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Chemical Classification of Sediments in JVX -Well, Greater Ughelli Depobelt Niger Delta Basin, Nigeria

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ABSTRACT: This study evaluate the Chemical classification of sediments in JVX well, Greater Ughelli Depo belt Niger Delta Basin. Samples collected from different intervals were analyzed using geochemical proxies. Agbada Formation was suggested for the sampled intervals due to the presence of shaleand sand intercalations. lithofacies units gotten from sampled intervals are Sand, Shale and Shaly sand facies . The sands are milky in colour, translucent to opaque, medium to coarse grain, subangular to subrounded and are moderately sorted while the shales are Grey in colour, fissile with the presence of lignite streak and calcareous materials.The geochemical studies of the 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 CaO, K_2O, TiO_2, Na_2O and MgO constitute 10%. The sediments were classified as Fe-shale, Fe-sand and Quartz arenite. Samples that plotted in the quartz arenites region suggests an intense degree of weathering and reworking. The SiO_2/Al_2O_3 ratios for the sediments in the well 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 retiles.

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The Niger Delta Basin is economically important because of its petroliferous nature and the economy of Nigeria depends largely on the oil and gas derived from it. Geologically it is found in the Tertiary period in the geologic column, it lies mainly in the Gulf of Guinea to the southwest of the Benue – Trough and constitutes the most important Cenozoic deltaic construction in the south Atlantic. The combination of source rock, lithologic types, structures and thermal history of the basin are favorable for the generation, accumulation and retention of hydrocarbons (Whiteman, 1982; Stacher, 1995).The mineralogical and chemical composition of clastic sedimentary rocks are controlled by various factors, including :The composition of their source rocks, environmental parameters influencing the weathering of source rocks (e.g., atmospheric chemistry, temperature, rainfall and topography), Duration of weathering and transportation mechanisms of clastic material from source region to depocenter, depositional environment (e.g., marine versus fresh water) and Post-depositional processes (e.g diagenesis, metamorphism). Chemostratigraphy generally provides information to the larger geological community. Chemostratigraphy can be used to investigate environmental change on the local, regional, and global levels by relating variations in rock chemistry to changes in the environment in which the sediment was deposited. It is a technique used to correlate sedimentary successions based on subtle changes in concentration of key major, minor and trace elements Lucas *et al.,*(2016).

Geology of the Study Area: The Niger Delta Basin, which is the largest sedimentary basins of southern Nigeria, developed along the West Coast of the African continent during the Tertiary times. It is positioned at the intersection of the triple ridge junction in the eastern corner of the Gulf of Guinea from which the rifting and separation of the South American and African continents was initiated. The failure of the third arm (Benue Trough complex) to spread into an oceanic stage set the stage for the subsequent development of the Niger Delta Basin.

The modern Niger Delta covers an area of some $140,000km^2$ and lies on top of a thick prism of regressive clastic sequence, which reaches a maximum thickness of 12,000m at the basin centre Knox and Omatsola (1989). This prism of clastic sediments forms the prominent seaward bulge on the continental margin off southern Niger.

The Niger Delta Basin is a typical wave and tidal dominated delta, which appears to be constructive in the center and destructive on either flanks Doust and Omatsola (1990). It has evolved through Tertiary to present time.

Extensive hydrocarbon exploration and studies of data set obtained within the past three decades have led to vast information on the structures and sediments beneath the present subaerial Niger Delta and adjacent inner continental shelf (Short and Staube, 1967; Weber and Daukoru, 1975; Evamy *et al*, 1978; Avbovbo, 1978; Ejedawe, 1981; Whiteman, 1982; Omatsola, 1989 and Doust and Omatsola, 1990)

Lithostratigraphy of Niger Delta: The stratigraphic succession is an overall coarsening upward sequence of over 12,000m thick at the position of the ocean/continent transition. The lithofacies are diachronouns and represent a classical regressive deltaic off lap sequence (Figure 1).

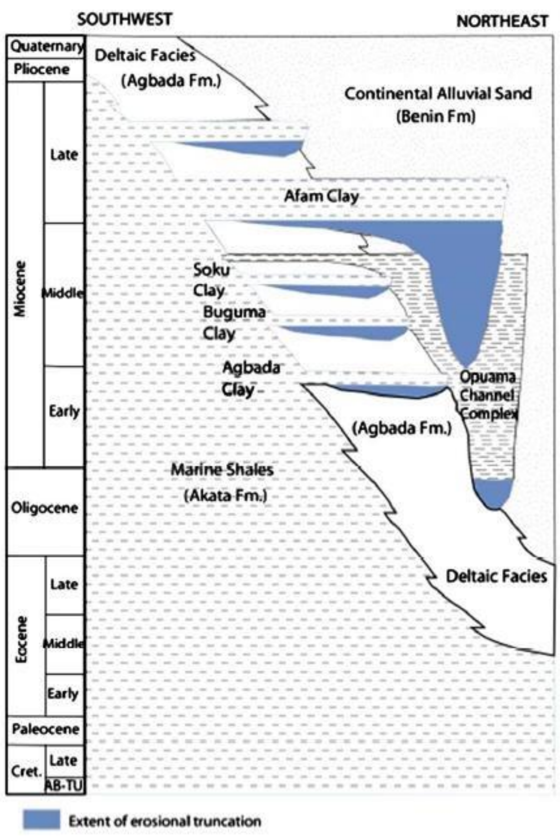

Fig1: Stratigraphic column displaying formations of the Niger Delta Basin Doust and Omatsola (1990)

The Tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The type sections of these formations are described in Short and Stäuble (1967) and summarized in a variety of papers (e.g. Avbobvo, 1978; Doust and Omatola, 1990; Kulke, 1995). However, the three stratigraphic units are: Akata Formation, Agbada Formation and Benin Formation Short and Stauble (1967). The three major lithostratigraphic units defined in the subsurface of the Niger Delta (Akata, Agbada and Benin Formations) becomes progressively younger farther into the basin, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalent units to these three formations are exposed insouthern Nigeria. The formations reflect a grosscoarsening-upward progradational clastic wedge Short and Stauble(1967), deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber, 1986).

Akata Formation: This is the major time transgressive lithological unit of the Niger Delta, it is mainly a marine mud facies with turbidity sand and continental slope channel fills. The type section of the Akata Formation was defined in Akata 1 Well, 80 km east of Port Harcourt Short and Stauble (1967). A total depth of 11,121 feet (3, 680 m) was reached in the Akata 1 well without encountering the base of this formation. The top of the formation is defined by the deepest occurrence of deltaic sandstone beds (7,180 feetin Akata well).the formation underlies the whole of the Niger delta complex Whiteman (1982).The Akata formation consist of dark grey shales andsilts, with rare streaks of sand of probable turbidite flow origin Doust and Omatsola(1989) in the upper part,in some localities it tend to be sandy were it grades in to the Agbada formation.The formation is taught to range from 2000ft(610m) to 20,000ft(6,100m) in thickness Merki (1972). The Akata formation is Paleocene to Recent in Age Doust and Omatsola (1989), rich in Planktic foraminifera which indicate deposition on a shallow marine shelf. Marine planktonic foraminifera make up to 50% of the microfauna assemblage and suggest shallow marine shelf deposition Doust and Omatsola(1989).

Agbada Formation: Short and Stauble (1967) named the middle part of the tripartite Niger delta stratigraphic succession as the Agbada formation. The Agbada formation is defined in the Agbada 2well drilled about 11km north-northwest of Port Harcourt Short and Stauble (1967).The mangrove swamp to coastal barrier and fluviomarine zone of the present day delta constitute the surface exposure of the Agbada formation of recent age. The well reached a total depth of 9500 feet without penetrating the base of the formation (the base was defined as the top of the Akata Formation in Akata 1 well).the top of the formation is usually taken as the shallowest occurrence of shale bearing a brackish or marine fauna. The Agbada formation is often seen in seismic as an erosional surface demarcating it from the overlying unfaulted Benin sand. The lithologies consist of alternating sands, silts and shales arranged within ten to hundred feet successions defined by progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have formed in fluvial-deltaic environments. The formation ranges in age from Eocene to Pleistocene. The thickness of the Agbada formation varies greatly across the delta, Merki (1970) indicate a maximum thickness of 4,500m while Weber and Daukoru (1975) gave a range from 9,600ft to 14000ft (2,927m - 4,268m). The Agbada formation is thickest on the central swamp and coastal swamp depobelt which is where the Benin formation is also thickest and regarded as the zone of maximum subsidence. The sequence is associated with sedimentary growth faulting and contains the bulk of the hydrocarbon reservoirs. The top of the Agbada Formation is often defined as the base of fresh water sand.

Benin Formation: The name Benin sand series was first used by Parkinson (1907) which was later change by the Geologic survey of Nigeria to Coastal plain sand (Tattam 1944; Simpson 1955) all referring to the continental fluvial sand underlying an extensive area of southern Nigeria. The Benin Formation comprises the top part of the Niger Delta clastic wedge, from the Benin-Onitsha area in the north to beyond the present coastline Short and Stauble (1967). Its type section is Elele 1 Well, drilled about 38 km north-northwest of Port Harcourt Short and Stauble (1967). The top of the formation is the recent sub-aerially-exposed delta top surface and its base extends to a depth of 4600 feet. The base is defined by the youngest marine shale. Shallow parts of the formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta Doust and Omatsola (1989). The formation thins basin ward and ends near the shelf edge. Although lack of preserved fauna inhibits accurate age dating, the age of the formation is estimated to range from Oligocene to Recent Short and Stauble (1967). It is a continental latest Oligocene to Recent deposit of alluvial and upper coastal plain that are up to 2000m thick Avobovbo (1978). It is deposited in the upper coastal plain environments following a southward shift of deltaic deposition into a new depobelt. Benin Formation is the youngest formation in the Niger Delta; the formation consists of massive, highly porous, freshwater bearing sandstones with local thin shale interbed which is considered to be of braided stream origin. The formation is identifiable in the subsurface on account of its high sand percentage (70-80%), few shale breaks which increase in frequency towards the base and the general absence of brackish water and marine faunas. The sand and sandstone of the Benin Formation are coarse to fine grain in general and are poorly sorted. The formation thins basinward and ends near the shelf edge. This study is aimed at using chemical finger print to classify the sedimentary succession penetrated by the drill. The objectives of this research are to describe the lithofacies present in the sample and to characterize the samples in terms of their geochemical contents.

Fig 2. Map of Depo Belts within the Niger Delta and the location of the study area within the Greater Ughelli Depo beltEjedawe (1981)

MATERIALS AND METHOD

Ten (10) Ditch Cutting samples were collected at different intervals between 4100ft and 12430ft from the sedimentary succession penetrated by the drills and were lithologically described using a reflected light microscope in order to obtain the texture, sorting, color, shapes/roundness and post depositional diagenetic effect. These properties are vital for the analysis of lithofacies. Consequently a Geological model embracing Lithofacies was generated for the Well's sedimentary succession. The Sampled intervals were from the Agbada Formation.

The samples there after were prepared using standard geochemical sample processing technique such as X-ray fluorescence (XRF) and Atomic absorption spectroscopy (AAS).

Sample preparation for XRF analysis: The samples were pulverized, Pellets were prepared from the pulverized sample, by mixing the powdered sample (10 g) with 1 g of stearic acid (binder) and thoroughly homogenized in an agate mortar. Stearic acid is an organic binder which increases mechanical stability of the sample. The mixture was then transferred into a 40 mm in-diameter hardened steel disc and pressed into a pellet at a pressure of 25 tons using hydraulic pressure press. The pellet were loaded into each sample holder of the x-ray machine for analysis. . Minipal 4 EDXRF at NGRL Kaduna was used for the analysis. This method operates on the principle of atomic physics and quantum chemistry. The specimens were exposed to the entire spectrum of photons consisting of primary radiation emitted from a standard x-ray tube which irradiated each specimen causing the element in it to emit secondary fluorescence with their characteristics x-ray line spectra. The spectral line energies or wavelength of the emitted lines was used in the quantitative analysis of elements in the specimen. The intensities of the emitted lines were related to their elemental concentration.

X-ray fluorescence method was used to determine the concentration of major and trace element in order to infer the environment of deposition.

Sample preparation for AAS analysis: 1 g of the powdered sample was weighed into a beaker and digested with 30 ml of concentrated hydrochloric acid and 10 ml of nitric acid on the thermostat regulated hot plate inside the fume cabinet. The digested sample was filtered using whatman filter paper into a 100ml plastic bottle and the volume made up to mark with distilled water. The sample solution was analyzed for the minor and trace elements by AAS. The elements standard solutions and their hollow cathode lamps were used for plotting calibration graphs after which the sample solution was aspirated into the Spectrometer.

RESULT AND DISCUSSION

Lithologic Description: Samples collected and analyzed using a reflected light microscope shows that the sampled intervals were from the Agbada Formations which comprises of shale and sand intercalation. lithofacies units gotten from sampled intervals are Sand, Shale and Shaly sand facies respectively. The sands are milky in colour, translucent to opaque, medium to coarse grain, sub-angular to sub-rounded and are moderately sorted while the shales are Grey in colour, fissile with presence of lignite streak .it is calcareous.

Table1: Results of Major element compositions (wt. %) for sampled intervals of the well

% Oxide Composition	4100ft	4900ft	5270ft	6930ft	8149ft	8606ft	11080ft	11700ft	11831ft	12430ft
SiO_2	93.55	93.37	62.09	61.99	36.19	71.18	50.90	35.14	77.56	93.22
TiO_2	0.30	0.15	0.521	4.33	1.91	2.66	3.28	1.09	0.722	0.554
Al_2O_3	1.70	1.90	14.11	13.51	14.27	15.20	12.61	14.70	4.33	1.40
Fe_2O_3	1.760	0.973	5.523	4.26	19.76	3.33	9.64	30.41	2.954	0.905
SO_3	Nd	Nd	8.14	Nd	22.50	Nd	10.20	Nd	3.12	Nd
Cl	Nd	0.914	Nd	Nd	Nd	Nd	0.67	Nd	0.646	Nd
Br	0.010	Nd	0.008	Nd	Nd	Nd	0.002	0.02	Nd	0.009
CaO	0.16	0.010	0.095	0.16	0.765	0.15	3.24	3.76	0.037	0.091
MgO	0.11	0.007	0.04	0.033	0.12	0.023	0.35	0.79	0.010	0.013
Na_2O	0.008	0.073	0.391	1.384	0.65	1.30	1.29	0.47	0.54	0.57
K_2O	0.005	0.020	0.479	1.686	0.75	1.08	0.81	0.36	0.76	0.82
MnO	0.003	<0.001	<0.001	<0.001	0.057	0.017	0.070	0.48	<0.001	<0.001
V_2O_5	0.013	0.034	0.01	0.084	0.03	0.02	Nd	0.03	0.01	0.01
Cr_2O_3	0.019	0.040	0.016	0.033	0.021	0.014	Nd	0.005	0.021	<0.001
CuO	0.021	0.022	0.023	0.040	0.033	0.023	0.055	0.044	0.011	0.018
ZnO	Nd	0.037	0.008	0.046	0.034	0.011	0.062	0.033	Nd	Nd
Ga_2O_3	Nd	0.005	Nd	0.009	Nd	Nd	Nd	Nd	Nd	Nd
Rb_2O	Nd	Nd	Nd	0.038	0.030	0.014	0.047	0.01	0.011	0.010
SrO	0.014	0.016	0.018	0.099	0.073	0.048	Nd	0.066	0.026	0.038
ZrO_2	0.029	0.026	0.055	0.547	0.17	1.15	0.25	0.20	0.098	0.075
BaO	0.075	0.19	0.07	Nd	0.23	0.70	0.70	0.49	0.31	0.53
PbO	0.018	0.017	Nd	0.043	0.11	0.020	0.13	0.17	0.020	0.027
As_2O_3	0.008	0.001	Nd	0.003	Nd	0.010	Nd	Nd	0.007	0.005
Ta_2O_5	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.03	Nd	Nd
L.O.I.	2.20	2.20	8.40	11.70	2.30	3.05	15.70	11.70	8.80	1.70

Major Elements Geochemistry: Clastic sediments from the well at different intervals have fluctuating values for $SiO_2$with SiO_2 values ranging from (35.14 - 93.55%), with an average of (67.51) respectively. The average SiO_2 valueis slightly higher than the average of 66% by weight for Upper Continental Crust (UCC) Taylor and McLennan (1985). The source of silica is mainly quartz, chert, quartzite, feldspars, and clay minerals. The Al_2O_3 values ranges from (1.40-15.20%) with an average of 9.37%. MgO values ranges from (0.007%– 0.79%), CaO values ranges from (0.01%– 3.76%), K_2O values ranges from

(0.005%– 1.686%), Fe_2O_3 values ranges from (0.905%– 30.41%). The Al_2O_3 and K_2O content in the samples may be related to the presence of K-feldspars (orthoclase and microcline), illite and mica. The low K_2O content in the sampled intervals indicated low amount of illite or K-feldspar present in the shale sediment samples (Akpokodje *et al.*, 1991). The MgO and CaO content may be related to the presence of carbonate cements why the Fe_2O_3 content may be related to the abundance of iron oxide heavy minerals and partly to Fe-containing clay minerals. In contrast, the samples possesses low average contents of Na_2O, TiO_2, MgO, and CaO. MgO content is related mostly to the presence of ankerite and dolomite cements. Carbonate cement are the main sources for CaO. The low values for CaO in the well samples indicate they have little or no carbonates (Calcite $CaCO_3$) materials in the sampled intervals. Average CaO value is 0.84%.

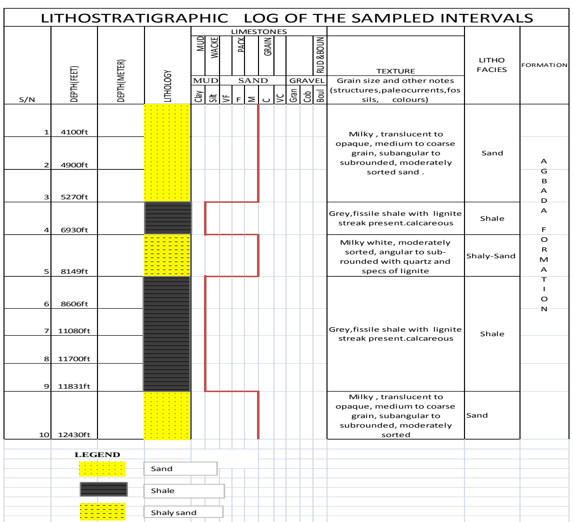

Fig3: Lithofacies description of the sampled intervals

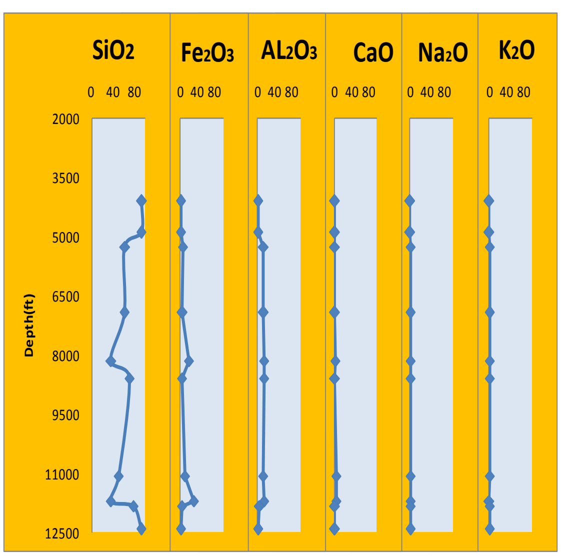

Fig 4: Graphical trend of major oxides

Table 2: Showing 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)

Depth(ft)	log (Fe_2O_3/K_2O)	log (SiO_2/Al_2O_3)
4100	2.55	1.74
4900	1.69	1.69
5270	1.06	0.64
6930	0.40	0.66
8149	1.42	0.40
8606	0.48	0.67
11080	1.07	0.60
11700	1.92	0.37
11831	0.58	1.25
12430	0.04	1.82

Using the guidelines as proposed by Lindsey (1999) for chemical classification of sandstone, four reference sets are as shown below:

1) Quartz arenite: log ($SiO2/Al_2O_3$) ≥ 1.5

2) Graywacke: log (SiO_2/Al_2O_3) < 1 and log (K_2O/Na_2O) < 0

3) Arkose (includes subarkose): log (SiO_2/Al_2O_3) <1.5 and log (K_2O/Na_2O) ≥ 0 and log ((Fe_2O_3+MgO)/(K_2O+Na_2O)) < 0

4) Lithic arenite (subgraywacke, includes protoquartzite): log (SiO_2/Al_2O_3) < 1.5 and either log (K_2O/Na_20) < 0 or log ((Fe_2O_3+MgO)/ (K_2O+Na_2O)) > 0.

The well samples plotted within the Fe-shale, Fe-sand and Quartz arenite region (Fig 5.), which is an indication of the heterogeneous nature of the formation penetrated by the drill. The sampled intervals are highly depleted in most of the major elements except SiO_2 (due to enrichment in quartz and chert). Using the geochemical classification diagram of Herron (1988), Samples that plotted in the quartz arenites region suggests an intense degree of weathering and reworking that removed ferromagnesian minerals and feldspars. While those that plotted in Fe-Shale and Fe-Sand suggests low degree of weathering and reworking that couldn't remove ferromagnesian minerals and feldspars.

Crook (1974) proposed a cross plot of K_2O versus Na_2O to classify sediments according to their quartz/silica components. In his plot he differentiated samples into three categories which are Quartz rich, Quartz intermediate and Quartz poor.

The K_2O vs Na_2O plots of the sampled intervals falls in Quartz rich ,Quartz intermediate and Quartz poor but majorly fall in quartz intermediate field of Crook (1974) (Fig.6). McLennan *et al.*, (1993) also observed same result from this type of study and suggested the derivation of the samples are from a granite dominated upper continental crust.

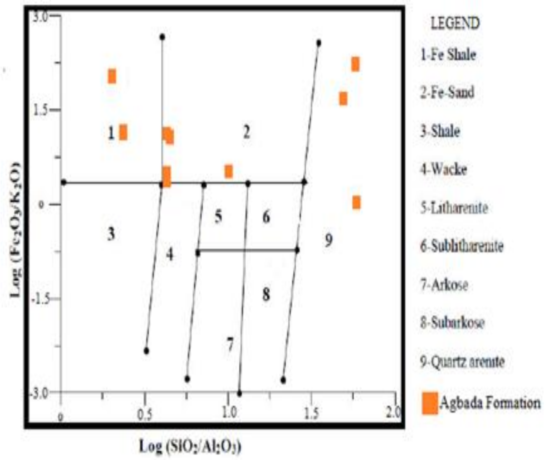

Fig.5. Chemical classification of sediments After Herron (1988)

Table 3: Values of Na_2O andK_2O for JVX well

Depth(ft)	Na_2O	K_2O
4100	0.01	0.01
4900	0.07	0.02
5270	0.39	0.47
6930	1.38	1.68
8149	0.65	0.75
8606	1.30	1.08
11080	1.29	0.81
11700	0.47	0.36
11831	0.54	0.76
12430	0.57	0.82

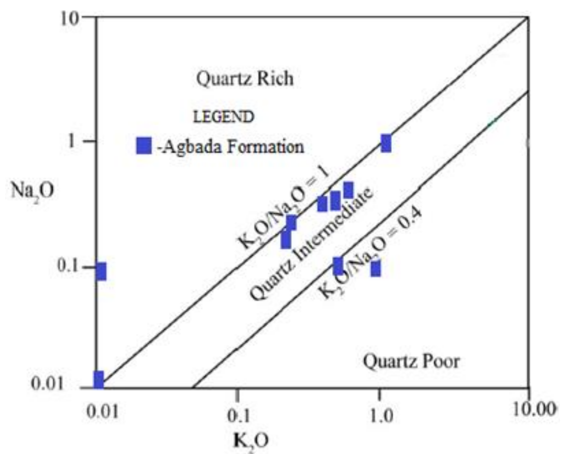

Fig 6: K_2O vs Na_2O Plots after Crook (1974)

Conclusion: The geochemical studies of the sediments revealed that SiO_2 is the dominant oxide followed by Al_2O_3 and Fe_2O_3 which constitutes over 90% while others such as CaO, K_2O, TiO_2, Na_2O and MgO constitute the rest. The SiO_2/Al_2O_3 ratios for the sediments in the well 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 retiles.

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