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Geochemical Fingerprints; Implication for Provenance, Tectonic and Depositional Settings of Lower Benue Trough Sequence, Southeastern Nigeria

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Abstract
The study areas, Asu River Group (ARG) and Cross River Groups (CRG) belong to Lower Benue Trough. The Trough is thought to have been deposited by marine transgression and regression. ARG covers Awi, Abakaliki and Mfamosing Formations while Ekenkpon, Eze-Aku, New Netim, Awgu and Agbani Formations fall within CRG. Sampling was done to cover both the Abakaliki Anticlinorium and Calabar Flank. The study aimed at using geochemical approach to deduce weathering, provenance, tectonic setting as well as depositional environment in a holistic manner which hitherto has not been used by any worker.
A total of 56 fresh outcrop samples were obtained from the study area. The samples were subjected to detailed lithologic description by visual examination. Geochemical analysis was done using Inductively Coupled Plasma Mass Spectroscopy and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-MS/AES) to determine major, trace and rare-earth elements using lithium metaborate/tetraborate fusion method.
Weathering Indices of Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA), Chemical Index of Weathering (CIW) and Ruxton Ratio (RR) of ARG has a range of (0.18-86.1, 0.13-99.3, 0.18-99.5 and 1.80-25.2) with median of (76.7, 92.6, 93.5 and 5.76) respectively while CRG has a range of (2.93-97.7, 2.78-99.7, 2.94-99.7 and 1.83-46.4) and median of (76.1, 85.5, 87.7 and 10.9) respectively, indicating moderate to high weathering at the source. The Al_2O_3-(K_2O+CaO+MgO)-(Fe_2O_3+MgO), (AKF) ternary plots reveals sediments of ARG and CRG deposited in Continental, Transition and Marine zone and dominated by argillaceous, carbonaceous argillite, carbonaceous and a ferruginous argillites confirming a chemically altered sediments deposited in oxidizing and shallow marine environment. The plots of Log (Fe_2O_3/K_2O) vs Log (SiO_2/Al_2O_3) reveals sediments deposited in the Fe Shale, Shale, Wacke, Subarkose and Quartz arenite field. The discriminant function plots of Herron characterized the sediments as been derived from Quartzose sedimentary provenance, Intermediate igneous and Felsic provenance. Trace elements ternary plots of La-Th-Sc, Th-Sc-Zr/10 and Th-Co-Zr/10 reveal deposition within Continental Island Arc, Passive Margin and Oceanic Island Arc settings. This confirmed the tectonic discriminant plots of K_2O/Na_2O vs SiO_2. This discriminant function diagram proposed by Roser and Korsch (1986) distinguish the sources of the sediments into four provenance zones, mafic, intermediate, felsic, igneous and quartzose sedimentary using ratio plots and raw oxides. Most of the sediments of ARG and CRG fall in, quartzose sedimentary provenance using raw oxide plots, and exceptions are the limestones that fall in intermediate igneous provenance this also corroborates with the ratio plots.
Conclusively, the study shows that the Cretaceous clastic sediments of ARG and CRG have multiple provenances subjected to moderate to high weathering conditions and were deposited within an oxidizing and shallow marine setting and derived from Upper Continental Crust (UCC).
Keywords: Asu River Group, Cross River Group, Provenance, Geochemistry, Tectonic settings.
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1. Introduction

The Benue Trough is a unique rift feature on the African continent in that it occupies an intracontinental position and has a thick compressionally folded Cretaceous supracrustal fill (Cratcheley and Jones 1965; Wright 1968; Grant 1971; Burke et al. 1971; Burke and Whiteman 1973; Nwachukwu 1972; Olade 1975). The Benue Trough has a lateral extent of about 250km in the south and includes the Anambra Basin, the Abakaliki anticlinorium and the Afikpo syncline. The Lower Benue Trough is a linear, intracratonic, graben basin, tending NE-SW. Its origin is associated with the separation of the African and South American continents in the Early Cretaceous. The trough is characterized by an uplifted basement block, flanked by deep basin containing about 6km of sediments. The intracontinental Benue Trough was initiated during the lower Cretaceous in relation with the Atlantic Ocean opening

This paper describes the geochemical composition of Sandstones, Shales, Marls, Limestones from the Asu River and Cross River Group of the Lower Benue Trough, Southeastern Nigeria as exposed in Abakaliki Area and Calabar Flank (Fig. 1). Fifty-Six (56) outcrop samples were collected from eight (8) Formations: Awi, Abakaliki, Mfamosing Formations which constitute ARG while Ekenkpon, Eze-Aku, New Netim Marl, Awgu and Agbani Formations constitute CRG. The geochemistry of the siliciclastic sediments is of similar importance, because such studies can give information about the provenance, tectonic setting and weathering history of the source rocks. The geochemical composition of terrigenous sedimentary rocks is a function of the complex interplay of various variables, such as provenance, weathering, transportation and diagenesis (Bhatia, 1983). Recent investigations on geochemical characteristics of ancient and modern detritus have been carried out in order to infer the source rocks, provenance and tectonic setting (e.g., Potter, 1978; Bhatia, 1983; Hiscott, 1984; Bhatia and Crook, 1986; Roser and Korsch, 1986, 1988). Hence the study aimed at using geochemical approach to deduce weathering, provenance, tectonic setting as well as depositional environment in the Groups in a holistic manner which hitherto has not been used by any worker.

1.1 Geological Setting

The intracontinental Benue Trough was initiated during the lower Cretaceous in relation with the Atlantic Ocean opening. The first stage of its evolution started in the Aptian, forming isolated basins with continental sedimentation. In the Albian times, a great delta developed in the Upper Benue Trough, while the first marine transgression coming from the opening Gulf of Guinea occurred in the south and reached the Middle Benue. The widespread Turonian transgression made the Atlantic and Tethys waters communicate through the Sahara, Niger basins and the Benue Trough. The tectonic evolution of the Benue Trough was closely controlled by transcurrent faulting through an axial fault system, developing local compressional and tensional regimes and resulting in basins and basement horsts along releasing and restraining bends of the faults. Two major compressional phases occurred in the Abakaliki area (southern Benue) during the Santonian and at the end of the Cretaceous in the Upper Benue Trough. In Abakaliki, the sedimentary infilling was severely deformed through folding and flattening, and moderate folding and fracturing occurred in the northeast. The Cretaceous magmatism was restricted to main fault zones in most of the trough but was particularly active in the Abakaliki Trough, where it has alkaline affinities. From Albian to Santonian, the magmatism was accompanied in part of the Abakaliki Trough by a low-grade metamorphism.

1.2 Asu River Group

The Abakaliki-Benue Phase (Aptian-Santonian), have more than 3000m of rocks sequence comprising the Abakaliki, Eze-Aku and Awgu Formations, deposited during the first phase in the Abakaliki-Benue Basin, the Benue Valley and the Calabar Flank. Structural inversion affected the Abakaliki region and displaced the depositional axis further to the south of the Anambra Basin (Obi et al., 2001). In the Lower Benue, regression ended during the Santonian and the Abakaliki area emerged completely, however the effects of the Santonian phase are restricted to the Abakaliki anticlinorium, the Anambra syncline does not display traces of this tectonic episode (Benkhelil, 1986). The upliftment and folding of the the Abakaliki anticlinorium led to the exposure and subsequent erosion of the Coniacian, Turonian and Albian Formations. Consequent to this upliftment, two depressions were formed flanking the Abakaliki anticlinorium, They consist of the wide Anambra basin to the Northwest (NW) and the narrow Afikpo syncline to the Southeast (SE). ARG (Fig. 2) representing the first and the oldest cycles of the shallow marine to brackish water sediment, which were deposited in Albian and end around the Cenomanian. These sediments were deposited on the Basement Complex and consist of roughly 2000-3000m of poorly bedded shales (Abakaliki Shales), siltstone and limestone, and mudstone. The presence of Cenomanian sediments and Santonian intrusions of dykes and sill extrusions that possess important mineralization zones along the gently folded axis of the Abakaliki anticline had been reported.

1.3 Cross River Group

The Cross River Group as exposed within Calabar Flank is part of the continental margin of Nigeria dominated by block faults with NW-SE trending horst and graben structures, such as the Ituk high and the Ikang trough. The Calabar Flank forms that part of the southeastern continental margin lying between the Cameroon volcanic trend on the east, Ikpe platform on the west, Oban massif to the north and Calabar hinge line to the south. Some authors had included Calabar Flank as part of the Benue Trough. The Calabar Flank contains up to 4000 m of Albian to Maastrichtian marine sediments in outcrop sections. Overlying the Asu River Group is the Cross River Group comprising of Ekenkpon Formation, Eze-Aku Formation, New Netim Formation, Awgu Formation and Agbani Formation. The Eze-Aku Shale is represented by the Ekenkpon Shale which overlies the Odukpani Formation in the Calabar Flank and is underlying the Awgu Shale which is also represented by New Netim Marl and both represent the Nkalagu Formation (Fig. 2).

2.0 Materials and Methods

A total of Fifty (56) fresh outcrop samples were obtained from the study area; Sampling was done to cover both Asu River (ARG) and Cross River Groups (CRG) within Benue Trough. ARG covers Awi, Abakaliki and Mfamosing Formations while Ekenkpon, Eze-Aku, New Netim, Awgu and Agbani Formations fall within CRG. The study area fall within the coordinate (longitude 7°00′E and 8°35′E and latitude 5°00′N and 6°45′N) Lower

Benue Trough, Southeastern Nigeria, samples were collected from Amaseri quarry, Enyingba quarry, Nigercem quarry, Setraco quarry, Ishiagu bridge, Ugwueme, and Ugwuokwute in ARG (Fig .3 and Fig. 5) while in CRG (Fig. 4 and Fig. 5), samples were collected from Unicem quarry, Unicem junction, Km7 Awi, Km7 farmland, Km 7 Ekenkpon, Odukpani junction and New netim. Fifty (56) samples were subjected to detailed lithologic description by visual examination and were analysed for major, trace and rare-earth elements by Acme Laboratories Limited (code: 4A4B), Vancouver, Canada. Major elements (Table. 1) were analysed by lithium metaborate/tetraborate fusion Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) and trace elements (Table. 2) by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

2.1 Sample Preparation

Sediment was dried (60°C) and sieved to -80 mesh (-180 µm). A 250g aliquot was riffle split and pulverized to 85% passing 200 meshes (75 µm) in a mild-steel and puck mill.

2.2 Results

Lithologies observed include sandstone, shale, marl, limestone as well as lignite. Megascopically, the sandstones are fine to medium grained, well sorted and sub-angular to sub-rounded, while the shales are organic ranging from light grey to black. Majority of the shale samples were very fissile while, others were highly indurated with laminations and specs of mica. The lignite is black in colour and could represent sub-bituminous to bituminous coal. It is also worthy of note that some of the sandstone samples appear reddish brown in colour as a result of ferruginisation. Observed limestone samples were fossilliferous with some of the fossil fragments visible to the naked eye.

3.0 Discussion

3.1 Major Elements Geochemistry

The clastic sediments of the ARG have fluctuating values for their SiO_2 ranging from 0.18-3.72% for Mfamosing Formation, 51.48-67.24% for Abakaliki Formation, and 55.49-80.76% for Awi Formation with an average of (1.16, 56.86 and 73.99) respectively. Only Awi Formation in the ARG has average SiO_2 higher than the average of 66% by weight for Upper Continental Crust (UCC) (Taylor and McLennan, 1985). Likewise in CRG, the (SiO_2) content is from 68.83% to 95.02% for Agbani Formation, 46.97-63.34% for Awgu Formation, 27.33-53.92% for New Netim Marl, 5.84-87.84% for Eze-Aku Formation and 6.72-58.21% for Ekenkpon Formation with an average of (89.06%, 55.20%, 44.42%, 41.32%, 44.48%) respectively. Only Agbani Formation in the CRG has average SiO_2 higher than the average of 66% by weight for Upper Continental Crust (UCC) (Taylor and McLennan, 1985). The limestones of Mfamosing have extremely low SiO_2 contents as low as 0.18% and which is primarily due to the fact that it consists basically of volatile constituents that were combusted as is evident from their average loss on ignition (43.42%). The high value values for CaO in the Mfamosing limestones indicate they are carbonates and are mainly calcite (97% $CaCO_3$). In similar vein, the limestones of Eze-Aku and Ekenkpon of CRG have high SiO_2 contents of 5.84% and 6.72% with loss of ignition (LOI) of (41.1% and 32.0% respectively) when compared to Mfamosing Limestone, indicating that they have lower volatile constituents. The high value values for CaO in the limestones indicate they are carbonate. The value Al_2O_3 ranges from (0.1-0.48%, 10.67-23.13% and 3.66-14.11% with an average of 0.21%, 19.96%, 8.96% and 15.21% for Mfamosing, Abakaliki, Awi Sandstone and Awi Lignite respectively, while in CRG, Al_2O_3 ranges from (1.9-3.87%, 17.58-25.71%, 6.21-13.25%, 1.45-15.03% and 2.29-19.85%) with an average of (2.82, 21.65, 10.12, 5.19 and 15.76%) for Agbani Formation, Awgu Formation, New Netim Formation, Eze-Aku Formation and Ekenkpon Formation respectively). The mean high value of Al_2O_3 in Abakaliki shale, Awi sandstone and Lignite within (ARG) and in Awgu, New netim marl, Eze-Aku Shale and Ekenkpon Shale (CRG) may indicate a high kaolinite/illite ratio (Besly and Clearl, 1997) and presence of aluminosilicate materials (feldspar and mica). The limestones of Mfamosing, Eze-Aku and Ekenkpon are depleted in Al_2O_3. Also a corresponding high average value of $Al_2O_3/(Na_2O+CaO)$ (111.49) in Awi Formation (ARG), (64.15) in Agbani Sandstone and (240.6) in Awgu Shale (CRG) which is a ratio of the most immobile to the most mobile element confirm high content of clastic materials over carbonate materials, while low values of (0.01) for Mfamosing limestone (ARG), (0.65, 0.79 and 11.34) for New Netim, Eze-Aku and Ekenkpon Formations confirm high content of carbonate materials over clastic materials. Generally, the MgO, $Fe_2O_{3\,(t)}$ and ($MgO+Fe_2O_3$) content ranges from (0.25-0.43%, 0.06-0.45% and 0.37-0.78% for Mfamosing Formation, (0.94-2.31%, 4.21-10.34% and 5.15-12.56%) for Abakaliki Formation, (0.12-0.20%, 1.02-2.85% and 1.14-3.67%) for Awi Formation, However, shales of Abakaliki are ferruginised due to appreciable amount of Fe_2O_3. In similar vein for CRG, MgO, $Fe_2O_{3\,(t)}$ and ($MgO+Fe_2O_3$) content ranges from (0.01-0.03%, 0.44-23.93% and 0.23-23.94%) respectively for Agbani Sandstone, (0.18-0.37%, 2.4-3.69% and 2.58-4.06%) for Awgu Shales, (1.03-1.65%, 1.01-2.50%, and 2.04-3.95%) for New Netim Marl, (0.41-1.33%, 0.83-5.12% and 1.18-6.45%) for Eze-Aku Fm, (0.58-2.26%, 2.51-13.63% and 3.55-15.89%) for Ekenkpon Fm. However, Ekenkpon Shale and Agbani Sandstone are ferruginised due to appreciable amount of Fe_2O_3. $Al_2O_3/(Fe_2O_3+MgO)$ ranges from (0.14-0.62, 1.69-3.06 and 3.21-6.54) for Mfamosing, Abakaliki and

Awi Formations respectively in ARG and (0.09-11.78) in Agbani Formation, (6.33-6.81) in Awgu Shales, (3.00-3.36) in Netim Marl, (0.97-4.43) in Eze-Aku Formation and (0.38-3.83%) in Ekenkpon with an average of (2.9%, 6.57%, 3.17%, 1.96% and 1.98%) respectively. This indicates moderate diagenetic alteration especially in Awi Formation (ARG), Awgu Formation and Agbani Formations within CRG. K_2O/Al_2O_3 values ranges from (0.21-0.30) in Mfamosing, (0.08-0.15) in Abakaliki Formation and (0.21-0.34) in Awi Formation within ARG, and (0.02-0.08, 0.04-0.06, 0.21-0.31, 0.05-0.21, 0.11-0.21) in Agbani, Awgu, New Netim, Eze-Aku and Ekenkpon Formations within CRG. The very low value in Abakaliki, Agbani and Awgu Formations suggests sedimentary recycling or increase in the degree of source area weathering (Bauluz et al., 2000). This can be backed-up by increase in the value of Al_2O_3 and Fe_2O_3 which corresponds to decrease in the value of SiO_2 and vice versa (see Table 1). It is an indication of weathering and alteration. The relatively high values of K_2O/Na_2O ratios especially in shales of CRG is attributed to the presence of albitic plagioclase, K-feldspar, mica and illite (Pettijohn et al., 1963, McLennan et al., 1983, Nath et al., 2000, Osae et al., 2006). Awgu Formation has high value of K_2O/Na_2O up to about 25%. Average values of Al_2O_3/SiO_2 are (0.29, 0.36, and 0.16) in Mfamosing, Abakaliki and Awi Formations respectively within ARG, and (0.03, 0.41, 0.24, 0.18 and 0.35) for Agbani, Awgu, New Netim, Eze-Aku and Ekenkpon Formations within CRG. The low average value in Awi Formation (ARG), Agbani, New Netim and Eze-Aku Formations (CRG) is an indication of quartz enrichment (Bhatia, 1983), this supports the relatively high average value of SiO_2/Al_2O_3 for Awi Sandstone (10.31), Agbani (32.82) and Eze-Aku (8.06).Within Asu River Group, CaO is the most abundant major elements in Mfamosing Limestone, with average values of 54.5% this is backed up by high loss of ignition, Other major elements in the limestones has low values in the following order (MgO, Na_2O, K_2O, TiO_2, P2O5, MnO, and Cr_2O_3) having 0.35, 0.005, 0.06, 0.01, 0.04, 0.09 and 0.002% respectively. In Abakaliki Formation, Al_2O_3, Fe_2O_3 and MgO decreases with increasing SiO_2 with while others (TiO_2, P_2O_5, MnO and Cr_2O_5) have very low concentrations in the following order (0.9,0.12, 0.08 and 0.014%) respectively. In Awi Formation, Fe_2O_3 and K_2O are the most abundant major elements besides Al_2O_3 and SiO_2 with an average of 1.7% and 2.7% respectively, while others (MgO, CaO, Na_2O, TiO_2, P_2O_5, MnO and Cr_2O_5) have very low concentrations in the following order, 0.49, 0.02, 0.07, 0.53, 0.06, 0.008 and 0.006, respectively. Similarly in CRG, Fe_2O_3 is the most abundant major element in Agbani Sandstone besides Al_2O_3 and SiO_2 with an average of 5.5% while others (MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, MnO and Cr_2O_5) have very low concentrations in the following order, 0.02, 0.03, 0.02, 0.10, 0.07, 0.11, 0.01, and 0.001 respectively. In Awgu Shale, (CaO, Na_2O, K_2O, TiO_2, P_2O_5, MnO and Cr_2O_5) have very low average concentrations in the following order, 0.06, 0.04, 0.98, 1.26, 0.16, 0.008 and 0.013 respectively, In Eze-Aku Formation, CaO and Fe_2O_3 are the most abundant major element besides Al_2O_3 and SiO_2 with an average of 24.79% and 2.23% respectively while others (MgO, Na_2O, K_2O, TiO_2, P_2O_5, MnO and Cr_2O_5) have very low concentrations in the following order, 0.68, 0.54, 0.73, 0.3, 0.18, 0.23 and 0.005% respectively, while Ekenkpon Shale has high value of Fe_2O_3 and K_2O with an average of 7.22% and 3.02% respectively, other major elements in the shale has low average concentration (MgO, 1.78%, CaO, 1.41%, Na_2O, 0.86%, P_2O_5, 0.61%, TiO_2, 0.91%, MnO_2, 0.04% and Cr_2O_3, 0.013%). The summary of major element of ARG and CRG is given in Table 3 and 4 respectively.

3.1.1 Classification of the Sediments

Standard plot of Herron (1988) using log (Fe_2O_3/K_2O) against log (SiO_2/Al_2O_3) which is a modified version of Pettijohn et al., (1972) was employed to classify the sediments of the ARG and CRG. Abakaliki Shales plotted within the Fe shale, while Awi Sandstones fall within the subarkose region (Fig. 6). In CRG, the sandstone of Agbani Formation falls within the quartz arenite, region which is also an indication of the enrichment of quartz in the samples. Agwu Shale and Ekenkpon Shale are plotted in shale region, Eze-Aku Sandstone fall in the subarkose region, while New Netim Marl and few samples of Eze-Aku Shale were plotted in wacke region (Fig. 7). A Ternary plot was used to classify the limestone of Eze-Aku, Ekenkpon and New Netim Marl which falls in carbonate region (Fig. 8). With a sample of New Netim Marl plotted close to siderite.

3.1.2 Paleo-Weathering Indices and Maturity

The Chemical Index of Alteration (CIA) and Plagioclase index of Alteration (PIA) are the most widely used indices for quantitative estimation of the degree of chemical weathering undergone by the rocks of the provenance area of clastic sediments by (Fedo et al., 1995) which gives an indication of the degree of weathering in the source region (Nesbitt and Young, 1982). Other indices also used are the Chemical Index of Weathering (CIW) (Harnois, 1988) and Ruxton Ratio (RR).

The $CIA=100[Al_2O_3/ (Al_2O_3+CaO+Na_2O+K_2O)]$

The $PIA=100[(Al_2O_3-K_2O) / (Al_2O_3+CaO+Na_2O-K_2O]$

The $CIW=100[Al_2O_3/ (Al_2O_3+CaO+Na_2O)]$

The $RR= Si0_2/Al_20_3$

CIA, PIA and CIW for ARG has median of (76.7, 92.6 and 93.5) % respectively while CRG having median of (76.1, 85.5, and 87.7) % respectively indicating moderate to high weathering at the source (see Table 5). These values are variable and it may be as a result of multiple provenances for the sediments which have variable proportions of source area weathering and related processes or may be due to low concentrations of the alkalis and alkaline earth elements. However, majority of the samples show CIA, PIA and CIW values greater than 60% indicating moderate to high (intensive) weathering either at the source or during transport before deposition (McLennan, 1993; Fedo et al., 1995). Exceptions are the limestone samples and some shales showing extremely low values. From the high alteration indices, it can be inferred that the sediments are geochemically and texturally mature. In ARG, the CIA values were also plotted in Al_2O_3 - (CaO + Na_2O) - K_2O (A - CN - K) diagram (Fig. 9). In the A-CN-K diagram, the sediments comprising of Awi Sandstones, Abakaliki Shales and Awi lignite were plotted mostly within the kaolinite-chlorite and illite region. The fact that the samples did not plot very close to the plagioclase-k-feldspar join line is an indication of high weathering at the source with the limestone having extremely low value of CIA. In CRG sediments, Agbani Sandstone, Agwu Shale, Ekenkpon Shale with a sample of Eze-Aku Sandstone were plotted within the kaolinite-chlorite, and smectite-illite region, an indication of high weathering at the source, while New Eze-Aku Shales are plotted near plagioclase indicating low to moderate weathering in the source (Fig.10). Also, the relationship between Th/U ratio and Th concentration can also be applied as an estimate of the degree of weathering in sedimentary rocks. Both Th and U are relatively immobile during weathering, although, U may change its redox state from U^{2+} to U^{6+}, (the latter being more soluble) during re-working under oxidizing conditions as this is the case and it is thus more readily removed from the system thereby increasing the Th/U ratio above upper crust igneous values. The Th/U ratio in most upper continental rocks is typically between 3.5-4.0 (McLennan et al., 1993). In sedimentary rocks, Th/U values higher than 4.0 may indicate intense weathering in the source areas or sedimentary recycling. ARG sediments has Th/U ratios of 0.03-7.90 with median of 3.82, these fall within the Th/U value for upper continental rocks which is typically between 3.5-4.0 (McLennan et al., 1993), while CRG range from 0.36-7.33 with median of 3.98 indicating moderate to high weathering the source area or sediment recycling. Sediments from active margin tectonic settings have Th/U significantly below 3.5 accompanied by low Th and U contents (Fig.11 and Fig.12) and this is interpreted as dominantly reflecting a low ratio in the source rock (McLennan 1989b, McLennan and Taylor, 1990). This can be seen for the ARG and CRG sediments which have a variable proportion of low Th/U ratios. Low Th/U ratios are rather common in mantle derived volcanic rocks and reflect the geochemically depleted nature of such reservoirs (Newman et al., 1984). Also, it is worthy of note to add that high Th/U ratios are seen in recycled sedimentary source rocks (McLennan et al., 1993) and this is also reflected in the sediments because an appreciable percentage of the sediments have high Th/U ratios as well. From this, it can also be ascertained that the ARG and CRG are from both active continental margins as well as passive margins which translates into mixed environments for the sediments. In ARG, Abakaliki Shale and Awi Sandstone has high Th/U ratio greater than 3.5 while In CRG, Ekenkpon Shale, and few samples of Agbani Sandstone have Th/U ratio above 3.5 thus exhibiting sedimentary recycling. Also, a bivariant plot of SiO_2 against total (Al_2O_3+K_2O+Na_2O) proposed by Suttner and Dutta, 1986 (Fig.13 and Fig.14) was used in order to identify the maturity of the sandstones of Awi and Agbani and Eze-Aku as a function of climate. The plot revealed semi-humid conditions for the sandstones and most other sediments with exceptions of shale in both groups.

3.1.3 Depositional Environment and Provenance Signatures

The depositional environments for sediments of the ARG and CRG were classified based on the ternary plots of Englung and Jorgensen (1973). This involves the chemical classification on the basis of (Al_2O_3)-(K_2O+ Na_2O+CaO)-(Fe_2O_3+MgO) contents (AKF). As can be observed from the plots, there is a gradual transition of the sediments from continental to transitional environments which depicts a somewhat shallow-marine environment. (Fig.15) shows that Awi Sandstone, Awi Lignite and Abakaliki Shales fall under transition zone while carbonaceous Mfamosing limestones fall into marine zone. (Fig.16) shows that the Agbani sandstone of CRG mainly plotted in the continental zone and are ferruginised thus named Ferruginous argillite, Ekenkpon Shales and few samples of Eze-Aku Shales, New Netim Marl and sandstone of Eze-Aku falls in the transition zone but are tending towards marine zone where there are plotting of limestones of both Eze-Aku and Ekenkpon Formation. Both limestones are carbonaceous while the New Netim Marl, Eze-Aku Sandstones and few shales of Eze-Aku falls under carbonaceous argillite. Awgu Shales are plotted in the continental zone which is also Argillaceous. This shows that some of the sediments were transported from the continental environment before being deposited in the shallow-marine environment elucidating the fact that the sediments underwent moderate to high transportation levels under oxidizing conditions.

Several classifications have been proposed to discriminate from various tectonic settings (Maynard et al., 1982; Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986. The provenance signature study employed for this study helps distinguish the sources of the sediments into four provenance zones, mafic, intermediate or felsic, igneous and quartzose sedimentary. This discriminant function diagram proposed by Roser and Korsch (1986) makes use of the oxides of Ti, Al, Fe, Mg, Ca, Na and K to effectively differentiate the sediments into four provenance zones. They also noted that biogenic CaO and SiO_2 in provenance determination could be eliminated by a plot in which the discriminant functions are based upon the ratios of TiO_2, Fe_2O_3, MgO and K_2O all to Al_2O_3 though it is not as effective as the one based upon the raw oxides. The discriminant functions for the two plots used to discriminate the sediments from the study area are as follows:

The formula for raw oxides is given as:

Discriminant Function (DF1) = $-1.773TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_{3\,(T)}$. $1.5MgO + 0.616CaO + 0.509Na_2O - 1.224K_2O - 9.09$

Discriminant Function (DF2) = $0.445TiO_2 + 0.07Al_2O_3 - 0.25Fe_2O_{3\,(T)} - 1.42MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.861$.

While that of the ratio plot is given as:

Discriminant Function (DF1) = $30.638\ TiO_2/Al_2O_3 - 12.541\ Fe_2O_{3(T)}/Al_2O_3 + 7.329\ MgO/Al_2O_3 + 12.031Na_2O/Al_2O_3 + 35.402\ K_2O/\ Al_2O_3 - 6.382$

Discriminant Function (DF2) =$56.500TiO_2/Al_2O_3 - 10.879\ Fe_2O_{3(T)}/Al_2O_3 + 30.875\ MgO/Al_2O_3 - 5.404\ Na_2O/Al_2O_3 + 11.112\ K_2O/Al_2O_3 - 3.89$.

From the plots (Fig.17 and Fig.18), Awi sandstone falls in felsic igneous provenance, Abakaliki shale from quartzose sedimentary source, Awi sandstone were derived from recycled sources or felsic igneous provenance and the derivation of the sediments could be from a highly weathered granite-gneiss terrain and/or from a pre-existing sedimentary terrain Roser and Korsch (1986). The plots using the raw oxides (Fig.19) revealed that the CRG sediments were sourced majorly from quartzose sedimentary provenance, while ratio plots (Fig.20) also correspond with the oxide plots showing sediments plotting majorly in the quartzose sedimentary provenance. However, Agbani sandstone, Eze-Aku Sandstone, Awgu Shale, Eze-Aku Shale and Ekenkpon Shale were derived from quartzose sedimentary provenance. The felsic input must have come from pre-existing sedimentary terrain probably recycled orogen provenance.

3.2 Trace Elements geochemistry

3.2.1 Provenance and Tectonic setting

The high field strength elements (HFSE) such as Zr, Nb, Hf, Y, Th, are preferentially partioned into melts during crystallization (Feng and Kerrich, 1990) and as a result, these elements are enriched in felsic rather than mafic sources. These elements are thought to reflect provenance compositions as a consequence of their generally immobile behavior (Taylor and Mclennan, 1985). The ferromagnesian trace elements Cr, Ni, Co and V show generally similar behavior in magmatic processes but they may be fractionated during weathering (Feng and Kerrich, 1990). In the studied samples, Cr and Ni are enriched with respect to the average composition of the upper continental crust (UCC). This enrichment of Cr and Ni may suggest some basic input from the source terrane. The elevated values of Cr (>150ppm) and Ni (>100ppm) and the ratio of Cr/Ni between 1.3-1.5, are diagnostic of ultramafic rocks in the source region (Garver et al., 1996). In comparison, Cr concentrations range from 6.84 to 103ppm with an average of 46.4 in CRG sediments, while Ni ranges from <20 to 81ppm with an average of 40.6. while in Asu river sediments, the Cr concentrations range from 6.84 to 123ppm with an average of 50.9, Ni ranges from <20 to 61ppm with an average of 22.8. This comparison implies that the existence of ultramafic rocks in the source region was unlikely. Also, the Co enrichment which has an average value of 8.5 for CRG and 7.03 for ARG sediments are lower than the Average Upper Continental Crust (AUC) (10.00) confirms a much reduced mafic input from the source area (Taylor and McLennan, 1985). Therefore it can be concluded that the sediments of both groups are from mixed environments of felsic igneous provenance, intermediate igneous and with quartzose sedimentary provenance dominant. Summary of the trace elements geochemistry of ARG and CRG is given on Table 6 and 7 respectively.

Bhatia and Crook (1986) used La, Th and Sc concentrations as well as Th, Sc and Zr/10 and Th, Co and Zr/10 concentrations to discriminate sediments derived from oceanic island arc, from continental island arcs and from active and passive continental margins. Using Th-Co-Zr/10 and Th-Sc-Zr/10 ternary plots, for ARG sediments (Fig.21 and Fig.22), shows Awi Sandstone, Awi lignite plotted in passive margin while Abakaliki Shales falls into continental island arc together with Mfamosing Limestone, these plots also correlate with ternary plot of La-Th-Sc (Fig.23). Using La-Th-Sc, Th-Co-Zr/10 and Th-Sc-Zr/10 ternary plots, the CRG sediments showed affinity for continental island arc and passive margin with few plotting in oceanic island arc and active continental margin. Ternary diagram of both Th-Co-Zr/10 and Th-Sc-Zr/10 (Fig.25 and Fig.26) shows Ekenkpon Shales, Eze-Aku Shales, Awgu Shales and Eze-Aku limestones were derived from continental island arc. While Agbani Sandstone, New Netim Marl and Eze-Aku sandstone were derived from passive margin, these also have similarity with that of La-Th-Sc ternary plot (Fig.24). Th-Co-Zr/10 plot indicates that Ekenkpon Limestones tectonic setting is from Oceanic island arc. Roser and Korsch (1986) established a discriminating diagram using log (k_2O/Na_2O) Vs SiO_2 (Fig.27 and Fig.28) to discriminate tectonic settings of terrigenous sedimentary rocks. From the diagram the sediments plotted in the active continental margin as well as the passive margin field correlates with the ternary diagram to discriminate tectonic settings by Bhatia and Crook (1986).

4. **Conclusion**

The inorganic geochemical analysis has been applied to study the sediments of Lower Benue Trough with attendant information derived from the work, the bulk geochemical studies of the ARG and CRG sediments revealed that SiO_2 is the dominant oxide followed by Al_2O_3 and Fe_2O_3 which constitutes over 90% while others like K_2O, TiO_2, Na_2O, MgO and P_2O_5 constitute the rest. The SiO_2/Al_2O_3 ratios for the sediments in both groups are appreciably high indicating that the samples have been heavily weathered evidenced from the enrichment of quartz and depletion of feldspars. Also, the relatively high concentrations of Fe_2O_3 and TiO_2 is an indication of iron-titanium minerals such as haematite and anatase rutiles, high concentration of CaO in limestones of Mfamosing in ARG, Eze-Aku and Ekenkpon in CRG is an indication of carbonate as well as, the high K_2O/Na_2O ratios especially in shales is attributed to the presence of plagioclase. The mean high values of Al_2O_3 in Abakaliki Shale (ARG), Agwu Shale, New Netim Marl, Eze-Aku Shale and Ekenkpon Shale (CRG) may also indicate a high kaolinite/illite ratio.

Using the major element geochemistry, the application of source area weathering using CIA, CIW, PIA and RR median value of (76.7, 92.6, 93.5 and 5.76) respectively in ARG and (76.1, 85.5, 87.7 and 10.9) respectively in CRG reveals that the sediments have been subjected to intense weathering at the source area as well as high levels of chemical weathering and transportation especially in Abakaliki Shale and Awi Sandstone in ARG and Agbani Sandstone, Awgu Shale and Ekenkpon Shale in CRG. In the A-CN-K diagram, the sediments comprising of Awi sandstones, Abakaliki shales and Awi lignite were plotted mostly within the kaolinite-chlorite and illite region, In CRG sediments, Agbani Sandstone, Agwu Shale, Ekenkpon Shale with a sample of Eze-Aku sandstone were plotted within the kaolinite-chlorite, and smectite-illite region, an indication of high weathering at the source. While New Netim Marl, Eze-Aku shale plotted near plagioclase indicating low to moderate weathering in the source. Th/U ratios of the sediments in ARG sediments have Th/U ratios of 0.03-7.90 with median of 3.82, while CRG range from 0.36-7.33 with median of 3.98 indicating high weathering at the source.

Bivariate plot of SiO_2 against total $Al_2O_3+K_2O+Na_2O$ proposed by Suttner and Dutta, 1986 was used in order to identify the maturity of the sandstones, In ARG, there is increasing chemical maturity from Abakaliki Shale to Awi Sandstone, while in CRG, there is increasing chemical maturity from Ekenkpon Shale, New Netim Marl, Awgu Shale, Eze-Aku Sandstone to Agbani Sandstone.

The use of Herron's model classified the sediments of ARG as Fe Shale, Sub arkose while in CRG sediments plotted in Shale, Wacke, Subarkose and Quartz arenite. Ternary plot to classify the limestones of Mfamosing, Eze-Aku, Ekenkpon and Marl of New Netim reveals they are Calcitic with a sample of Eze-Aku limestone plotted in Magnesite. (AKF) ternary plots reveals sediments of ARG and CRG deposited in Continental, Transition and Marine zone and dominated by Argillaceous, Carbonaceous Argillite, Carbonaceous and a Ferruginous argillites confirming a chemically altered sediments deposited in oxidizing and shallow marine environment. Furthermore, the discriminant function plots of Roser and Korsch for the provenance signature studies reveals sediments of ARG and CRG dominants in quartzose sedimentary provenance with few inputs from intermediate igneous, as well as felsic igneous provenances. The trace elements geochemistry through the use of La-Th-Sc, Th-Sc-Zr/10 and Th-Co-Zr/10 after (Bhatia and Crook, 1986) reveals that sediments of both ARG and CRG plotted in the Continental Island Arc, Passive margins and Oceanic Island Arc. This is also conforming to tectonic discriminant plots of K_2O/Na_2O vs SiO_2 by (Roser and Korsch 1986). It therefore implies that the sediments were deposited in plate interiors or in an intracratonic basin. Thus, the source of ARG and CRG sediments was from Quartzose sedimentary terrain, this corroborates with the plot of Th/Sc versus Zr/Sc (after Mclennan et al., 1993) in which most of the sediments of both groups have been reworked or recycled. Th/U average values are 3.65 and 3.71 in ARG and CRG suggesting they are from UCC.

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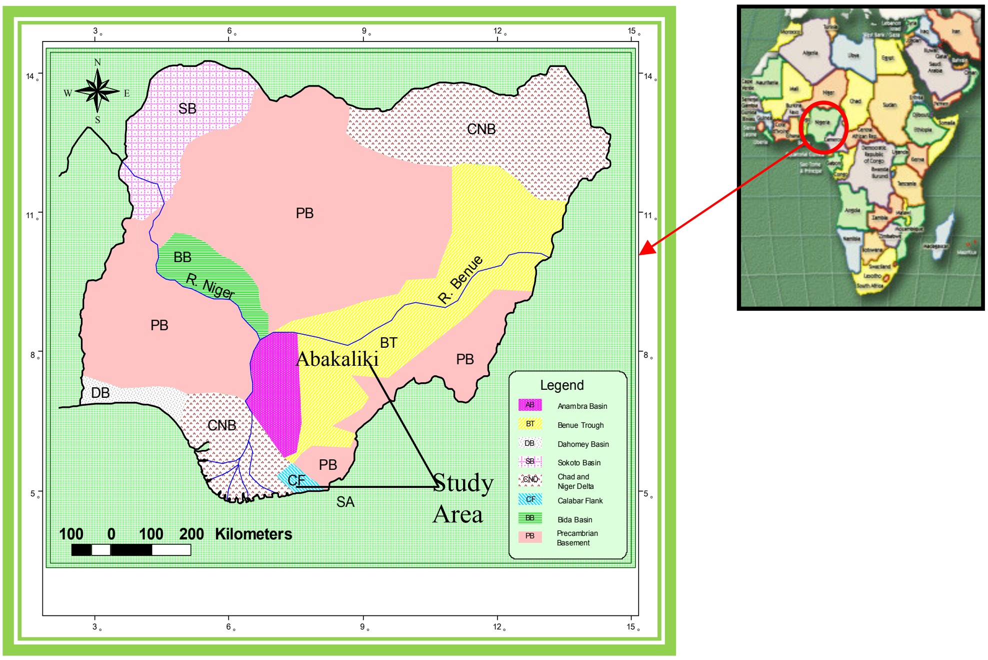

Fig 1: **Geological map showing different basin in Nigeria, note the Benue trough (BT), Abakaliki (ARG) and Calabar Flank (CRG) modified after Obaje, 2004.**

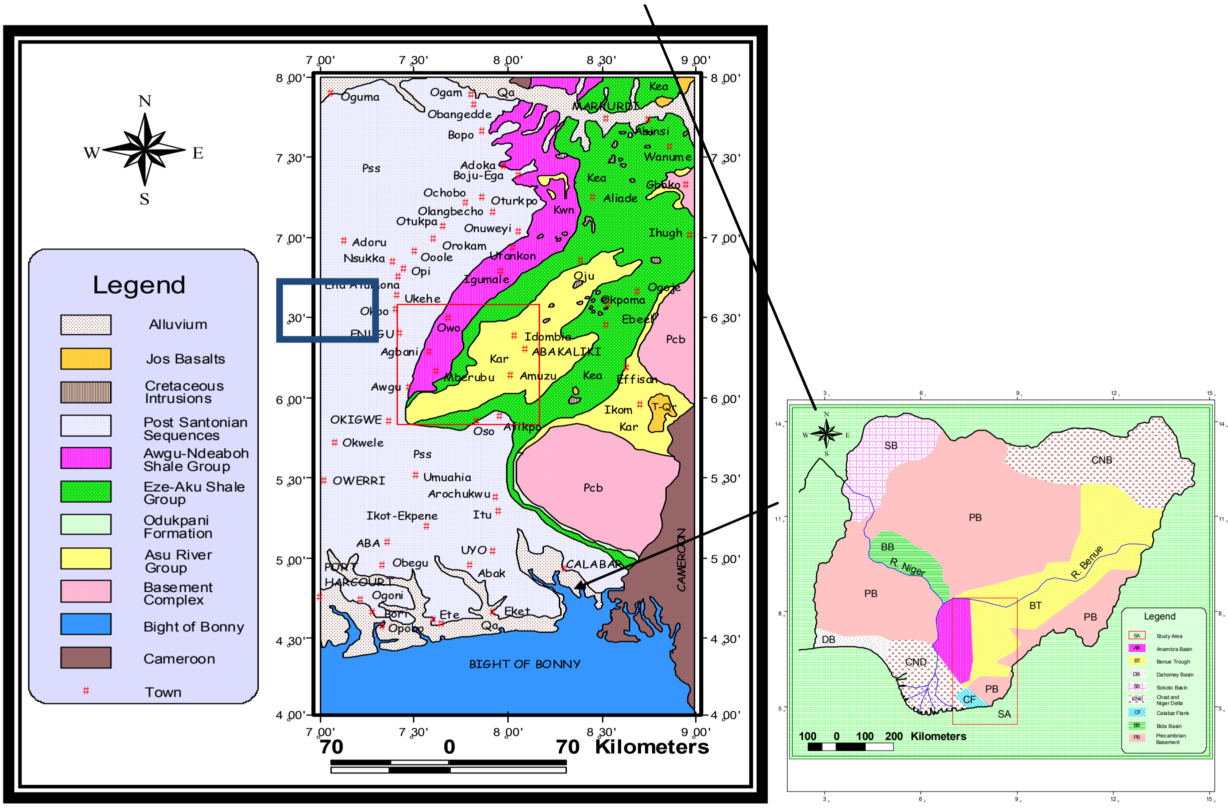

Fig 2: Geological Map of Southeastern Nigeria Covering the Study Area (ARG, i.e Red Thin line) and (CRG, i.e Blue Thick line)

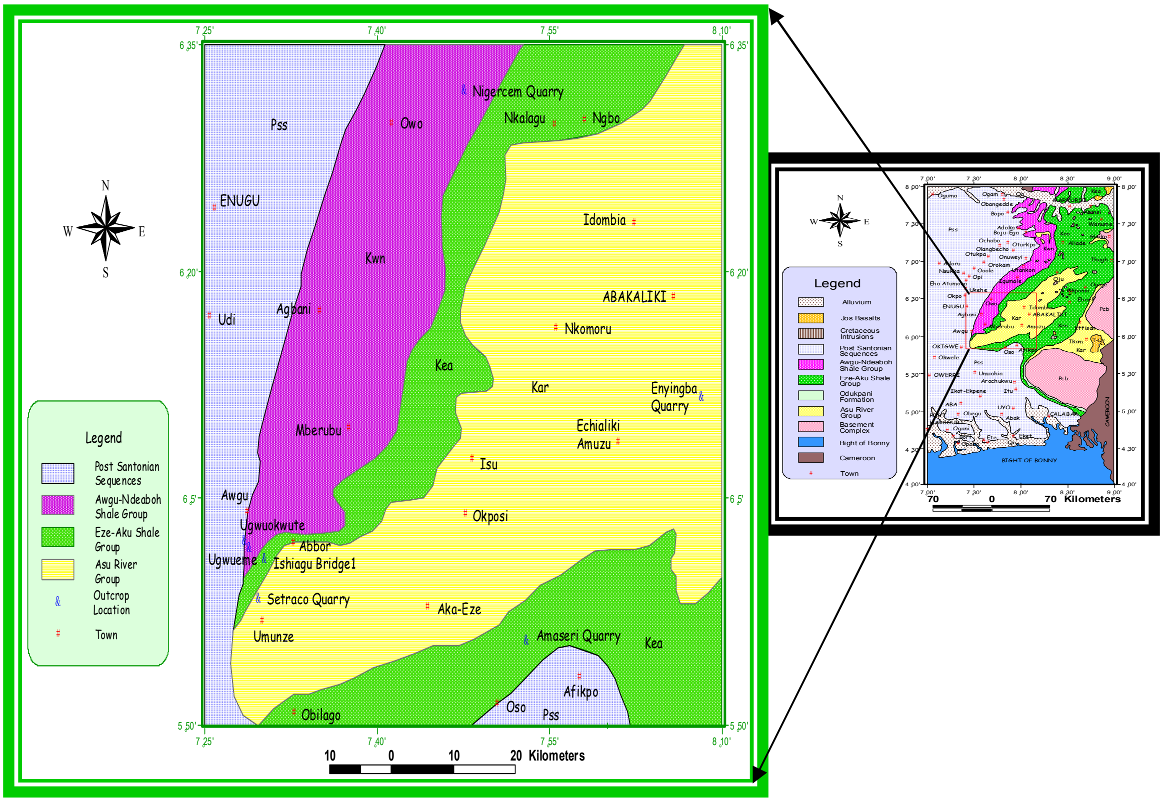

Fig 3: Geological map of the ARG showing sample location

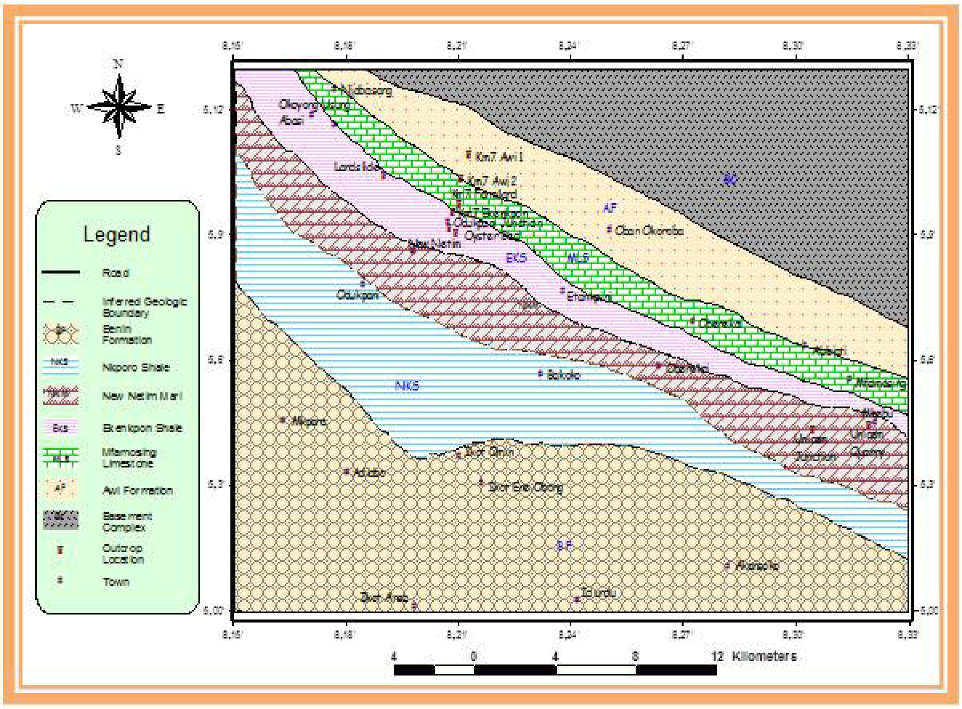

Fig. 4: Geological map of the CRG showing sample location

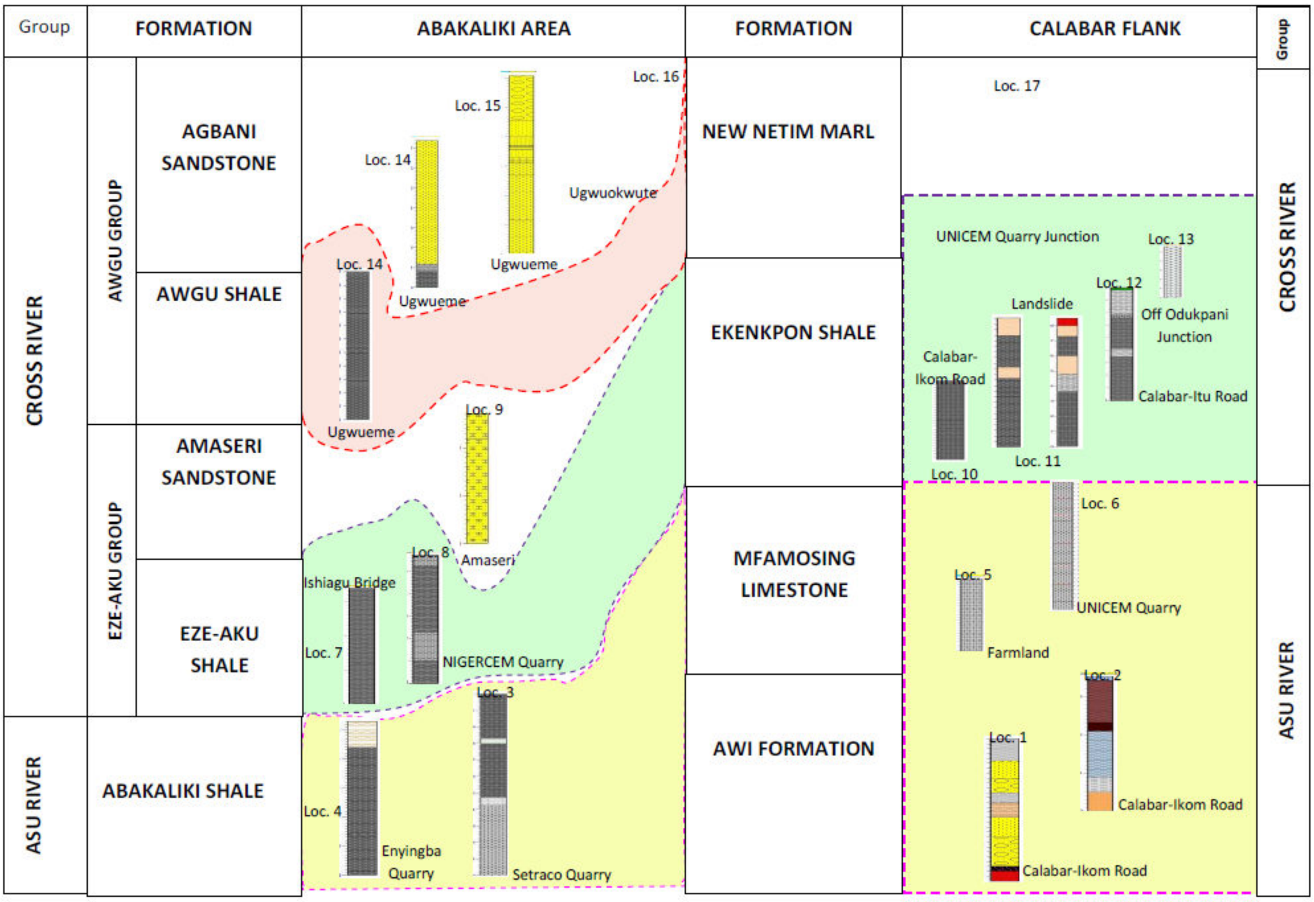

Fig. 5: Correlation Chart of all Outcrops Studied showing their Locations, Formations and Groups.

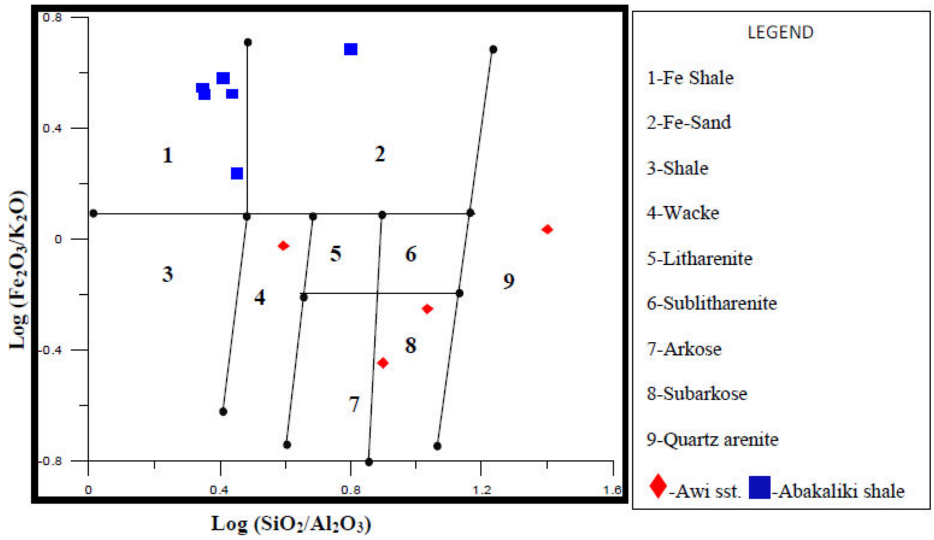

Fig. 6: Classification of Siliclastic sediments of ARG (After Herron, 1988)

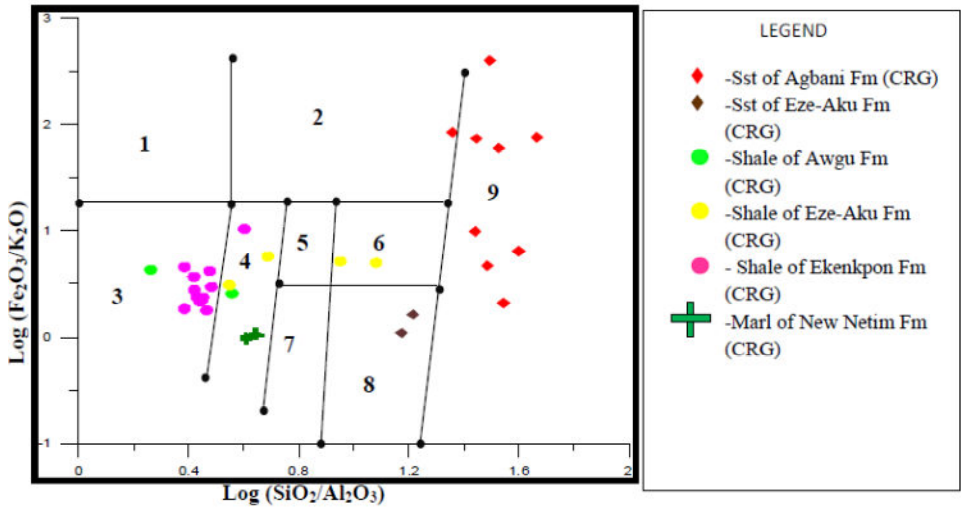

Fig. 7: Classification of Siliclastic sediments CRG (After Herron, 1988)

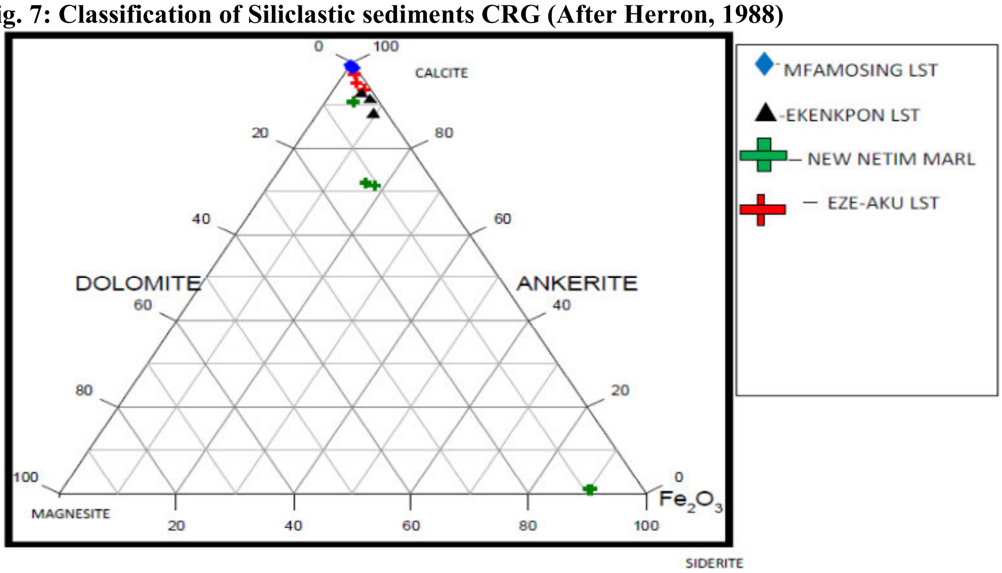

Fig. 8: Ternary diagram classifying carbonate rocks of both ARG and CRG

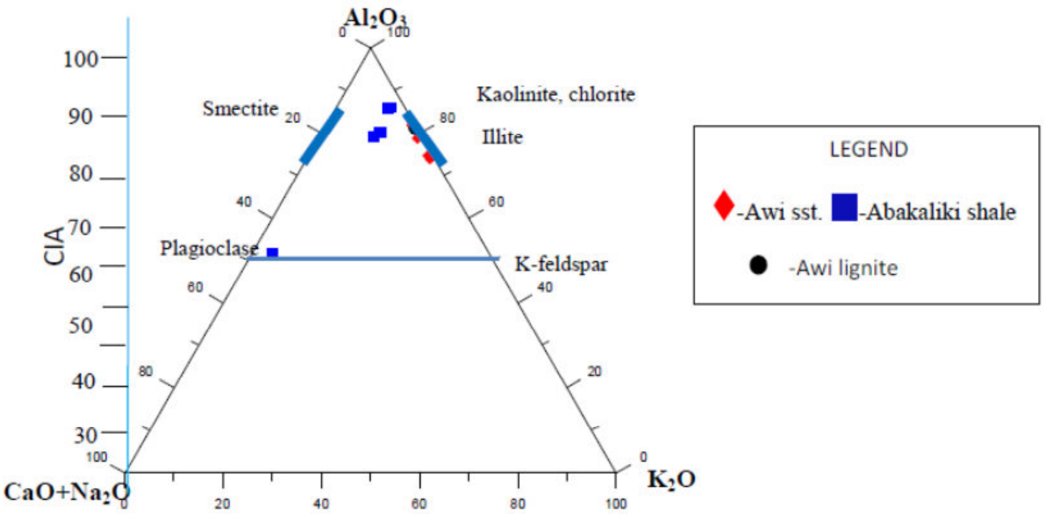

Fig 9: CIA ternary diagram (Al_2O_3-$CaO+Na_2O$-K_2O) for Asu River Group (after Nesbitt and Young, 1982).

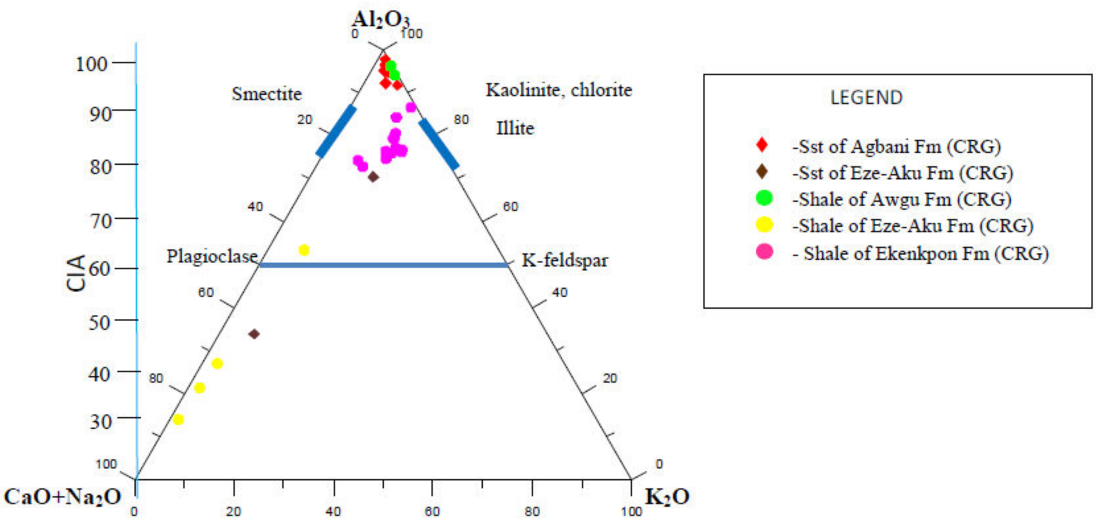

Fig 10: CIA ternary diagram (Al_2O_3-$CaO+Na_2O$-K_2O) for Cross River Group (after Nesbitt and Young, 1982).

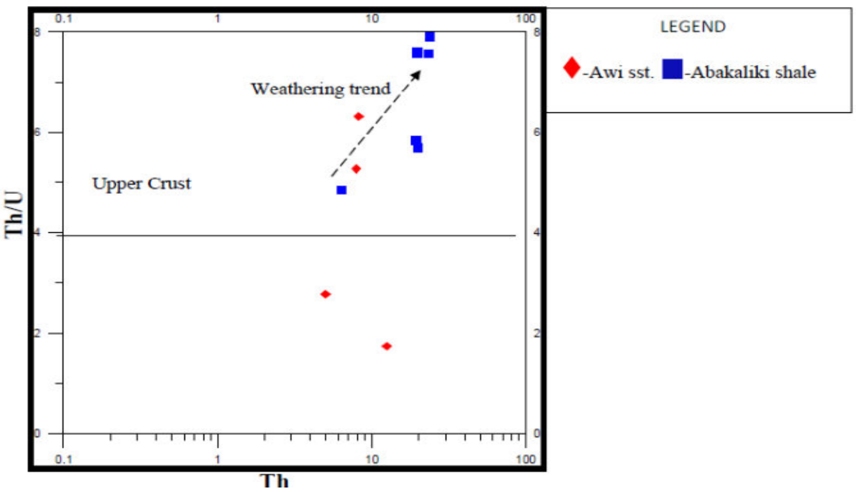

Fig 11: Plot of Th/U vs Th for Asu River Group sediments (after McLennan et al., 1993).

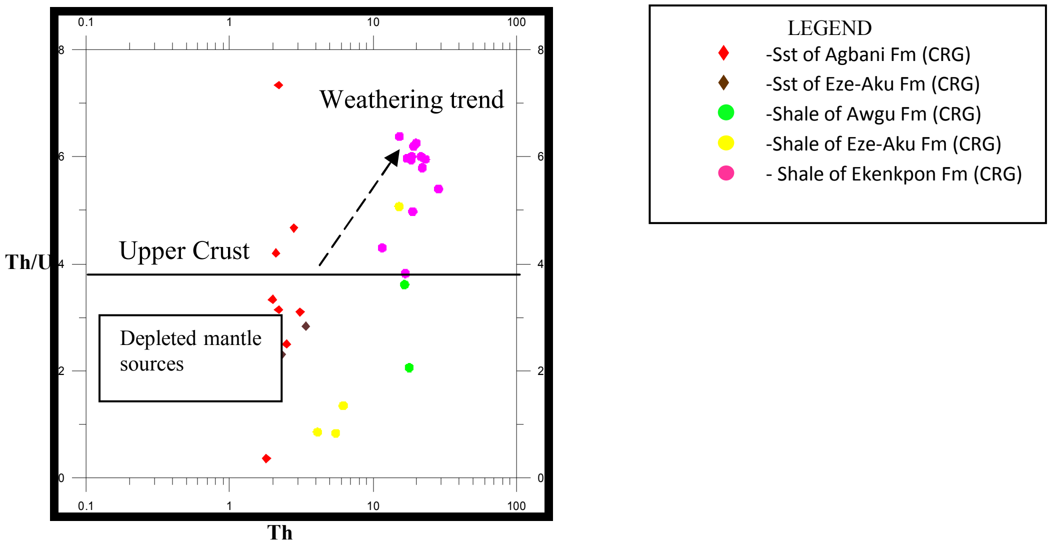

Fig 12: Plot of Th/U vs Th for Cross River Group sediments (after McLennan et al., 1993).

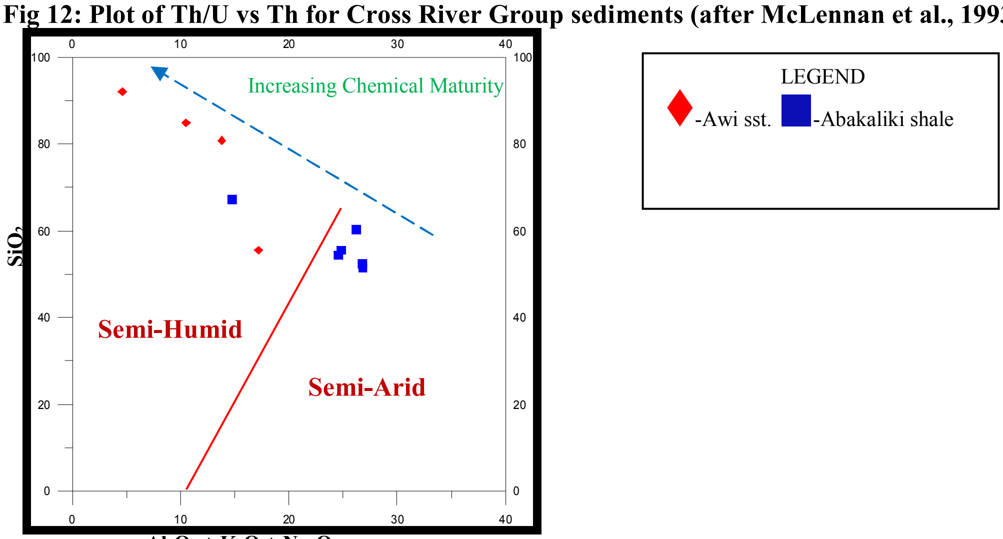

Fig 13: SiO_2 versus (AL_2O_3+K_2O+Na_2O) for Asu River Group sediments showing trend of Maturity (after Suttner and Dutta, 1986)

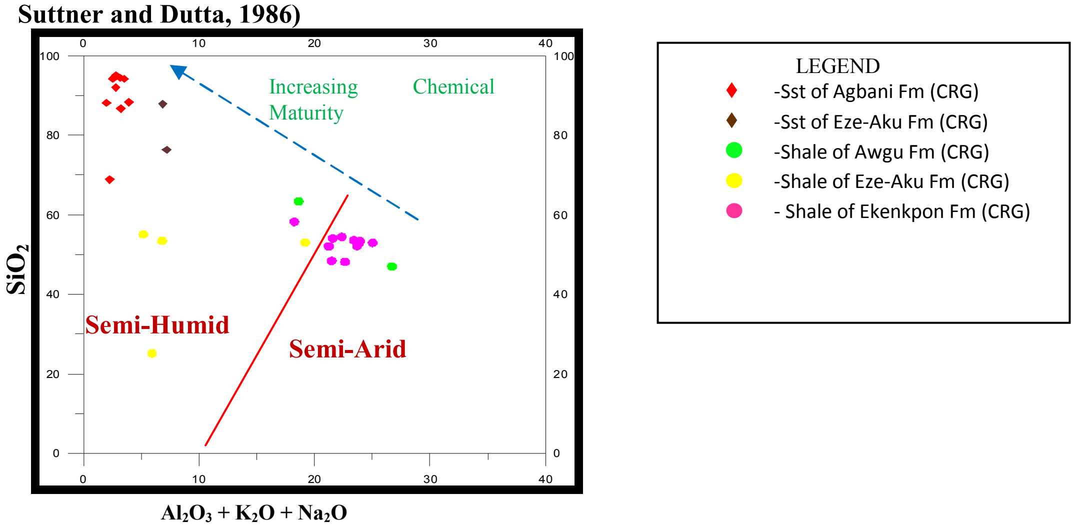

Fig.14: SiO_2 versus (Al_2O_3+K_2O+Na_2O) for Cross River Group sediments showing trend of Maturity (after Suttner and Dutta, 1986).

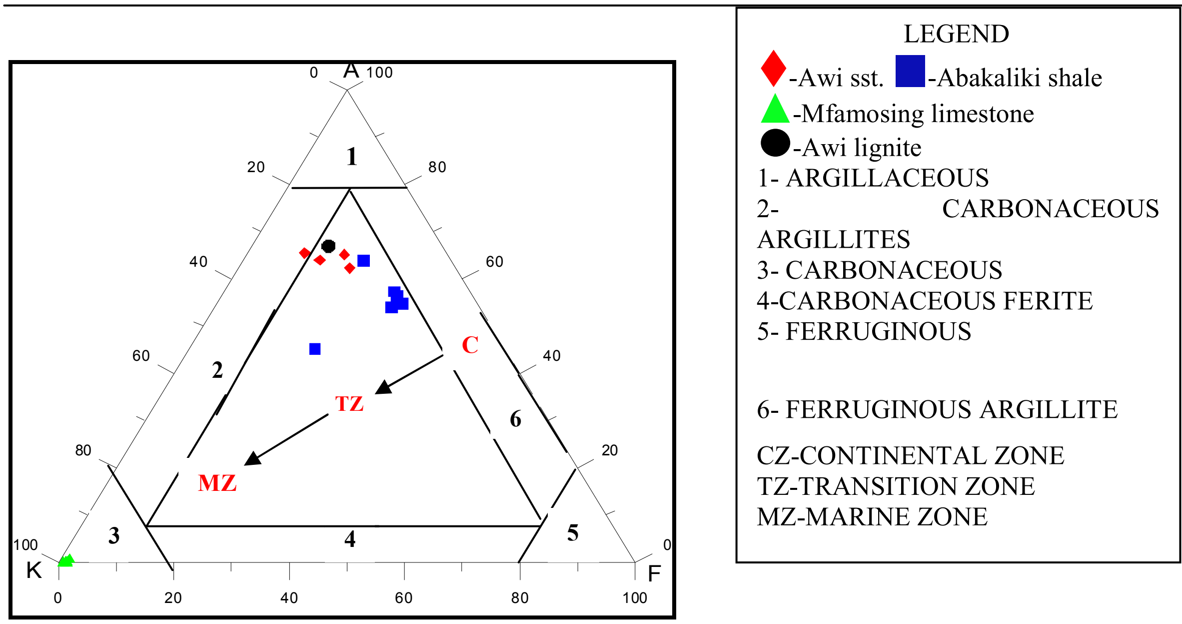

Fig. 15: [AKF] Ternary plots for ARG

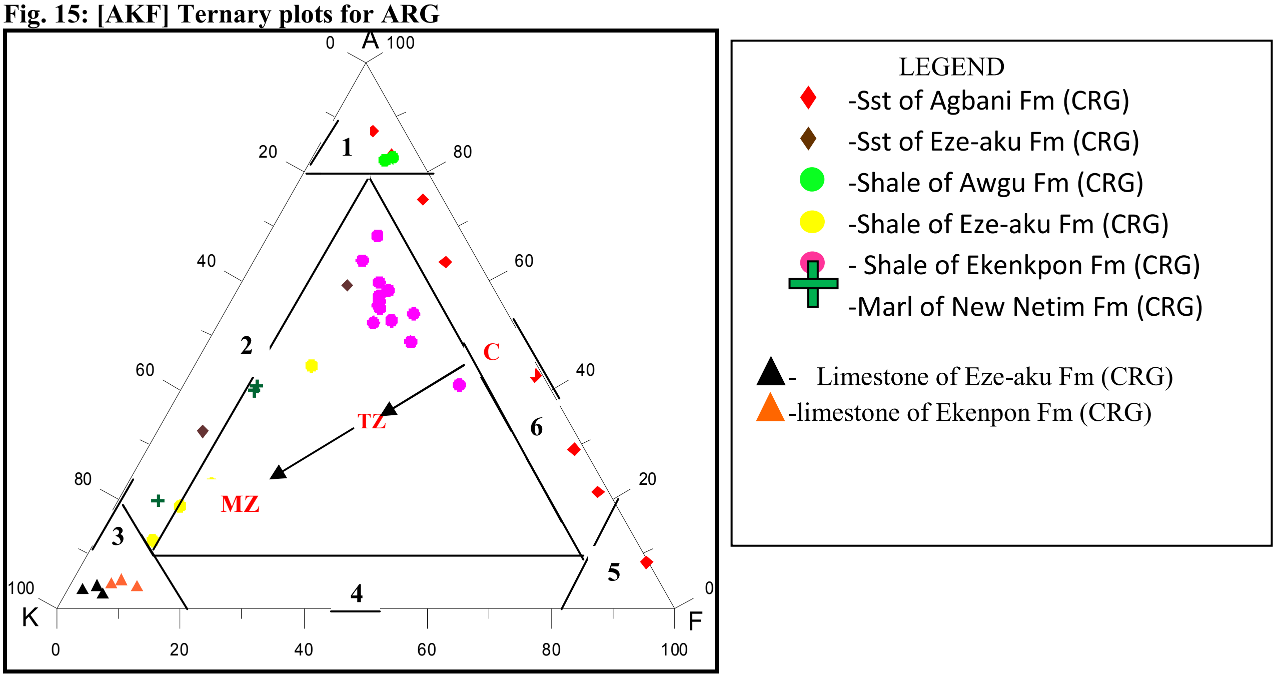

Fig. 16: Al_2O_3 - (K_2O+CaO+MgO) - (Fe_2O_3+MgO) [AKF] Ternary plots for CRG

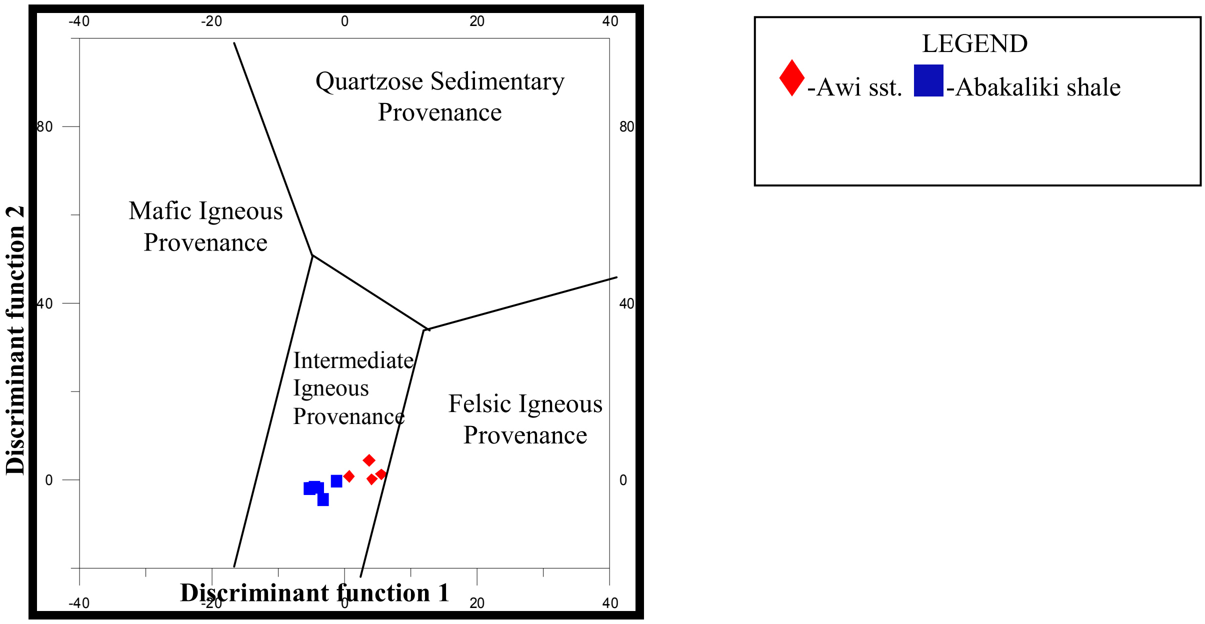

Fig 17: Discriminant Function diagram for provenance signature for Asu River Group sediments using ratio plot (after Roser and Korch 1988)

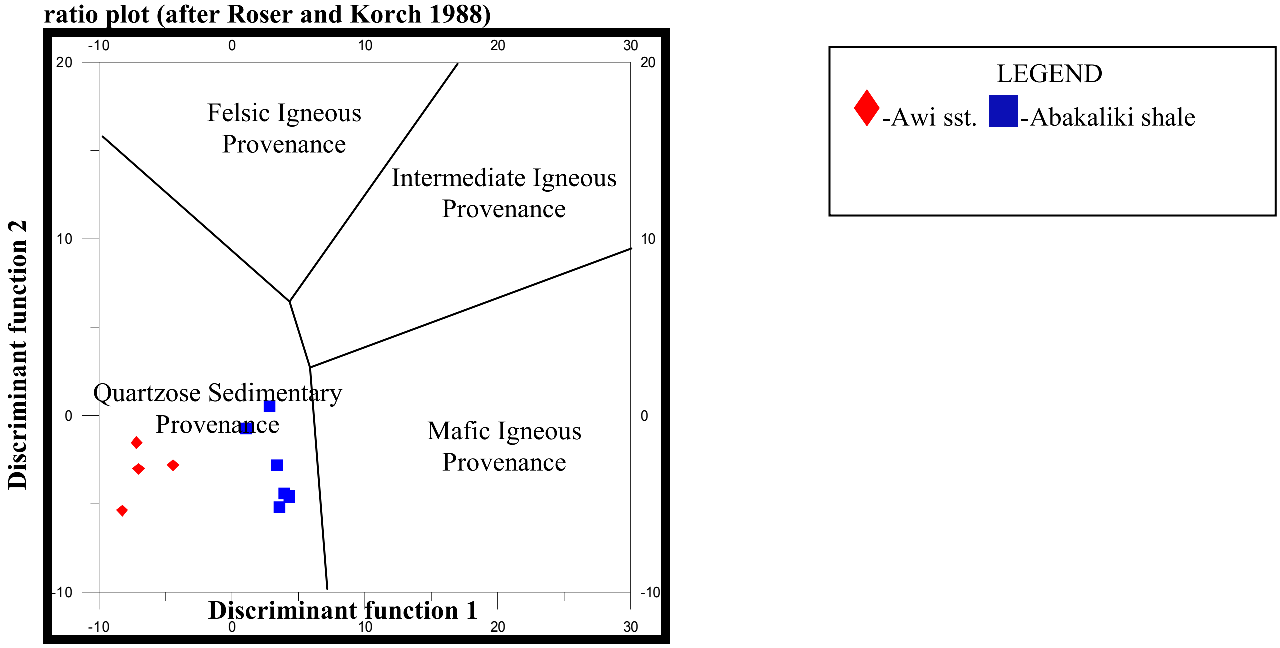

Fig 18: **Discriminant Function diagram for provenance signature for Asu River Group sediments using raw oxide (after Roser and Korch 1988)**

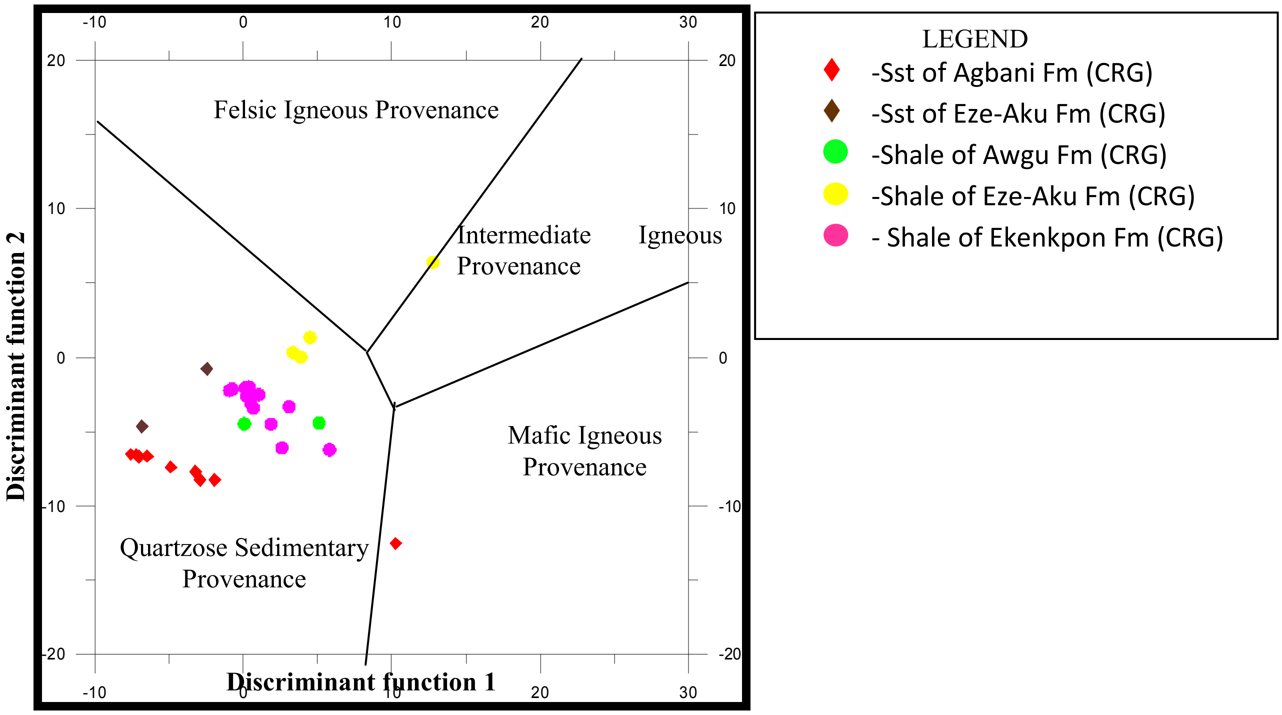

Fig 19: **Discriminant Function diagram for provenance signature for Cross River Group sediments using raw oxide (after Roser and Korch 1988)**

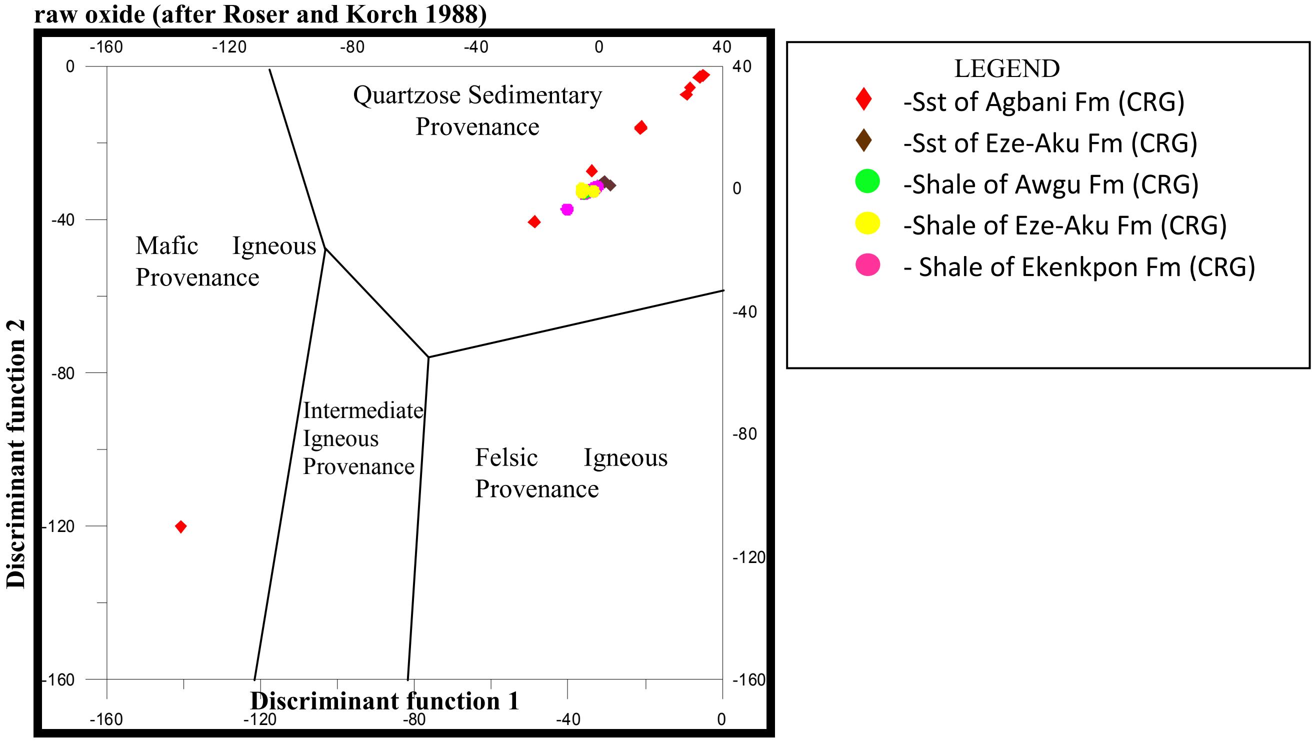

Fig 20: **Discriminant Function diagram for provenance signature for Cross River Group sediments using ratio plot (after Roser and Korch 1988)**

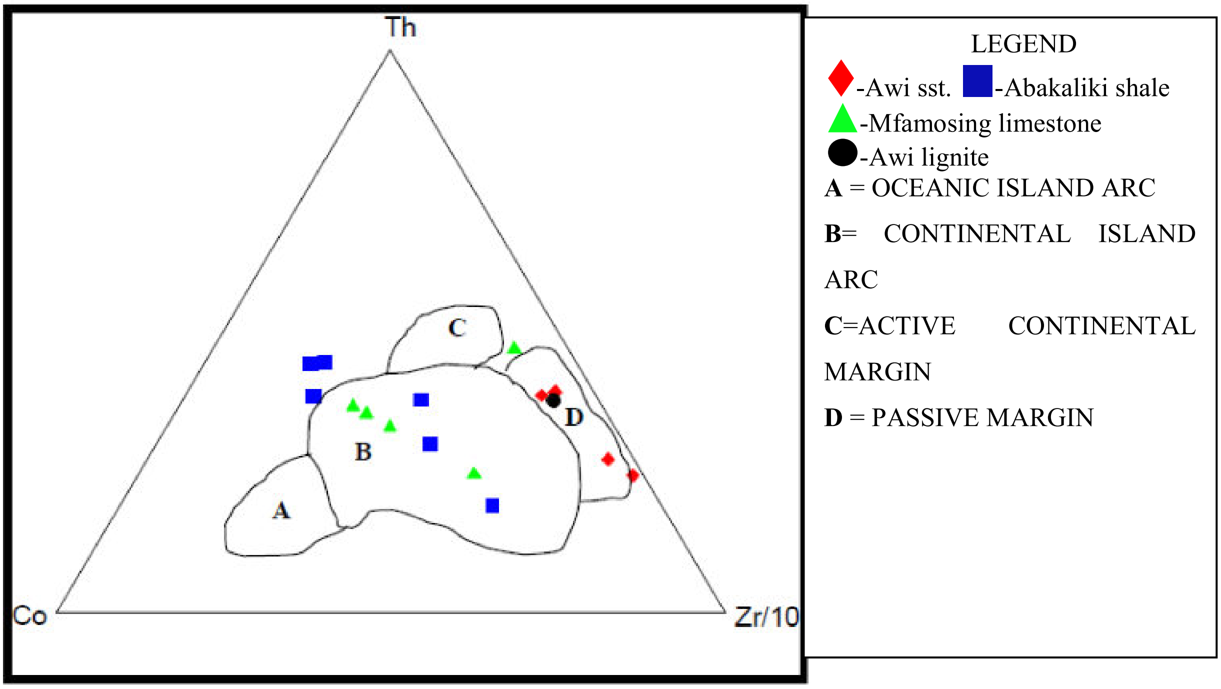

Fig. 21: Th-Co-Zr/10 Plots for the Sediments of ARG (After Bhatia and Crook, 1986).

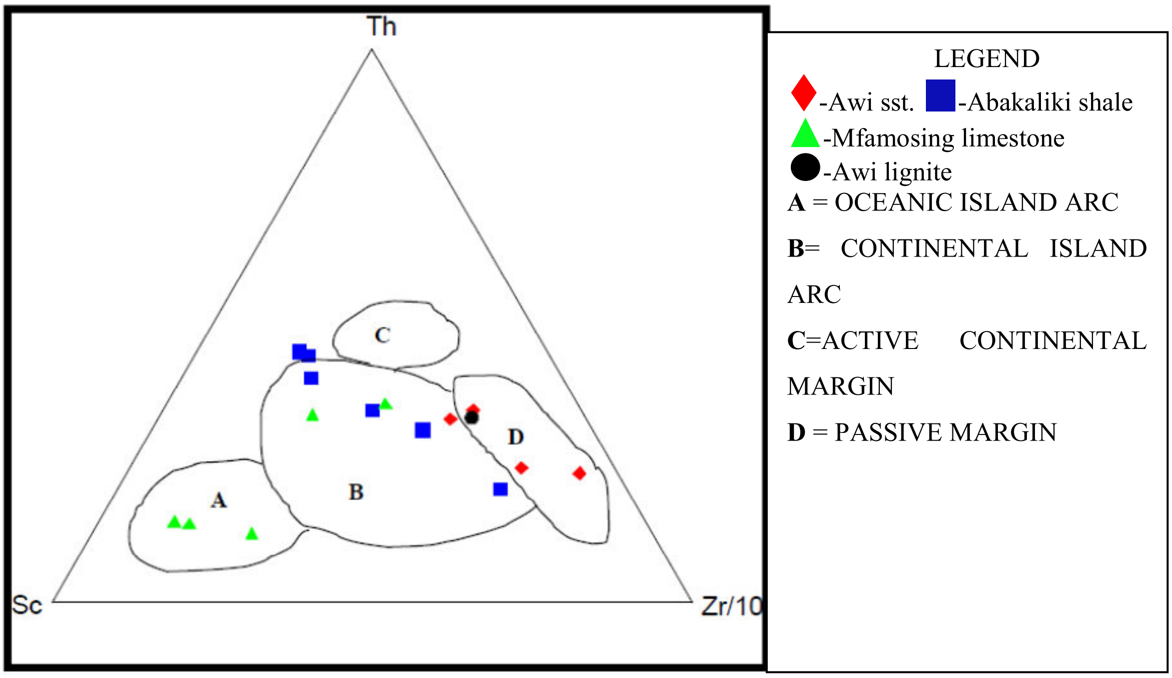

Fig. 22: Th-Sc-Zr/10 Plots for Sediments of ARG (After Bhatia and Crook, 1986)

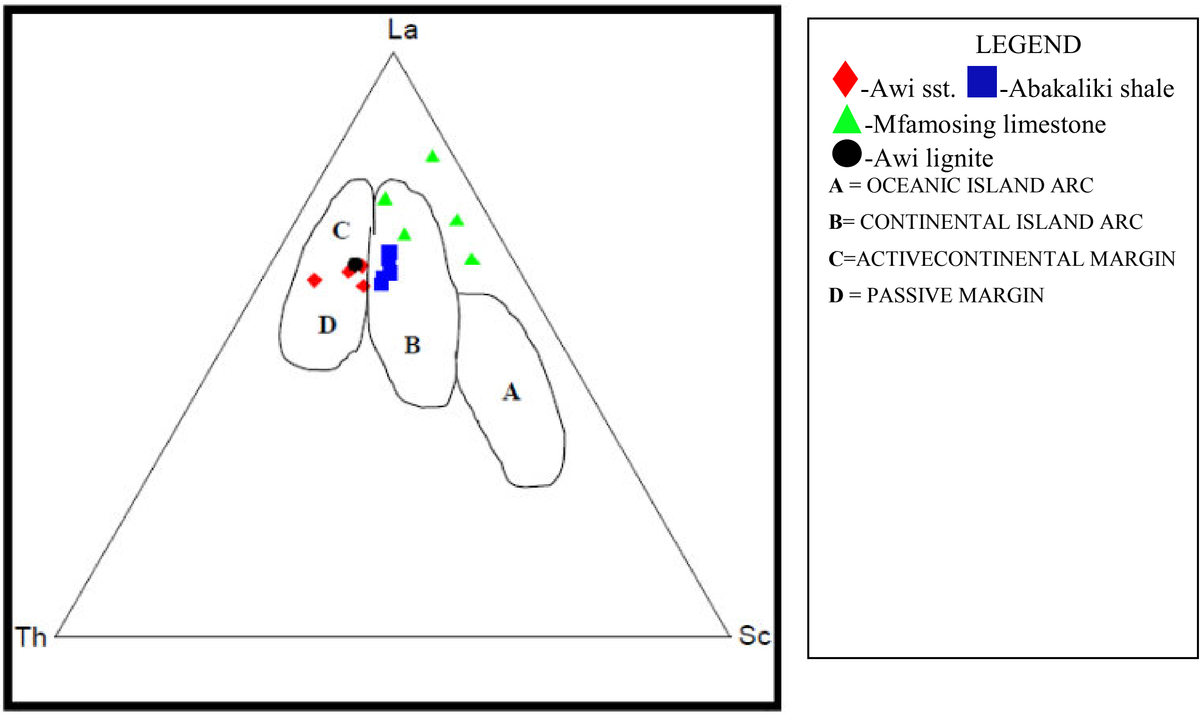

Fig. 23: La-Th-Sc Plots for Sediments of ARG (After Bhatia and Crook, 1986)

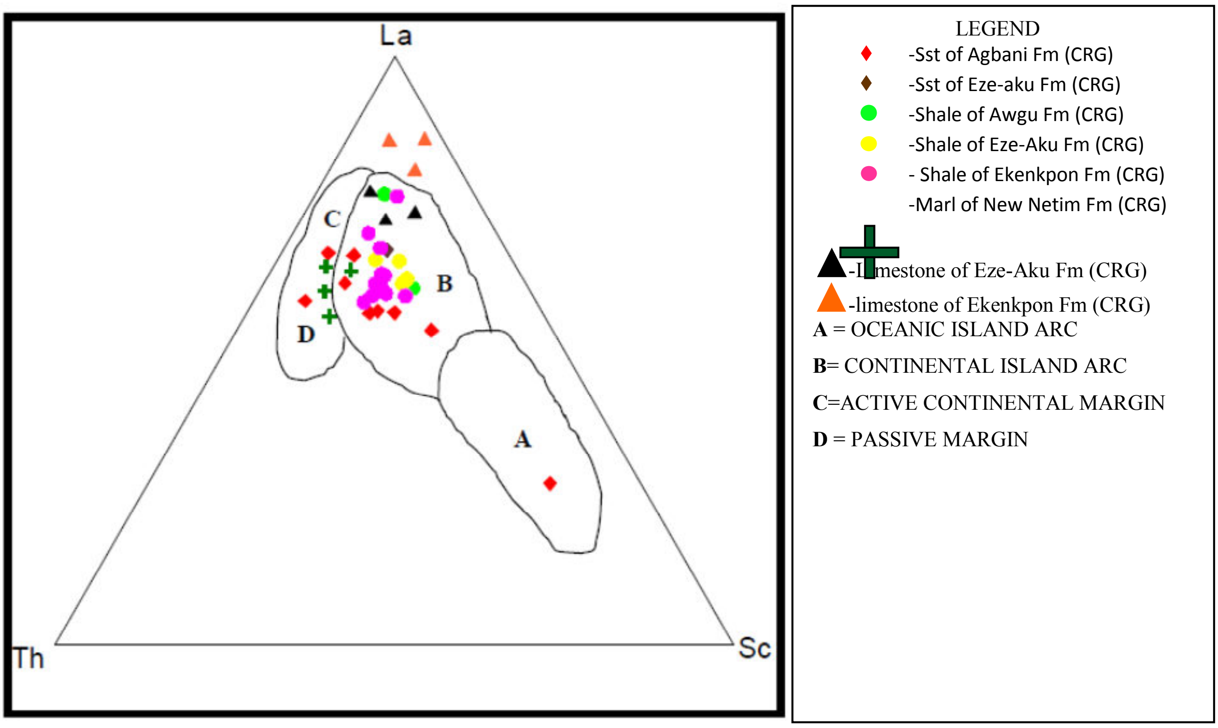

Fig. 24: La-Th-Sc Plots for Sediments of CRG (After Bhatia and Crook, 1986)

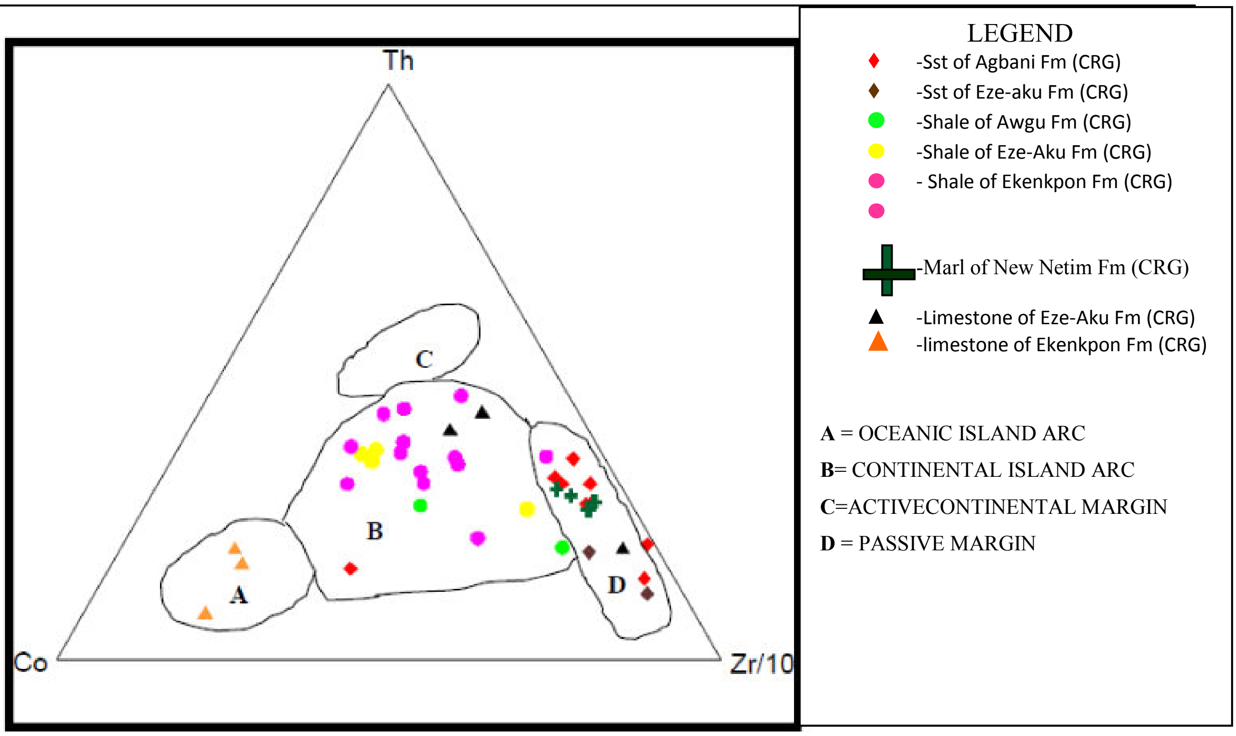

Fig. 25: Th-Co-Zr/10 Plots for the Sediments of CRG (After Bhatia and Crook, 1986).

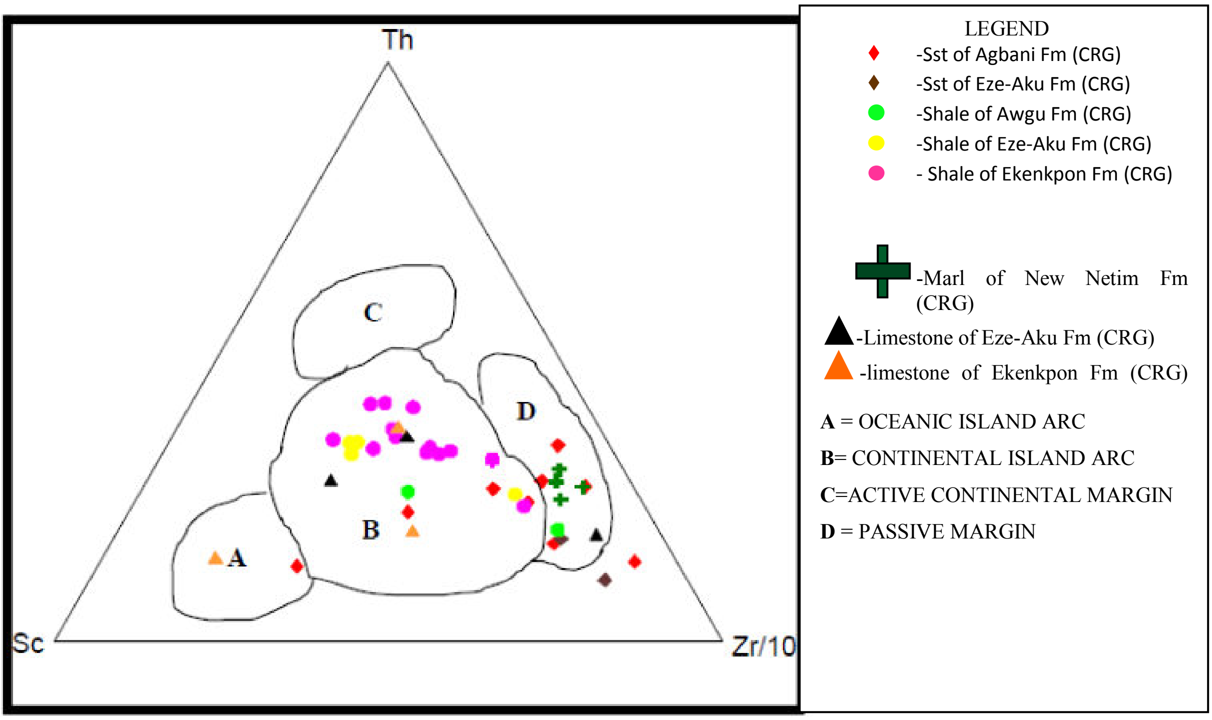

Fig. 26: Th-Sc-Zr/10 Plots for Sediments of CRG (After Bhatia and Crook, 1986)

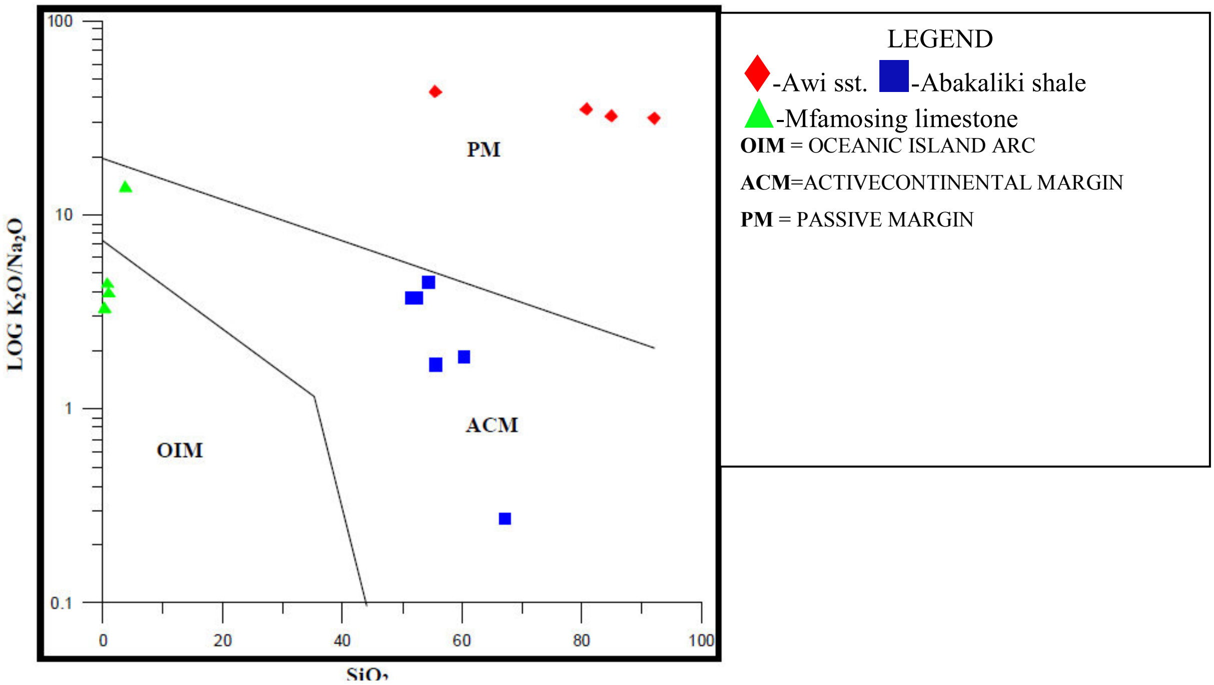

Fig. 27: Tectonic Discriminant Diagram for ARG sediments (After Roser and Korsch, 1986).

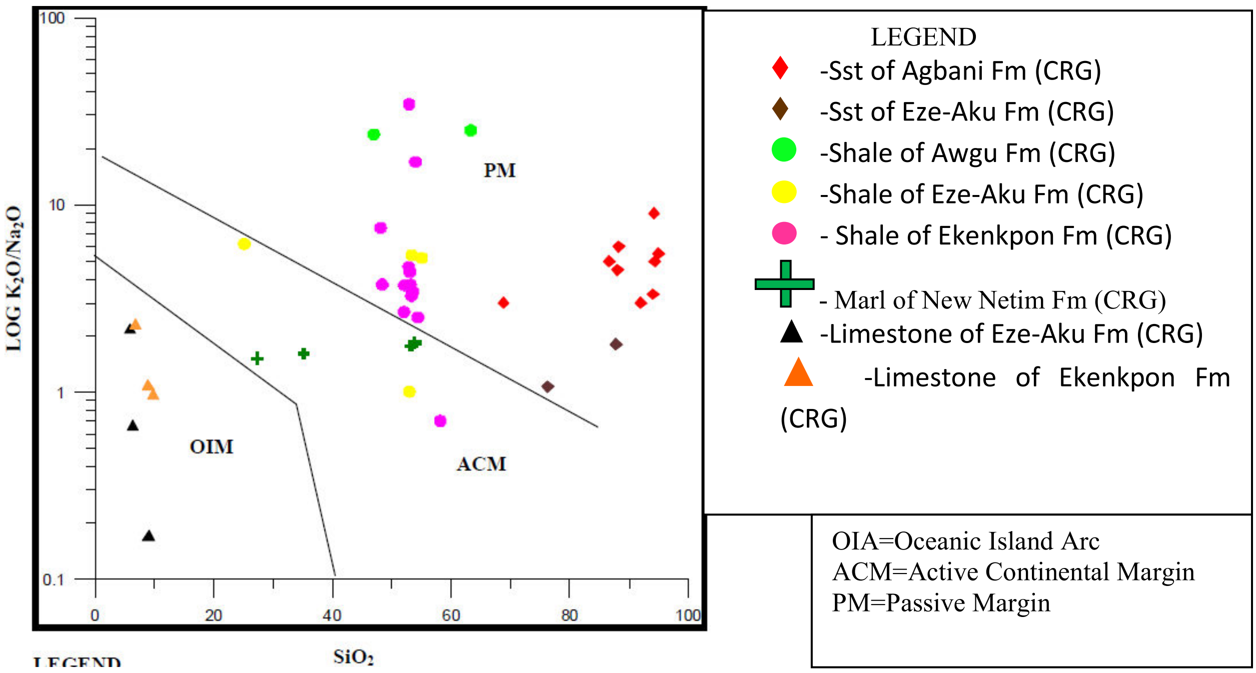

Fig. 28: Tectonic Discriminant Diagram for CRG sediments (After Roser and Korsch, 1986).

Table 1: Results of Major Oxides for, sediments of Asu River and Cross River Group, Lower Benue Trough, Southeastern Nigeria

Rock no	Formation	group	Lithology Type	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B	4A-4B
			Major Oxide	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	LOI	Total
			(%)	%	%	%	%	%	%	%	%	%	%	%	%	%
			MDL	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.002	-5.1	0.01
RK 056	AGBANI	CRG	SANDSTONE	88.29	3.87	5.06	0.02	0.02	0.01	0.06	0.13	0.04	<0.01	<0.002	2.5	99.94
RK 055	AGBANI	CRG	SANDSTONE	68.83	2.2	23.93	<0.01	0.03	0.02	0.06	0.07	0.31	<0.01	0.004	4.5	99.92
RK 054	AGBANI	CRG	SANDSTONE	91.98	2.73	3.59	<0.01	0.02	0.02	0.06	0.07	0.04	<0.01	<0.002	1.5	99.89
RK 053	AGBANI	CRG	SANDSTONE	94.38	3.08	0.44	0.03	0.03	0.02	0.1	0.1	0.03	<0.01	<0.002	1.8	100.03
RK 052	AGBANI	CRG	SANDSTONE	88.08	1.9	6.83	0.02	0.05	0.02	0.09	0.05	0.31	<0.01	<0.002	2.7	100.00
RK 051	AGBANI	CRG	SANDSTONE	86.68	3.1	7.33	0.03	0.05	0.02	0.1	0.09	0.15	<0.01	<0.002	2.5	92.42
RK 050	AGBANI	CRG	SANDSTONE	95.02	2.71	0.2	0.03	0.02	0.02	0.11	0.07	0.02	<0.01	<0.002	1.9	100.01
RK 049	AGBANI	CRG	SANDSTONE	94.2	2.36	1.15	0.01	0.01	0.02	0.18	0.03	0.07	<0.01	<0.002	2	99.81
RK 048	AGBANI	CRG	SANDSTONE	94.11	3.4	0.97	0.02	0.03	0.03	0.1	0.05	0.05	<0.01	<0.002	1.3	99.84
RK 047	AWGU	CRG	SHALE	63.34	17.58	2.4	0.18	0.07	0.04	1	1.08	0.21	<0.01	0.011	13.8	99.83
RK 046	AWGU	CRG	SHALE	46.97	25.71	3.69	0.37	0.04	0.04	0.95	1.44	0.11	<0.01	0.015	20.5	99.83
RK 045	NEW NETIM	CRG	MARL	53.92	13.25	2.5	1.44	9.87	2.23	4.09	0.56	0.38	0.02	0.006	11.5	99.98
RK 044	NEW NETIM	CRG	MARL	53.27	13.1	2.3	1.65	10.21	2.23	3.92	0.57	0.31	0.02	0.006	12.1	99.81
RK 043	NEW NETIM	CRG	MARL	35.14	8.02	1.38	1.29	26.21	1.55	2.48	0.28	0.21	0.02	0.003	23.1	99.91
RK 042	NEW NETIM	CRG	MARL	27.33	6.11	1.01	1.03	32.84	1.29	1.95	0.2	0.17	0.02	0.002	27.8	99.88
RK 041	EZE-AKU	CRG	SANDSTONE	76.29	5.12	0.69	0.49	7.92	1.01	1.08	0.19	0.23	0.03	0.002	6.9	99.85
RK 040	EZE-AKU	CRG	SANDSTONE	87.84	5.34	1.17	0.41	0.73	0.54	0.97	0.44	0.36	<0.01	0.003	2.2	99.86
RK 039	EZE-AKU	CRG	LIMESTONE	6.26	1.45	2.62	0.63	47.81	0.12	0.08	0.05	0.08	0.7	<0.002	40	99.83
RK 038	EZE-AKU	CRG	SHALE	52.97	15.03	5.12	1.33	8.95	2.07	2.08	0.82	0.16	0.05	0.01	11.2	99.87
RK 037	EZE-AKU	CRG	LIMESTONE	5.84	2.28	1.51	0.85	47.51	0.16	0.35	0.12	0.08	0.1	<0.002	41.1	99.78
RK 036	EZE-AKU	CRG	LIMESTONE	8.97	1.81	0.83	0.45	47.66	0.64	0.11	0.08	0.15	0.07	<0.002	39.1	100.03
RK 035	EZE-AKU	CRG	SHALE	53.38	5.98	2.99	0.63	15.36	0.13	0.7	0.38	0.19	0.03	0.008	20.1	99.85
RK 034	EZE-AKU	CRG	SHALE	55.03	4.56	2.08	0.52	16.19	0.1	0.52	0.3	0.15	0.03	0.005	20.4	100.00
RK 033	EZE-AKU	CRG	SHALE	25.11	5.16	3.06	0.84	30.97	0.11	0.68	0.35	0.21	0.03	0.011	33	99.83
RK 032	EKENKPON	CRG	LIMESTONE	8.94	2.29	4.88	1.18	45.4	0.34	0.37	0.11	0.43	0.47	<0.002	35.4	99.82
RK 031	EKENKPON	CRG	LIMESTONE	6.72	2.48	2.51	1.04	46.42	0.16	0.37	0.13	1.87	0.59	0.002	37.5	100.03
RK 030	EKENKPON	CRG	SHALE	54.41	17.9	7.66	1.79	1.64	1.27	3.18	0.92	0.1	0.05	0.012	10.9	100.02
RK 029	EKENKPON	CRG	SHALE	52.06	17.37	9.53	2.18	1.51	1.05	2.81	0.9	0.14	0.11	0.012	12.1	99.84
RK 028	EKENKPON	CRG	SHALE	54.03	18.53	4.34	0.78	1.76	0.17	2.88	0.85	3.21	<0.01	0.012	13.1	100.02
RK 027	EKENKPON	CRG	SHALE	48.4	18.44	7.13	1.72	3.85	0.64	2.4	0.91	2.33	0.04	0.013	13.9	99.91
RK 026	EKENKPON	CRG	SHALE	58.21	14.54	13.63	2.26	1.33	2.18	1.53	0.54	0.64	0.02	0.007	4.9	99.87
RK 025	EKENKPON	CRG	SHALE	48.11	19.83	9.08	2.24	0.89	0.33	2.48	0.89	0.13	0.09	0.015	15.8	99.80
RK 024	EKENKPON	CRG	SHALE	52.91	21.84	4.52	1.18	0.19	0.09	3.1	0.98	0.16	<0.01	0.013	14.9	99.75
RK 023	EKENKPON	CRG	LIMESTONE	9.73	2.83	3.59	0.58	45.02	0.47	0.46	0.13	13.4	0.28	0.004	23.2	99.81
RK 022	EKENKPON	CRG	SHALE	53.33	19.84	5.65	1.77	1.07	0.96	3.13	0.95	0.09	0.03	0.013	13	99.84
RK 021	EKENKPON	CRG	SHALE	52.16	19.85	6.47	1.89	0.97	0.81	3.01	0.96	0.07	0.03	0.014	13.6	99.83
RK 020	EKENKPON	CRG	SHALE	52.86	19.17	6.4	1.98	1.13	0.83	3.87	0.99	0.14	0.06	0.014	12.4	99.83
RK 019	EKENKPON	CRG	SHALE	53.05	18.98	6.63	1.94	1.14	0.89	3.89	0.97	0.14	0.06	0.014	12.2	99.98
RK 018	EKENKPON	CRG	SHALE	53.2	19.43	6.32	1.7	1.29	0.94	3.52	1.02	0.33	0.03	0.014	12	99.81
RK 017	EKENKPON	CRG	SHALE	53.53	18.96	6.46	1.65	1.54	1	3.44	0.98	0.44	0.03	0.014	11.8	99.91
RK 016	MFAMOSING	ARG	LIMESTONE	0.18	0.1	0.45	0.25	55.71	<0.01	0.03	<0.01	0.05	0.18	<0.002	43	99.88
RK 015	MFAMOSING	ARG	LIMESTONE	0.28	0.1	0.06	0.31	55.03	<0.01	0.03	<0.01	0.02	0.07	<0.002	44.1	99.85
RK 014	MFAMOSING	ARG	LIMESTONE	0.73	0.16	0.29	0.36	54.95	<0.01	0.04	<0.01	0.06	0.08	<0.002	44.3	99.86
RK 013	MFAMOSING	ARG	LIMESTONE	3.72	0.48	0.39	0.39	52.57	0.01	0.14	0.02	0.03	0.05	<0.002	42.1	99.83
RK 012	MFAMOSING	ARG	LIMESTONE	0.91	0.19	0.27	0.43	54.43	0.01	0.04	<0.01	0.05	0.06	0.003	43.6	99.87
RK 011	ABAKALIKI	ARG	SHALE	67.24	10.67	4.21	0.94	5.96	3.21	0.87	0.33	0.13	0.18	0.003	6.2	99.78
RK 010	ABAKALIKI	ARG	SHALE	60.23	21.34	5.48	1.5	0.41	1.71	3.17	1.12	0.1	0.02	0.014	4.7	100.03
RK 009	ABAKALIKI	ARG	SHALE	55.47	20.3	9.49	2.08	0.84	1.69	2.84	1.05	0.12	0.1	0.013	5.8	99.81
RK 008	ABAKALIKI	ARG	SHALE	52.42	23.1	9.68	2.25	0.1	0.78	2.91	1.08	0.11	0.09	0.018	7.3	99.84
RK 007	ABAKALIKI	ARG	SHALE	54.33	21.24	10.34	2.2	0.1	0.61	2.71	1.05	0.11	0.08	0.018	7.1	99.83
RK 006	ABAKALIKI	ARG	SHALE	51.48	23.13	10.25	2.31	0.16	0.78	2.92	1.07	0.13	0.06	0.017	7.5	99.91
RK 005	AWI	ARG	SANDSTONE	80.76	10.21	1.25	0.31	0.03	0.1	3.49	0.32	0.04	<0.01	0.003	3.4	99.87
RK 004	AWI	ARG	SANDSTONE	84.9	7.86	1.44	0.2	0.01	0.08	2.57	0.23	0.05	<0.01	<0.002	2.6	99.80
RK 003	AWI	ARG	SANDSTONE	92.08	3.66	1.02	0.12	0.02	0.03	0.94	0.49	0.03	<0.01	<0.002	1.6	99.75
RK 002	AWI	ARG	LIGNITE	56.74	15.21	2.05	0.99	0.01	0.07	3.48	0.89	0.11	<0.01	0.013	20.3	99.81
RK 001	AWI	ARG	SANDSTONE	55.49	14.11	2.85	0.82	0.04	0.07	3.01	0.7	0.08	<0.01	0.011	22.7	99.84

Sample No: (1-16) – Asu River Group
Sample No: (17-56) – Cross River Group

Table 2: Results of Trace Elements for, sediments of Cross river and Asu River Group, Lower Benue Trough, Southeastern Nigeria

Sample	Lithology Type	Ba	Be	Co	Cr	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Zr	Ni	Sc	Y
		PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
		1	1	0.2	1	0.1	0.5	0.1	0.1	0.1	1	0.5	0.1	0.2	0.1	8	0.5	0.1	20	1	0.1
RK 056	SANDSTONE	39	<1	0.9	6.84	0.5	4.4	1.7	3.9	4.3	<1	11.4	0.3	3.1	1	28	<0.5	58.3	Ni	5	3
RK 055	SANDSTONE	18	3	5.5	27.37	0.2	2.6	1.3	1.7	5	<1	6	0.2	1.8	5	166	<0.5	41.8	<20	8	5.9
RK 054	SANDSTONE	100	<1	<0.2	6.84	0.3	2.6	2.2	1.8	4.5	<1	30.1	0.1	2	0.6	<8	<0.5	79.3	<20	2	1.7
RK 053	SANDSTONE	33	<1	0.7	6.84	0.4	3.3	3.5	2.8	7	<1	15.9	0.2	2.2	0.7	9	<0.5	128.5	<20	1	2.6
RK 052	SANDSTONE	36	<1	0.7	6.84	0.3	2.3	1.4	1.1	6.7	<1	16.1	0.1	2.5	1	10	<0.5	49.9	<20	2	2.1
RK 051	SANDSTONE	71	<1	0.7	6.84	0.4	2.9	1.9	2.3	8.5	<1	28.7	0.2	2.8	0.6	37	<0.5	69.1	<20	2	2.7
RK 050	SANDSTONE	25	<1	0.3	6.84	0.4	2.6	1.2	1.6	7.6	<1	19.5	0.2	2.1	0.5	8	<0.5	44.9	<20	1	2.1
RK 049	SANDSTONE	88	<1	0.3	6.84	0.2	1.8	1	0.6	3.7	<1	65.2	<0.1	2.2	0.3	<8	<0.5	38.1	<20	<1	1
RK 048	SANDSTONE	24	<1	0.4	6.84	0.4	3.2	1.5	1.2	8.6	<1	13	0.1	1.9	0.7	<8	<0.5	46.9	<20	<1	1.5
RK 047	SHALE	846	2	13	75.26	3	24.3	16.9	27	43.2	3	283.6	1.9	17.9	8.7	83	1.1	614	<20	14	38.4
RK 046	SHALE	325	3	19.8	102.63	4.6	32.8	7.1	33.1	46.8	5	136.7	2.5	16.6	4.6	130	2	258.2	24	22	29.9
RK 045	MARL	1086	2	5.2	41.05	4.8	17.5	9.2	11.9	123.4	2	707.1	0.9	15.6	3.5	36	0.7	320.9	38	5	16.8
RK 044	MARL	1018	2	4.4	41.05	4.6	18.6	10.1	11.5	124.6	2	690.5	0.9	15.1	3.6	37	0.7	336.3	<20	6	15.1
RK 043	MARL	737	2	2.2	20.53	2.4	10.5	6.1	5.3	72.9	1	1306.6	0.4	8.3	2	18	<0.5	214.7	<20	4	12.7
RK 042	MARL	558	1	1.4	13.68	1.7	7.5	4.7	3.8	55.2	<1	1441.3	0.4	7.2	1.6	13	<0.5	177.7	<20	2	10.2
RK 041	SANDSTONE	273	<1	1.3	13.68	0.4	4.5	2.3	2.9	27.4	<1	288	0.2	2.3	1	14	<0.5	87.7	<20	2	6.2
RK 040	SANDSTONE	261	<1	1.6	20.53	0.4	5.2	6.5	5.1	23.5	<1	60.7	0.4	3.4	1.2	24	<0.5	250.7	<20	4	9.7
RK 039	LIMESTONE	26	<1	0.4	6.84	0.1	1.7	0.3	0.9	3.3	<1	1061.1	0.1	1.2	1	21	<0.5	11.9	<20	1	3.9
RK 038	SHALE	194	2	9.4	68.42	3.8	18.3	9	15.7	98.2	3	347.5	1.2	15.2	3	79	1.1	337.7	<20	11	30.5
RK 037	LIMESTONE	53	<1	1.3	6.84	0.6	3.5	0.9	2.2	17	<1	577.1	0.2	2.5	5.2	29	<0.5	24.6	25	4	9.8
RK 036	LIMESTONE	29	<1	0.5	6.84	0.1	1.7	2.2	1.7	4.3	<1	484.4	0.1	1.9	1.3	10	<0.5	74.5	<20	1	10.3
RK 035	SHALE	260	1	6.3	54.74	2.1	8.5	1.2	9.1	41.2	1	414.5	0.6	6.2	4.6	258	0.8	49.1	<20	7	11.9
RK 034	SHALE	221	<1	4.2	34.21	1.6	6.4	1	6.9	30.1	1	399.5	0.4	4.1	4.8	228	0.6	36	73	5	8.7
RK 033	SHALE	451	<1	5.1	75.26	2	7.7	1.2	8.8	40.7	1	833.7	0.6	5.5	6.6	853	0.6	45.3	81	6	12.7
RK 032	LIMESTONE	71	2	23.9	6.84	1.3	4.4	1.9	2.8	17	<1	622.8	0.3	2.6	1.2	15	<0.5	59.9	70	5	59.2
RK 031	LIMESTONE	56	<1	8.8	13.68	1.9	3.6	0.8	2.8	18.4	<1	632.7	0.1	2.3	1.6	15	<0.5	27.2	21	11	141.2
RK 030	SHALE	533	4	18.2	82.10	9.2	23.8	6.8	18.1	134.6	4	357	1.5	18.9	3.8	88	1.2	247.3	<20	14	24.4
RK 029	SHALE	538	3	15.3	82.10	8.9	23.6	6.3	16.7	123.2	4	302.7	1.1	17.3	2.9	88	1.2	204.8	34	14	25.6
RK 028	SHALE	1044	5	7	82.10	5.5	25.7	13	16.2	103.7	4	426.8	1.2	28.6	5.3	78	1.1	455.6	33	17	100.7
RK 027	SHALE	289	3	22.6	88.95	8.3	24.3	4.3	18.4	112	4	269.5	1.3	16.8	4.4	95	1.3	157.6	<20	18	171.9
RK 026	SHALE	347	2	14.4	47.89	1.6	15.8	8.4	11.2	48.7	2	232.1	0.8	11.6	2.7	51	0.5	292.8	52	9	44.3
RK 025	SHALE	192	3	15.4	102.63	9.1	26.4	2.8	16.8	119.9	4	142.5	1.1	15.3	2.4	111	1.3	107.3	44	18	20.3
RK 024	SHALE	398	3	8.2	88.95	9.5	26.3	5.8	20.5	130.5	5	96.4	1.7	23.2	3.9	98	1.5	193	36	15	24.6
RK 023	LIMESTONE	233	2	36.5	27.37	0.8	3.5	2.4	2.4	15.7	<1	1172.8	0.2	11.1	9.2	17	<0.5	99	<20	9	147.6
RK 022	SHALE	340	3	13.1	88.95	9.8	27.6	5	20.1	142.2	5	156.6	1.4	22	3.8	108	1.5	154.8	44	16	16
RK 021	SHALE	314	4	14.9	95.79	10.4	27.6	3.6	19.6	147.1	4	152.8	1.5	21.6	3.6	114	1.2	141.8	27	17	18.5
RK 020	SHALE	312	3	15.3	95.79	12.2	26.4	5.7	19.5	165.1	4	167.9	1.6	20	3.2	109	1.7	176.8	35	17	20.4
RK 019	SHALE	307	4	16.2	95.79	11.5	26.3	5	19.7	163.6	4	165.7	1.4	19.2	3.1	103	1.3	181.7	32	17	20.3
RK 018	SHALE	360	3	11.9	95.79	10.1	26	6.4	19.9	146.8	4	192.1	1.4	18.6	3.1	100	1.3	225.1	36	16	26.8
RK 017	SHALE	350	3	12.3	95.79	9.3	25.8	6.1	19.2	145.1	4	192.7	1.2	18.4	3.1	95	1.1	236.2	34	15	31.4
RK 016	LIMESTONE	9	<1	<0.2	6.84	<0.1	<0.5	<0.1	<0.1	1.3	<1	261.2	<0.1	<0.2	3.5	17	<0.5	1	33	<1	2.4
RK 015	LIMESTONE	8	<1	<0.2	6.84	<0.1	<0.5	<0.1	<0.1	1.4	<1	323	<0.1	<0.2	0.6	<8	<0.5	0.8	<20	<1	1.2
RK 014	LIMESTONE	31	<1	0.4	6.84	0.2	0.8	<0.1	0.2	1.9	<1	293.9	<0.1	0.4	4.3	20	<0.5	2.8	<20	<1	2.3
RK 013	LIMESTONE	15	<1	<0.2	6.84	0.3	0.8	0.1	0.4	5.9	<1	310.8	<0.1	0.6	0.9	9	<0.5	5.7	<20	<1	3.9
RK 012	LIMESTONE	7	<1	<0.2	20.53	0.1	<0.5	<0.1	0.1	1.8	<1	276.6	<0.1	<0.2	0.7	<8	<0.5	2	<20	<1	2.2
RK 011	SHALE	177	1	8.3	20.53	0.8	12.9	5	6.9	27.6	2	165.8	0.5	6.3	1.3	31	<0.5	183.3	<20	6	22
RK 010	SHALE	539	3	19.4	95.79	4.4	28.3	7.8	23.7	134.6	4	203.3	1.6	19.9	3.5	119	1.4	272.1	<20	17	27.6
RK 009	SHALE	468	5	13.4	88.95	6.5	29.2	5	22.4	131.9	5	144.5	1.6	19.2	3.3	115	2.9	180.9	38	18	33.8
RK 008	SHALE	345	4	21	123.16	16.3	32.3	2.8	21.7	149.6	4	142.1	1.5	23.4	3.1	144	2.2	83.7	38	20	26.5
RK 007	SHALE	326	3	21.6	123.16	12.8	30.2	3	21.4	142.1	5	131.7	1.5	19.7	2.6	101	1.5	98.5	58	19	26.9
RK 006	SHALE	346	4	20	116.31	16	32.7	2.9	23.8	150.9	4	149.1	1.5	23.7	3	142	1.5	94.9	61	20	30
RK 005	SANDSTONE	299	1	1.2	20.53	7.5	10.8	3.3	6.9	142.2	2	160.7	1.3	8.2	1.3	34	0.9	114.8	59	4	9.3
RK 004	SANDSTONE	288	<1	0.7	6.84	5.8	9.9	3.7	5.1	94.8	2	180.9	0.9	5	1.8	32	1	126.3	<20	3	12.5
RK 003	SANDSTONE	76	<1	0.5	6.84	3.3	3.9	7.1	6.2	39.2	15	78.4	3	7.9	1.5	26	1.3	239.6	<20	2	9.6
RK 002	LIGNITE	110	4	3	88.95	12.6	24.1	6.9	15.4	149.3	4	433.8	1.6	16.9	9.4	113	1.1	248.1	<20	9	14.7
RK 001	SANDSTONE	111	3	2.6	75.26	9.5	20.3	5	11.4	122.4	4	245.9	1.3	12.5	7.2	99	0.9	172.3	<20	8	12

Table 3: Summary of major, elemental analyses of the clastic sediments of ARG

		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3
SST	*Min.*	55.49	3.66	1.02	0.12	0.01	0.03	0.94	0.23	0.03	0.01	0.003
	Max.	92.08	14.11	2.85	0.82	0.04	0.1	3.49	0.7	0.08	0.01	0.011
	Avg	78.3	8.96	1.04	0.36	0.03	0.07	2.50	0.43	0.05	0.01	0.007
SH	*Min.*	51.48	10.67	4.21	0.94	0.1	0.61	0.87	0.33	0.1	0.1	0.003
	Max.	67.24	23.13	10.34	2.31	5.96	3.21	3.17	1.08	0.13	0.18	0.018
	Avg	56.9	19.96	8.24	1.88	1.26	1.46	2.57	0.95	0.11	0.088	0.014
LST	*Min.*	0.18	0.1	0.06	0.25	52.57	0.01	0.03	0.01	0.02	0.05	0.002
	Max.	3.72	0.48	0.45	0.43	55.71	0.01	0.14	0.02	0.06	0.18	0.003
	Avg	1.16	0.21	0.29	0.35	54.54	0.01	0.06	0.02	0.04	0.09	0.003

Table 4: Summary of major, elemental analyses of the clastic sediments of CRG

		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3
SST	*Min.*	68.83	1.9	0.2	<0.01	0.01	0.01	0.06	0.03	0.02	<0.01	<0.002
	Max.	95.02	5.34	23.93	0.49	7.92	1.01	1.08	0.44	0.36	0.03	0.004
SH	*Min.*	25.11	4.56	2.08	0.18	0.04	0.04	0.52	0.30	0.07	<0.01	0.008
	Max.	63.34	25.71	13.63	2.26	30.97	2.18	3.89	1.44	3.21	0.11	0.015
MARL	*Min.*	27.33	6.11	1.01	1.03	9.87	1.29	1.95	0.20	0.17	0.02	0.002
	Max.	53.92	13.25	2.50	1.65	32.84	2.23	4.09	0.57	0.38	0.02	0.006
LST	*Min.*	5.84	1.45	0.83	0.45	45.02	0.12	0.08	0.05	0.08	0.07	<0.002
	Max.	9.73	2.83	4.88	1.18	47.81	0.64	0.46	0.13	13.4	0.7	0.004

Table 5: CIA, PIA and CIW values for ARG AND CRG sediments

(CRG)	**CIA**	**PIA**	**CIW**	**(ARG)**	**CIA**	**PIA**	**CIW**
Min.	2.93	2.78	2.94		0.18	0.13	0.18
Max	97.73	99.68	99.69		86.13	99.32	99.48
Median.	76.1	85.5	87.7		76.7	92.6	93.5

Table 6: Summary of Trace and Rare-earth elemental oxide for clastic sediments of ARG

Trace Elements	Minimum	Maximun	Average
Ba	7	539	197
Be	1	5	3.11
Co	0.2	21.6	7.03
Cr	6.84	123	50.9
Cs	0.1	16.3	6.86
Ga	0.5	32.7	18.2
Hf	0.1	7.8	4.38
Nb	0.1	23.8	11.8
Rb	1.3	150.9	81
Sn	1	15	4.64
Sr	78.4	433.8	218
Ta	0.1	1.6	1.48
Th	0.2	23.4	12.6
U	0.6	9.4	3
V	8	144	71.6
W	0.5	2.9	1.47
Zr	0.8	292.1	115
Y	1.2	33.8	14.8
La	1.1	68.2	30.3
Ce	1.7	136.8	57.8
Pr	0.2	15.97	6.69
Nd	1.1	63.3	25.6
Sm	0.14	10.25	4.3
Eu	0.03	2.02	0.85
Gd	0.13	7.78	3.37
Tb	0.02	1.19	0.51
Dy	0.14	6.15	2.68
Ho	0.03	1.13	0.50
Er	0.07	3.06	1.43
Tm	0.01	0.49	0.22
Yb	0.09	2.98	1.39
Lu	0.01	0.44	0.2
Th/U	0.03	7.90	3.65
Zr/Sc	1.00	119	20.36
Th/Co	0.8	15.8	3.5
La/Co	2.9	33	13
Cr/Th	0.87	205	25.98
Eu/Eu*	0.6	1.15	0.73
Ce/Ce*	1.01	1.62	1.20

Table 7: Summary of Trace and Rare-earth elemental oxide for clastic sediments of CRG

Trace Elements	Minimum	Maximun	Average
Ba	18	1086	312
Be	1	5	2.7
Co	0.3	36.5	8.50
Cr	6.84	103	46.4
Cs	0.1	12.2	8.7
Ga	1.7	32.8	13.2
Hf	0.3	16.9	4.5
Nb	0.6	33.1	10.2
Rb	1.3	165.1	60.6
Sn	1	5	3.2
Sr	6	1441	363
Ta	0.1	2.5	0.8
Th	1.2	28.6	10.3
U	0.3	9.2	3.01
V	8	853	91.2
W	0.5	2	1.13
Zr	1	614	159
Y	1	172	29
La	3.7	122.8	38
Ce	2.9	312	71
Pr	0.57	49.7	9.1
Nd	2.1	232	37.4
Sm	0.28	49.27	6.78
Eu	0.05	11.08	1.76
Gd	0.21	43.54	5.99
Tb	0.03	6.44	1.04
Dy	0.14	32.47	4.77
Ho	0.04	5.43	0.99
Er	0.1	13.04	2.38
Tm	0.02	7.69	0.82
Yb	0.13	11.14	2.08
Lu	0.02	1.68	0.3
Th/U	0.36	7.33	3.71
Zr/Sc	2.47	128.5	29.48
Th/Co	0.1	20	2.7
La/Co	0.7	52	8.4
Cr/Th	1.9	15.21	4.75
Eu/Eu*	0.6	0.8	0.74
Ce/Ce*	1.0	4.3	1.75