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# Provenance and Tectonic Setting of Leuma Field Sediments, Coastal Swamp Depobelt, Niger Delta Basin, Nigeria

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**ABSTRACT:** Geochemical analysis of sediments recovered from NS-1 well and NS-2 well, Leuma Field, Coastal Swamp Depobelt, Niger Delta Basin was done to establish tectonic setting and provenance. Data for ten major elements and forty-three trace elements were obtained from two boreholes. The geochemical signals display systematic stratigraphic trends in the two wells that depict one source terrain. To determine the provenance of NS-1 well and NS-2 well sediments, Th/Co vs La/Sc plot was utilized which inferred that the sediments from NS-1 and NS-2 wells were derived from felsic source rocks. $TiO_2$ versus Ni bivariate plot was also used to establish the provenance and it revealed that the source of the sediments penetrated by NS-1 and NS-2 wells is predominantly acidic in nature. The provenance of NS-1 and NS-2 wells sediments was further confirmed by considering the ratios of Thorium/Scandium (Th/Sc), Thorium/Cobalt (Th/Co), Chromium/Thorium (Cr/Th) and Lanthanum/Scandium (La/Sc). For NS-1 well, Thorium/Scandium (Th/Sc) range from 1.12-2.01, Thorium/Cobalt (Th/Co) range from 0.91-1.66, Chromium/Thorium (Cr/Th) range from 4.21-16.04 and Lanthanum/Scandium (La/Sc) range from 3.69-8.78. For NS-2 well, Thorium/Scandium (Th/Sc) range from 0.95-2.05, Thorium/Cobalt (Thko/Co) range from 0.94-1.91, Chromium/Thorium (Th/Cr) range from 4.32-15.43 and Lanthanum/Scandium (La/Sc) range from 2.58-6.66. These values inferred that the sediments recovered from NS-1 and NS-2 wells were transported from felsic source rocks. Inorganic geochemical results infer that the tectonic setting for NS-1 and NS-2 wells facies is passive continental margin.

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The conventional objective of provenance studies is to reconstruct and interpret the history of sediment supply from initial erosion of a parent rock to the final burial of its detritus. Provenance study is done to deduce the geographic location and characteristics of the source area**.** Important factors such as the location and nature of source area, hinterland drainage pattern and pathways through which sediments have been transferred from source to basin influence the composition of the sedimentary rocks. This evolution may be recorded in the characteristics of the sediment that are deposited in a basin (Cox *et al.*, 1995; Nesbitt, 1990; Nesbitt and Young, 1982). Rare earth elements have historically been applied to many rock types to help decipher the origin and provenance evolution of rocks (Bhatia, 1985; Davies and Pickering, 1999; McLennan *et al.*, 1990). Low contents of Cr imply a felsic provenance, and high levels of Cr and Ni are essentially found in sediments derived from ultramafic rocks (Wronkiewicz and Condie, 1990; Cullers and Podkovyrov, 2000; Nagarajan *et al.*, 2007). Ratios such as La/Sc, Th/Sc, Th/Co, and Th/Cr are significantly different in felsic and basic rocks and may possibly allow constraints on the average provenance composition (Cullers, 1994, 1995). Using major elemental compositions, provenance can be discriminated into mafic, intermediate, felsic igneous rocks and Quartzose sedimentary rocks fields. The ratio of $Al_2O_3/TiO_2$ in shales has been suggested to be similar to that of the source rock as such it is used as an index of provenance (Hayashi *et al.*, 1997). They stated that values greater than twenty-one impliy sediments from felsic origin. (Floyd and Leveridge, 1987) proposed a plot of La/Th against Hf to

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discriminate provenance. (McLennan *et al*., 1990) plotted Th versus Sc to infer provenance. (Gao *et al*., 1995) used Co/Th versus La/Sc diagram for provenance discrimination. Redox-sensitive trace element concentrations or ratios are among the main extensively used indicators of redox conditions in modern and ancient sedimentary deposits (Calver and Pedersen, 1993; Jones and Manning, 1994; Crusius *et al.,* 1996; Dean *et al.,* 1997, 1999; Yarincik *et al.,* 2000; Morford *et al.,* 2001; Pailler *et al.*, 2002; Algeo and Maynard, 2004). Plate tectonic processes impart a distinctive geochemical signature to sediments in two separate ways. Firstly, different tectonic environments have distinctive provenance characteristics and, secondly, they are characterized by distinctive sedimentary processes. Sedimentary basins may be assigned to the following tectonic settings for active continental margin, passive continental margin, oceanic island-arc, continental island-arc, and collisional setting. (Bhatia, 1985; Roser and Korsch, 1986) stated that the chemical compositions of clastic rocks are significantly controlled by plate tectonic settings of their provenances, consequently clastic rocks from different tectonic settings possess terrain-specific geochemical signatures.

*Geologic Background:* The Niger Delta Basin ranks among the world's most prolific petroleum producing Tertiary Deltas (Selley, 1997). It occupies the Gulf of Guinea continental margin in equatorial West Africa between Latitude $3^0$ and $6^0$ N and Longitude $5^0$ and $8^0$E. The Niger Delta is framed on the northwest by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif (Murat, 1972). Well sections through the Niger Delta generally display three vertical lithostratigraphic subdivisions: an upper delta top facies; a middle delta front lithofacies; and a lower pro-delta lithofacies. These lithostratigraphic units correspond respectively with the Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) of (Short and Stauble, 1967) respectively.

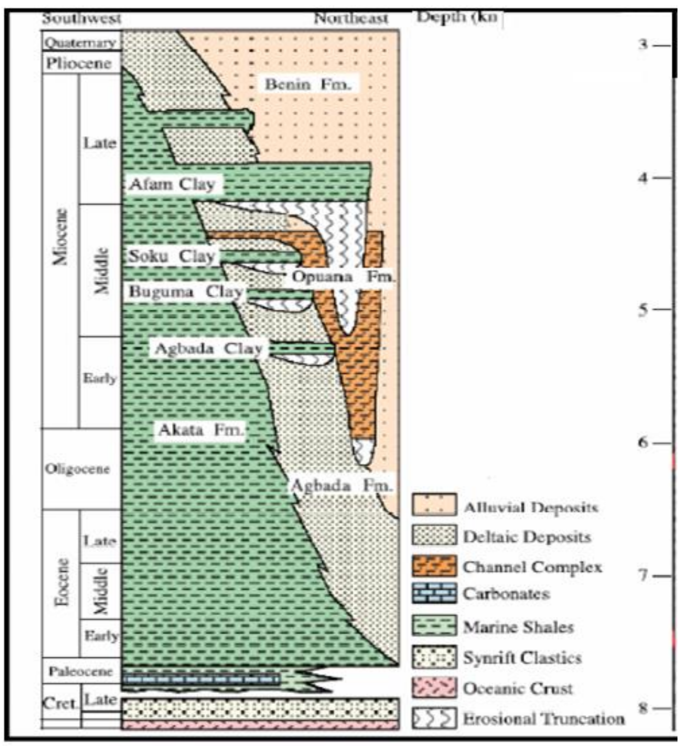


**Fig 1:** Stratigraphic column showing the three formations of the Niger Delta (modified after Doust and Omatsola, 1990).

The evolution of the Niger Delta was controlled by pre- and syn-sedimentary tectonics described by (Evamy *et al*., 1978; Knox and Omatsola, 1989 and Stacher, 1995). The tectonic framework of the continental margin along the West Coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the West African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. Rifting started in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977). In the Niger Delta region, rifting diminished altogether in the Late Cretaceous and the gross paleogeography of the region as well as the relative position of the African and South American plates since rifting began. After rifting ceased, gravity tectonics became the primary deformational process. For any given depobelt, gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapirs, roll-over anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy *et al*., 1978; Xiao and Suppe, 1992). These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation. The study wells (NS-1 well and NS-2 well) are located in Leuma Field, Coastal Swamp Depobelt, Niger Delta Basin. Figure 2 shows the location of NS-1 well and NS-2 wells.

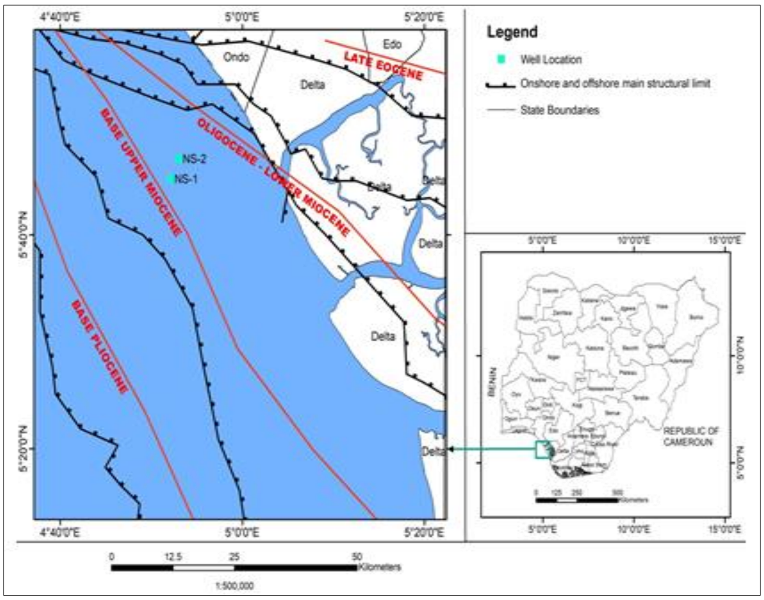


**Fig 2:** Map showing Location of NS-1 well and NS-2 well

*Methodology:* The pulverized ditch cutting samples were analyzed with X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) techniques. Twenty four samples (twelve from NS-1 well and twelve from NS-2 well) comprising of sands and shales were selected for this study using the aforementioned methods. The results derived from the analysis were used for the geochemical characterization of the wells. These analytical methods yielded results for ten (10) major elements, reported as oxide percent by weight ($SiO_2$, $Al_2O_3$, $Fe_2O_3$, MgO, MnO, CaO, $TiO_2$, $Na_2O$, $K_2O$ and $P_2O_5$). Results for forty-three (43) trace element(V, Co, Cr, Ni, Cu, Zn, Ga, Ge, As, Rb, Sc, Y, Zr, Nb, Mo, Lu, Ag, In, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Hf, Ta, W, Tl, Pb, Bi, Th, U) reported in ppm were also recorded. Although data for a total of 53 elements was acquired, tectonic setting and provenance study was done with few selected elements or ratios of elements (Pearce *et al*, 2005a; Ratcliffe *et al*, 2006). These key elements and element ratios, termed key indices, were used for inorganic geochemical characterization.

## RESULTS AND DISCUSSION

Tables 1, 2, 3, and 4 show the findings of the investigation. Table 1 and table 2 display major element data for NS-1 and NS-2 wells, respectively, while table 3 and table 4 display trace element data for NS-1 and NS-2 wells. The findings were used to determine the sediments' provenance and tectonic setting.

*Provenance Studies***:** Using major elemental compositions, provenance can be discriminated into mafic, intermediate, felsic igneous rocks and Quartzose sedimentary rocks fields as reported. As suggested by (Cullers, 2002), the plot of Th/Co versus La/Sc can be used to establish the provenance of sediments. To determine the provenance of NS-1 and NS-2 sediments, the Th/Co vs. La/Sc plot of Cullers,

2002) was utilized which inferred that the sediment from NS-1 and NS-2 wells were derived from felsic source rocks (Fig 3). Furthermore, the concept of (Floyd *et al.*, 1989) was also adopted to establish the source of the sediments penetrated by NS-1 well and NS-2 well. $TiO_2$ versus Ni bivariate plot was used and it revealed that the source of the sediments penetrated by NS-1 and NS-2 wells is predominantly acidic in nature (Fig 4). The provenance of NS-1 and NS-2 wells sediments was further confirmed by considering the ratios of Thorium/Scandium (Th/Sc), Thorium/Cobalt (Th/Co), Chromium/Thorium (Cr/Th), Lanthanum/Scandium (La/Sc). The ratios of these elements were calculated from the result shown in table 5, For NS-1 well, Thorium/Scandium (Th/Sc) range from 1.12-2.01, Thorium/Cobalt (Th/Co) range from 0.91-1.66, Chromium/ Thorium (Cr/Th) range from 4.21-16.04 and Lanthanum/Scandium (La/Sc) range from 3.69-8.78. For NS-2 well, Thorium/Scandium (Th/Sc) range from 0.95-2.05, Thorium/Cobalt (Th/Co) range from 0.94-1.91, Chromium/Thorium (Th/Cr) range from 4.32-15.43 and Lanthanum/Scandium (La/Sc) range from 2.58-6.66.

**Table 1:** Major Elements of the Selected Sandstone and Shales from NS-1 Well

| Sample Number | Depth Interval (ft) | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | MnO (%) | MgO (%) | CaO (%) | $Na_2O$ (%) | $K_2O$ (%) | $TiO_2$ (%) | $P_2O_5$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1(SHALE) | 4920-4950 | 75.82 | 9.82 | 5.26 | 0.05 | 0.72 | 0.71 | 0.82 | 2.10 | 1.31 | 0.26 |
| 2(SHALE) | 5220-5250 | 75.66 | 8.44 | 6.04 | 0.06 | 0.74 | 0.82 | 0.91 | 1.91 | 1.09 | 0.31 |
| 3(SHALE) | 5280-5310 | 75.13 | 9.81 | 7.72 | 0.05 | 0.65 | 0.54 | 0.83 | 1.83 | 1.06 | 0.39 |
| 4(SAND) | 5400-5430 | 89.76 | 2.56 | 2.95 | 0.02 | 0.14 | 0.15 | 0.81 | 0.29 | 0.17 | 0.03 |
| 5(SAND) | 5460-5490 | 90.31 | 2.78 | 3.02 | 0.03 | 0.13 | 0.15 | 0.69 | 0.31 | 0.17 | 0.03 |
| 6(SHALE) | 5700-5730 | 74.21 | 10.72 | 6.98 | 0.06 | 0.52 | 0.69 | 0.79 | 2.00 | 0.98 | 0.29 |
| 7(SHALE) | 6180-6210 | 76.95 | 7.64 | 7.91 | 0.05 | 0.77 | 0.52 | 0.77 | 1.76 | 0.87 | 0.32 |
| 8(SAND) | 6600-6630 | 91.44 | 2.30 | 3.01 | 0.02 | 0.15 | 0.12 | 0.73 | 0.34 | 0.19 | 0.04 |
| 9(SAND) | 6660-6690 | 89.93 | 2.53 | 3.04 | 0.04 | 0.12 | 0.14 | 0.82 | 0.28 | 0.18 | 0.03 |
| 10(SAND) | 7260-7290 | 91.64 | 2.36 | 2.88 | 0.02 | 0.11 | 0.16 | 0.76 | 0.36 | 0.17 | 0.03 |
| 11(SHALE) | 7440-7470 | 73.41 | 8.63 | 7.24 | 0.05 | 0.87 | 0.66 | 0.74 | 1.65 | 1.04 | 0.91 |
| 12(SAND) | 7500-7530 | 89.87 | 2.72 | 3.00 | 0.03 | 0.16 | 0.17 | 0.64 | 0.29 | 0.16 | 0.03 |

**Table 2:** Major Elements of the Selected Sandstone and Mudstone from NS-2 Well

| Sample Number | Depth Interval (ft) | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | MnO (%) | MgO (%) | CaO (%) | $Na_2O$ (%) | $K_2O$ (%) | $TiO_2$ (%) | $P_2O_5$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1(SHALE} | 5010-5040 | 75.6 | 9.36 | 5.67 | 0.05 | 0.67 | 0.77 | 0.17 | 0.88 | 1.37 | 0.04 |
| 2(SHALE) | 5250-5280 | 76.7 | 10.14 | 6.78 | 0.06 | 0.56 | 0.82 | 0.21 | 0.71 | 0.97 | 0.02 |
| 3(SAND) | 5490-5520 | 87.7 | 2.72 | 2.86 | 0.02 | 0.21 | 0.19 | 0.19 | 0.92 | 0.16 | 0.16 |
| 4(SAND) | 5820-5850 | 85.2 | 2.65 | 3.01 | 0.03 | 0.35 | 0.18 | 0.18 | 0.86 | 0.17 | 0.18 |
| 5(SHALE) | 6120-6150 | 74.4 | 8.75 | 4.98 | 0.05 | 0.21 | 0.61 | 0.22 | 0.96 | 0.86 | 0.19 |
| 6(SAND) | 6300-6330 | 90.1 | 2.86 | 2.75 | 0.04 | 0.28 | 0.19 | 0.27 | 0.77 | 0.18 | 0.07 |
| 7(SAND) | 6370-6600 | 87.8 | 2.55 | 3.66 | 0.04 | 0.36 | 0.16 | 0.17 | 0.87 | 0.18 | 0.05 |
| 8(SHALE) | 6750-6780 | 75.5 | 9.24 | 5.22 | 0.06 | 0.55 | 0.56 | 0.28 | 0.79 | 1.46 | 0.14 |
| 9(SHALE) | 7260-7290 | 74.7 | 9.94 | 2.76 | 0.05 | 0.37 | 0.78 | 0.17 | 0.66 | 1.13 | 0.14 |
| 10(SAND) | 7350-7380 | 90.4 | 2.93 | 3.44 | 0.02 | 0.19 | 0.15 | 0.17 | 0.97 | 0.15 | 0.02 |
| 11(SAND) | 7620-7650 | 89.3 | 2.47 | 5.37 | 0.03 | 0.34 | 0.16 | 0.27 | 0.98 | 0.16 | 0.03 |
| 12(SHALE) | 7860-7890 | 75.1 | 8.56 | 5.37 | 0.06 | 0.48 | 0.67 | 0.16 | 1.32 | 0.96 | 0.16 |

**Table 3:** Results of selected trace elements for NS-1 well

| Sample Number | Depth Interval (Ft) | Co | Cr | Ni | Sc | Th | La |
|---|---|---|---|---|---|---|---|
| 1(SHALE) | 4920-4950 | 14.7 | 82 | 35 | 12 | 13.4 | 56.7 |
| 2(SHALE) | 5220-5250 | 14.3 | 87 | 41 | 14 | 15.7 | 59.2 |
| 3(SHALE) | 5280-5310 | 13.8 | 93 | 35 | 11 | 18.9 | 70.3 |
| 4(SAND) | 5400-5430 | 3.8 | 35 | 20 | 2.1 | 4.12 | 10.2 |
| 5(SAND) | 5460-5490 | 3.9 | 40 | 18 | 1.9 | 3.81 | 12.1 |
| 6(SHALE) | 5700-5730 | 12.1 | 99 | 45 | 17 | 20.1 | 62.7 |
| 7(SHALE) | 6180-6210 | 11.9 | 87 | 37 | 16 | 18.2 | 81.2 |
| 8(SAND) | 6600-6630 | 4.0 | 49 | 10 | 2.2 | 3.66 | 12.9 |
| 9(SAND) | 6660-6690 | 3.6 | 52 | 15 | 2.0 | 3.85 | 12.3 |
| 10(SAND) | 7260-7290 | 3.2 | 60 | 14 | 2.1 | 3.74 | 114.7 |
| 11(SHALE) | 7440-7470 | 12.3 | 83 | 36 | 14 | 19.7 | 83.5 |
| 12(SAND) | 7500-7530 | 3.1 | 57 | 11 | 1.8 | 3.56 | 15.8 |

**Table 4:** Results of selected trace elements for NS-2 well

| Sample Number | Depth Interval (Ft) | Co | Cr | Ni | Sc | Th | La |
|---|---|---|---|---|---|---|---|
| 1(SHALE) | 5010-5040 | 14.9 | 85 | 37 | 15 | 14.3 | 56.3 |
| 2(SHALE) | 5250-5280 | 13.3 | 80 | 43 | 12 | 15.4 | 61.5 |
| 3(SAND) | 5490-5520 | 3.8 | 37 | 20 | 2.5 | 4.45 | 11.3 |
| 4(SAND) | 5820-5850 | 3.9 | 45 | 18 | 2.0 | 3.95 | 13.4 |
| 5(SHALE) | 6120-6150 | 12.8 | 97 | 34 | 13 | 17.8 | 73.7 |
| 6(SAND) | 6300-6330 | 4.0 | 48 | 10 | 2.6 | 3.77 | 12.8 |
| 7(SAND) | 6570-6600 | 3.6 | 52 | 15 | 2.0 | 3.87 | 12.3 |
| 8(SHALE) | 6750-6780 | 11.1 | 92 | 42 | 18 | 21.3 | 67.8 |
| 9(SHALE) | 7260-7290 | 10.5 | 87 | 37 | 17 | 19.7 | 85.1 |
| 10(SAND) | 7350-7380 | 3.2 | 59 | 14 | 1.9 | 3.91 | 14.1 |
| 11(SAND) | 7620-7650 | 3.1 | 54 | 11 | 2.7 | 3.50 | 15.9 |
| 12(SHALE) | 7860-7890 | 12.6 | 95 | 39 | 13 | 20.3 | 86.7 |

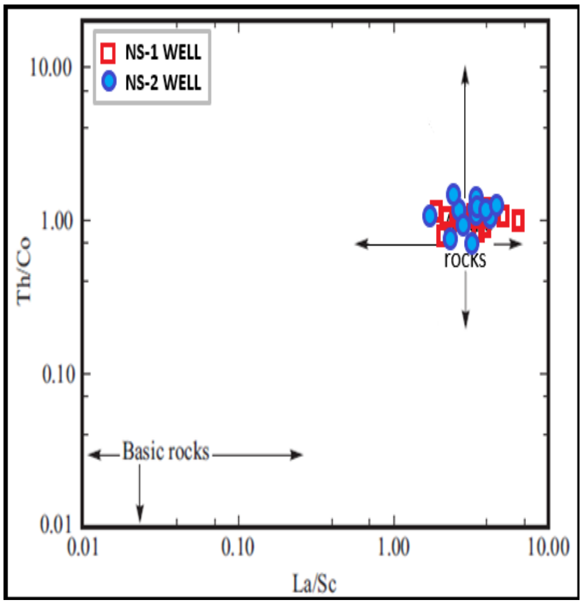


**Fig 3:** Th/Co versus La/Sc diagram for NS-1 and NS-2 wells. (After Culler, 2002)

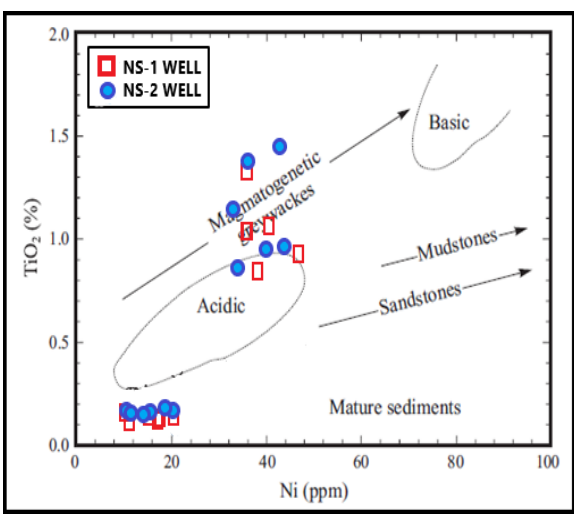


**Fig 4:** $TiO_2$ versus Ni bivariate of NS-1 and NS-2 wells (After Floyd *et al*. 1989)

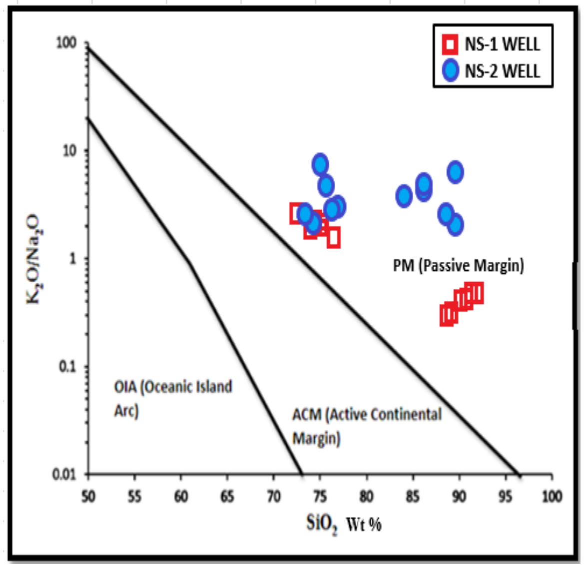


**Fig 5:** Tectonic discrimination plot for NS-1 and NS-2 wells. After Roser and Korsch (1986). PCM: passive continental margin, ACM: active continental margin and OIA: oceanic island arc.

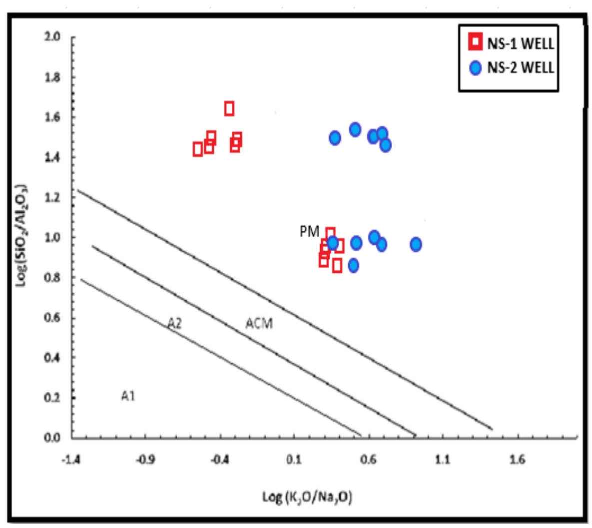


**Fig 6:** Log ($K_2O/Na_2O$) ratio versus Log ($SiO_2$/Al2$O_3$) ratio tectonic discrimination diagram of NS-1 and NS-2 wells. After Maynard *et al.* (1982). Al - arc setting and andesitic detritus, A2 - evolved arc setting, felsic pluton detritus, ACM - Active continental margin, PM - Passive Continental Margin.

As prescribed by Taylor and McLennan (1985), Cullers (1994), (2000), the values recorded above were compared to those of sediments resulting from typical felsic and basic rocks as well as to upper continental crust (UCC) and PAAS values, it was inferred that the sediments recovered from NS-1 and NS-2 wells were transported from felsic source rocks.

**Table 5:** Range of Elemental Ratios of NS-1 compared to the Ratios in Similar Fractions derived from Felsic and Mafic Rocks, Upper Continental Crust (UCC) and Post-Archean Australian Average Shale. After Cullers (1994) (2000), Taylor and Mclenna (1985).

| Elemental Ratio | NS-1 Well Range | Range For Felsic Rocks | Range For Mafic Rocks | PAAS | UCC |
|---|---|---|---|---|---|
| Th/Sc | 1.12-2.01 | 0.84-20.5 | 0.05-0.22 | 0.90 | 0.79 |
| Th/Co | 0.91-1.66 | 0.67-19.4 | 0.04-1.40 | 0.63 | 0.63 |
| Cr/Th | 4.21-16.04 | 4.0-15.0 | 25-100 | 7.53 | 7.76 |
| La/Sc | 3.69-8.78 | 1.2-6.6 | 0.43-0.86 | 2.40 | 2.21 |

**Table 6:** Range of Elemental Ratios of NS-2 well compared to the ratios in similar fractions derived from felsic and mafic rocks, Upper Continental Crust (UCC) and Post-Archean Australian Average Shale. After Cullers (1994) (2000), Taylor and Mclenna (1985).

| Elemental Ratio | NS-2 Well Range | Range For Felsic Rocks | Range For Mafic Rocks | PAAS | UCC |
|---|---|---|---|---|---|
| Th/Sc | 0.95-2.05 | 0.84-20.5 | 0.05-0.22 | 0.90 | 0.79 |
| Th/Co | 0.94-1.91 | 0.67-19.4 | 0.04-1.40 | 0.63 | 0.63 |
| Cr/Th | 4.32-15.43 | 4.0-15.0 | 25-100 | 7.53 | 7.76 |
| La/Sc | 2.58-6.66 | 1.2-6.6 | 0.43-0.86 | 2.40 | 2.21 |

*Tectonic Setting:* The concept of (Roser and Korsch, 1986) was applied to determine the tectonic setting of NS-1 and NS-2 wells sediments. (Roser and Korsch, 1986) plotted $K_2O/Na_2O$ vs $SiO_2$ to determine the provenance of sediments. The recognized tectonic settings on the $K_2O/Na_2O$ versus $SiO_2$ discrimination diagram of (Roser and Korsch, 1986) are: the passive continental margin (PCM), active continental margin (ACM) and oceanic island arc (OIA). When applied for the samples recovered from NS-1 and NS-2 wells, they plotted mainly in the passive continental margin zone. It was therefore inferred that the tectonic setting for NS-1 and NS-2 well facies is passive continental margin (Figure 5) Log ($K_2O/Na_2O$) versus Log ($SiO_2/Al_2O_3$) was used to determine the tectonic setting as proposed by (Maynard *et al*., 1982). The recognized tectonic settings on the Log ($K_2O/Na_2O$) ratio versus Log ($SiO_2/Al_2O_3$) ratio discrimination diagram of (Maynard *et al*., 1982) are: A1 - arc setting and andesitic detritus; A2 - evolved arc setting, felsic pluton detritus; ACM - Active continental margin; PM - passive margin. When utilized for the samples of NS-1 and NS-2 wells, they plotted mainly in the passive margin zone which infer that the tectonic setting for the NS-1 and NS-2 wells facies is passive continental margin (Figure 6).

*Conclusion:* The provenance and tectonic setting of the sandstones and shales from NS-1 well and NS-2 well, Leuma Field, Coastal Swamp Depobelt, Niger Delta Basin were investigated with geochemical methods. The study revealed that the sediments from the two wells were derived from felsic/acidic source. Tectonic studies reveal that the sediments were deposited on a passive margin setting that received most of its detritus from the nearby Southwestern Nigeria Basement Complex Rocks. From the tectonic history, it is believed that the studied field was not affected by major tectonic activities.

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