SEDIMENTOLOGICAL AND GEOCHEMICAL ANALYSIS OF THE SEDIMENT IN THE NIGER DELTA BASIN

Oyintare Brisibe[1], Owonaro B. Jennifer[2], Timiyan T. Kingsley[3], Akosubo I. Stevyn[4]

[1,2] Lecturer, Department of Marine Geology, Nigeria Maritime University Okerenkoko, Delta State, Nigeria.
[3] Lecturer, Department of Petroleum and Gas Engineering, Nigeria Maritime University Okerenkoko, Delta State, Nigeria.
[4] Lecturer, Department of Civil Engineering, Nigeria Maritime University Okerenkoko, Delta State, Nigeria.

ABSTRACT

The Niger Delta underlies an area of about 256,000km^2 and was initially built over an older transgressive Paleocene prodelta. Sedimentological and geochemical studies have been carried out on the sediments of the Y-field in the Niger Delta Basin with a view to deducing the provenance, palaeodepositional characteristics and tectonic history of the sediments. Twenty-one core samples were collected, washed, dried, grinded, pulverized and subjected to inorganic analysis which includes major oxides, trace elements, and rare earth element. The provenance and prevalent conditions of deposition from various elemental ratios indicate that the Th/U ratio has an average of 4.1 which is very close to that of the upper continental crust of 3.8. The high ratios of Th/Sc and Zr/Sc indicate a slight input of felsic materials from recycled sedimentary provenance. Elevated values of thorium with respect to uranium may imply a felsic source. Th/Sc values for the analyzed samples were in the range of 0.83-2.83, implying a felsic igneous provenance. The same applies for the Th/Co ratio as most of the values are above 0.27 and less than 19.5 (Th/Sc and Th/Co values for felsic rocks are 0.84-20.05 and 0.27-19.5, resp.). From major oxides, it can be concluded that the tectonic setting of the Niger delta is an active continental margin. The trace elements confirmed the tectonic settings of the sediments as active continental margins. The trivariate plots of La-Th-Sc, Th-Sc-Zr/10, and Th-Co-Zr/10 all show the provenance of the sediments to be active continental margins.

Keyword: *Geochemical, Sedimentological, tectonic settings, Niger Delta Basin*

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1. INTRODUCTION

The mineralogical and chemical composition of clastic sedimentary rocks are controlled by various factors, including (1) the composition of their source rocks, (2) environmental parameters influencing the weathering of source rocks (e.g., atmospheric chemistry, temperature, rainfall and topography), (3) duration of weathering (4) transportation mechanisms of clastic material from source region to depocenters, (5) depositional environment (e.g., marine versus fresh water), and (6) post-depositional processes (e.g., diagenesis, metamorphism) (Hayashi et al., 1997). Numerous investigations are substantiating the above aspects pertaining to genesis of both ancient and modern siliciclastic sediments (e.g., Dickenson et al., 1983; Nesbitt and Young, 1982, 1984; Bhatia, 1983; Roser and Korsch, 1988; McCann, 1991; Condie et al., 1992; Condie, 1993; McLennan et al., 1993; Nesbitt et al., 1996; Cullers, 2000; Hessler and Lowe 2006; Nagarajan et al., 2007; Spalletti et al., 2008). Several studies have also been focused on the identification of palaeotectonic settings of provenances based on geochemical signatures of siliciclastic rocks (e.g., Dickinson and Suczek, 1979; Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch 1986; McLennan and Taylor, 1991). Among the terrigenous sedimentary rocks, shales are considered to represent the average crustal composition of the provenance much better than any other siliclastic rocks (e.g., McCulloch and Wasserburg, 1978). Shales retain most of the mineral constituents of the source and their bulk chemistry preserves the near-original signature of the provenance and more faithfully reveal palaeo weathering conditions (e.g., Pettijohn, 1975; Graver and Scott, 1995). The present note examines the geochemistry of sediment from part of the subsurface Niger Delta Basin province, attempts to constrain their paleo redox and tectonic setting and provenance. Owing to limitations of analytical facilities, the present work is based on chemical analyses data of major and select trace elements of the investigated sediment of the study area.

2. MATERIALS AND METHOD

2.1 Study Area

The study area lies between latitude and longitude. The area is situated in the central Delta sedimentary basin of southern Nigeria. The samples were taken from Y-field in Niger delta. The coordinates of the study area were not given because of the proprietary nature of the data but the estimated location is shown in Figure 1. The Niger delta extends from about longitudes 3◦ E and 9◦ E and latitudes 4◦30 N to 5◦21 N. The Niger delta is located in the southern part of Nigeria. The Niger delta is situated in the Gulf of Guinea, which northwards merges with the structural basin in the Benue and middle Niger terrain holding thick marine paralic and continental sequence. The onshore portion of the Niger delta province is delineated by the geology of southern Nigeria and southwestern Cameroon. The Niger delta was formed as a result of basement tectonics related to the crustal divergence during the late Jurassic to cretaceous continental rifting of Gondwanaland that led to the separation of South American African continents. The Niger delta is large arcuateto lobate tropical constructive wave of dominated type. Active deposition is presently occurring simultaneously in these depobelts under fluviatile conditions where there is interplay between terrestrial and marine influences. The Niger delta basin to date is the most prolific and economic sedimentary basin in Nigeria. It is an excellent petroleum province. The Niger delta is situated in the Gulf of Guinea and extends throughout the Niger delta province. From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development [3].
These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 [13], a sediment volume of 500,000 km^3 [8], and a sediment thickness of over 10 km in the basin depocenter [11].
The Niger delta province contains only one identified petroleum system [13, 4]. This system is referred to here as the tertiary Niger delta (Akata-Agbada) petroleum system.

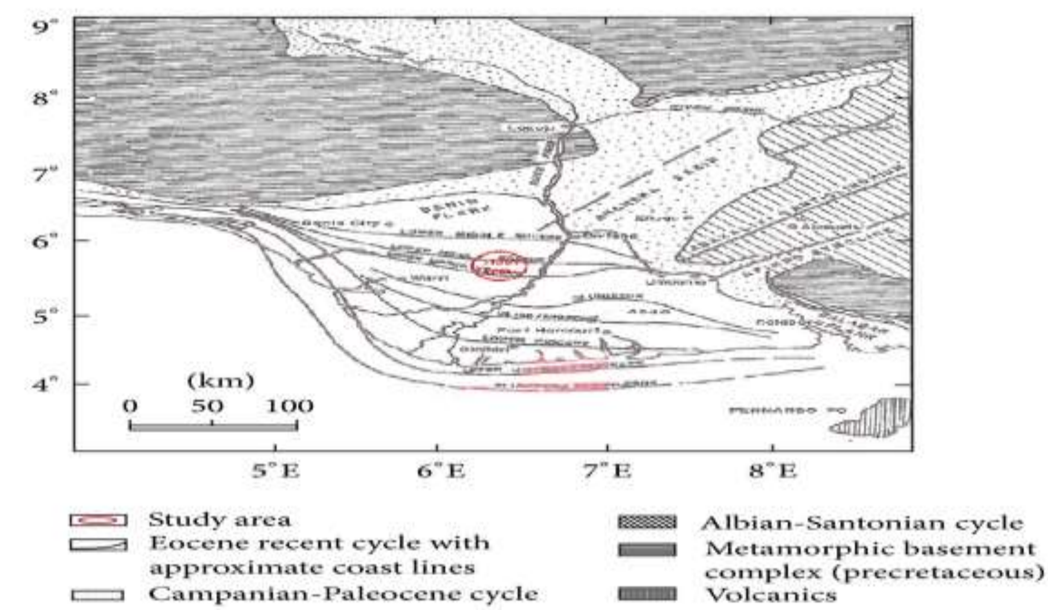

Fig. 1: Generalized and simplified geological map of Niger delta basin.
(Source: http://www.intechopen.com)

The maximum extent of the petroleum system coincides with the boundaries of the province. The minimum extent of the system is defined by the areal extent of fields and contains known resources (cumulative production plus proved reserves) of 34.5 billion barrels of oil (BBO), 93.8 trillion cubic feet of gas (TCFG), and 14.9 billion barrels of oil equivalent (BBOE) [16]. Currently, most of this petroleum is in fields that are onshore or on the continental shelf in waters less than 200 meters deep and occurs primarily in large, relatively simple structures. Among the provinces ranked in the U.S. Geological Survey's World Energy Assessment [12], the Niger delta province is the twelfth richest in petroleum resources, with 2.2% of the world's discovered oil and 1.4% of the world's discovered gas [16].

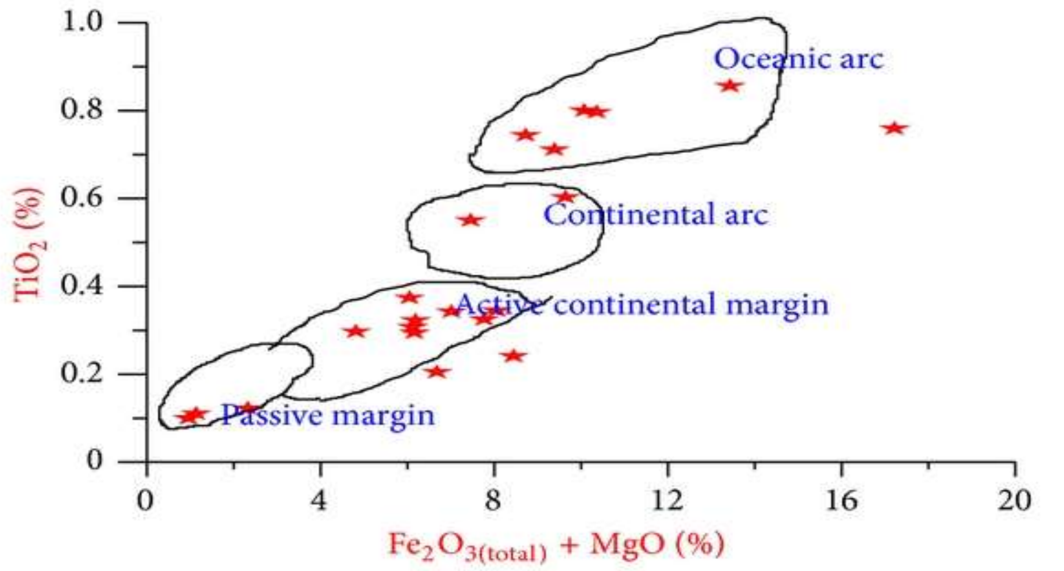

Fig. 2: Bivariate plot of TiO_2 versus (Fe_2O_3+MgO) diagrams for sandstones.
(Source: Bhatia, 1982)

2.2 Sample Collection and Analysis

Twenty-one core samples were collected and subjected to inorganic analysis which includes major oxides, trace elements, and rare earth element. The samples are first dried. To avoid contamination, the samples are then washed in deionized water and dried again. After preparation, the samples are grinded and pulverized. Sample reduction entails comminuting by sieving or crushing and grinding. Standard procedure at most laboratories is to sieve soils and sediments to <75 m. The samples are thus sieved with <75 m. This is because sample preparation must reduce the sample volume to a size suitable for analysis yet preserves the bulk geochemical signature of the larger body. About 3g of the pulverized sample was then packed in a suitable bag and sent to Acme labs, for analysis.

3. RESULT

3.1 Tectonic Settings of Niger Delta Based on Major Oxides.

The tectonic settings of the Niger Delta Basin based on major oxides are as shown in Table 1 and Fig. 2.
The fields in Fig 2 are oceanic island arc, continental island arc, active continental margin, and passive margins.

Table 1: Table of the eleven major element oxides in percentages

Sample (in meters)	Lithology	K/Cs ratio	Th/U ratio	Cr/Th	Th/Co	Al_2O_3/SiO_2	La/Sc	Th/Sc
1160–1180	Sand	0.2	4.9	2.9	1.8	17	7.42	2.83
1560–1580	Sand	0.3	4.3	2.7	1.9	15	7.36	2.36
1960–1980	Sand	0.4	4.0	3.8	0.8	17	5.75	2.00
2960–2980	Shale	1.1	3.4	6.5	0.4	17	5.22	1.72
3960–3980	Shale	1.1	3.5	7.1	0.8	16	4.24	1.39
4560–4580	Shale	1.0	3.7	7.7	0.8	19	3.69	1.21
5460–5480	Shale	2.0	4.8	16.6	0.4	13	3.64	1.52
5760–5780	Shale	1.3	4.8	14.1	0.3	8	2.18	1.32
6160–6180	Shale	0.9	4.0	9.9	0.7	18	3.09	0.91
7060–7080	Sand	3.2	5.2	23.5	0.2	10	4.68	1.37
7260–7280	Sand	3.3	1.5	55.3	0.1	15	1.70	0.63
7560–7580	Sand	2.9	2.8	56.8	0.1	18	2.06	0.71
7760–7780	Shale	2.0	4.1	8.6	0.5	15	3.29	1.35
7960–7980	Shale	3.3	3.1	75.5	0.1	18	2.03	0.76
8060–8080	Shale	1.4	3.1	12.1	0.3	18	4.50	1.89
8160–8180	Sand	1.6	4.3	8.0	0.5	16	6.17	2.21
8560–8580	Sand	2.3	4.8	51.8	0.1	20	4.60	1.52
8960–8980	Shale	1.9	4.3	9.4	1.2	15	4.13	1.59
10,360–10,380	Shale	3.4	6.0	7.0	0.6	15	7.15	2.54
11,060–11,080	Shale	1.1	5.3	9.2	0.5	17	4.04	1.09
11,460–11,480	Shale	0.8	4.7	10.7	0.4	16	2.68	0.83
Average		1.7	4.1	19.0	73.7	15.9		

Table 2: Th/Sc-Zr-Sc, La, Co, Th, and Sc values

Samples depth	Lithology	Th/Sc	Zr/Sc	La	Co	Th	Sc	Zr/10
1160–1180	Sand	2.8	36.6	8.9	1.9	3.4	1.2	4.39
1560–1580	Sand	2.4	29.5	8.1	1.4	2.6	1.1	3.24
1960–1980	Sand	2.0	27.5	9.2	3.9	3.2	1.6	4.4
2960–2980	Shale	1.7	28.3	16.7	13	5.5	3.2	9.04
3960–3980	Shale	1.4	23.0	30.1	13.2	9.9	7.1	16.3
4560–4580	Shale	1.2	17.2	31.7	12.9	10.4	8.6	14.8
5460–5480	Shale	1.5	37.3	9.1	9	3.8	2.5	9.33
5760–5780	Shale	1.3	40.1	9.6	17.4	5.8	4.4	17.65
6160–6180	Shale	0.9	20.6	23.2	9.7	6.8	7.5	15.48
7060–7080	Sand	1.4	40.9	8.9	11.7	2.6	1.9	7.78
7260–7280	Sand	0.6	37.3	4.6	12	1.7	2.7	10.07
7560–7580	Sand	0.7	27.0	6.4	19.2	2.2	3.1	8.36
7760–7780	Shale	1.3	23.6	16.1	13.2	6.6	4.9	11.56
7960–7980	Shale	0.8	26.3	5.9	29.4	2.2	2.9	7.63
8060–8080	Shale	1.9	38.3	8.1	11.5	3.4	1.8	6.9
8160–8180	Sand	2.2	36.3	17.9	12.4	6.4	2.9	10.52
8560–8580	Sand	1.5	21.5	11.5	41.4	3.8	2.5	5.38
8960–8980	Shale	1.6	24.8	26	8.5	10	6.3	15.6
10,360–10,380	Shale	2.5	37.5	18.6	11.4	6.6	2.6	9.76
11,060–11,080	Shale	1.1	19.6	37.6	21.4	10.1	9.3	18.23
11,460–11,480	Shale	0.8	17.5	29.2	22.4	9	10.9	19.08
Average value		1.5	29.1					

Table 3: Table of various elemental ratios

Sample (in meters)	Lithology	K/Cs ratio	Th/U ratio	Cr/Th	Th/Co	Al_2O_3/SiO_2	La/Sc	Th/Sc
1160–1180	Sand	0.2	4.9	2.9	1.8	17	7.42	2.83
1560–1580	Sand	0.3	4.3	2.7	1.9	15	7.36	2.36
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7760–7780	Shale	2.0	4.1	8.6	0.5	15	3.29	1.35
7960–7980	Shale	3.3	3.1	75.5	0.1	18	2.03	0.76
8060–8080	Shale	1.4	3.1	12.1	0.3	18	4.50	1.89
8160–8180	Sand	1.6	4.3	8.0	0.5	16	6.17	2.21
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10,360–10,380	Shale	3.4	6.0	7.0	0.6	15	7.15	2.54
11,060–11,080	Shale	1.1	5.3	9.2	0.5	17	4.04	1.09
11,460–11,480	Shale	0.8	4.7	10.7	0.4	16	2.68	0.83
Average		1.7	4.1	19.0	73.7	15.9		

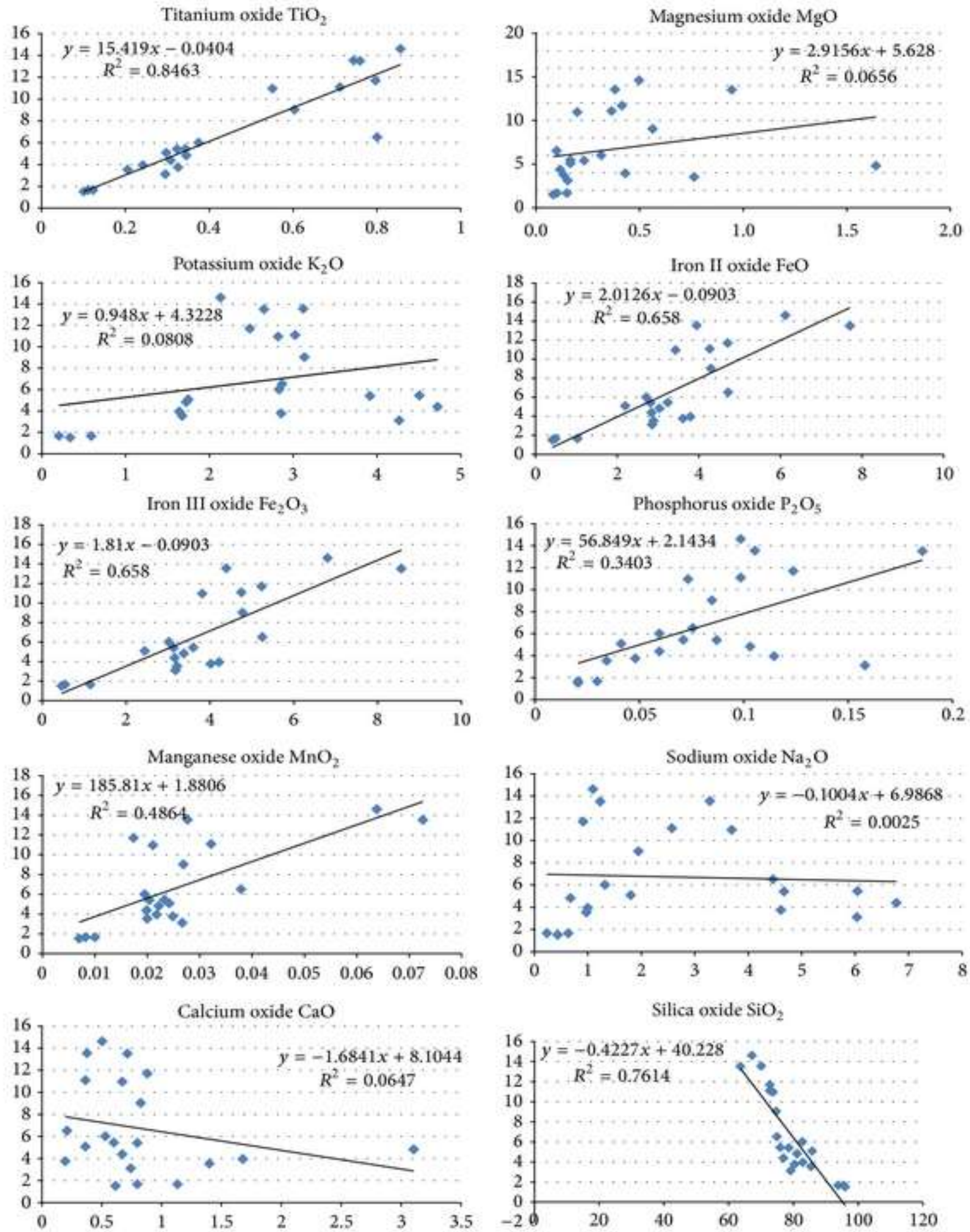

Fig. 3: Covariation of Al_2O_3 versus major elements for the 11 major oxides. There is a positive correlation of Al_2O_3 with almost all the major elements; SiO_2 shows negative correlation.

3.2 Results and Discussion.

Understanding the tectonic setting of a basin is important for the exploration of petroleum and other resources as well as for paleogeography. Some authors have described the usefulness of major element geochemistry of sedimentary rocks to infer tectonic settings. This is because plate tectonics processes impart distinctive geochemical signature to sediments in two separate ways. Firstly, tectonic environments have distinctive provenance characteristics and secondly, they are characterized by distinctive sedimentary process.

Bhatia [2] proposed major element geochemical criteria to discriminate plate tectonic settings for sedimentary basins from identified well-defined sandstone suites. He compiled the average chemical compositions of medium- to fine-grained sandstones (e.g., arkose, greywacke, lithic arenite, and quartz arenite) and modern sands from various regions of the world and used these average values to propose discrimination diagrams.

Bhatia [2] used these diagrams to infer the tectonic settings of five Paleozoic sandstone suites of eastern Australia. He then proposed discriminant functions (functions 1 and 2) by using 11 major element oxides (shown in Table 1) as discriminant variables to construct a territorial map for the tectonic classification of sandstones. Discriminant scores of functions 1 and 2 were calculated from the unstandardized function coefficient and the actual abundance of major element oxides in the average. Bhatia [2] considered the tectonic setting of sandstones that he studied and generally concluded that sedimentary basins may be assigned to the following tectonic settings based on the 11 major oxides (Table 1): oceanic arc: fore arc or back arc basins, adjacent to volcanic arcs developed on oceanic or thin continental crust; continental island arc: inter arc, fore arc, or back arc basins adjacent to a volcanic arc developed on a thick continental crust or thin continental margins; active continental margin: Andean type basin developed on or adjacent to thick continental margins and strike-slip basins also developed in this environment; passive continental margin: rifted continental mar-gins developed on thick continental crust on the edges of continents and sedimentary basins on the trailing edge of continent.

These diagrams are used for the recovered sediments from well-Y, southwestern Niger delta in order to determine the tectonic setting of the area.

Bhatia [2] proposed a discrimination diagram based on a bivariate plot of first and second discriminant functions of major element analysis. The sandstones were chosen to represent the four different tectonic settings, assigned on the basis of comparison with modern sediments. When this diagram is used, samples with high content of CaO as carbonate must be corrected for carbonate content. This discrimination diagram is used to classify the suites of various samples into different tectonic settings. The discriminant functions are

discriminant function 1: $- 0.0447SiO_2 - 0.972TiO_2 + 0.008Al_2O_3 - 0.267Fe_2O_3 + 0.208FeO - 3.082MnO + 0.140MgO + 0.195CaO + 0.719Na_2O - 0.032K_2O + 7.510P_2O_5 + 0.303$;

discriminant function 2: $- 0.421SiO_2 + 1.998TiO_2 - 0.526Al_2O_3 - 0.551Fe_2O_3 - 1.610FeO + 2.720MnO + 0.881MgO - 0.907CaO - 0.177Na_2O - 1.840K_2O + 7.244P_2O_5 + 43.57$(after [2]).

The discriminant plot is shown in Figure 2.

Modern sandstones from oceanic and continental arcs and active and passive continental margins have variable composition, especially in their Fe_2O_3+MgO, Al_2O_3/SiO_2, K_2O/Na_2O, and $Al_2O_3/(CaO + Na_2O)$ contents. Bhatia [2] used this chemical variability to discriminate between different tectonic settings on a series of bivariate plots. Figure 3 shows the discrimination diagrams for sandstones based upon a bivariate plot of TiO_2 versus (Fe_2O_3+MgO). The fields are oceanic island arc, continental island arc, active continental margin, and passive margins.

Roser and Korsch tectonic settings determinant diagrams are as follows: the three tectonic settings, passive continental margin PM, active continental margin ACM, and oceanic island arc (ARC) are recognized on the K_2O/Na_2O-SiO_2 discrimination diagrams of Roser and Korsch [17] for sandstone mudstone suites as shown in Figure 4. Where sediments are rich in carbonate components, the analysis was recalculated as $CaCO_3$-free. Failure to do this will shift samples to lower SiO_2 values and from passive margin field into volcanic arc field. The other data values are plotted in active continental margin but could not show on the negative side of the vertical logarithmic scale (Figure 4).

For the Provenance or Source Rock Determination Using Major Oxides, discrimination diagram proposed by Roser and Korsch [17] distinguish the sources of the sediments into four provenance zones, mafic, intermediate, felsic, igneous provenances. The analysis was based on the chemical analyses in which Al_2O_3/SiO_2, K_2O/Na_2O, and Fe_2O_3+MgO proved the most valuable discriminant. The plot of the two discriminant functions is based upon the oxides of Ti, Al, Fe, Mg, Ca, Na, and K and most effectively differentiates between the provenances in Figure 5. The plot is based on the discriminant functions 1 and 2 which are ratio for raw plots. The plots using the raw oxides revealed that the sediments in the well were sourced from felsic and very little from quartzoze sedimentary provenances. The problem of biogenic CaO in $CaCO_3$ and also biogenic SiO_2 is circumvented by using ratio plots in which the discriminant functions are based upon the ratios of TiO_2, Fe_2O, MgO, Na_2O, and K_2O all to Al_2O. The formula for the raw oxides used in Figure 5 is given as discriminant function 1: − $1.773TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3$(total) − $1.5MgO + 0.616CaO + 0.509Na_2O$ − $1.224K_2O$ − 9.09.

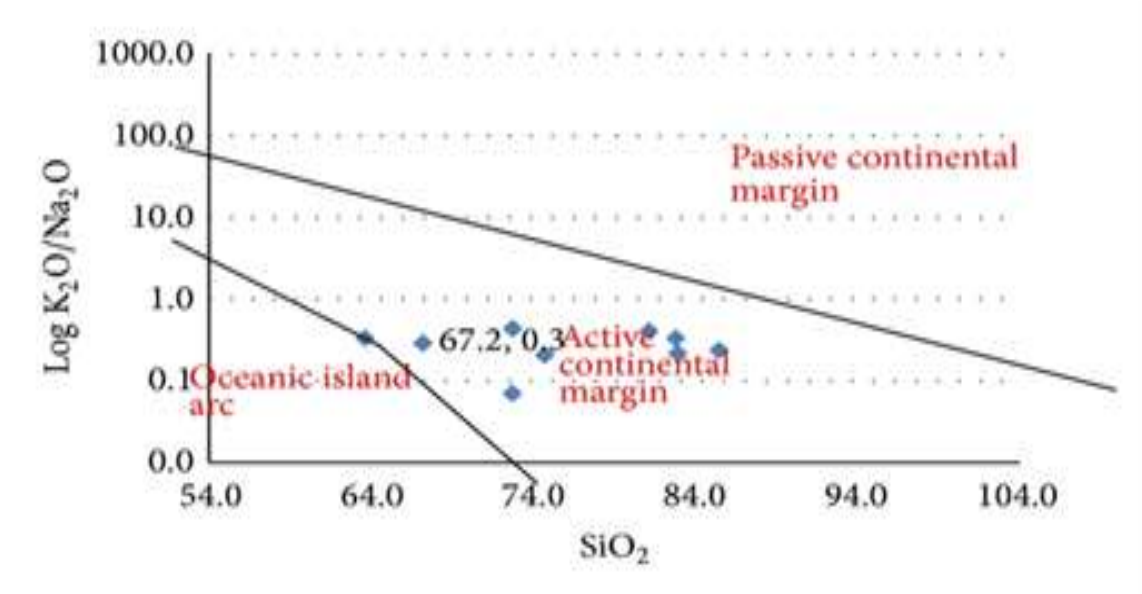

Fig. 4: The plot of log K2O/Na2O-SiO2 discrimination diagrams of Roser and Korsch [17] for sandstone mudstone suites showing the different tectonic settings.

3.3 Findings

Floyd and Winchester, in a series of papers e.g., [19, 5, 6, 20], specifically addressed the identification of rock type. The most commonly used approach is their Zr/TiO_2-Nb/Y diagram [19], which has subsequently been updated using a much larger dataset and statistically drawn boundaries by Pearce [15]. This diagram is essentially a proxy for the TAS classification diagram, where Nb/Y is a proxy for alkalinity ($Na_2O + K_2O$) and Zr/TiO_2 is a proxy for silica. Nb/Y increases from subalkalic to alkalic compositions and Zr/TiO_2 increases from basic to acid compositions.

Th/Sc-Z/Sc diagram after McLennan et al. [14] plot gives insight in the degree of fractionation of the source rocks which is expressed in Th/Sc ratio. Furthermore, this plot describes the degree of sediment recycling that is expressed in the Zr/Sc ratio. Increased recycling concentrates zircon in sedimentary rocks (increase in Zr concentration) at the expense of volcanic material contained in the detritus (decrease in Sc-concentrations). The plot of Th/Sc versus Zr/Sc diagram is shown in Figure 8, describing most of the sediments found in the zone of recycling and zircon concentration of upper continental crust.

Trace elements such as La, Th, Zr, Nb, Y, Sc, Co, and Ti have been recognized as valuable provenance signatures for shales, arenites, and wackes [1, 18]. Bivariate plots of Ti/Zr-La/Sc as well as triangular La-Th-Sc, Th-Sc-Zr/10, Th-Sc-Zr/10, and Th-Co-Zr/10 plots are useful means to discriminate the tectonic settings of clastic sedimentary rocks [1].

Distinctive fields for four environments are recognized on the trivariate plots of La-Th-Sc, Th-Sc-Zr/10, and Th-Co-Zr/10. On La-Th-Sc plot, the fields of active continental margin sediments and passive continental margin sediments.

4. CONCLUSIONS

Provenance of the Sediments. Based on major oxides most of the sample plots in the fields were felsic igneous provenances suggesting high content of silica from an acid rock most probably granite or gneiss or dacite or any acidic (felsic) igneous rock.

The provenance and prevalent conditions of deposition from various elemental ratios indicate that the Th/U ratio has an average of 4.1 which is very close to that of upper continental crust of 3.8. The high ratios of Th/Sc and Zr/Sc indicate a slight input of felsic materials from recycled sedimentary provenance. Higher abundances of incompatible elements like Th indicate felsic rather than mafic sources. Elevated values of thorium with respect to uranium may imply a felsic source. It will be observed that most values for the Al_2O_3/TiO_2 ratio fall between 15 and 70 (the range for igneous rock) which is an indication that the source rock is felsic or acidic igneous rock such as granite, granodiorite, rhyolite, dacite, or aplite. Th/Sc values for the analyzed samples were in the range of 0.83-2.83, implying a felsic igneous provenance. The same applies for the Th/Co ratio as most of the values are above 0.27 and less than 19.5 (Th/Sc and Th/Co values for felsic rocks are 0.84-20.05 and 0.27-19.5, resp.). Thus, the source of the rock weathered to give the sediment is a felsic or acidic igneous rock, probably granite. Th/Co versus La/Sc logarithmic plot shows that the samples are sourced from felsic or acidic silicic rocks, and very few of the samples tend towards intermediate provenance.

Tectonic Settings. From major oxides it can be concluded that the tectonic setting of the Niger delta is active continental margin and this confirms the cretaceous rift systems of West and Central Africa. The rift system extends for over 4000 km from Nigeria northwards into Niger and Libya and eastwards to Sudan and Kenya. This cretaceous rift system forms a trough in which those sediments are deposited. The trace elements confirmed the tectonic settings of the sediments as active continental margins. The trivariate plots of La-Th-Sc, Th-Sc-Zr/10, and Th-Co-Zr/10 all register the provenance of the sediments to be active continental margin. The Th/Sc versus Zr/Sc diagram after McLennan et al. [14], confirms the zone of sediment recycling in upper crust input

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