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Geochemistry and Petrographic Analysis of Sandstone Facies of Eze-Aku Formation in Amasiri Area, Lower Benue through Nigeria: Implications for Provenance and Tectonic Setting.

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Abstract

This study was undertaken to determine the provenance and tectonic setting for the sandstones of Eze-Aku Formation in Amasiri area through evaluation and re-appraisal of the petrography and geochemistry of sandstones. Local stratigraphy and field relationship show that the lithologic succession consists of thick sequence of shale alternating with sandstone ridges trending NE-SW direction. Two units were delineated namely: Unit I which is composed of calcareous/ siliceous sandstone and dark grey shale, and Unit II which consists of friable and slightly consolidated pebbly sandstone belonging to Turonian sediments. Analysis and interpretation of the sedimentary structures, mostly cross-beds and structures of quartz grains indicates that the sandstones were derived primarily from granitic Basement complex rocks from the Oban Massif in a humid paleoclimate. Petrographic analysis show that the sandstones essentially contain quartz, feldspar and few rock fragment and are classified as subarkosic sandstone using calculated framework grains. The application of Q-F-RF diagram, suggest plutonic igneous and metamorphic rocks, from the Craton interior, recycled Orogen and transitional continental field as the provenance for the sandstones. The geochemistry of the major element oxides (SiO_2, Fe_2O_3, Na_2O, Al_2O_3, K_2O, MgO, MnO, TiO_2 and SO_3) suggests the Active Continental Margin as the tectonic setting of the area.

Keywords: Amasiri area, Benue Trough, sandstones, geochemistry, petrography

1. Introduction

Amasiri area (Figure 1) lies in the Afikpo Synclinorium, lower Benue Trough which is a depression formed in the eastern flank of southeastern edge of the trough as a result of Santonian tectonism and uplift of the Abakaliki Anticlinorium. The area is made up of an alternating sequence of sandstone ridges trending NE-SW and the shales both of Turonian Eze-Aku Formation. Reyment (1965) first described the Eze-Aku Formation as comprising of dark grey to black shales, sandstone, subordinate limestone and siltstone deposited in a shallow marine environment. Offodile (1976) established the existence of an unconformity between the Turonian Eze-Aku Formation and the overlying Campanian-Maastrichtian Nkporo shale in the Afikpo Synclinorium of southern Benue Trough. He explained the absence of the Awgu Formation in the Afikpo Syncline to result from extensive erosion of older beds which accompanied the Santonian uplift. Hoque (1976, 1977) discussed petrographic differentiation of tectonically controlled Cretaceous sedimentary cycle in southeastern Nigeria and found out that the first sedimentary cycle was characterized by feldspar while that of the second cycle was characterized by quartz-arenites. Murat (1972) believed that the Eze-Aku Formation was deposited under marine conditions and sandstone coinciding with the regressive phases of epi-continental Sea Banerjee (1980) utilizes the process-response methodology to sedimentary facies analysis and suggested that the Eze-Aku Formation was deposited in a subtidal, tidal dominated environment. He however, preferred a barrier bar island origin for sandstone unit at Ibii, near Akpoha. Amajor (1987) suggested that bioturbated sandstone and limestone clasts of Eze-Aku Formation were probably derived from uplifted Asu River group shoreline sand bodies by the Cenomanian uplift. They were probably scattered on the foot of the uplift as screes and talus provably brought there by braided streams. Petters (1978) recognized three depositional cycles or sequences. He established the facts that Eze-Aku Formation belongs to the second trangressive/regressive phase, (Turonian) and that they represent the basal coastal shoreline and shallow sublittoral facies of a major marine onlap sequences. Reyment (1965) suggested that the Turonian Eze-Aku Formation of the Benue Trough (Figure 2) is dominated by shales. But on the southeastern part of the trough that is north of Afikpo Synclinorium, there are member of northeast-southwest trending sand-bodies, which are parallel to the axis of the trough and are themselves linear and parallel.

2. Methodology

The geological field mapping of the work involved description, measurements and sampling of the exposed sections of the sandstones of Eze-Aku Formation. The sandstone outcropping in Ibii, Amasiri, Ozara- ukwu, Crushed stone quarry and Amoha were studied. Thin sections were prepared from the representative sandstone samples obtained in the field for thin section petrography which was studied under transmitted light petrographic microscope. Petrographic classification was done using the framework elements of quartz (Q), feldspar (F) and rock fragment (RF). The mineral maturity calculated using the mineralogical maturity index (IMM) of Nwajide and Hoque(1985). Geochemical analyses (major elements) of eight samples were performed by x-ray difraction technique (Minipal 4ED Version). The required filters for each element were selected accordingly and probed. The initial results of concentration of the elements selected were shown in diffractions, which were then converted to concentration in weight percentage of the major oxide of the elements in question.

3. Results and Discussion

3.1. Lithostratigraphy and field descriptions

Based on local lithostratigraphy and field descriptions, the sandstones of Eze-Aku Formation in Amasiri area are grouped into two units: Ibii/Ozaraukwu Sandstone and Amasiri junction Sandstone.

Ibii/Ozaraukwu Sandstone unit consists dominantly of calcareous, araneceous and siliceous sandstones that occur in ridges, which trend in a NE-SW direction alternating with thick sequence of shales. The contact between the shale and the sandstone is very sharp and transitional in some places. There is gradation from shales to interbedded siltstones and mudstone interlamination to sandstone near Amasiri Junction. The sedimentary structures observed are mainly cross-stratificatios, burrows and mudstone laminations along Edda Road. In Ibii junction, bioturbated fine-grained sandstone with rip-up clast is observed, and the sandstone opposite Amasiri Community Primary School are micaceous and silty.. The shales have very high dips up to 32^0 to the SE at Crushstone Quarry. Outcropping along Edda Road is consolidated whitish sandstone that is highly siliceous. Generally, the sandstone beds dip to the southeast at angles ranging from 30^0-50^0 and strike in the NE-SW direction.

The Amasiri junction Sandston is friable to weakly consolidated, brownish to dark reddish in weathered parts and whitish sandstone. The grain size ranges from medium to very coarse and occasionally pebbly. It contains some clay siltstone bands. It shows coarsening upward sequence from coarse grain to pebbly at the base to the fine and medium grained at the tops of the beds. The sandstone is moderately sorted. The minerals are dominantly quartz and feldspars,. The sedimentary structures that characterize this unit are ripples and cross-beds.

3.2 Detrital Framework Components and Classification

Based on the petrographic study, the sandstones composed of quartz, feldspars, rock fragment and mica (Figures 3 & 4). Quartz being the dominant framework grains has a percentage range of 68% to 74% of the framework and dominantly subangular to subrounded (Figure 3) straight to strongly undulose extinction. The feldspars which are mainly k-feldspar have 5 to 17% of the framework grains. Rock fragments constitute a minute proportion of the framework grains with range of about 3-8%. The lithic fragments include igneous and metamorphic rocks. Micas include biotite and muscovite with muscovites being most common. It has percentage range of 1-7%. Matrix has a percentage range of 5-9% of the detrital fraction, and more common in fine to medium sandstone samples. Cement in the detrital framework grains are calcite, silica and iron oxide in their order of abundance. Cement however, constitute a significant percentage range of 4-8% in almost the entire sample. From the high matrix content (>5%), the sub angular to sub rounded grains are moderately sorting. The sandstones in the study area 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) (Figure 5 & Table 1).

3.3. Parent Rock Lithology

The abundance of quartz and feldspar minerals and their predominance over the lithic fragments in the Amasiri sandstone suggests a primary rather than reworked source for the sandstone (Pettijohn et al; 1987). The absence of volcanic rock fragments and quartz containing inclusion in the samples studied indicate a non-volcanic source for the sandstone (Moorehouse, 1959). The presence of polycrystalline quartz that are not elongated or flattened and of nearly equant grains (Figures 3) with sutured intercrystalline boundaries; non-undulose quartz extinction favour a plutonic igneous granitoid source as the dominant source rock of a humid environment (Pettijohn et al, 1987; Folk, 1974; Blatt et al; 1980; Basu, 1985). In addition, the presence of monocrystalline quartz (Figures 3 & 4) with strong undulose extinction and metamorphic rock fragment suggest contributions from metamorphic sources. To evaluate the importance of plutonic and metamorphic rocks as the Amasiri Sandstone sources, the compositional framework grain data was gotten or deduced by plotting the point count data on Suttner et al (1981) as shown in Figure. 6. This approach also points to both metamorphic and plutonic igneous source rocks for the Amasiri Sandstone.

3.3. Tectonic Provenance

In the QFR ternary diagram of Dickson et al, (1985), the compositional framework grain data plot in the craton interior, transitional continental and recycled Orogen fields as shown in Figure 7. As pointed out by Dickson et al (1985), 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-feldspathic sandstones of classic subarkosic character.

3.3. Source Area Weathering and Climatic Index

Petrographic evidences of Amasiri sandstones such as the presence of quartz with sub angular to sub rounded grains and weathered feldspar imply the significance of both mechanical and chemical weathering in the grains of the sandstone. They therefore, suggest that the compositional submaturity of these sandstones may be due to the short distance transport, relatively low source relief and relatively close provenance which may be related to humid climatic condition. Also, using the Q-R-F 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 fields as shown in Figure 6. This suggests that the parent rocks were situated in a humid climatic setting during Turonian time.

3.4. Geochemistry

From Table 2, the result shows a slight variation in element composition of all the samples analysed, reflecting homogeneity of all the sediment suit and indicating constancy of provenance and sedimentary environment of the rock. This variation reflects changes in the chemical and mineralogical composition of the sediment, especially in the quartz-feldspar ratio and SiO_2 abundance. Also, to characterize the tectonic setting of the depositional basin, the major element geochemistries of Amasiri Sandstones are discussed in terms of discrimination diagram of Kroonenberg (1994). The discrimination diagram shows that the Amasiri Sandstone was deposited in an active continental margin as shown in Figure 8, analogous to conclusions from the petrographic studies.

The Chemical Index of Alteration(CIA) defined by Nesbitt and Young (1982) as $CIA=100xAl_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)$ which has a narrow range of 62-71, and Chemical Index of weathering (CIW) defined by Harnois (1988) as: $CIW=Al_2O_3/(Al_2O_3+CaO+Na_2O)x100$ with also a narrow range of about 80-89 indicate the degree of weathering in sediment source areas, thus reflecting their tectonic setting and prevailing paleoclimatic condition. The sandstones of Eze-Aku Formation shows a narrow range of both CIA values (62-71) and CIW values (80-89), indicate intense of weathering of the sandstone as shown in Table 3. These values, in general, can be due to either intense recycling in humid or arid/semiarid climatic conditions (Osae et al; 2006; Wanas and Andel-Maguid, 2006). Therefore, petrographic evidences, 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 sandstones.

3.5. Paleocurrent

Paleocurrent indicators are oriented sedimentary structures interpreted to have been deposited by ancient flows. Crossbeds, slip face, pebble imbrications, parting lineation, toolmarks, and groove casts, and ripple crest orientation are all examples of possible paleocurrent indicators (Pettijohn, 1975). Some paleocurrent indicators are unidirectional- that is, their shape provides unique information about the direction of the ancient paleoflow. Unidirectional paleocurrent indicators include fore-sets, flute casts, and clast imbrication. Some paleocurrent indicators are bi-directional-that is, their shape eliminates all but two possible directions (upcurrent or downcurrent). Bi-directional paleocurrent indicators include oriented wood fragments or other elongate clasts, tool marks or elongate sole marks and parting lineation. In the study area, the predominant paleocurrent indicator is crossbeds. Some cross beds data were measured (Table 4), about 300metres from Amasiri junction along Okigwe Road. The southwesterly, westerly and northwesterly directed paleocurrent modes (Figure 9), suggest the Basement Complex of Oban Massif to the east as probably the major source (provenance) for the sandstones.

4. Conclusion

The sandstones of Eze-Aku Formation in Amasiri area are made up of calcareous and non-calcareous, medium to coarse grain, poorly to moderately sorted, subarkosic Sandstones occur in fairly parallel, linear, Northeast-Southwest trending ridges alternating with thick sequence of shales and characterized by a coarsening upward textural sequence. Petrographic and paleocurrent study suggest the sandstones probabaly emanated from the Basement Complex rocks of Oban massifs under humid climatic setting during Turonian time. The sandstones are typically quartzo-feldspathic sandstones of classic subarkosic character. The geochemical and petrographic plots show the tectonic setting of the Amasiri sandstone lies in active continental margin, and the provenance signatures from the plots suggests the craton interior, transitional continental and recycled Orogen as the provenance fields.

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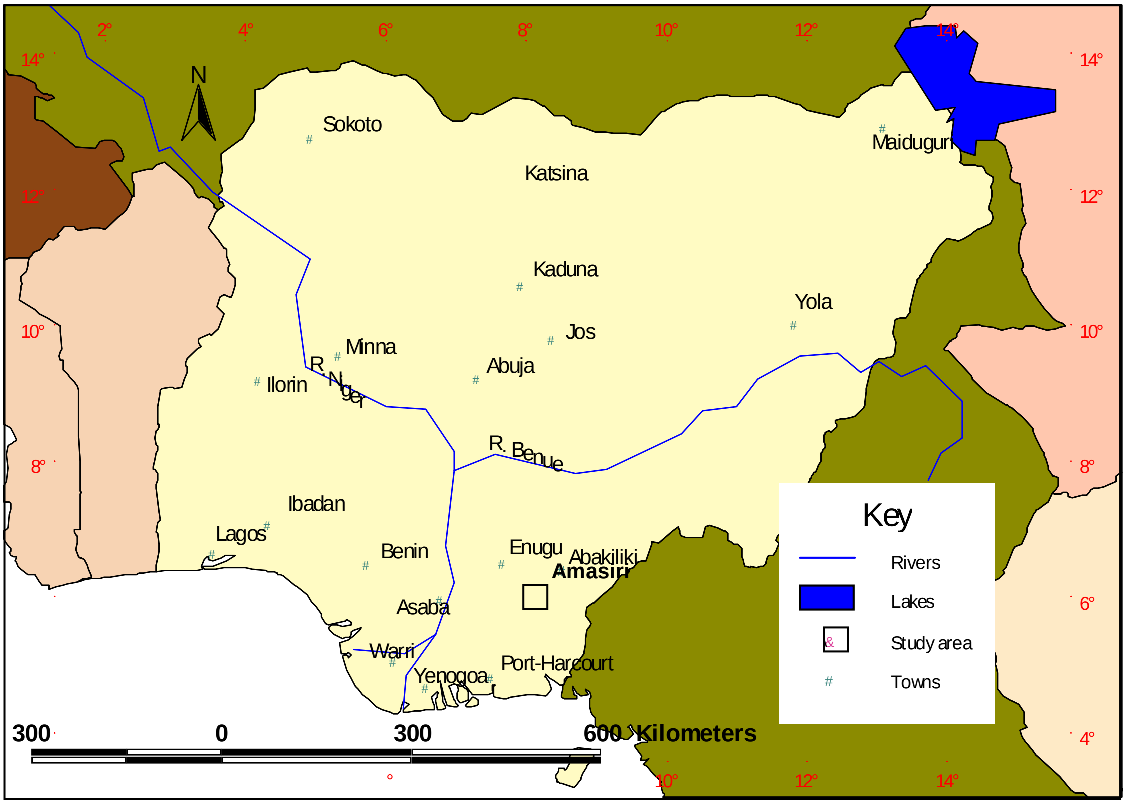


Figure 1: Geographic map of Nigeria showing Amasiri and other major cities

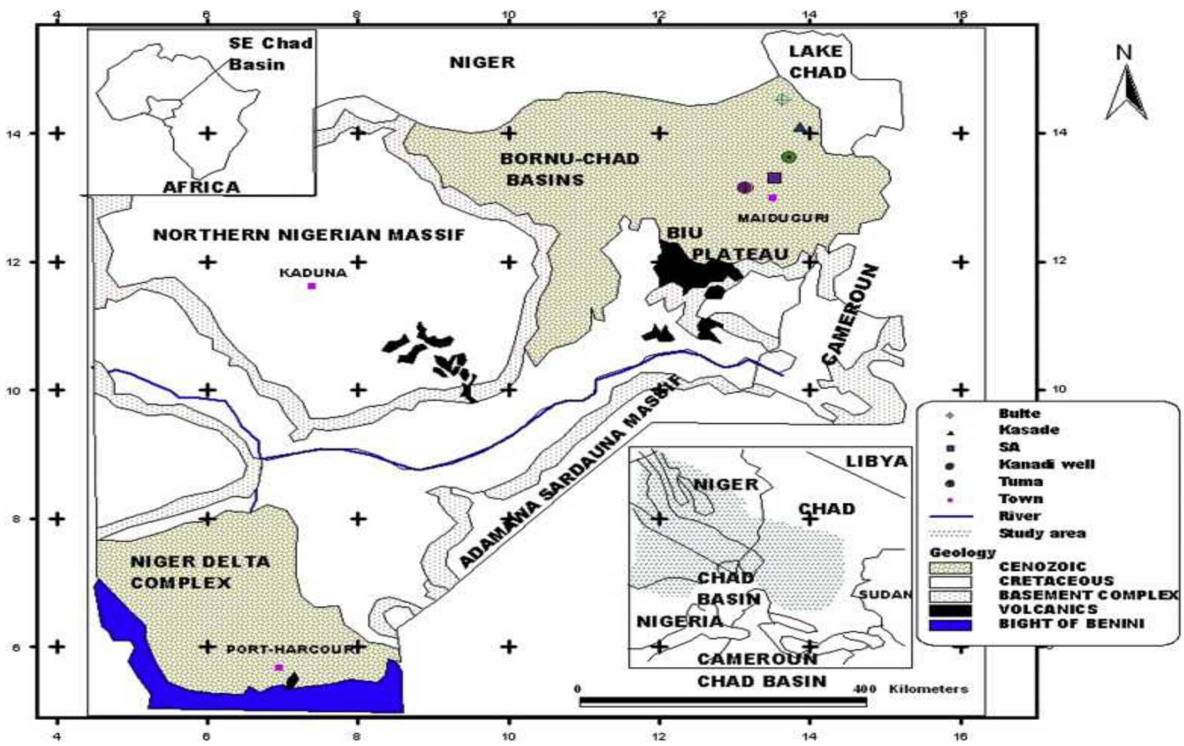


Figure 2**:** Geology of the Cretaceous sediments of the Benue Trough (After Cratchley and Jones, 1965).

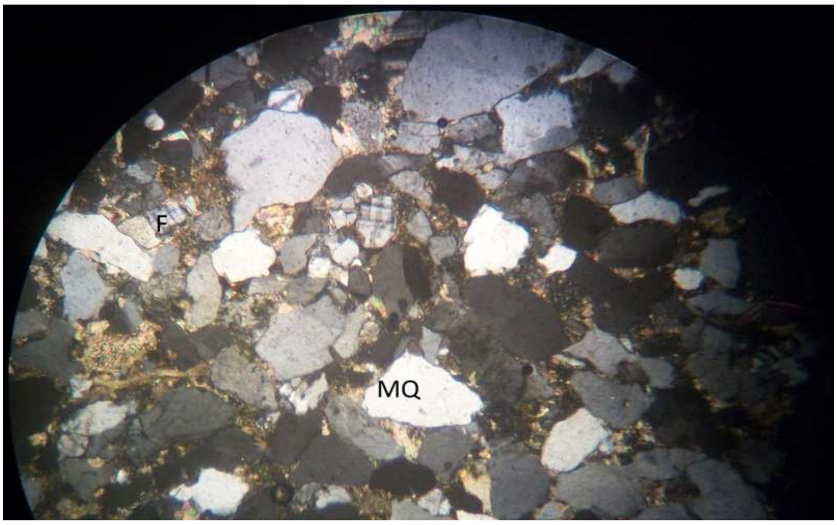
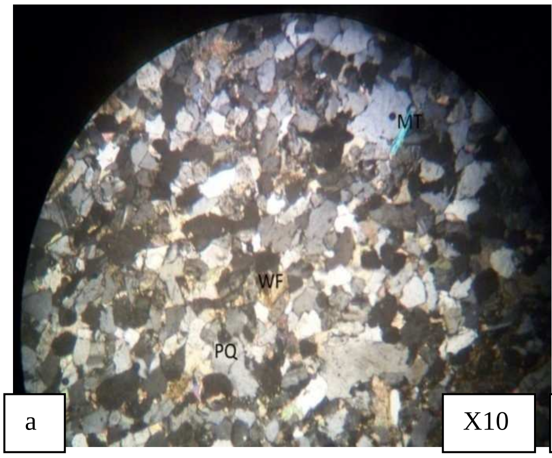


Figure 3 : Photomicrograph of sample IUO7 under XPL, showing feldspar (F) and monocrystalline quartz (MQ).



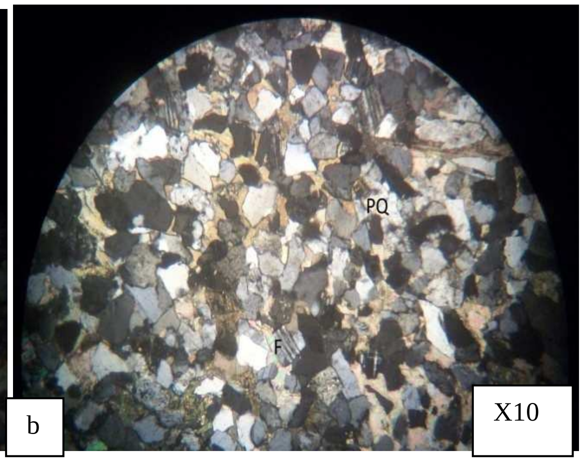


Figure 4: a and b: photomicrograph of samples IU10A and IU17 respectively under XPL showing feldspar (F) and polycrystalline quartz (PQ). a cylindrical muscovite (MT) and weathered feldspar (WF).

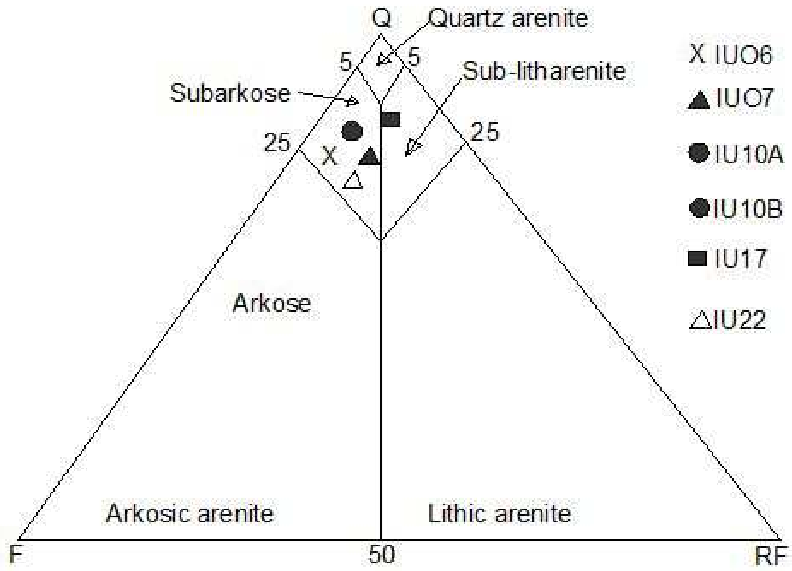


Figure 5: QFR triangular classification plot for the sandstones in Amasiri using (Folk, 1974).

Table 1: Recalculated Modal Analysis Data For Framework Composition

Sample No.	Quartz %	Feldspar %	RF %	Total %
IU06	80	17	3	100
IU07	77	14	9	100
IU10A	87	6	7	100
IU10B	87	6	7	100
IU17	85	11	4	100
IU22	76	19	5	100

RF= Rock Fragment

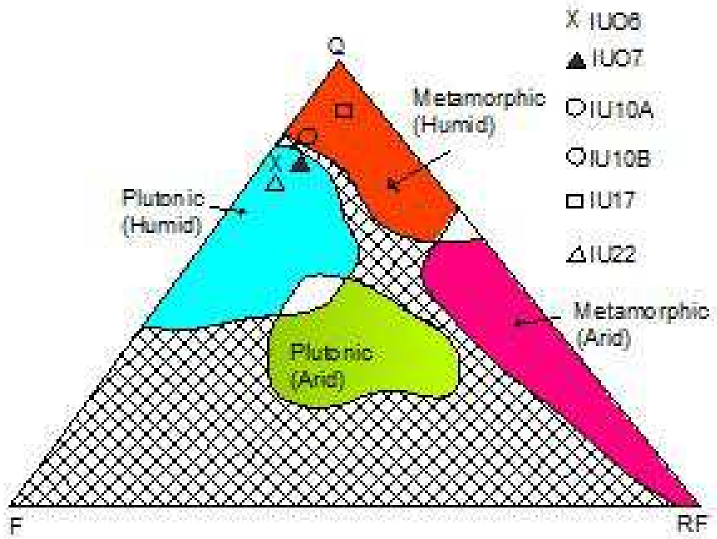


Figure 6: The Effect of Source Rock on Composition of the Amasiri Sandstone using Suttner et al., (1981) Diagram

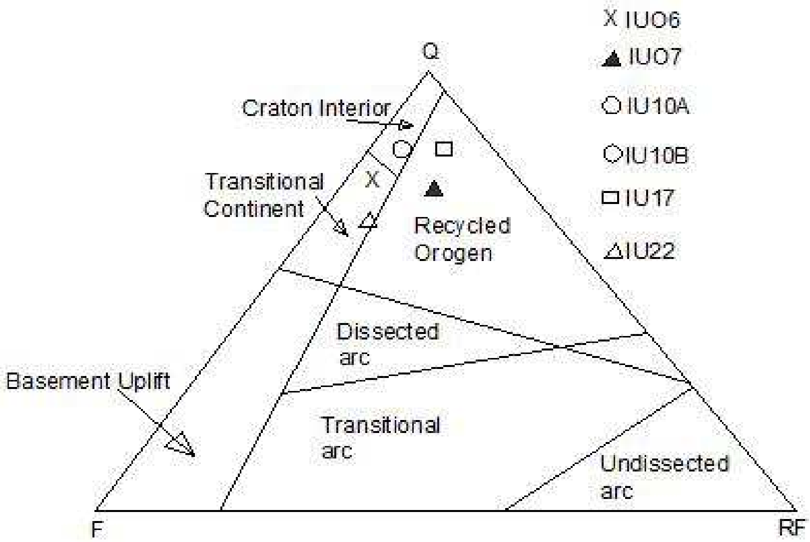


Figure 7: QRF Diagram plot for the Sandstones at Amasiri, using Dickson et al., (1983).

Table 2: Major Element Composition in Percentage.

Major oxides	IU06	IU07	IU08	IU10	IU17	IU22	IU23
SiO_2	67.45	66.41	63.45	66.94	66.43	62.90	66.06
Al_2O_3	16.95	15.29	17.14	15.67	15.38	17.66	15.00
Fe_2O_3	0.79	0.87	1.88	0.77	1.52	1.86	1.84
CaO	0.42	0.49	0.60	0.43	0.50	0.64	0.63
MgO	0.24	0.31	0.49	0.28	0.50	0.51	0.60
K_2O	5.89	5.67	5.94	5.65	4.31	5.39	4.44
Na_2O	3.12	2.87	3.11	3.43	1.31	1.99	1.84
MnO	0.01	0.01	0.02	0.01	0.01	0.02	0.03
TiO_2	0.12	0.11	0.18	0.13	0.09	0.25	0.15
SO_3	0.18	0.11	0.17	0.19	0.06	0.03	0.09
Fe_2O_3+MgO	1.03	1.18	2.37	1.05	2.02	2.37	2.44
Al_2O_3+SiO_2	0.25	0.23	0.27	0.23	0.23	0.28	0.23
K_2O/Na_2O	1.89	1.98	1.91	1.65	3.29	2.71	2.41
$Al_2O_3/(CaO+Na_2O)$	4.79	4.55	4.62	4.06	8.50	6.71	6.07

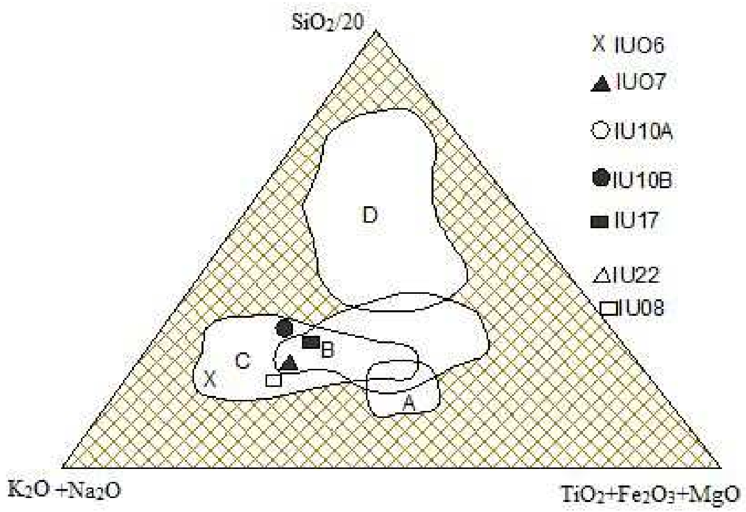


Figure: 8: Plot of the Major Element Composition of the sandstones in the study area on the Tectonic Setting Discrimination Diagram of Kroonenberg (1994). A: Oceanic Island; B: Continental Island Arc; C: Active Continental Margin; D: Passive Margin

Table 3: Chemical Index of Alteration (CIA) (Nesbitt and Young, 1982) and Chemical Index of Weathering (CIW) (Harnois, 1988).

Sample No	CIA= $Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)x100$	CIW= $Al_2O_3/(Al_2O_3+CaO+Na_2O)x100$
IU06	64.25	82.72
IU07	62.87	81.98
IU08	63.97	82.21
IU10	62.23	80.23
IU17	71.53	89.47
IU22	68.77	87.03
IU23	68.46	85.86

Table 4: Crossbeds analysis using front Azimuth and its back equivalence and class interval of 30^0

S/N	Class interval	Equivalent	Frequency
1	0-30	181-210	0
2	31-60	211-240	0
3	61-90	241-270	9
4	91-120	271-300	8
5	121-150	301-330	3
6	151-180	331-360	0
			∑f=20

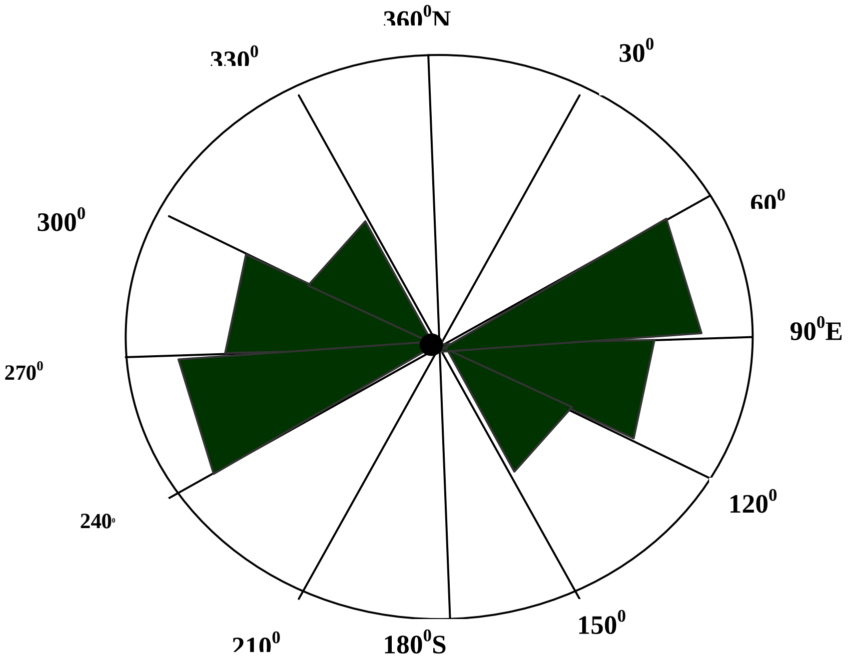


Figure 9 : Plot of rose diagram for the cross-beds data along Amasiri-Okigwe Road. The paeocurrent direction trends SE-NW direction