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Weathering, Maturity And Tectonic Setting Of The Eocene Sediments Of Ogwashi-Asaba Formation

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Abstract:
Nine samples of fine grained clastic rocks which includes shales, fine sandstones, lignites siltstons and white clays were obtained from the outcropping unit of the Ogwashi-Asaba Formation in order to determine weathering, maturity and tectonic setting of the sediments. The results of the X-Ray Fluorescence analaysis (XRF) showed enrichment of major oxides like SiO_2, Al_2O_3 and TiO_2, while Na_2O were depleted. The chemical index of Alteration (CIA), chemical index of weathering (CIW) and the plagioclase Index of Alteration (PA) showed averages of 91.84 (with a range of 77.8 – 98.46), 97.73 (94.40-99.56) and 96.83 (91.21-99.8) respectively. These values suggests a high intensity of source rock weathering. SiO_2/Al_2O_3, K_2O/Na_2O and the Index of composition variability (ICV) has averages of 3.8 (with a range of 1.8-8.42), 21-6 (with a range of 53.52-21.66) and 0.472 (1.04-0.863) respectively, indicating maturity variations from moderate to dominantly low and interpreted as the deposition of the sediments from multiple sources. A plot of SiO_2 vs $Al_2O_3 + Na_2O + K_2O$ indicates a semi-humid to humid paleoclimatic conditions of deposition, while the tectonic discrimination plot suggests a passive margin setting.

Keywords: *Outcropping, Formation, Weathering, Maturity, tectonic setting, source rock*

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I. Introduction

Numerous sedimentary basins in Nigeria were formed as a result of the South Atlantic Ocean opening up during the Cretaceous period, 65 million years ago, when Gondwanaland broke apart, causing the North American and African plates to separate. About 75,000 km^2 make up the Niger Delta Basin, and 12,000 km is made up of clastic fill [1]. The marine shales of the Akata Formation, the parallic deposits of the Agbada Formation, and the continental facies of the Benin Formation are the three diachronous units that make up the clastic fill of the basin. These units were all deposited during the Tertiary geological era. The same formations have been dubbed Imo-Shale (Akata), Ameki-Bende (Agbada), and Ogwashi-Asaba (upper Agbada facies) along the Northern axis of the Niger Delta where proximal portions of these lithostratigraphic units are visible. The Ogwashi-Asaba Formation's well-exposed rock facies are located in Onitsha, the Ogwashi-Uku region of Asaba, and Umuahia. According to [2] and [3], the formation is characterized by medium coarse planar cross-bedded ferrugenized sandstones, white clays and claystones, silty muds, seams of black lignites, grey shales, and laterites.

II. Location And Accessibility

The outcropping Ogwashi-Asaba formation under investigation is located at the Ogbunike area of Onitsha toll gate, along the Enugu-Awka Express way and bounded by the coordinates $6^0$10’55.8”N and $06^0$51’55”E. It is a laterally and vertically extensive quarry which exposed a wide variation of interbedded rock facies. The facies comprise lignities, siltstones, shales, white clay (kaolin clays), coarse, medium and fine plannar cross bedded sandstones, silts and siltstones, claystones and laterites.

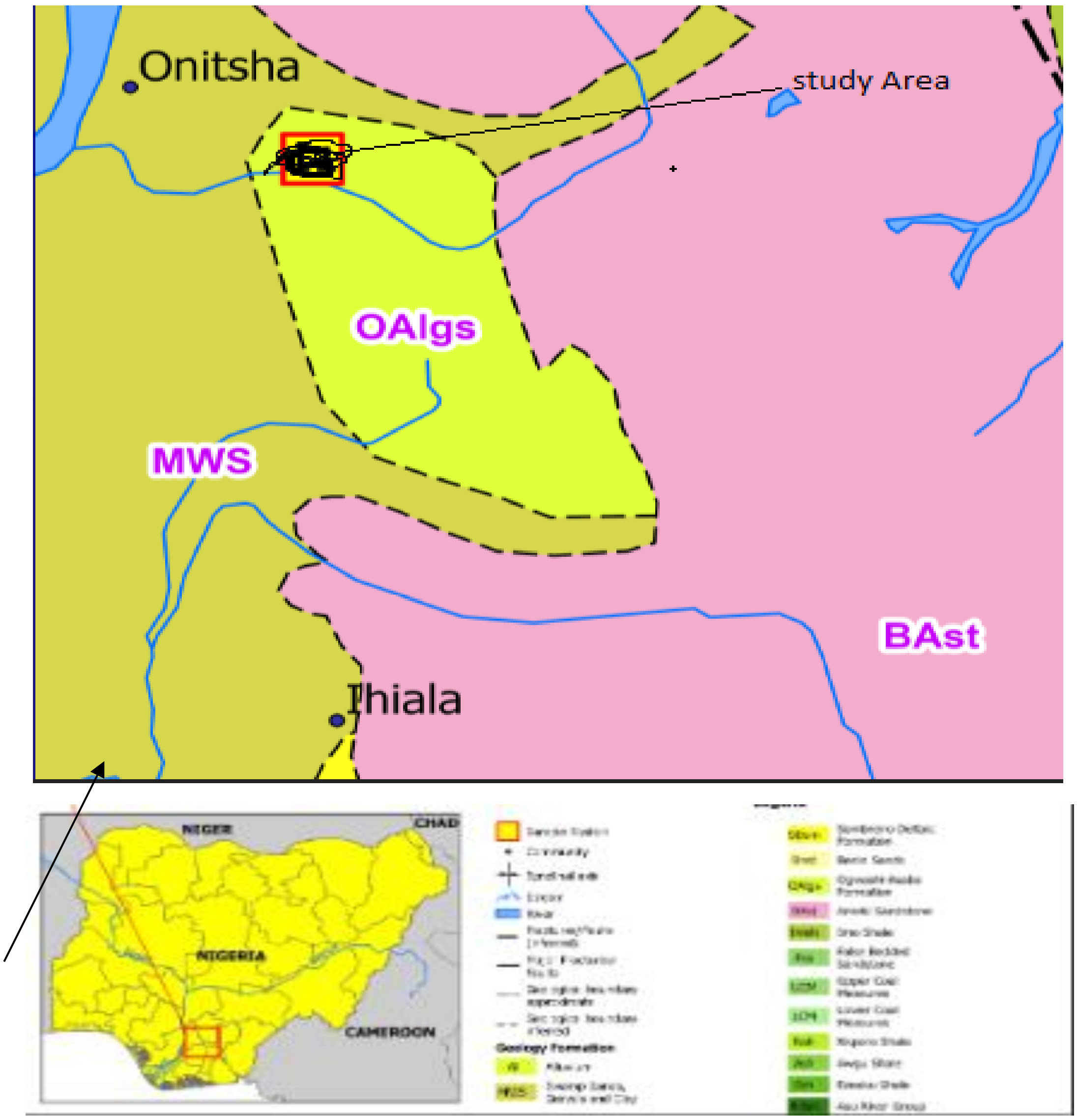

Figure 1: The study area

III. Materials And Methods

Both field and laboratory methods were employed in the study. A one day field work was undertaken to the outctrop in order to determine bed thicknesses, grain sizes, strike-and dip and recorded in the course of the study. Both lateral and vertical sampling was done. Three different sections of the quarry was measured, sampled and labelled 1, 2 and 3. With the aid of the geological hammer and chisel, three samples were obtained from each of the measure sections of the quarry, making a total of nine samples of different lithologies including lignite, fine sands, siltstones, white clays (Kaolin) and shales. The nine samples were stored and lebelled in polythene bags and subsequently sent to the research laboratory of the Geological Survey Agency, Kaduna for X-Ray Fluorescence Analysis (XRF) .

Using an arget pulverizing machine, the samples were ground up. It was made sure that the ground samples could pass through 150 micromesh sieves. 5g of the pulyerized sample and 1g of binding aid (starch soluble) were weighed into a beaker to check homogeneity. After the mixture was well combined to ensure homogeneity, it was pressed under high pressure (6 tones) to create pellets, which were then packed and labeled for examination. Model "minipal 4" Energy Dispersive x-ray fluorescence (EDXRF) spectrometry was used for the study. After the pellets were carefully positioned in their designated measurement positions on the machine's sample changer, the following conditions were created as the machine was turned on: the nature of the samples to be analyzed as pressed power (pellets), and the elemental composition of the samples were determined.For main oxides, 14 KV of current was employed, and for trace elements and rare earth metals, 20 KV. Ag/Al-thin for trace elements and rare earth metals, and "Kapton" for significant oxides were the chosen filters. A specific periodic table that was employed for the elemental analysis served as a reference for the filter selection.Every sample was measured for 100 seconds, with air serving as the medium the whole time. After calibrating the machine, % results were obtained.

The depletion or enrichment of elemental oxidesin the samles is discussed in terms of the Elementl Enricment factor (EF), defined as:

$$EF = \frac{\left\{\frac{X}{AL}\right\} sample}{\left\{\frac{X}{AL}\right\} UCC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where X = element; AL = Aluminum in sample; XUCC = element concentration in the upper continental crust; ALUCC = Aluminium concentration in the upper continental crust.

IV. Results And Discussion

The enrichment or depletion of element is interpreted as follows: EF>1 is enriched; EF<1 is depleted, while EF= 1 implies no change in concentration. The enrichment or depletion of elemental concentration in clastic rocks is due to sources rock composition, resistance to chemical weathering or digenesis and distance of recycling during transportation [4]. The calculated enrichment factor in table 2 showed that the samples are enriched in SiO_2 which ranges from 2.16 – 6.6 with an average of 5.02, TiO_2 Ranges from 0.16 – 4.09, and averaged 2.57, and Al_2O_3 with a range of 0.83 – 1.86, averaging 1.2. Their enrichment may be due to their resistance to chemical destruction during weathering, grain size effect and slow decomposition [5]. The depleted element includes CaO which has an average EF of 0.09 (with range of 0.003 – 0.37), MgO averaged 0.03, K_2O averaged 0.59 Na_2O average 0.17, MgO averaged 0.11 and Fe_2O_3 is 0.7. Their depletion may also be due largely due to their source of composition and the ease of chemical destruction during weathering.

Table 1: Oxides' enrichment factor in samples

Oxide	Lithology	1A	1B	1C	2A	2B	2C	3A	3B	3C	Average
SiO_2	White clay	64.51	68.248	51.960	57.80	74.127	51.435	65.302	44.549	75.867	61.52
CaO	Fine sandstone	0.017	0.124	0.120	0.220	Nd	Nd	Nd	0.368	Nd	0.569
MgO	Lignite	0.050	0.021	0.020	0.032	Nd	0.129	Nd	0.176	Nd	0.146
K_2O	Siltstone	0.225	0.131	0.315	1.780	2.855	2.854	2.435	1.820	3.015	1.9
Na_2O	Siltstone	0.010	0.007	0.008	0.044	0.650	0.540	0.120	0.034	0.760	0.227
TiO_2	Lignite	1.369	0.892	2.944	0.879	1.197	2.209	1.670	2.28	1.703	1.694
MnO	Shale	0.002	0.012	0.006	0.008	0.003	0.015	0.005	0.055	0.008	0.0123
Fe_2O_3	Fine sandstone	1.519	11.617	2.166	5.545	1.310	6.866	3.119	12.177	2.278	4.002
Al_2O_3		24.28	16.770	28.789	23.000	18.458	20.052	19.107	19.436	12.802	20.11
$SiO2/Al_2O_3$		2.660	4.070	1.80	2.51	4.016	2.57	8.42	2.29	5.926	3.82
K_2O/Na_2O		22.50	18.714	39.375	26.81	4.392	5.285	20.435	53.529	3.963	18.88
CIA		98.35	98.460	98.48	91.849	84.04	85.52	88.2	89.74	77.48	98.81
CIW		99.26	99.22	99.56	98.87	96.60	97.38	99.37	94.98	94.40	98.19
PIA		99.25	99.21	99.8	91.21	96.00	96.96	96.96	99.29	92.79	104.96
ICV		0.104	0.757	0.187	0.369	0.326	0.650	0.386	0.868	0.606	0.464

Table 2: Elemental enrichment factor in samples

Element	IA	IB	IC	2A	2B	2C	3A	3B	3C	AV EF	UCC
SiO_2	2.65	0.94	6.6	3.34	4.26	5.217	1.79	4.49	3.17	5.02	66.60
MgO	0.12	0.08	0.004	0.001	Nd	0.04	Nd	0.06	Nd	0.03	2.480
K_{20}	0.06	0.05	0.07	0.50	0.9	0.91	0.81	0.59	1.50	0.59	2.800
Na_{20}	0.002	0.002	0.001	0.009	0.17	0.12	0.29	0.08	0.28	0.17	3.270
$Ti0_2$	1.7	0.16	3.20	1.14	3.3	3.3	2.7	3.6	4.09	257	0.500
Mno	0.012	0.11	0.32	0.05	0.025	0.15	0.20	0.04	0.09	0.11	0.100
Fe_{203}	0.17	1.9	0.21	0.65	0.08	0.96	0.50	1.80	0.60	0.76	5.400
Al_{203}	1.6	1.08	1.86	1.49	1.19	1.30	1.24	1.26	0.83	1.2	15.40

Weathering

The degree or intensity of chemical weathering at a source area is measured by application of various weathering indices. The chemical composition of clastic rocks is a function of their sources area composition and weathering [6]. Thus Nesbitt and Young, 1989 proposed the Chemical Index of Alteration (CIA), defined as:

$$CIA = \left\{\frac{Al_2O_3}{Al_2O_3 + CaO^* + Na_2O + K_2O}\right\} x\ 100 \ldots\ldots\ldots\ldots\ldots (2)$$

CaO^* is the amount of CaO incorporated in the silica fraction of the samples [7]. The CIA measures the ratio of primary minerals and secondary products such as clay minerals, which result from the destruction of plagioclase, hence Na,Ca, and K are progressively depleted from source rocks during chemical weathering [8]. The chemical index of weathering (CIW) proposed by [9] is also used for the evaluation of intensity of weathering. It is similar to the CA, except the removal of K_2O in the equation.

The CIW proposed by Harnois is expressed as

$$CIW = \left\{\frac{Al_2O_3}{Al_2O_3 + Cao^* + Na_2O}\right\} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

According to [10] Mchennan et al., 1993, and [11] Mongelli et al., 1996, the CIA and CIW are interpreted similarly, with values of 50 for unweathered top continental crust and around 100 for extensively weathered material with full elimination of alkali and alkaline earth element. The CIA values of the sample ranges from 77.8 – 98. 46 with an average of 91.84. while the CIW ranges from 94.40 – 99.56 with an average of 97.73. These values are indication of a high intensity of weathering at the source area. This is also demonstrated in the bivariate plot of AL_2O_3 versus CIA [12](Madukwe et al, 2014) showing a clustering of the data points in the segments of high weathering intensity (figure 2). The plagioclase Index of Alteration (PIA)by [7](Fedo et al, 1995) is another weathering indices defined as:

$$PIA = \left\{\frac{Al_2O_3 + K_2O}{Al_2O_3 + Cao^* + Na_2O + K_2O}\right\} x\ 100 \ldots\ldots\ldots\ldots\ldots (4)$$

Where CaO* is the Cao content in the silicate fraction. The CIA determines the progressive breakdown of feldspars to clay minerals. It is also interpreted like the CIA and CIW where 0 – 50 indicates unweathered plagioclase, while 50 – 100 is an indication of moderate to high intensity of the chemical destruction of plagioclase. The samples of The Ogwashi Asabs Formation displayed PIA values that are quite similar to those of CIA and CIW with value ranges 91.21 – 99.8, averaging 96.83. This also suggest an intense weathering of source rocks.

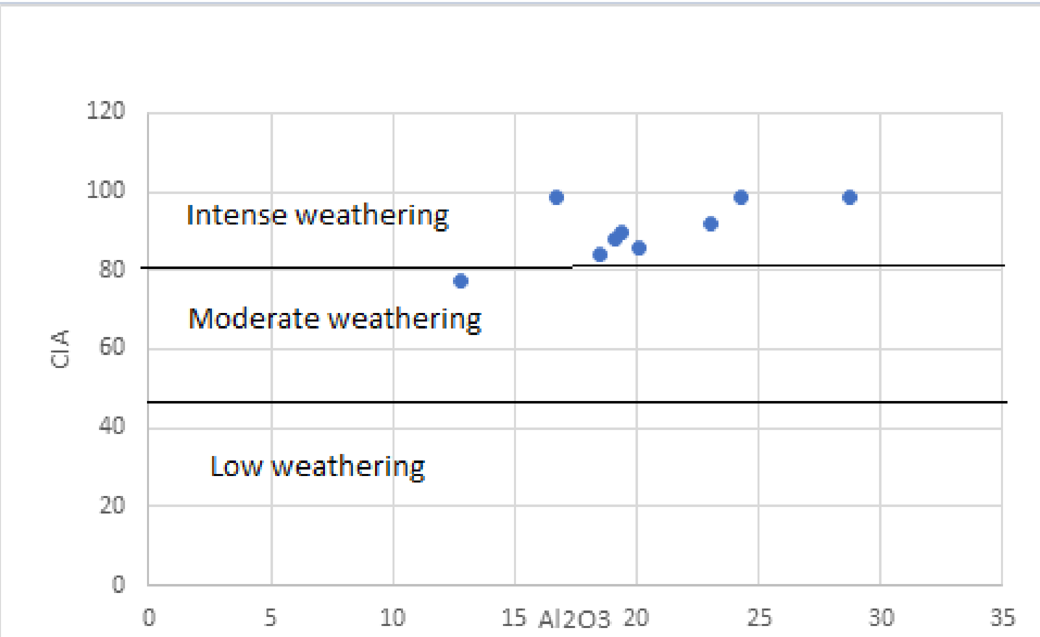

Figure 2: Al_2O_3 vs CIA Plot showing intensity of weathering in the samples [After 12]

Maturity

The SiO_2/Al_2O ratio is very sensitive to weathering, recycling and digenetic alteration processes, hence can be used as an index of sediment maturity. It is a measure of the quartz context of siliciclastic rocks. Consequently, quartz outlives feldspar, mafic minerals, and lithics as sediment maturity increases [13](Roser and Korsch, 1986). Those that are chemically immature are represented by low ratios, while those that are mineralogically mature (quartzose, rounded) exhibit high ratios.

Finer grain sizes may indicate maturity, however the true indicator of immaturity is more closely linked to the amount of clay present. In unmodified igneous rocks, the average SiO/Al_2O_3 ratios vary from 3.0 in basic rocks to 5.0 in siliceous rocks. Values of SiO_2/Al2O3 ratios of the sample under investigation ranged between 1.80 – 8.42 with an average of 3.81, which suggest immaturity (low maturity) of the sediment. Also the K_2O/Na_2O ratio is also used as a maturity index which measures the alkali concentration in sediments. Abundant feldspar represented by Na_2O and K_2O is a reflection of immaturity in sandstones and shales. The K_2O/Na_2O ratio in the sample has value range of 3.96 – 53.52 averaging 21.66, which suggest a variation between moderate and low maturity. This suggest that the sediments were derived from different sources and depositional settings. A plot of SiO_2 vs $Al_2O_3 + K_2O/ Na_2O$ (figure 4) [14] (Suttner and Dutter,1986) showed that the data points are plotted in the Humid – semi humid climatic axis. Humid climate promote the intensity of chemical weathering, leading to the progressive maturity of clastic rocks. It could therefore be inferred that the humid conditions may have accelerated the intensity of weathering and maturity of the samples. The Index of Compositional variability (ICV) is another important geochemical proxy used for the maturity of clastic rocks. The ICV proposed by [15] is expressed as;

$$ICV = \left\{\frac{Fe_2O_3+CaO+K_2O + Na_2O+MgO+MnO+TiO_2}{Al_2O_3}\right\} \ldots\ldots\ldots\ldots\ldots (5)$$

According to [15], ICV > 1 indicates compositionally immature, derived from a cratonic basin, while ICV < 1 are compositionally mature and deposited in a tectonically quiescent cratonic environment. The samples under study has ICV values that ranges from 0.104 – 0. 868 with an average of 0.472, which is an indication of matured sediments that were recycled by long distance transport and deposited in a tectonically stable basin.

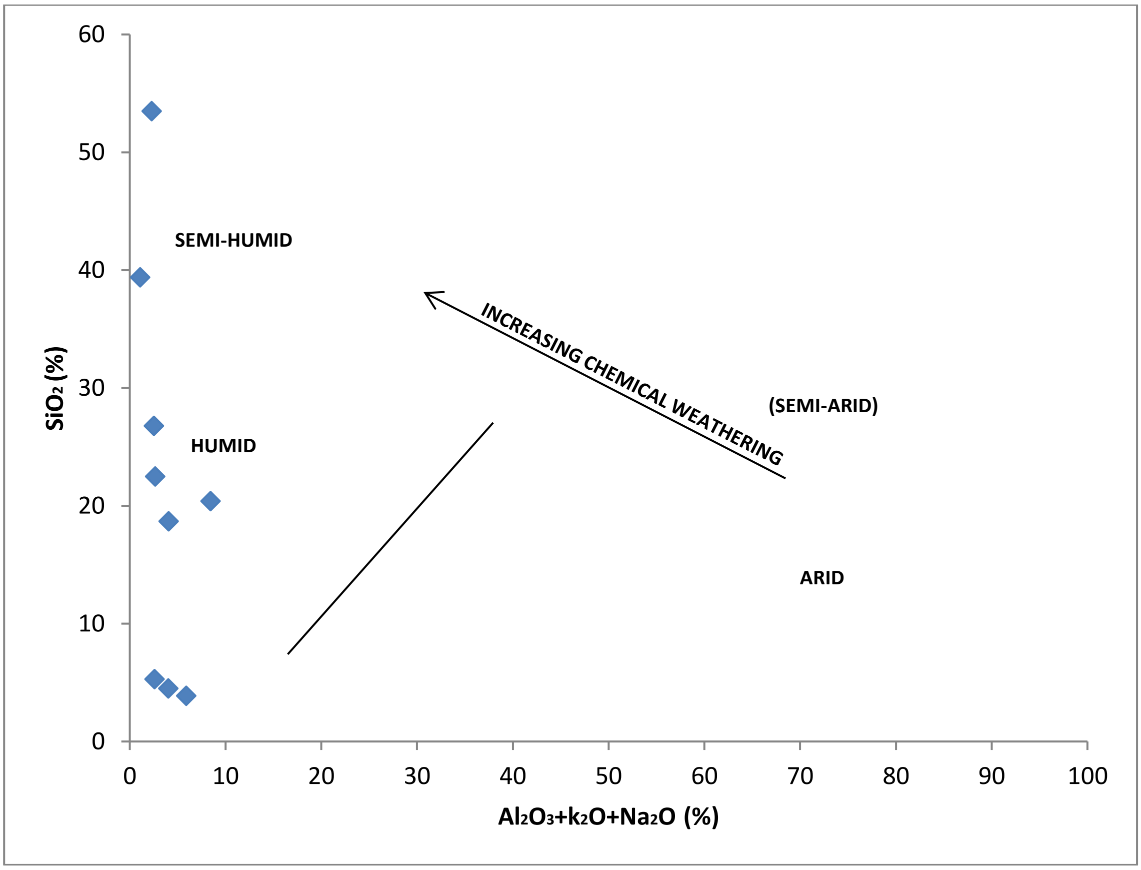

Figure 3: Climatic condition and maturity of the samples, [After 14]

Tectonic Setting

The tectonic origin (setting) of silicclastic rocks may also be inferred from major elements concentrations in sediments. In order to ascertain the tectonic setting of clastic sedimentary rocks, [13] constructed a tectonic decimation diagram (figure 4) using the ratio K_2O/Na_2O versus SiO_2.

Sediments deposited in the passive margin (PM), active continental margin (ACM), and oceanic island arc (OIA) may be distinguished from one another using a bivariate graphic. The plot suggest that the samples of the Ogwashi Asaba Formation were deposited in a passive margin tectonic setting (figure 5).

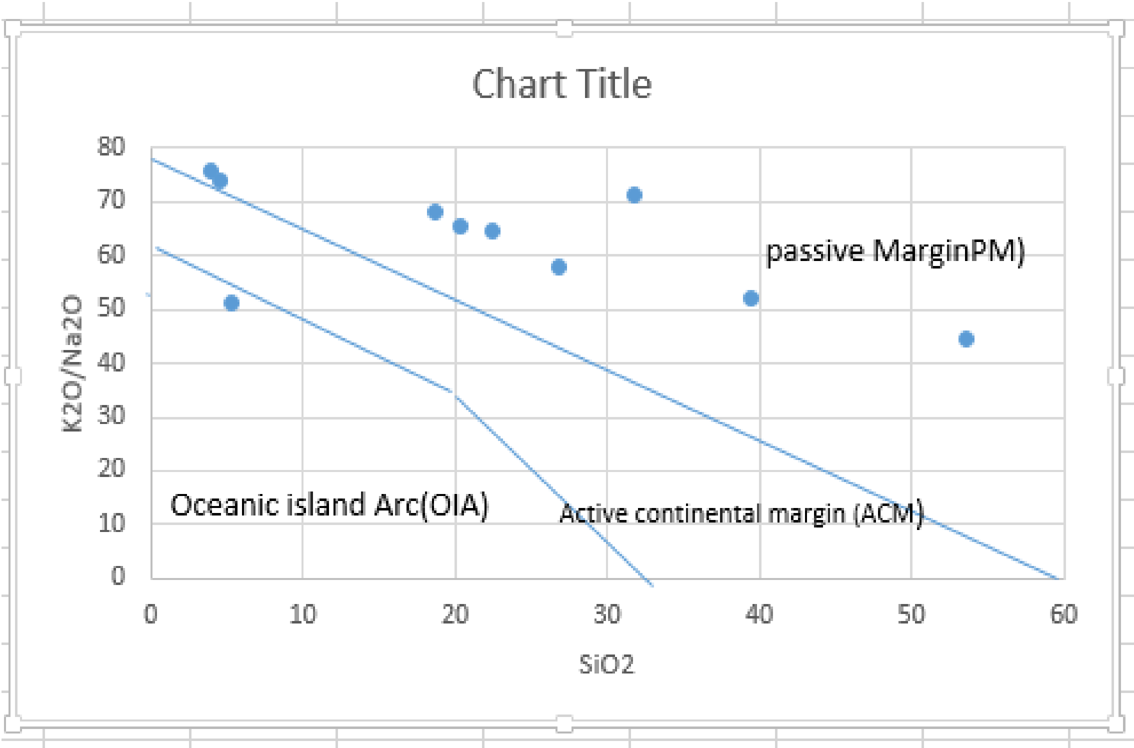

Figure 5: Tectonic Discrimintion Diagram of the samples [After [13]

V. Conclusion

In order to study the intensity of weathering, maturity and tectonic setting of the outcropping Eocene Sediments of the Ogwashi Asaba Formation, nine samples of mixed lithologies including lignites, fine sandstones, shales and white clays were retrieved from three sections of the Ogbunike quarry (Onitsha) during a one day field work. The samples were analyzed using the x-ray fluorescence (XRF) technique to determine major elemental concentrations in the fine grained sediments. From the results obtained, major oxides like SiO_2, Al_2O_3 and TiO are enriched. This was attributed to their stable and immobile characteristics during weathering and recycling. Conversely, mobile alkali oxides like Na_2O, CaO, K_2O, Fe_2O_3 and MnO were depleted due to their susceptibility to chemical destruction during weathering and diagenesis, sources area composition and grain size effect. Average values of CIA, CIW and PIA includes 90.23, 97.73 and 96.83 respectively which indicates an intense weathering at the source areas. SiO_2/Al_2O_3, K_2O/Na_2O and ICV maturity indices has average values of 3.81, 21.66 and 0.472 respectively. These figures indicates a maturity variation from moderate to low maturity. These variations possibly suggests a deposition of the sediments from different sources. The bivariate tectonic discrimination plot placed the sediments in the passive margin field.