PRINT ISSN 1119-8362
ELECTRONIC ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://ww.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 23 (1) 111–119 January 2019

# Major and Trace Element Evaluation of the Campano-Maastrichtian Sediments of Anambra Basin Exposed around Enugu, Nigeria

*[1]HARUNA, KA; [2]OJO, OJ

[1]*Al-Hikmah University, Ilorin,Nigeria.*
[2]*Federal University Oye-Ekiti, Ekiti State, Nigeria*
**Corresponding Author Email: preciousrasaq@yahoo.com; Tel: +2348038113783*

**ABSTRACT:** An integrated geochemical and sedimentological study of the Campano- Maastrichtian sediment of Ajali and Owelli Formation exposed within the southern portion of the Anambra basin was undertaken to determine the sandstone provenance, tectonic setting, and paleo-weathering conditions. All sandstone samples are enriched in quartz (Q) but poor in feldspar (F) andlithic-fragments (L). The major-element concentrations of these sandstones reveal the relative homogeneity of their source. Geochemically, the sandstones are classified as quartzarenite, sub-litharenite, and subarkose. Tectonic setting discrimination diagrams suggest a passive continental margin. The sediments are enriched in $SiO_2$ and depleted in $Na_2O$, CaO and $TiO_2$.Chemical index of weathering (CIW) of the sample suggests intense recycling and high degree of weathering in a humid climatic condition. Results of the elemental ratios critical of provenance compared to those of felsic and basic derived sediment of UCC and PAAS values suggests a felsic source rock. Cu/Zn, U/Th, Ni/Co and (Cu+Mo)/Zn paleo-oxygenation ratios used as redox parameters depicts an oxic environment. Finally, presence of minerals, like Anatase, Rutile and Microcline depicts an igneous and metamorphic source terrain.

**DOI: https://dx.doi.org/10.4314/jasem.v23i1.17**

**Dates:** Received: 17October 2018; Revised: 05 January 2019; Accepted 17 January 2019

**Keywords**: Provenance, Sub-litharenite, Sandstone, Minerals.

The Anambra Basin is one of the Cretaceous sedimentary Basin of Nigeria, bounded on the Southwestern flank by the Niger Delta hinge line, northwest by the Benue flank and southeast by the Abakaliki fold belt. The Basin is roughly triangular in shape and covers an area of about 40,000 square kilometres with sediment thickness increasing southwards to a maximum thickness of 12,000m in its central part. It was developed during the late Campanian to early Maastrichtian allocyclic incursion of the sea and this has been of great significance to several workers interested in the post-Santonian deposition. The basin is one of the sub-basins of the Benue rift structure which form a part of the West African Rift System (WARS). The combination of petrographic and geochemical data of sedimentary rocks can reveal the nature, source regions, tectonic setting and paleoclimatic conditions of sedimentary basins (McLennan *et. al.,* 1993; Armstrong-Altrin*et. al.,* 2004).Paleoenvironments of deposition of the sediments in the basin were deduced on the basis of textural attributes of strata inferred by Nwajide (1990) and Nwajide and Reijers, (1996). Fluvio-deltaic to fluviatile environment has been suggested for Ajali Formation by various workers, which include Hoque and Ezepue (1977). Paleo-current direction and paleogeography of the formation based on inferred exposed crossbedded sandstones indicated that the sediment transport was generally in NE-SW direction. Hoque and Ezepue (1977) have classified the Ajali Sandstone as a quartz arenite on the basis of four parameters earlier mentioned. The present scheme is based on log plots of $Fe_2O_3/K_2O$ and $SiO_2/Al_2O_3$ of Herron (1988). This study focuses on the Campano- Maastrichtian (Ajali and Owelli) sediments of Anambra basin exposed around Enugu in order to infer the provenance and paleotectonics using certain analyses such as X-ray diffraction, X-ray florescence, and petrographic analysis. The study area falls between latitudes 6°00$^{I}$ N-6°30$^{I}$ N and longitudes 7°12$^{I}$ E-6°42$^{I}$ E (Fig. 1).

## MATERIAL AND METHOD

*Geologic Setting and Stratigraphy of the Study Area:* The Benue - Abakaliki Trough, originated in the early Cretaceous as a failed rift associated with the opening of the south Atlantic (Wright *et al,* 1985). In early Albian – Coniacian periods, two stable areas could be distinguished on either side of the Benue Abakaliki

Trough, namely, the Anambra and the Ikpe platforms in the west and east of the southern trough respectively.

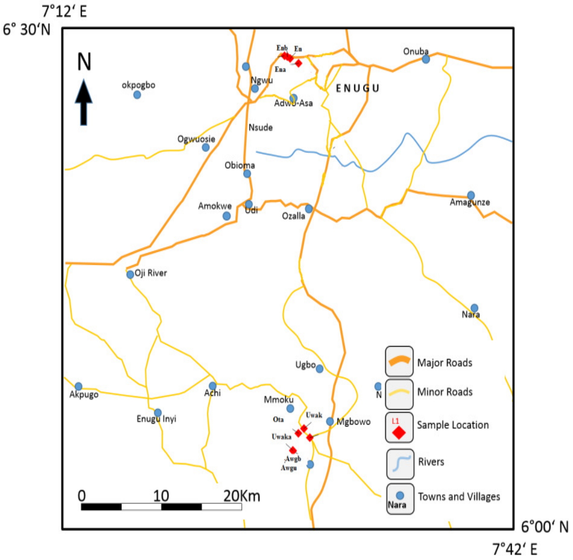
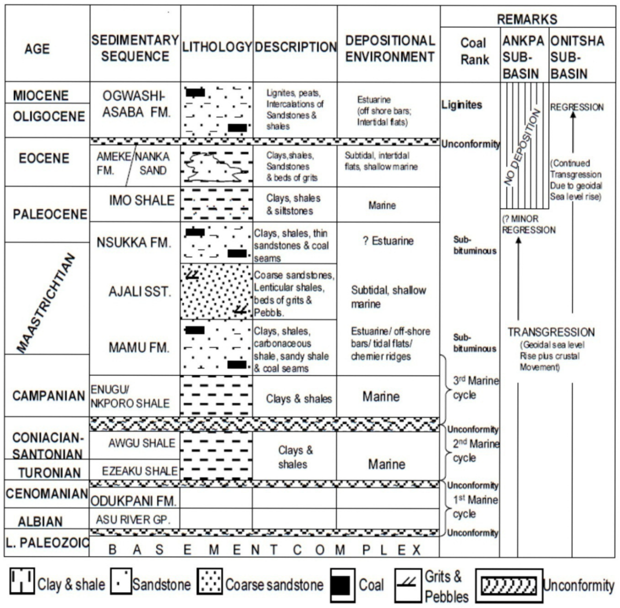


**Fig.1**: Location Map of study Area

On the south eastern–most part of Trough, the NW-SE trending structure, the Calabar flank consisting of the Ikang Trough, the Itu High as well as the Eket platform persisted without significant change right into the Tertiary (Murat, 1972).Tectonic movement resulted in the Santonian epierogenic uplift and folding of the Albian – Coniacian sediments into the Abakaliki Anticlinorium along a NE-SW axis. The structural inversion of the trough led to the subsidence of the Anambra Basin and Afikpo Synclines on the west and southeast of the Anticlinorium respectively. These newly subsided sedimentary basins, including the Afikpo Syncline, received sediments from the Campanian to the Paleocene.

The origin, tectonic evolution and stratigraphic settings in the Benue Trough and the Anambra Basin have been reviewed and widely discussed by several authors (Murat, 1972; Kogbe, 1976; Petters, 1977; Hoque and Nwajide, 1984;Benkhelil, 1987;Reijers and Nwajide,1998).The sedimentary infilling of the Southern Benue Trough can be grouped into three (3) major unconformity bounded depositional successions viz;(a) The first phase (Albian – Cenomanian), (b) The second phase (Turonian - Coniacian), (c) The third phase (Campanian - Pliocene) (Table.1). *Methodology:* The method adopted in this study involved both field studies and laboratory analyses. The mapping exercise involved identifying the various rock types and establishing stratigraphic succession of the rocks on the basis of their field relationships. Field observations including texture, colour, grains orientation, mineralogical composition, cross-beddings, thickness andlateral extent of beds, and logging of exposed vertical sections were done

**Table 1**: Stratigraphy of Anambra Basin, South-eastern Nigeria (afterAkande*et al.* 1992)



| AGE | SEDIMENTARY SEQUENCE | LITHOLOGY | DESCRIPTION | DEPOSITIONAL ENVIRONMENT | REMARKS | | |
|---|---|---|---|---|---|---|---|
| | | | | | Coal Rank | ANKPA SUB-BASIN | ONITSHA SUB-BASIN |
| MIOCENE<br>OLIGOCENE | OGWASHI-ASABA FM. | | Lignites, peats, Intercalations of Sandstones & shales | Estuarine (off shore bars; Intertidal flats) | Liginites | NO DEPOSITION | REGRESSION |
| | | | | | Unconformity | | |
| EOCENE | AMEKE/NANKA FM. / SAND | | Clays,shales, Sandstones & beds of grits | Subtidal, intertidal flats, shallow marine | | | (Continued Transgression Due to geoidal Sea level rise) |
| PALEOCENE | IMO SHALE | | Clays, shales & siltstones | Marine | | | |
| | NSUKKA FM. | | Clays, shales, thin sandstones & coal seams | ? Estuarine | Sub-bituminous | (? MINOR REGRESSION | |
| MAASTRICHTIAN | AJALI SST. | | Coarse sandstones, Lenticular shales, beds of grits & Pebbls. | Subtidal, shallow marine | | | |
| | MAMU FM. | | Clays, shales, carbonaceous shale, sandy shale & coal seams | Estuarine/ off-shore bars/ tidal flats/ chemier ridges | Sub-bituminous | TRANSGRESSION (Geoidal sea level Rise plus crustal Movement) | |
| CAMPANIAN | ENUGU/ NKPORO SHALE | | Clays & shales | Marine | 3rd Marine cycle | | |
| | | | | | Unconformity | | |
| CONIACIAN-SANTONIAN | AWGU SHALE | | Clays & shales | Marine | 2nd Marine cycle | | |
| TURONIAN | EZEAKU SHALE | | | | | | |
| | | | | | Unconformity | | |
| CENOMANIAN | ODUKPANI FM. | | | | 1st Marine cycle | | |
| ALBIAN | ASU RIVER GP. | | | | | | |
| | | | | | Unconformity | | |
| L. PALEOZOIC | BASEMENT COMPLEX | | | | | | |

Clay & shale · Sandstone · Coarse sandstone · Coal · Grits & Pebbles · Unconformity

.

Ten (10) samples from Ajali and Owelli formations were selected for Bulk geochemical analysis using standard preparatory techniques.The analysis sampled for major elements (oxides), trace and rare earth elements (RRE) using X-ray Fluorescence (XRF). The x-ray diffraction was analyzed using a PanalyticalX'Pert Pro powder diffractometer with an X'Celerator detector and variable divergence and fixed receiving slits with Fe filtered Co-Kα radiation (λ=1.789Å). The phases were identified using X'Pert High score plus software. Petrographic analysis was carried out in order to access the maturity of the sandstone at the Geology laboratory of the University of Ibadan, Ibadan, Oyo State.

## RESULTS AND DISCUSSION

*Sandstone Classification:*Major and trace elements analyses of the 10 sandstone samples from Ajali and Owelli formation in the studied area are listed in Table 2. Results showsmost of the samples are high in $SiO_2$with the Ajali sandstone having a range of91.59 to 95.2%and the Owelli sandstone ranges from55.59 to 95.4%. The $Al_2O_3$ contents is low (Ajali; 1.12- 4.22%, and Owelli; 2.33- 21.71). Ajali and Owelli formations have low contents of $TiO_2$, MnO, CaO,$Na_2O$, $Fe_2O_3$ and MgO respectively.The high $K_2O/Na_2O$ ratios (Table 3) are attributed to the relative presence of K-bearing minerals such as K-feldspar and some mica (Kalsbeek*et al.*, 2008; McLennan *et al.*, 1983; Nath*et al.*, 2000; Zhang, 2004; Osa*et al.*, 2006). A positive correlation between $K_2O$ and $Al_2O_3$ implies that the concentrations of the K-bearing minerals have significant influence on $Al_2$ distribution, this suggest that the relative abundance of these elements is primarily controlled by the contents of the clay minerals (McLennan *et al.*, 1983). Based on these ratios, some of the studied sandstones samples can be classified chemically as sub-arkose (En2), Fe-sand (Enb1, Enb2, Enb4, Awgb1, Uwak1, Uwak2, Ota1) and Awgb2 as Fe-shale (Fig.2a and 2.b). These results are further supported by low $Al_2O_3/SiO_2$ ratios which further classifies some of the samples as being quartz- arenites (Ena1) as shown in Fig. 2.a and 2.b (Pettijohn*et al.*, 1987)

**Table 2.** Results of major oxides, trace and REE (ppm) of Ajalli and Owelli Formation

| Composition (ppm) | Ajali | | | | | Owelli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | En2 | Ena1 | Enb1 | Enb2 | Enb4 | Awgb1 | Awgb2 | Uwak1 | Uwak2 | Ota1 |
| **Ni** | 1 | 1.4 | 1 | 0.8 | 0.5 | 1.6 | 0.9 | 28.6 | 6.8 | 1.2 |
| **Co** | 0.6 | 0.5 | 0.4 | 0.5 | 0.4 | 0.5 | 0.3 | 21.3 | 4.5 | 0.6 |
| **V** | 3 | <2 | 5 | 3 | 5 | 27 | 2 | 22 | 6 | 3 |
| **Th** | 6.2 | 13.6 | 5.6 | 5.6 | 6.6 | 6.6 | 2.7 | 8 | 2.9 | 1.3 |
| **Sr** | 3.7 | 2.5 | 2.1 | 1.3 | 1.1 | 11 | 3.7 | 11.7 | 5.9 | 17.4 |
| **Zr** | 5.1 | 8 | 3.6 | 3.6 | 3.9 | 10.6 | 2.4 | 17.9 | 2.6 | 1.5 |
| **Cu** | 3.74 | 3.37 | 2.48 | 2.38 | 2.21 | 2.97 | 3.94 | 23.26 | 5.54 | 2.96 |
| **U** | 0.5 | 0.8 | 0.3 | 0.4 | 0.4 | 1.2 | 0.8 | 5.2 | 3.9 | 0.2 |
| **Sc** | 0.9 | 0.4 | 0.6 | 0.7 | 0.7 | 3.1 | 1.4 | 4.1 | 0.9 | 0.5 |
| **Zn** | 3 | 1.3 | 1.1 | 0.5 | 1.3 | 3.6 | 1.3 | 4.5 | 2.2 | 1.3 |
| **Cr** | 3.4 | 5.1 | 3.1 | 3.4 | 2.8 | 12.9 | 14.1 | 13.6 | 4.4 | 3.3 |
| **Rb** | 1 | 0.5 | 0.3 | 0.1 | 0.1 | 2.3 | 0.3 | 4.9 | 0.2 | 0.4 |
| **La** | 14.5 | 29.4 | 8.8 | 4.9 | 9 | 8.8 | 1.2 | 18.8 | 4.9 | 2.8 |

**Table 3.** Ratios of some major and trace element in the studied samples

| Composition | Ajali | | | | | Owelli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EN2 | ENA1 | ENB1 | ENB2 | ENB4 | AWGB1 | AWGB2 | UWAK1 | UWAK2 | OTA1 |
| **Ni/Co** | 1.67 | 2.8 | 2.4 | 1.6 | 1.25 | 3.2 | 3.0 | 1.3 | 1.5 | 2.0 |
| **Cr/Th** | 0.55 | 0.38 | 0.55 | 0.61 | 0.42 | 1.95 | 5.22 | 1.7 | 1.52 | 2.54 |
| **Th/Co** | 10.33 | 27.2 | 14.0 | 11.2 | 16.5 | 13.2 | 9.0 | 0.38 | 0.64 | 2.17 |
| **La/Sc** | 16.11 | 73.5 | 14.67 | 13.57 | 12.86 | 2.84 | 0.86 | 4.59 | 5.44 | 5.6 |
| **Th/Sc** | 6.89 | 34.00 | 9.33 | 9.0 | 9.43 | 2r.13 | 1.93 | 1.95 | 3.22 | 2.6 |
| **Rb/Sr** | 0.27 | 0.2 | 0.14 | 0.07 | 0.09 | 0.21 | 0.08 | 0.42 | 0.03 | 0.02 |
| **Th/U** | 12.4 | 17.0 | 18.6 | 14.0 | 16.5 | 5.5 | 3.3 | 1.5 | 0.7 | 6.5 |
| **Cu/Zn** | 1.24 | 2.59 | 2.25 | 4.76 | 1.7 | 0.84 | 3.03 | 5.16 | 2.25 | 2.24 |
| **U/Th** | 0.08 | 0.05 | 0.05 | 0.07 | 0.06 | 0.18 | 0.29 | 0.65 | 1.3 | 0.15 |
| **(Cu+Mo)/Zn** | 1.52 | 3.47 | 2.94 | 5.94 | 2.06 | 1.06 | 3.7 | 5.30 | 2.78 | 3.02 |
| **$Al_2O_3/TiO_2$** | 5.91 | 0.76 | 6.7 | 7.22 | 5.67 | 23 | 58.25 | 15.51 | 7.32 | 16.64 |
| **Log ($K_2O/Na_2O$)** | 1.82 | 1.51 | 0.65 | 0.85 | 0.05 | 1 | 0.52 | 1.57 | 0.35 | 0.52 |

*Mineralogy***:** The X-ray diffractograms (XRD) for the whole rock samples from Ajali and Owelli formation shows the presence of minerals such as Quartz, Kaolinite, Microcline, Hematite Zircon, Rutile, Anatase, pyrite and Muscovite. Quartz is the dominant mineral in all the samples analysed, followed by kaolinite while, Microcline, Hematite, Zircon, Rutile, Anatase, pyrite and Muscovite are present as minor minerals (Table 4).Higher percentage of Quartz in the mineralogical analysis (XRD) and presence of minerals like Microcline, Anatase and Rutile enhances the compositional maturity of these sediments. The kaolinite proportion that follows may be derived from igneous rock, metamorphic rock and sedimentary rocks during frequent rainfall and sufficient hydrolysis under tropical to subtropical climate (De Visser, 1991). Intense weathering of the source makes kaolinite present as its end product. Kaolinite is also a common product of weathering and degradation of feldspar and the other alumina-silicates, occasionally proceeding to Aluminium oxides and hydroxides (Grim, 1968). Therefore, it can be concluded that these sediments are from mixed environments of felsic and an intermediate igneous and metamorphic origin.

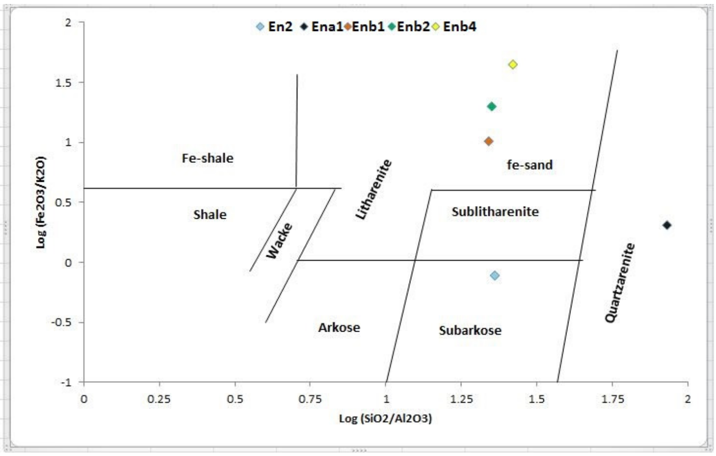


**Fig. 2.a.** Chemical classification of the Ajali sandstone (after Herron, 1988)

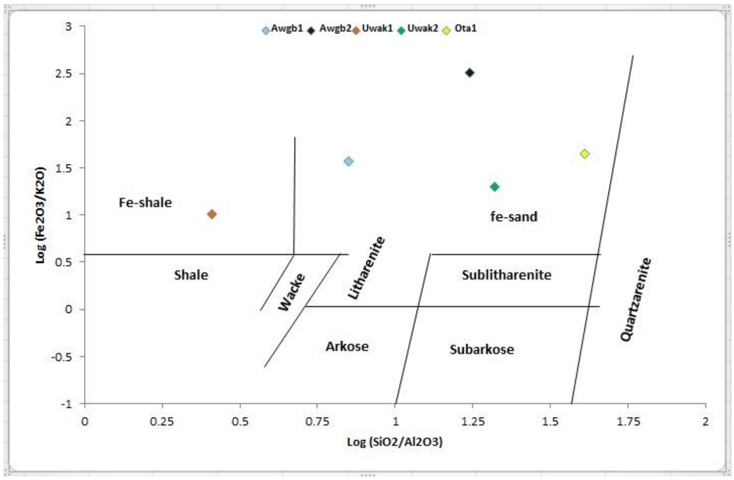


**Fig.2 b.** Chemical classification of the Owelli sandstone (After Herron, 1988)

*Provenance:*Use of discriminant function analysis of major element compositions is one of the methods for determining the provenance of sandstones (Roser and Korsch, 1988). $Al_2O_3$, $TiO_2$, $Fe_2O_3$, MgO, CaO, $Na_2O$, and $K_2O$ contents are used as variables. These were designed to discriminate between four sedimentary provenance fields. These are: Mafic - ocean island arc; Intermediate - mature island arc; Felsic - active continental margin; and Recycled – granitic, gneissic or sedimentary source. On this diagram, the Ajali sandstone and Owelli formation plot in the Quartzose sedimentary field (Fig.3 and Fig. 4) except for Awgb1 and Uwak1 (Owelli formation) that plot on felsic and intermediate province respectively, supporting the interpretation that they were derived from granitic-gneissic or sedimentary source area, similar to Passive Margin, (Roser and Korsch, 1988). The REE and Th abundances are higher in felsic igneous rocks and in their weathering products, whereas Co, Sc, Ni, and Cr are more concentrated in mafic than in felsic igneous rocks.

**Table 4.** List of minerals identified by XRD on different samples of the two formations

| Sample | Sample No | Quartz | Kaolinite | Microcline | Hematite | Rutile | Zircon | Anatase | Pyrite | Muscovite |
|---|---|---|---|---|---|---|---|---|---|---|
| Ajali | EN2 | *** | ** | * | - | - | - | - | - | - |
| | ENA1 | *** | - | * | *** | ** | ** | - | - | - |
| | ENB1 | *** | ** | - | - | - | - | - | - | - |
| | ENB2 | *** | * | - | - | - | - | ** | - | - |
| | ENB4 | *** | ** | - | - | - | - | - | - | - |
| Owelli | AWGB1 | *** | ** | - | * | - | - | * | - | - |
| | AWGB2 | *** | ** | - | ** | - | - | - | - | - |
| | UWAK1 | *** | ** | - | - | - | - | * | *** | ** |
| | UWAK2 | *** | ** | - | - | - | - | - | - | - |
| | OTA1 | *** | ** | - | - | - | - | - | - | - |

(Major***, minor**, trace*)

**Table 5.** Range of Ajali and Owelli Formation elemental ratios in this study as compared to ratios of similar fractions derived from felsic rocks, mafic rocks, Upper Continental Crust and Post-Archean Australia shale

| **Elemental ratio** | **Present study** | **Range of sediments** | | **UCC** | **PAAS** |
|---|---|---|---|---|---|
| | | Felsic rocks | Mafic rocks | | |
| **Th/Co** | 0.38 – 27.2 | 0.67 – 19.4 | 0.04 – 1.4 | 0.63 | 0.63 |
| **La/Sc** | 0.86-73.5 | 2.5 – 16.3 | 0.43 – 0.86 | 2.21 | 2.4 |
| **Th/Sc** | 1.95 -34 | 0.84 – 20.5 | 0.05 – 0.22 | 0.79 | 0.9 |
| **Cr/Th** | 0.37- 5.22 | 4.00-15.00 | 25 – 500 | 3.27 | 7.53 |

The low concentrations of ferromagnesian trace elements such as Cr, Ni, Sc and V in the Ajali and Owelli formation (Table 2) indicates very minimal mafic rocks were exposed in the source area. The unusual Co enrichment in sample Uwak1 with respect to average upper continental crust (Table 2) may suggest some input of mafic materials from the source terrain; however, the simultaneous depletion of Cr, Ni, and V in all the samples suggests that other factors such as post-depositional alterations might have played a role in concentrating Ni in the sandstones. Furthermore, ratios of, La/Sc, Th/Sc, and Cr/Th are significantly different in mafic and felsic source rocks and can therefore, provide information about the provenance of sedimentary rocks (Amstrong- Altrin et al., 2004). These ratios in both formation are similar to those of sediments derived from felsic source rocks (Table 5). The Th/Co, Th/Sc and La/Sc ratios for Ajali and Owelli samples from this study (Table 5) were compared to those of felsic and basic rock-derived sediment (fine fraction) upper continental crust (UCC) and post Achaean Australian (PAAS) values. This comparison suggests that the studied samples are within the range of felsic source rocks. The Th/Co compared to La/Sc plot (Fig 5) Cullers, 2002, also suggested that the sandstone samples were derived from felsic source rocks. According to Hayashi et al., (1997), the $Al_2O_3/TiO_2$ ratio ranges from 3 to 8 for mafic igneous rocks, from 8 to 21 for intermediate rocks and from 21 to 70 for felsic igneous rocks. Hence, this $Al_2O_3/TiO_2$ ratio obtained suggests mafic source rock for sample of Ajalli formation and Intermediate source for Owelli formation samples (Table 4).

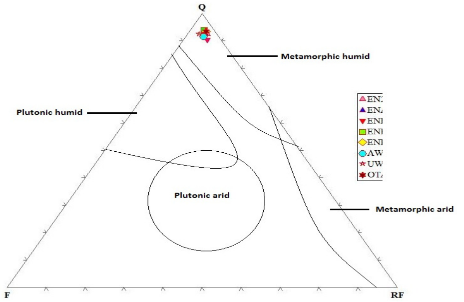


**Fig. 3.** The Effect of Source Rock on Composition of the Ajali and Owelli formation using Suttner *et al.* (1981) Diagram

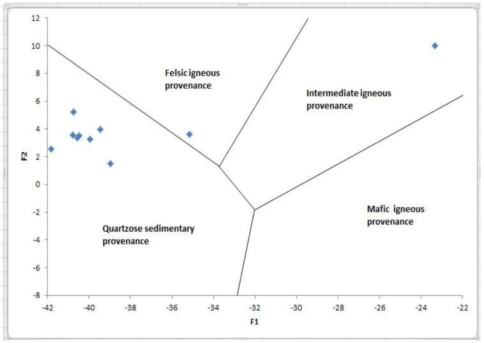


**Fig. 4.** Discriminant Function Diagram for the Provenance Signatures of the Ajali and Owelli formation using Major Elements. Boundaries between Different Fields are taken from Roser and Korsch (1988)\

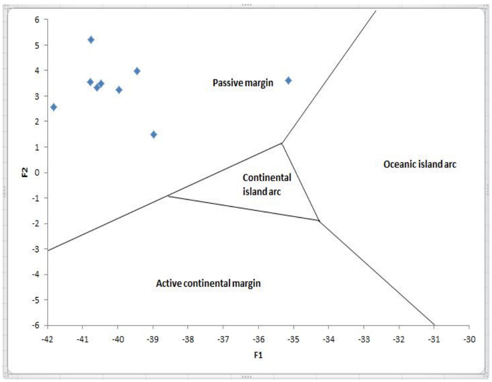


**Fig. 5**. Discriminant function analysis classification plot of function I and function II scores for Ajali and Owelli formation (after Bhatia, 1983)

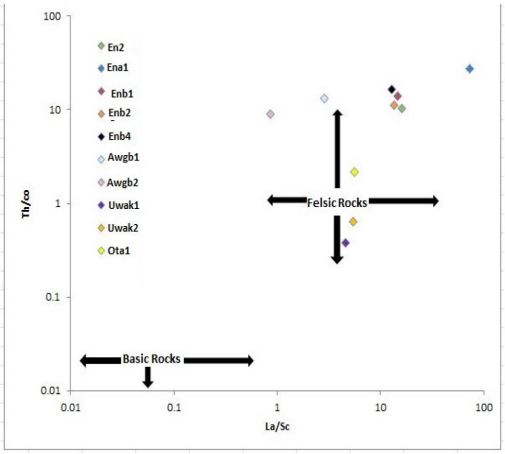


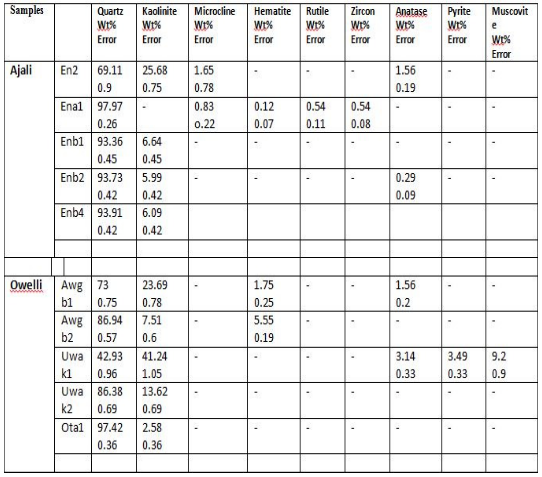
**Fig. 6**.Th/Co vs La/Sc for clayey sandstone samples from Ajali and Owelli Formation (After Cullers, 2002).

*Source-Area Weathering*: Alteration of igneous rocks during weathering results in depletion of alkali and alkaline earth elements and preferential enrichment of $Al_2O_3$ in sediments. Therefore, the weathering history of ancient sedimentary rocks can be evaluated in part by examining relationships among the alkali and alkaline earth elements (Nesbitt and Young, 1982). A good measure of the degree of chemical weathering can be obtained by calculating the Chemical Index of Alteration (Nesbitt and Young, 1982) and Plagioclase Index of Alteration (Fedo*et al*., 1995). The CIA (chemical index of alteration) and CIW (chemical index of weathering) values have been established as a general indicator of the degree of weathering in any provenance region (Nesbitt and Young, 1982).High CIA and PIA values (i.e., 75–100) indicate intensive weathering in the source area whereas low values (i.e., 60 or less) indicate low weathering in source area. In the studied samples of Ajali and Owelli formation, the CIA and PIA values of both formations are high (i.e., 78–99; 97-99 and 97-99; 99-100 respectively) as shown in Table 6. Most of the samples have CIA and PIA values greater than 90 indicating very high and intense weathering conditions in the source area. Based on the Q-F-R ternary diagram of Suttner *et. al.* (1981), the climatic setting at the time of depositionof bothAjali and Owelli plot on the metamorphic humid field (Fig.2), which suggest that the parent rocks were situated in a humid climatic setting.Rb/Sr ratio value of the samples from the investigated areas ranges between 0.37ppm - 5.22ppm (Table 5), as compared to standards of Mclennan (1983) suggests highly weathered source area. Mclennan(1993) also suggested that Th/U ratios is a good indicator for weathering and recycling, in which typical loss of U leads to elevation of Th/U in UCC (3.5-4.0ppm), whereby >4.0 ppm indicates intense weathering and sediment recycling. Th/U ratio shows that all samples from Ajali formation indicates long sediment transportation, and also depicts intense weathering from the source area and sediment recycling. While in the Owelli formation, sample Awgb1 and Ota1 are highly weathered whereas sample Awgb2, Uwak1 and Uwak2 most have undergone moderate, low to very low weathering with 3.3ppm, 1.5ppm, and 0.7ppm respectively.

**Table 6.** PIA and CIA Values Used in Deducing Source- area Weathering

| SAMPLE | | PIA | CIA |
|---|---|---|---|
| | EN2 | 99.50 | 85.37 |
| AJALI | ENA1 | 97.9 | 78.43 |
| | ENB1 | 99.57 | 98.64 |
| | ENB2 | 99.57 | 99.10 |
| | ENB4 | 99.50 | 99.22 |
| | AWGB1 | 99.05 | 100 |
| OWELLI | AWGB2 | 98.98 | 99.60 |
| SANDSTONES | UWAK1 | 98.33 | 99.70 |
| | UWAK2 | 99.13 | 100 |
| | OTA1 | 97.98 | 99.20 |

**Table 7.** Showing XRD mineralogical composition of studied sample



| Samples | | Quartz Wt% Error | Kaolinite Wt% Error | Microcline Wt% Error | Hematite Wt% Error | Rutile Wt% Error | Zircon Wt% Error | Anatase Wt% Error | Pyrite Wt% Error | Muscovite Wt% Error |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ajali** | En2 | 69.11<br>0.9 | 25.68<br>0.75 | 1.65<br>0.78 | - | - | - | 1.56<br>0.19 | - | - |
| | Ena1 | 97.97<br>0.26 | - | 0.83<br>o.22 | 0.12<br>0.07 | 0.54<br>0.11 | 0.54<br>0.08 | - | - | - |
| | Enb1 | 93.36<br>0.45 | 6.64<br>0.45 | - | - | - | - | - | - | - |
| | Enb2 | 93.73<br>0.42 | 5.99<br>0.42 | - | - | - | - | 0.29<br>0.09 | - | - |
| | Enb4 | 93.91<br>0.42 | 6.09<br>0.42 | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| **Owelli** | Awg b1 | 73<br>0.75 | 23.69<br>0.78 | - | 1.75<br>0.25 | - | - | 1.56<br>0.2 | - | - |
| | Awg b2 | 86.94<br>0.57 | 7.51<br>0.6 | - | 5.55<br>0.19 | - | - | - | - | - |
| | Uwa k1 | 42.93<br>0.96 | 41.24<br>1.05 | - | - | - | - | 3.14<br>0.33 | 3.49<br>0.33 | 9.2<br>0.9 |
| | Uwa k2 | 86.38<br>0.69 | 13.62<br>0.69 | - | - | - | - | - | - | - |
| | Ota1 | 97.42<br>0.36 | 2.58<br>0.36 | - | - | - | - | - | - | - |
| | | | | | | | | | | |

*Paleotectonics:* Sedimentary rocks have been used to confine Provenance and Paleotectonic setting by many specialists (Dickinson et al, 1983; Bhatia 1983; McLennan et al, 1993). The main assumption behind sandstone provenance studies is that, different tectonic settings contain characteristic rock types which when eroded produce sandstones with specific compositional ranges (Dickinson, 1985). The analysis of sandstones with known provenance has been used to define these ranges from which the provenance of other samples can be deduced. With this, Dickinson and co-workers have related detrital sandstone compositions to major provenance types such as stable cratons, basement uplifts, magmatic arcs and recycled orogens (Dickinson and Suczek, 1979; Dickinson et al., 1983). In the QFL and QmFLt ternary diagrams after Dickinson et al. (1983) shows that the analyzed samples plot exclusively in the craton interior field (Fig. 6). As pointed out by Dickinson et al. (1983), sandstones plotting in this field are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins. The studied samples of Ajali and Owelli units plot within the passive margin using a discriminant function diagram (Bhatia 1983). (Fig 4). The Roser and Korsch (1986) plot of log ($K_2O/Na_2O$) Vs$SiO_2$ discrimination diagram indicated a passive-margin tectonic setting (Fig.7). The passive-margin comprised Atlantic-type rifted continental margins developed along the edges of the continent, remnant ocean basins adjacent to collision orogens, and inactive or extinct convergent margins. Intra-cratonic and rift-bounded grabens (e.g. the Benue trough) were formed on thick continental crusts which were included in the passive-margin type tectonic setting.

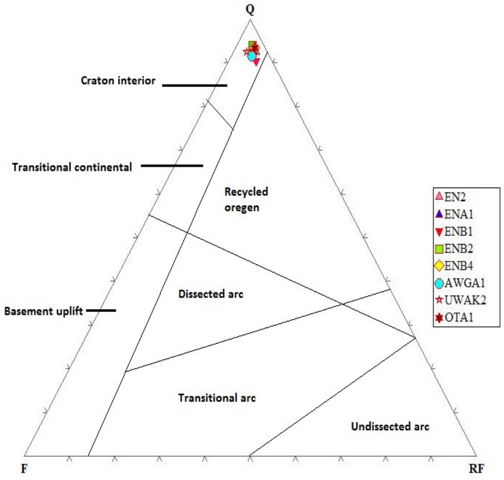


**Fig. 6.**QtFRF Ternary Diagram for the Ajali and Owelli formation (after Dickinson *et al.,* 1983)

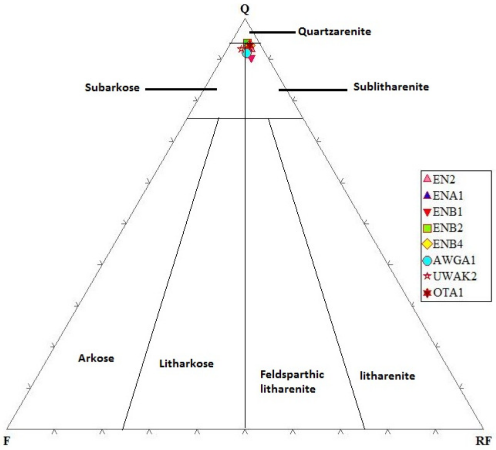


**Fig7**.Tectonic discrimination diagram for Ajali and Owelli Formation (Roser and Korsch, 1986)

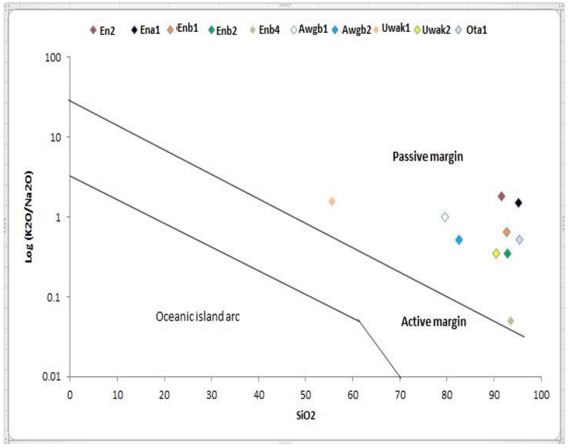


**Fig. 8.**QFR Triangular Classification Plot (Folk, 1974) for the Ajali and Owelli Sandstone Samples

The studied Ajali and Owelli samples Passive-margin type sandstone are generally enriched in $SiO_2$ and depleted in $Na_2O$, CaO and $TiO_2$, suggesting that they are highly recycled and mature in nature (Bhatia, 1983). The major element geochemistry of Ajali and Owelli samples discussed in terms of discrimination diagrams to characterize the tectonic setting as proposed by Bhatia (1983) and Kroonenber (1994), confirmed that the Ajali and Owelli Sandstone ware deposited in a passive continental margin.

*Paleo-Oxygenation***:** (Cu/Zn and (Cu+Mo)/Zn ratios have been put forward by Hallberg (1976) 1.24- 4.76, U/Th ratio by Jones and Manning, 1994, Nath*et al.*, 1997, ranging from 0.03- 1.3, and Ni/Co ratios by Dypvik (1984) and Dill (1986), (1.2- 3.0)used as a redox indicator to depict paleo oxygenation of sediment depositional environment. samples from both formations (Table 4), confirm that the sediments were deposited in oxic or oxidizing environment.

*Conclusion:*Owelli Formation were derived from felsic source rocks, probably a quartzose recycled provenance from plate interior or stable continental areas while Ajali samples were derived from mafic to intermediate sources. A passive continental margin was suggested for both Formations. Cu/Zn ratiossuggest oxidizing condition or oxic environments. U/Th values shows deposition in an oxic environment. CIA and PIA values indicate very high and intense weathering conditions in the source area. Q-F-R ternary diagram plotted suggests humid climatic setting for the parent rocks. Quartz mineral greater than 90% suggests maturity of the sandstones with an angular to sub angular which suggests that they have not being transported far away from their source.

## REFERENCES

Amstrong-Altrin, JS; Lee, YI; Verma, SP; Ramasamy, S (2004). Geochemistry of Sandstones from the Upper Miocene Kudankulam Formation, Southern India: Implication for Provenance, Weathering and Tectonic Setting. *J. of Sed. Res.* 74, p. 285–297.

Dypvik, H(1984). Geochemical Compositions and Depositional Conditions of Upper Jurassic and Lower Cretaceous Yorkshire clays, England: Geo. Magazine, vol. 121(5), p. 489-504.

Fedo, CM; Nesbitt, HW;Young, GM(1995).Unraveling the Effects of Potassium Metasomatism in Sedimentary Rocks and Paleosols, with Implications For Paleoweathering Conditions and Provenance, vol. 23, p. 921–924.

Jones, B;Manning, DC(1994). Comparison of Geochemical Indices Used for the Interpretation of Paleo-redox Conditions in Ancient Mudstones: *Chem. Geo.*, vol. 111(1-4), p. 111-129.

Kalsbeek, F; Frei D; Affaton, P(2008). Constraints on Provenance, Stratigraphic Correlation and Structural Con-text of the Volta Basin, Ghana, from Detrital Zircon Geo-chronology: An Amazonian Connection? *J. Sed. Geo.* Vol. 212, p. 86-95

King, L(1950). Speculations Upon the Outline and Mode of Distribution of the Gondwanaland. *Geo. Magazine,* 87: 352-359.

McLennan, SM; Taylor, SR;Eriksson, KA (1983). Geochemistry of Archaeanshales from the Pilbara Supergroup, Western Australia, GeochimicaetCosmochimicaActa, vol.47 (7), p. 1211- 1222.

Mclennan, SM; Hemming, S; Mcdaniel, DK;Hanson, GN (1993). Geochemical Approaches to Sedimentation, Provenance and Tectonics, In Johnson, M.J., Basu, A. Eds, Processes of Controlling the Composition of Clastic Sediment. Geo. Soc. of Am., Special Paper, vol. 284, p. 21-40.

Mclennan, SM; Hemming, S; Mcdaniel, DK;Hanson, GN (1993). Geochemical Approaches to Sedimentation, Provenance and Tectonics, In Johnson, M.J., Basu, A. Eds, Processes of Controlling the Composition of Clastic Sediment. Geo. Soc. of Am., Special Paper, vol. 284, p. 21-40.

Nath, BN; Kunzendorf, H;Pluger, WL (2000). Influence of Provenance, Weathering and Sedimentary Processes on the Elemental Ratio of the Fine-grained Fraction of the Bed Load Sediments from the Vembanad Lake and the Adjoining Continental Shelf, Southwest Coast of India*, J. of Sed. Res.*, vol. 70, p. 1081- 1094.

Nesbitt, HW;Young, GM (1982). Early Proterozoic Climates and Plate Motions Inferred from Major Element Chemistry of Lutites; Nature, vol. 299, p. 715–717.

Nwajide , CS (1990). Cretaceous Sedimentation and Paleogeography of the Central Benue Trough, In C.O.

Ofoegbu, E (2015). The Benue Structure and Evolution: Braunschweig and Wiesbaden, Germany, Virweg and SohneVerlag, p. 19-38.

Nwajide, CS; Reijiers, TJA (1997). Sequence Architecture of the Campanian Nkporo and the Eocene Nanka Formations of the Anambra Basin, Nigeria. *Nig. Ass. of Pet. Ex. Bul.,* vol. 12, n. 01, p.75-87.

Obaje, NG; Wehner, H;Schneeder, G; Abubakar, MB;Jauro, A(2004).Hydrocarbon Prospectivity of Nigeria's Inland Basin, From the View Point of Organic Geochemistry and Organic Petrology. *Am. Ass. of Pet. Geo. Bul., vol.* 88(3), p. 325-353.

Olade, MA(1975). Evolution of Nigeria Benue Trough (Aulacogen) a Tectonic Model. Geo. Magazine, vol. 112(6), p. 572-582.

Osae, S; Asiedu, DK; Banoeng-Yakubo, B; Koeberl, C;Dampare, SB (2006). Provenance and Tectonic Setting of Late Proterozoic Buem Sandstones of Southeastern Ghana: Evidence from Geochemistry and Detrital Modes, *J. of Afr. Earth Sci.,* vol. 44, p. 85- 96.

Pettijohn, FJ; Potter, PE; Siever, R(1987). Sand and Sandstone, Second edition, Springer, New York.

Roser, BP; Korsch, RJ (1988). Provenance Signatures of Sandstone and Mudstone Suites Determined Using Discriminant Function Analysis of Major-element Data. Chem. Geo. vol. 67, p. 119–139.

Short, KC;Stauble, AI (1967). Outline of the Geology of the Niger Delta. *Am. Ass. of Pet. Geo. Bul.,* vol. 51, p. 761-779.

Suttner, LJ; Basu, A; Mach, GH (1981). Climate and the Origin of Quartz-arenites. *J. of Sed. Pet.*, vol. 51, p. 1235- 1246.