
Ad/ 7	67.2	1.2	20.2	5.6	0.01	0.1	0.93	1.03	1.95	5.65	0.3	1.89	10.33
Ad/ 8	64.9	2.3	21.9	6.7	0.01	1.3	0.05	1.32	0.58	8.04	0.3	0.44	16
Ad/ 9	58.3	-	23.9	4.8	0.05	2.3	0.75	3.23	2.8	7.14	0.4	0.87	6.02
Ad/ 10	60.8	2.2	21.8	4.9	0.02	0.1	0.05	5.28	2.3	7.16	0.4	0.44	4.09
Ad/ 11	59.8	0.9	22.8	8.7	0.01	2.6	1.75	2.44	2.06	4.98	0.4	0.84	4.65
Ib/ 12	67.3	1.2	20.3	5.7	0.02	0.1	0.95	1.05	1.97	11.24	0.4	1.88	10.13
Ib/ 13	59.4	-	23.9	3.8	0.02	1.4	0.75	1.32	0.59	5.72	0.3	0.45	11.53
Ib/ 14	69.8	1.2	22.6	5.2	0.01	0.7	0.02	0.16	0.66	5.22	0.4	4.13	125.56
Ib/ 15	59.8	0.1	22.8	8.7	0.01	2.6	1.72	2.4	2.25	11.31	0.3	0.94	5.54
IG/ 16	59.4	1	20.3	8.6	0.02	1.5	0.05	5.28	2.83	10.09	0.3	0.54	3.81
IG/ 17	62.9	1.1	19.6	7.5	0.1	0.1	0.05	1.72	0.68	7.58	0.3	0.4	11.09
UG/ 18	67.5	1.1	20.7	6.2	0.02	4.1	0.03	0.65	0.91	10.31	0.4	1.4	30.4
UG/ 19	59.1	0.9	22.8	8.7	-	2.6	0.7	2.5	1.97	11.21	0.3	0.79	7.12
UG/ 20	69.8	1.3	22.6	5.3	-	1.3	0.03	1.35	0.58	6.57	0.3	0.43	16.38
UG/ 21	67.2	1.2	20.2	5.2	0.01	0.1	0.92	1.02	1.93	5.28	0.3	1.89	10.41
UG/ 22	59.8	0.9	22.8	8.2	0.01	2.6	1.73	2.45	1.97	10.78	0.4	0.8	5.45
Nb/ 23	64.9	2.3	21.9	6.8	0.01	1.4	0.05	1.32	0.55	8.1	0.3	0.42	15.99
Nb/ 24	69.8	1.2	22.6	5.1	0.01	0.8	0.02	0.15	0.68	5.81	0.3	4.53	132.8
Nb/ 25	59.4	-	23.9	3.8	0.02	1.4	0.72	1.34	0.56	5.21	0.4	0.42	11.58
Nb/ 26	67.5	1.7	20.7	5.3	-	1.2	2.45	0.68	0.93	6.53	0.3	1.37	6.6
Nb/ 27	59.4	1	19.9	9.6	0.02	1.5	0.05	5.38	2.66	11.08	0.3	0.49	3.67
Nb/ 28	58.7	1.3	21.7	9.8	0.01	2.6	0.07	2.38	1.81	12.44	0.4	0.76	8.87
IM/ 29	60.8	1.2	22.9	5	0.02	0.4	0.05	5.13	1.35	5.42	0.4	0.26	4.42
IM/ 30	64.8	-	23.8	6.8	0.01	1.3	0.05	1.38	0.55	8.14	0.4	0.4	16.67
UCC	65.0	0.6	15.2	5.0	0.08	2.2	4.20	3.90	3.40	7.23	0.2	0.87	1.88

UCC Upper continental crust (Taylor and McLennan, 1981)

Table 3: Semi-quantitative Weathering Index Based on Semi-quantitative Estimates for Climate and Relief (weltije *Et. Al.*, 1998)

Semi-quantitative weathering index (wi = c*r)	Relief (r)		
Climate (c)	High (mountains) 0	Moderate (hills) 1	Low (plains) 2
(Semi) Arid and Mediterranean 0	0	0	0
Temperate subhumid 1	0	1	2
Tropical humid 2	0	2	4

undulose extinction, metamorphic rock fragment and garnet suggest contributions from metamorphic sources.

To evaluate the importance of plutonic and metamorphic rocks as the sandstone sources, the compositional framework grain data was plotted on the Weltje *et al.* (1998) diagram. The Eze-Aku sandstone plots in the arrow-shaped field (Fig. 5) at the lower end, which confirms the plutonic igneous rock as the dominant source with minor input from the metamorphic rock. The effect of source rock on the composition of the Eze-Aku sandstone could also be distinguished by plotting the point count data on Suttner *et al.* (1981) diagram (Fig. 6). This approach also points to both metamorphic and igneous source rocks for these sandstones. The southwesterly, westerly and northwesterly directed paleocurrent modes (Hoque, 1976) suggest the Oban and Cameroon Basement rocks to the east as probably the major sources for this sandstone.

In order to use major elements for provenance interpretations, the discriminant function diagram of Roser and Korsch (1988) was considered, which used Al_2O_3, TiO_2, $Fe_2O_3^t$, MgO, CaO, Na_2O and K_2O contents as variables. In this diagram (Fig. 7), the majority of the sandstone samples plot on the intermediate igneous provenance.

Tectonic Provenance

In the QFR ternary diagram of Dickinson *et. al.*, (1983), the compositional framework grain data plot in the craton interior and recycled orogen fields (Fig. 8). As pointed out by Dickinson *et. al.* (1983), sandstones plotting in the craton interior field are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins. This low relief and short transport distance gave rise to typically quartzo-feldspartic sandstones of classic subarkosic character.

To characterize the tectonic setting of the depositional basin, the major elements geochemistry of Eze-Aku sandstone samples are discussed in terms of ternary plot and discrimination diagrams of Bhatia (1983) and Kroonenberg (1994). These diagrams show that Eze-Aku sandstone was deposited in a passive continental margin (Figs. 9 & 10), analogous to conclusions from petrography.

Source Area Weathering and Climatic Indexes

Petrographic evidences such as the presence of quartz with subangular to

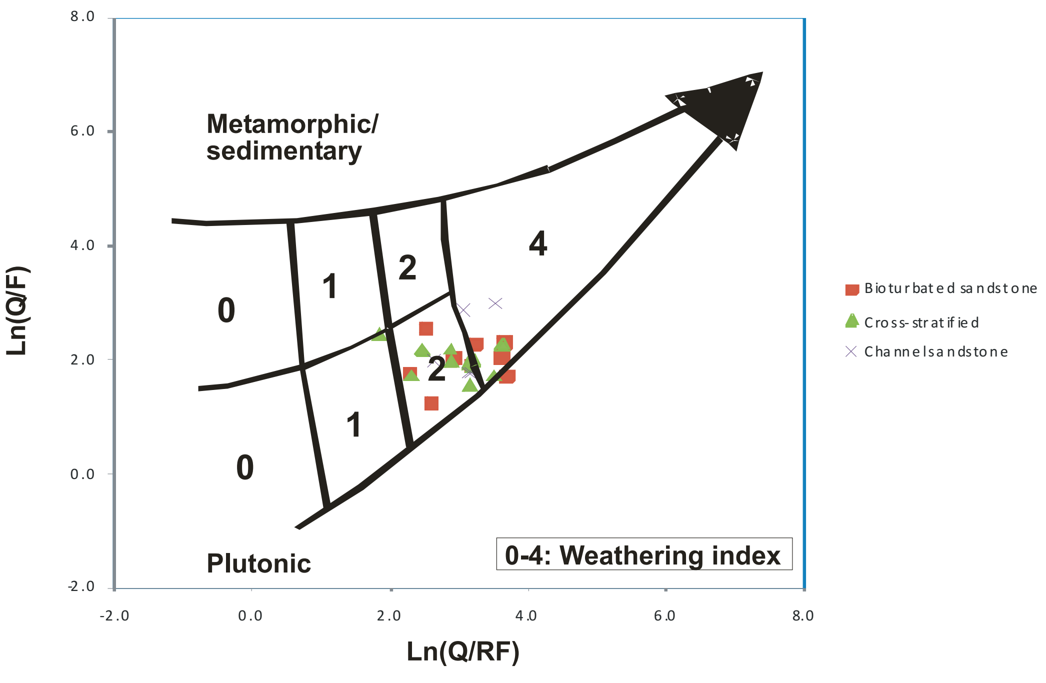


Fig. 5: Log-ratio Plot After Weltje *et al.* (1998). Q: Quartz, F: Feldspar, Rock Fragments. Fields 0,1,2 & 4 Refer to the Semi-quantitative Weathering Indices Defined on the Basis of Relief and Climate as Indicated in Table 3.

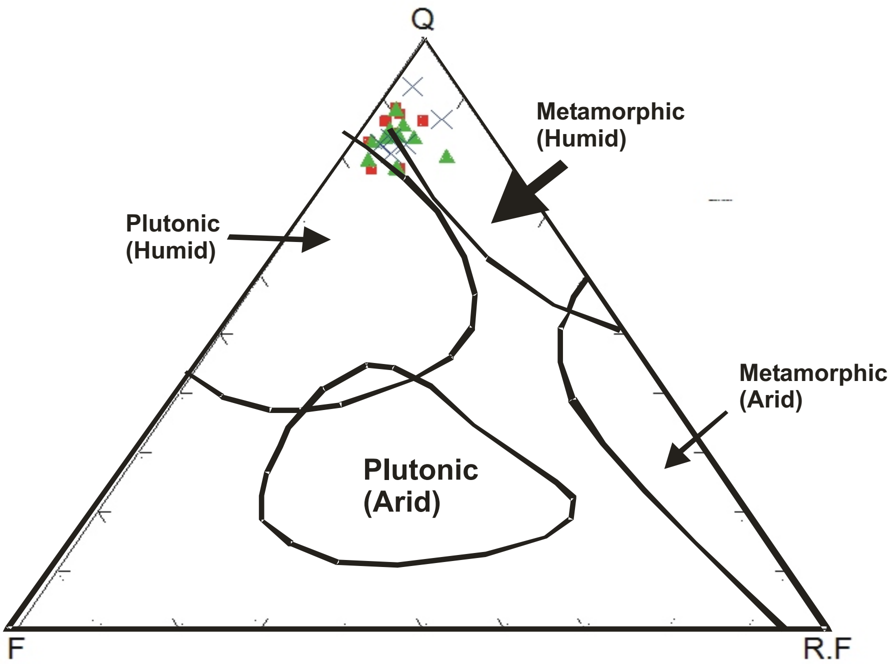


Fig. 6: The Effect of Source Rock on Composition of the Eze-Aku Sandstone using Suttner *et al.* (1981) Diagram

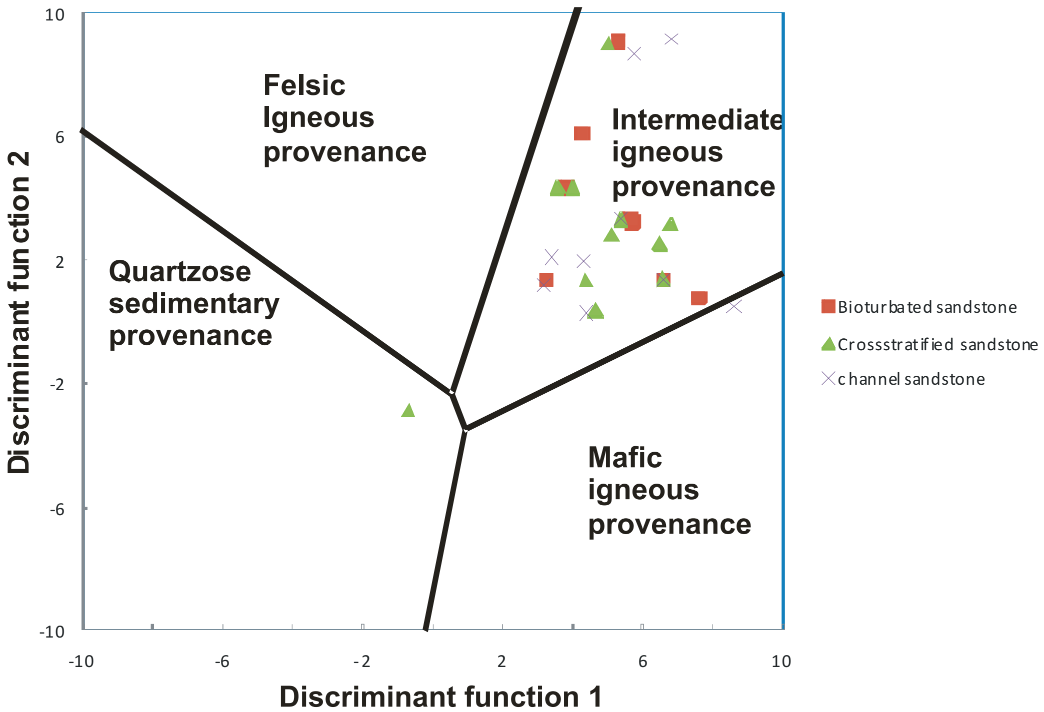


Fig. 7: Discriminant Function Diagram for the Provenance Signatures of the Eze-Aku Sandstone using Major Elements. Boundaries Between Different Fields are Taken from Roser and Korsch (1988).

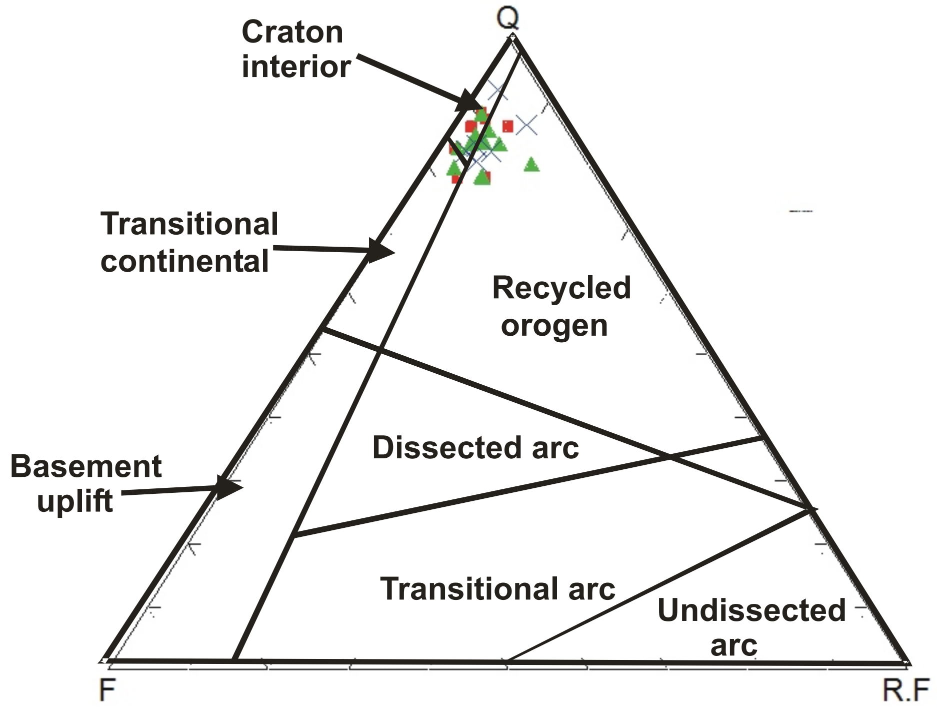


Fig. 8: QtFRF Ternary Diagram for the Eze-Aku Sandstone, after Dickinson *et al.* (1983)

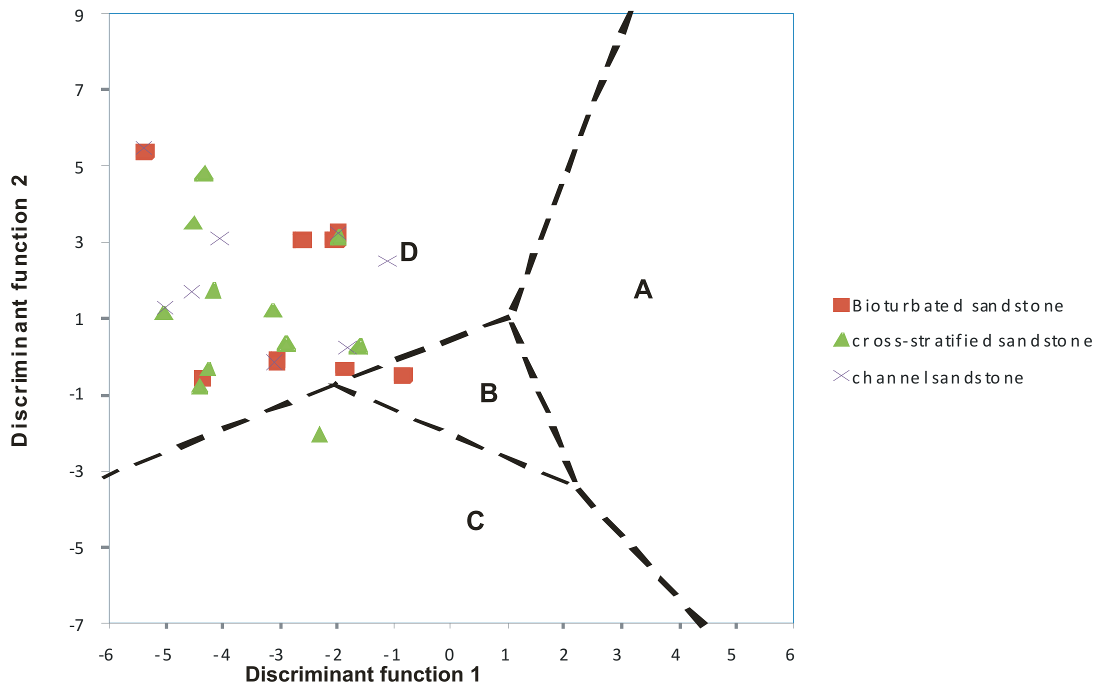


Figure 9: Plots of the Major Elements Compositions of the Eze-Aku Sandstone on the Tectonic Setting Discrimination Diagram of Bhatia (1983). A: Oceanic Island Arc; B: Continental Island Arc; C: Active Continental Margin; D: Passive Margin

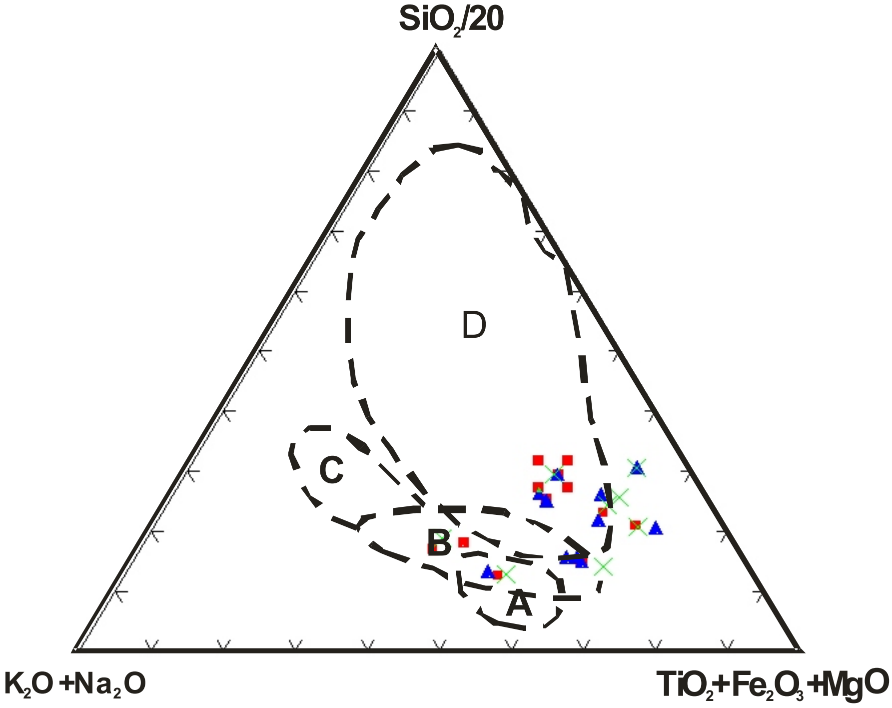


Figure 10: Plot of the Major Element Composition of the Eze-Aku Sandstone on the Tectonic Setting Discrimination Diagram of Kroonenberg (1994). A: Oceanic Island Arc; B: Continental Island Arc; C: Active Continental Margin; D: Passive Margin

subrounded grains and weathered feldspar imply the significance of both mechanical and chemical weathering on the grains of the sandstone. They therefore suggest that the compositional submaturity of these sandstones may be due to short distance transport, relatively low source relief and relatively close provenance which may be related to humid climatic condition.

The compositional framework grain data for the Eze-Aku sandstone samples on Weltje *et. al.* (1998) diagram (Fig. 5), indicate sedimentation in a moderate to low relief, tropical and humid climatic conditions. Also using the Q-F-R ternary diagram of Suttner *et. al.* (1981) to deduce the climatic setting at the time of deposition,the sand bodies plot in the plutonic humid and metamorphic humid fields (Fig. 6). These suggest that the parent rocks were situated in a humid climatic setting during Turonian time.

The chemical index of alteration (CIA), defined by Nesbitt and Young (1982) as 100 x Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_2O) and chemical index of weathering (Harnois, 1988) defined as CIW= Al_2O_3/ (Al_2O_3+CaO+Na_2O) x100, indicate the degree of weathering in sediment source areas, thus reflecting their tectonic setting and prevailing paleoclimatic condition. The Eze-aku sandstone shows a narrow range of both CIA values (82-88) and CIW values (78-99), indicating intense weathering of the sandstone. These values, in general, can be due to either intense recycling in a humid or arid/semiarid climatic conditions (Osae *et. al.*, 2006; Wanas and Andel-Maguid, 2006).

Petrographic evidence, point count and geochemical data as well as the CIA and CIW values are consistent with active recycling in a humid climatic condition for the Eze-aku sandstone. However, more accurate interpretation of climatic conditions of this sandstone will require further investigation such as clay mineral studies.

CONCLUSION

The Turonian sandstone of Eze-Aku Formation is made up of medium grain, moderately sorted, subarkosic sand-bodies that are fairly parallel, linear, northeastsouthwest trending ridges characterized by a coarsening upward textural sequence.

The field relationship shows that the sandstone is deposited in lower foreshore to shallow marine environments probably of storm origin. The sandstone is texturally and mineralogically submature and indicates a relatively short distance of transportation.

The petrographic and geochemical characteristics suggest basement igneous rocks as the main source rock, in addition to minor input from metamorphic rocks. From the foregoing, the sandstone could have been derived from the nearby Oban and the Cameroon massifs, which were under humid climatic setting during the Turonian times. The major elements abundance suggest a passive margin tectonic setting for the Benue Trough.

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