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# Inorganic Geochemical Study of the Siliciclastic Sediments penetrated by Ash-3 Well in the Greater Ughelli Depobelt, Niger Delta Basin, Nigeria

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**ABSTRACT:** Inorganic geochemical study of the siliciclastic sediments penetrated by Ash-3 Well was undertaken in order to classify the siliciclastic sediments, determine the provenance area, tectonic setting and the environment of deposition of the study area. Twenty eight (28) ditch cutting samples within the interval of 15ft to 11430ft were obtained for Xray fluorescence analysis to determine the major oxides composition. Using Herron's plot for classification shows that the siliciclastic sediments were classified into Fe-shale, Fe-sand and quartz arenites fields. Roser and Korsch's discriminant function diagrams for provenance signature and tectonic setting show quartzose sedimentary provenance and passive margin tectonic setting fields respectively. The environment of deposition from inorganic geochemical analysis shows that the sediments were deposited with in the continental and transitional environments.

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The Niger Delta Petroleum System is one of the major oil and gas regions in Africa. It is seated at the region where the separation of Africa plate and South America plate developed. The Niger Delta region represents a failed armed of a triple junction (aulacogen) after rifting ceased in the Mid-Cretaceous period (Short and Stauble, 1967). The inorganic geochemical study is the method through which scientists discover and unravel the chemical constituents that make up a rock, the earth and its seas. Inorganic Geochemical study can envisage where petroleum, solid minerals, metals, water, and economically valuable minerals can be found (Islam *et al*., 2015). In recent times, inorganic geochemical evaluation has been developed to characterize source rocks and to understand the migration and accumulation of petroleum (Islam *et al*., 2015). Studies have been carried out on inorganic geochemistry on ancient and modern sediments in order to classify the siliciclastic sediments, infer the provenance area, tectonic setting and environment of deposition (Potter, 1978; Bhatia, 1983; Hiscott, 1984; Bhatia and Crook, 1986; Roser and Korsch, 1986, 1988, Itiowe *et al*., 2021). Inorganic geochemistry study of the siliciclastic sediments was undertaken in order to classify the sediments, determine the provenance area, tectonic setting and the environment of deposition of the study area.These variables are important in understanding the quality of our source rock, reservoir rock and the nature of the sedimentary basin.The study area is geographically located between latitude $5^{O}30N$ and longitude $5^{O}45E$ (Figure 1).

*The Geology of the Niger Delta Basin:* The Niger Delta developed over the collapsed continental margin at the site of the triple junction during the Mid-Cretaceous period. The main sediment supply has been extensive drainage system (Burke *et al.*, 1971). Since the Late Cretaceous period, sediment input has been continuous. Episodic transgression affected the regressive records. The Niger Delta stratigraphic sequence encompasses of a coarsening upward association of regressive siliciclastic sediments that are diachronous (Weber and Daukoru 1975; Evamy *et al.*, 1978). The stratigraphic sequence of the Niger Delta consists of marine sediments which superimposes oceanic and continental crust (Corredor, Shaw and Bilotti 2005). The clastic unit is divided into three Formations which are - Akata, Agbada and Benin Formations (Table 1). The Akata Formation consists

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of broad shale succession at the base and it is believed to be the source rock for petroleum generation. It has a thickness ranging from 2500m to 8500m at the distal part and towards the continental shelf respectively. The Akata Formation is directly rest upon by the Agbada Formation; this is the main hydrocarbon bearing unit in the basin, with sedimentary thickness greater than 3500m. This petroleum bearing unit represents the deltaic section of the sequence. This unit is rest upon by the Benin Formation. This Formation is made up of continental deposit from Late Eocene to Holocene with up to 2000m thick (Avbovbo 1978). The geological age of the clastic sediment ranges from Cretaceous to Holocene. Itiowe and Lucas (2020a) established five palynological bio-zones which are the lumped P650-P670, lumped P620-P630, P580, P560 and P540 zones for the sediments from the Greater Ughelli depobelt and concluded that the age of the depobelt is from Oligocene to early Miocene epoch. Itiowe *et al*. (2020b) carried out a study on the foraminiferal and depositional environment of sediments penetrated by a well in the Northern part of the Delta, the study established five foraminiferal bio-zone which are the lumped P7-P13, P5-P6/P7, lumped P3-P4, lumped P1-P2 and M18 Zones, which tally to late Maastrichtian and late Eocene age. The Late Maastrichtian sediments in the study signify Cretaceous age. It could be that the Cretaceous Formation is beneath the known subsurface stratigraphic succession of the Delta.

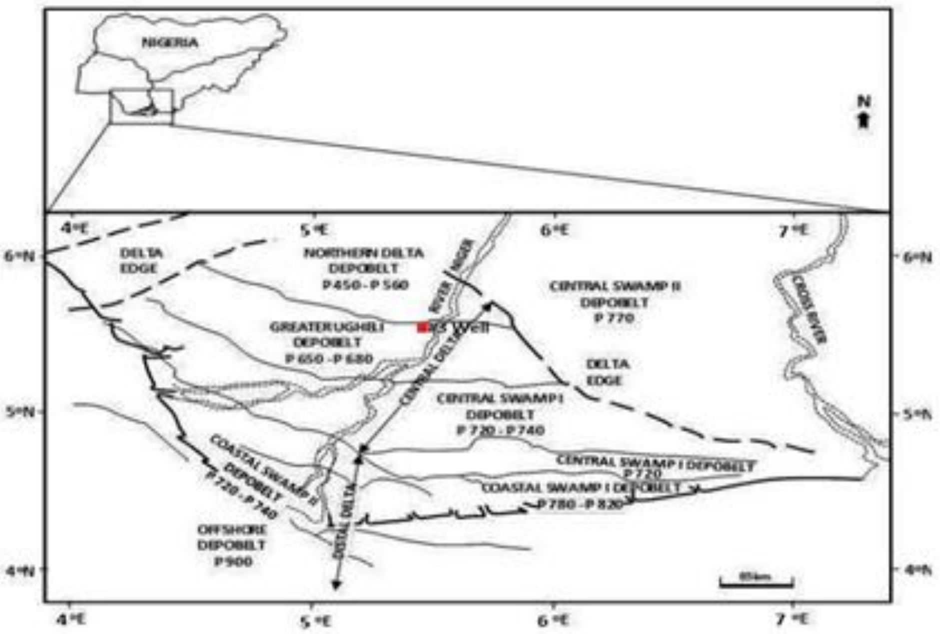


**Fig 1:** Map of study location (Doust and Omastola, 1990)

**Table 1:** Age and Formations of the Niger Delta Sedimentary Basin (Modified after Short and Stauble, 1967).

| **Subsurface** | | | **Surface Outcrop** | | |
|---|---|---|---|---|---|
| **Youngest Known Age** | **Formation** | **Oldest Known Age** | **Youngest Known Age** | **Formation** | **Oldest Known Age** |
| | | | Holocene | Alluvium | |
| Recent | Benin Fm. | Oligocene | Ear. Holo. To Late Pleistoc. | Deltaic Plain Deposits | Miocene? |
| | Afam Shale Member | | Plio. / Pleist. | Benin Fm. | |
| Recent | Agbada Fm. | Eocene | Miocene | Ogwashi - Asaba Fm. | Oligocene |
| | | | Eocene | Ameki Fm. | Eocene |
| Recent | Akata Fm. | Eocene | L. Eocene | Imo Shale | Paleocene |
| | Imo Shale | Paleocene | Paleocene | Nsukka Fm. | Maestrich. |
| | Nsukka Fm. | Maestrich. | Maestrich. | Ajali Fm. | Maestrich. |
| | | | Campanian | Mamu Fm. | Campanian |
| | Equivalent | | Camp./ Mae. | Nkporo Sh. | Santonian |
| | not known | | Conia/ Santo. | Agwu Shale | Turonian |
| | | | Turonian | Eze-Aku Shale | Turonian |
| | | | Albian | Asu River Gp. | Albian |

## MATERIAL AND METHODS

Twenty eight (28) ditch cutting were sampled from the shaly and sandy shale intervals of interest between the intervals of 15ft to 11430ft. The samples were evaluated for forty nine elemental components (13 major oxides and 36 trace/REE) using Xray fluorescence analytical method at Nigeria Geological Survey Agency, Kaduna.

*Procedures for X-ray fluorescence study:* The moisture content was removed by oven drying the cutting samples for 3hrs at 70ºC.

- Arget pulverizing machine was used to mill the dried samples.
- In order to ensure uniformity of the samples, the milled samples were passed through 75 micro mesh sieves.
- Twenty gram of the powdered samples were packed and labeled into cups.
- The cups were arranged into Energy Dispersive x-ray fluorescence (EDXRF) spectrometer for the analysis.

## RESULTS AND DISCUSSION

*Lithological representation of the Ash-3 Well:* The depth interval of this well is from 15ft to 11430ft (Figure 2). This well comprises of five lithofacies types names: sandstone, shaly sandstone, clayey sandstone, sandy shale and shale. The grain sizes vary from clay to boulder. This well consists of two Formations namely: the Benin and Agbada Formations.

*Benin Formation:* This Formation occurs within the interval of 15ft to 6000ft. The sandstones are mainly whitish to yellowish with clayey sandstone at the top (45ft to 245ft). The grain differs from very fine to boulder, angular to well-rounded and poorly sorted to very well sorted. Minerals found within this zone include mica, pyrite, iron oxide and carbonate. The coal presence within the formation ranges from 5 to 85%. Occasionally, thin laminae of shale are found within this zone. On the basis of the percentages of the sand and shale intercalation the environment of deposition is considered to be continental environment (Boggs, 2006).

*Agbada Formation:* This Formation occurs within the interval of about 6030ft to11430ft. It consists of intercalation of shale and sand with mainly shaly sandstone at the top and sandy shale at the base. The shale is mainly greyish, fine grained and fissile, which is an indicative of calm and an anoxic condition and the sand differs from very fine to very coarse. The minerals found within this zone include mica, pyrite and iron oxide. Rootlets and wood fragments were also present in this Agbada Formation. Based on the percentage of shale to sand from the ditch cuttings samples the environment of deposition is considered to be paralic to transitional (Boggs, 2006).

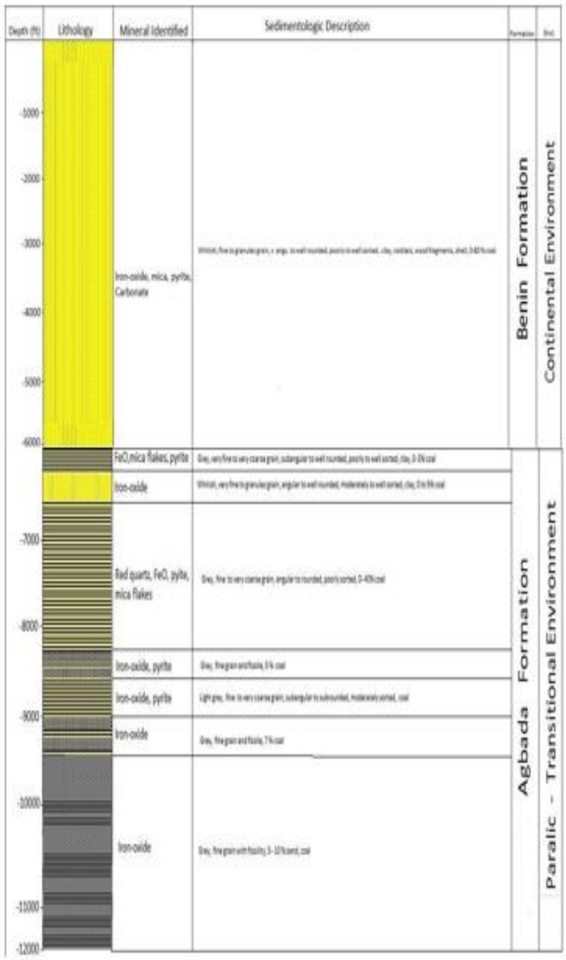


**Fig 2:** Lithological representation of Ash-3 Well

*Major oxide composition:* The analysis of the major oxides in wt. % differs widely. Table 2 shows the major oxide compositions.The range and average values of major elemental oxides are as follows: $SiO_2$ (84.20 – 38.80, average 44.70), CaO (8.80-0.71, average 2.31), MgO (0.98-0.009, average 0.27), $SO_2$ (10.00-1.01, average 4.75), Cl (0.83-0, average 0.154), BaO (1.80-0.29, average 0.77), $K_2O$ (3.10 - 0.87, average 1.95), $Na_2O$ (1.11-0.08, average 0.345), $TiO_2$ (4.19-0.77, average 2.041), MnO (0.10-0.075, average 0.043), $P_2O_5$ (0.01-0, average 0.00079), $Fe_2O_3$ (12.04-3.01, average 5.587), $Al_2O_3$ (20.94-4.40, average 17.38) and Lol (21.02-3.01, average 14.78).

**Table 2:** Analysis of the major oxides

| Oxides Comp. (%) | $SiO_2$ | CaO | MgO | $SO_3$ | Cl | BaO | $K_2O$ | $Na_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $Fe_2O_3$ | $Al_2O_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6255 | 47.33 | 3.16 | 0.78 | 5.79 | nd | 0.71 | 1.80 | 0.35 | 1.74 | 0.10 | 0.003 | 4.07 | 18.40 | 15.67 |
| 6600 | 50.00 | 1.03 | 0.21 | 5.40 | nd | 0.51 | 0.98 | 0.24 | 0.77 | 0.055 | 0.002 | 3.78 | 18.60 | 20.45 |
| 6885 | 42.90 | 1.80 | 0.22 | 6.30 | nd | 0.90 | 1.30 | 0.08 | 1.69 | 0.044 | nd | 4.06 | 20.32 | 18.40 |
| 7140 | 70.30 | 0.95 | 0.05 | 2.40 | 0.67 | 0.29 | 1.00 | 0.70 | 1.99 | 0.031 | 0.002 | 3.50 | 10.02 | 6.10 |
| 7380 | 81.80 | 0.98 | 0.08 | 1.01 | nd | 0.34 | 1.60 | 0.33 | 1,60 | 0.02 | nd | 3.01 | 8.25 | 1.20 |
| 8115 | 42.06 | 2.16 | 0.45 | 3.63 | 0.73 | 1.80 | 0.98 | 0.42 | 1.56 | 0.038 | 0.0006 | 3.13 | 20.12 | 15.01 |
| 8175 | 50.50 | 1.03 | 0.50 | 4.12 | nd | 0.38 | 1.50 | 0.28 | 1.48 | 0.037 | nd | 4.28 | 19.42 | 17.30 |
| 8265 | 60.90 | 2.30 | 0.74 | 4.33 | 0.0008 | 0.94 | 1.02 | 0.58 | 2.38 | 0.029 | 0.0009 | 6.05 | 11.04 | 8.05 |
| 8385 | 42.50 | 1.40 | 0.09 | 3.81 | 0.001 | 0.53 | 0.98 | 0.18 | 2.16 | 0.042 | 0.003 | 5.14 | 20.94 | 18.05 |
| 8460 | 84.20 | 0.71 | 0.009 | 2.93 | nd | 0.41 | 0.87 | 0.21 | 1.44 | 0.010 | nd | 3.20 | 4.40 | 1.01 |
| 8550 | 44.50 | 1.52 | 0.12 | 5.60 | nd | 0.64 | 1.60 | 0.22 | 2.00 | 0.045 | 0.002 | 5.44 | 20.08 | 17.40 |
| 8685 | 38.90 | 1.58 | 0.31 | 7.00 | nd | 0.74 | 0.78 | 0.25 | 1.67 | 0.049 | 0.0008 | 8.07 | 19.30 | 17.80 |
| 8760 | 42.10 | 2.37 | 0.40 | 6.05 | 0.675 | 0.49 | 1.87 | 0.17 | 2.78 | 0.042 | nd | 5.77 | 19.63 | 14.06 |
| 8925 | 38.80 | 2.54 | 0.32 | 4.60 | 0.83 | 1.00 | 1.78 | 0.31 | 2.80 | 0.053 | 0.001 | 7.48 | 21.06 | 16.93 |
| 9120 | 45.20 | 1.70 | 0.07 | 4.57 | nd | 0.80 | 1.05 | 0.31 | 2.08 | 0.041 | 0.0004 | 4.89 | 18.08 | 17.24 |
| 9195 | 40.00 | 1.10 | 0.04 | 7.70 | nd | 0.87 | 2.10 | 0.05 | 2.54 | 0.039 | nd | 8.60 | 19.05 | 15.50 |
| 9255 | 43.08 | 1.53 | 0.12 | 4.05 | nd | 0.67 | 2.40 | 0.22 | 2.90 | 0.069 | nd | 7.93 | 18.40 | 16.93 |
| 9315 | 42.00 | 2.50 | 0.06 | 4.10 | nd | 1.40 | 2.00 | 0.40 | 2.68 | 0.043 | nd | 6.07 | 18.20 | 14.01 |
| 9420 | 40.20 | 3.26 | 0.41 | 4.03 | nd | 0.84 | 2.02 | 0.21 | 2.35 | 0.056 | 0.002 | 5.50 | 16.00 | 14.68 |
| 9645 | 40.24 | 3.98 | 0.09 | 2.06 | 0.002 | 0.43 | 2.20 | 0.24 | 2.22 | 0.077 | 0.0004 | 7.50 | 19.00 | 15.20 |
| 10080 | 42.20 | 3.01 | 0.35 | 4.09 | nd | 1.78 | 2.01 | 0.34 | 2.44 | 0.032 | 0.0010 | 6.76 | 18.00 | 15.43 |
| 10320 | 40.60 | 8.90 | 0.24 | 5.70 | 0.53 | 0.75 | 3.10 | 0.24 | 1.06 | 0.075 | nd | 6.38 | 16.30 | 14.08 |
| 10485 | 40.50 | 3.87 | 0.44 | 5.30 | nd | 0.95 | 2.10 | 0.54 | 4.19 | 0.03 | nd | 6.50 | 19.02 | 15.03 |
| 10605 | 40.70 | 1.22 | 0.98 | 10.00 | 0.74 | 0.55 | 2.01 | 0.47 | 1.81 | 0.060 | 0.0007 | 12.04 | 18.00 | 12.45 |
| 10740 | 43.00 | 4.03 | 0.12 | 3.74 | 0.002 | 0.90 | 3.02 | 1.11 | 1.37 | 0.009 | 0.001 | 3.09 | 17.03 | 20.00 |
| 10830 | 43.70 | 3.05 | 0.30 | 3.80 | 0.040 | 0.61 | 2.20 | 0.54 | 2.11 | 0.023 | 0.0005 | 5.26 | 20.07 | 16.93 |
| 11070 | 44.00 | 2.01 | 0.22 | 5.40 | 0.10 | 0.62 | 1.24 | 0.60 | 1.99 | 0.041 | nd | 6.14 | 18.40 | 21.02 |
| 11205 | 45.00 | 2.03 | 0.12 | 5.74 | 0.002 | 0.90 | 2.02 | 0.11 | 1.37 | 0.009 | 0.001 | 3.09 | 20.03 | 18.00 |

*nd = not detected*

*Classification of the sediments***:** The sediments were classified using the standard Herron (1988) diagram of Log ($SiO_2/Al_2O_3$) against Log ($Fe_2O_3/K_2O$). The sediments was plotted within the Fe-shale, Fe-sand and quartz arenite regions; which is an indication that the sediments in the well could be rich in iron containing minerals such as illite, pyrite, jarosite and chlorite. Figure 3 shows the plot for the classification of the sediments collected for Ash-3 Well.

*Provenance area:* Provenance is the source area where sediments are derived from. The aim of any provenance study is to determine the source area of the sediments. Roser and Korch (1988) discriminant function diagram for provenance signature was employed to distinguish the source of sediments in the well into four provenances (Figure 4). They are the felsic igneous provenance, intermediate igneous provenance, mafic igneous provenance and quartzose sedimentary provenance. The discriminant function of two plots was based on the oxides of Al, Ca, Mg, Ti, Fe, Na and K was used to differentiate the provenance into four provenance groups. The discriminant functions for the two plots used to discriminate the sediments from both wells using raw oxide are given below:

Discriminant Function (DF1) = $-1.773TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3 - 1.5MgO + O.616CaO + 0.509Na_2O - 1.224K_2O - 9.09$

Discriminant Function (DF2) = $0.445TiO_2 + 0.07Al_2O_3 - 0.25Fe_2O_3 - 1.42MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.382$

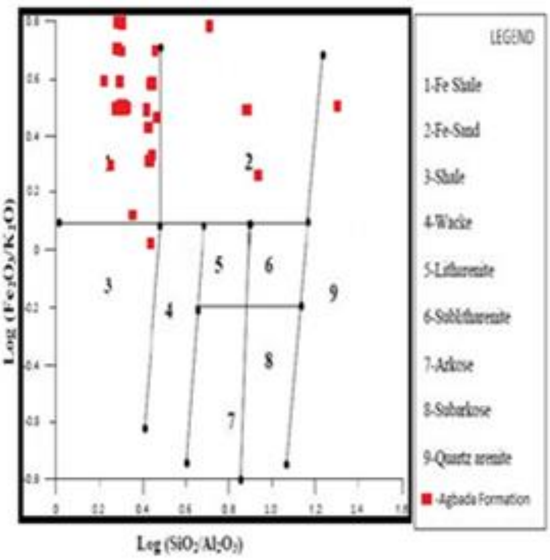


**Fig 3:** Classification of sediments (after Herron, 1988)

The plot reveals that the sediments from Ash-3 Well were majorly derived from quartzose sedimentary provenance. Sedimentary rocks that are quartzose are majorly silicate minerals and rock fragments that are transported by moving water and are deposited when the water came to rest (Islam *et al*., 2015). It could be that the sediments from well were derived mainly from already existing sedimentary sediments which could be sediments from the close by Benue Trough or other existing sedimentary terrain, which are now deposited in the Niger Delta Basin.

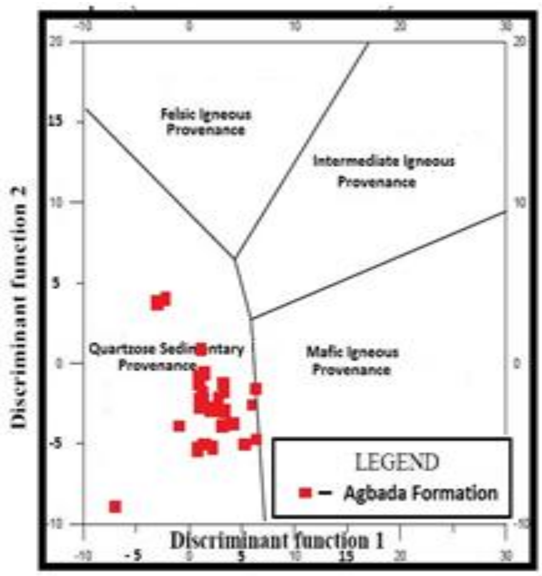


**Fig 4: D**iscriminant function diagram for provenance signature (after Roser and Korsch, 1988)

*Tectonic setting for the area:* Roser and Korch (1988) discriminant function diagram for tectonic setting was employed to distinguish the tectonic setting of the study area into three tectonic setting. They are as follows: Active continental margin, passive margin continental setting and oceanic island arc. The active continental margins are those areas that are tectonically active, and are characterized by earthquakes, mountain belts and volcanic activities; the passive continental margins are those areas that are not tectonically active, whereas the oceanic island arc or fore-arc or back-arc basins are adjacent to a volcanic-arc developed on oceanic or thin continental or oceanic crust. The plot of log ($K_2O/Na_2O$) and $SiO_2$ for Ash-3 Well reveals the sediments within these wells fall within the passive continental margin (Figure 5). This passive continental margin is consistent with the tectonic setting of the Niger Delta (Tuttle *et al*., 2015). Passive continental margin are areas that are not tectonically active, they do not experience reoccurrence tectonic activities such as earthquake, mountain belts and volcanic eruption. Hence, this passive margin is favourable for hydrocarbon formation.

*Environment of deposition:* The AKF ($Al_2O_3$ – ($K_2O$+CaO+MgO)-$Fe_2O_3$+MgO) plot was used to determine the environment of deposition (Figure 6). The sediments were plotted with in the continental and transitional zones, this is in concordance with the environment of depositional analysis from the lithostratigraphic model of Ash-3 Well (Figure 2).

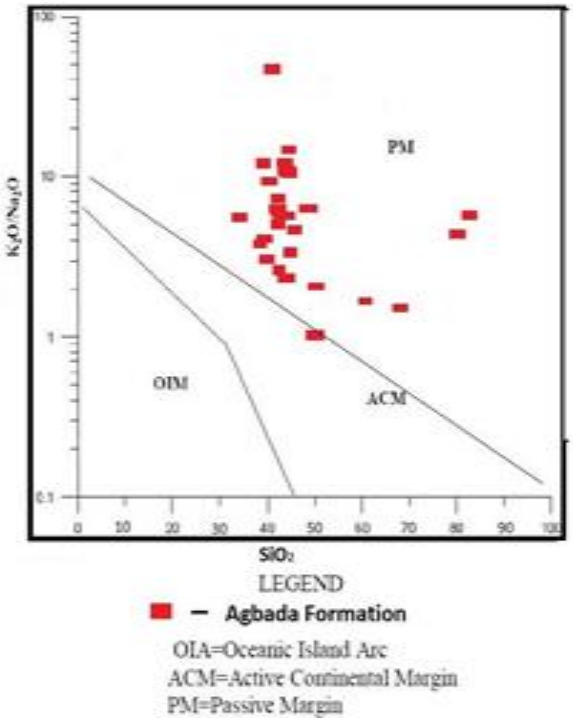


**Fig 5:** Discrimination Function diagram for tectonic setting (after Roser and Korsch, 1988)

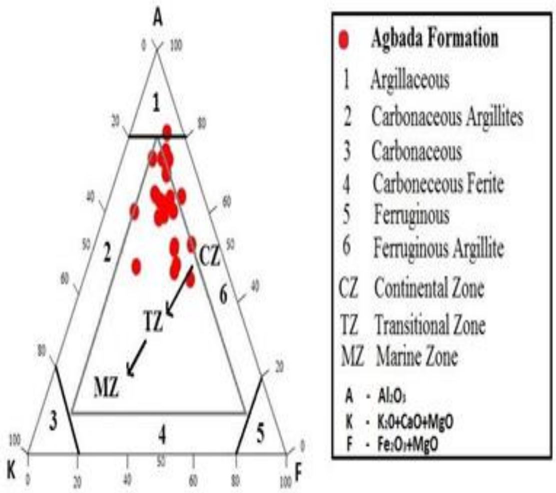


**Fig 6**: $Al_2O_3$-($K_2O$+CaO+MgO)-($Fe_2O_3$+MgO) Ternary plot for depositional environment (after Englund and Jorgensen, 1973)

*Conclusion:* Inorganic geochemical study of the siliciclastic sediment penetrated by Ash-3 Well was used to classify the sediments, reveal the provenance area, tectonic setting and environment of deposition.

The study shows that $SiO_2$ is the preponderant major oxide which constitutes averagely of about 44.7%, followed by $Al_2O_3$ and $Fe_2O_3$ while the remaining oxides constitute the rest. The sediments were plotted within Fe-Sand, Fe-Shale and quartz arentites regions which is an indication that the well is rich in iron containing minerals. The plot for provenance determination shows that the silisciclastic sediments were majorly derived from quartzose sedimentary provenance; which is an indication that the sediments from these well was derived mainly from already existing sedimentary sediments which could be the sediments from the Benue Trough or other existing sedimentary terrain, which was deposited in the Niger Delta Basin. The tectonic setting for the study area shows passive margin tectonic setting, this type of tectonic setting does not experience earthquake reoccurence, frequent volcanic eruption and hence favourable to oil and gas formation. The environment of deposition interpretation shows that the sediments were plotted within the transitional to continental zones.

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