GEOCHEMISTRY OF SHALLOW SUBSURFACE AGBADA FORMATION AND ITS OUTCROP EQUIVALENCE

Ani B. Memuduaghan*; Kingsley O. Okengwu; Selegha Abrakasa

*Nigerian Geological Survey Agency

Department of Geology, University of Port Harcourt Correspondence: animemuduaghan@gmail.com +2348063357386

ABSTRACT

The tripartite subsurface Formations in Niger Delta are known to have their surface equivalences. The most prolific among them is the Agbada Formation which is said to have Ogwashi-Asaba Formation and the Ameki Group as its outcropping equivalences. The aim of the study was to delineate the similarities and differences by understanding the geologic history elements of subsurface and surface Agbada Formation using the geochemistry of Agbada reservoirs sands encountered in Oloibiri and Akata Fields and those of the surface equivalences (Nanka and Nsugbe Formations). This was achieved by analysing the reservoir using Xray Fluorescence (XRF), Atomic Absorption Spectrometry (AAS) and Petrography for the elemental and mineralogical compositions. The results showed that Nanka Formation and Nsugbe Formation reservoirs have more similarities with their shallow subsurface Agbada Formation than the deep subsurface Agbada Formation reservoirs in their geologic history elements as characterized by their; Intermediate Igneous Provenance, Semi Humid to Semi Arid Paleoclimate, their immature compositional maturity, and in their chemical classification which was mostly Lithic Arenite.

Keywords: Geochemistry, Provenance, Paleoclimate, Maturity, Field, Formation, Group, Outcrop, Delta, Reservoir.

INTRODUCTION

Niger Delta Basin which accommodates Agbada Formation is part of the Africa-South America Continental Margin that was formed during the divergent continental rift of Gondwanaland between Early Cretaceous and Late Cretaceous (Genik, 1993; Brownfield, 2016). Agbada Formation is the most prolific of the tripartite subsurface formations and its outcropping equivalences are Ogwashi-Asaba Formation and the Ameki Group including Nanka, Nsugbe and Ameki Formations. The aim of the study was to establish the elements of similarities in the geochemistry of the subsurface Agbada Formation and the outcrop Nanka and Nsugbe Formations of Ameki Group. This was achieved by analysing the reservoirs samples using XRF, AAS and Petrography. The reservoir rocks used for analyses were core and drill cuttings from subsurface Agbada Formation and rock samples from outcrop Nanka

Formation and Nsugbe Formation of Ameki Group representing surface or outcropping Agbada Formation. The results (the elemental and mineralogical composition of the reservoirs) from the analyses were then interpreted using various discrimination tools to delineate the different elements that characterize geologic history including Provenance, Paleoclimate, source area weathering, chemical classification, environment of deposition and Maturity.

Geology of the Study Area

The study area includes Subsurface Agbada Formation from Akata and Oloibiri fields with their representative wells; Akata-2 and Oloibiri-1 wells which geographically lie within the Southern part of Nigeria (Figure 1). On the other hand are the outcrop equivalences; Nanka and Nsugbe Formation of Ameki Group. The samples were retrieved from core shed of the National Geosciences Research Laboratories (NGRL), a centre of Nigerian Geological Survey Agency (NGSA) in Kaduna.

The geology of the study area shows that the samples fall into the Agbada Formation reservoir assessment unit of Niger Delta according to Brownfield (2016). The geology of Niger Delta has been well studied due to its vast petroleum resources by previous workers such Tuttle (1999); Nwajide (2013); and Brownfield (2016); using both cores description and analysis of the subsurface Niger Delta (Akata, Agbada and Benin Formations); and outcrop studies of surface formations (the Ameki Group comprising of the Ameki Formation, Nanka Formation and Nsugbe Formation; Ogwashi-Asaba and Imo Formations) in the basin for its sedimentological features.

The structural features as well as the tectonic history have been studied using more of geophysical and remote sensing data. Trenches and ridges of the Cretaceous fracture zones of the West Coast of Equatorial Africa control the tectonic framework of the continental margin. After the rifting period, gravity became the primary deformational process which ended before the deposition of Benin Formation. This gravity tectonics has been observed in different complex structures such as shale diapirs, rollover anticlines, collapsed growth faults and back-to-back features (Doust and Omatsola, 1990; Stacher, 1995; Brownfield, 2016).

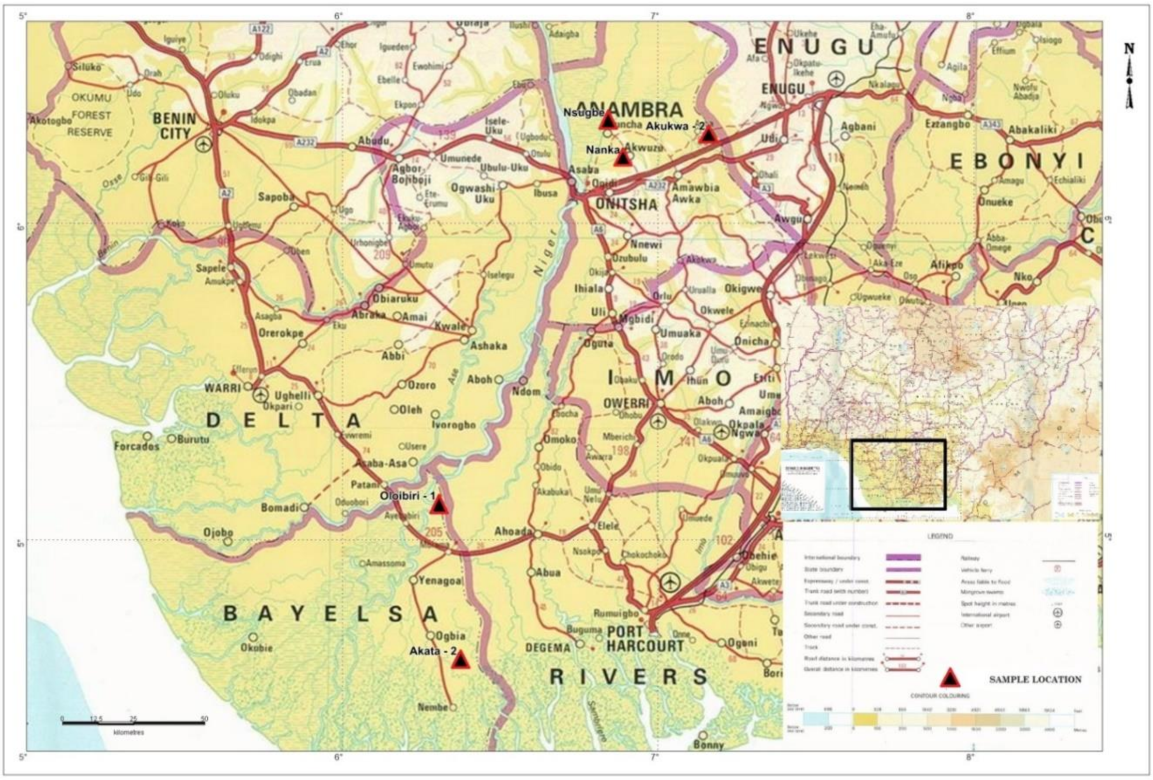


Figure 1: Location of the study area

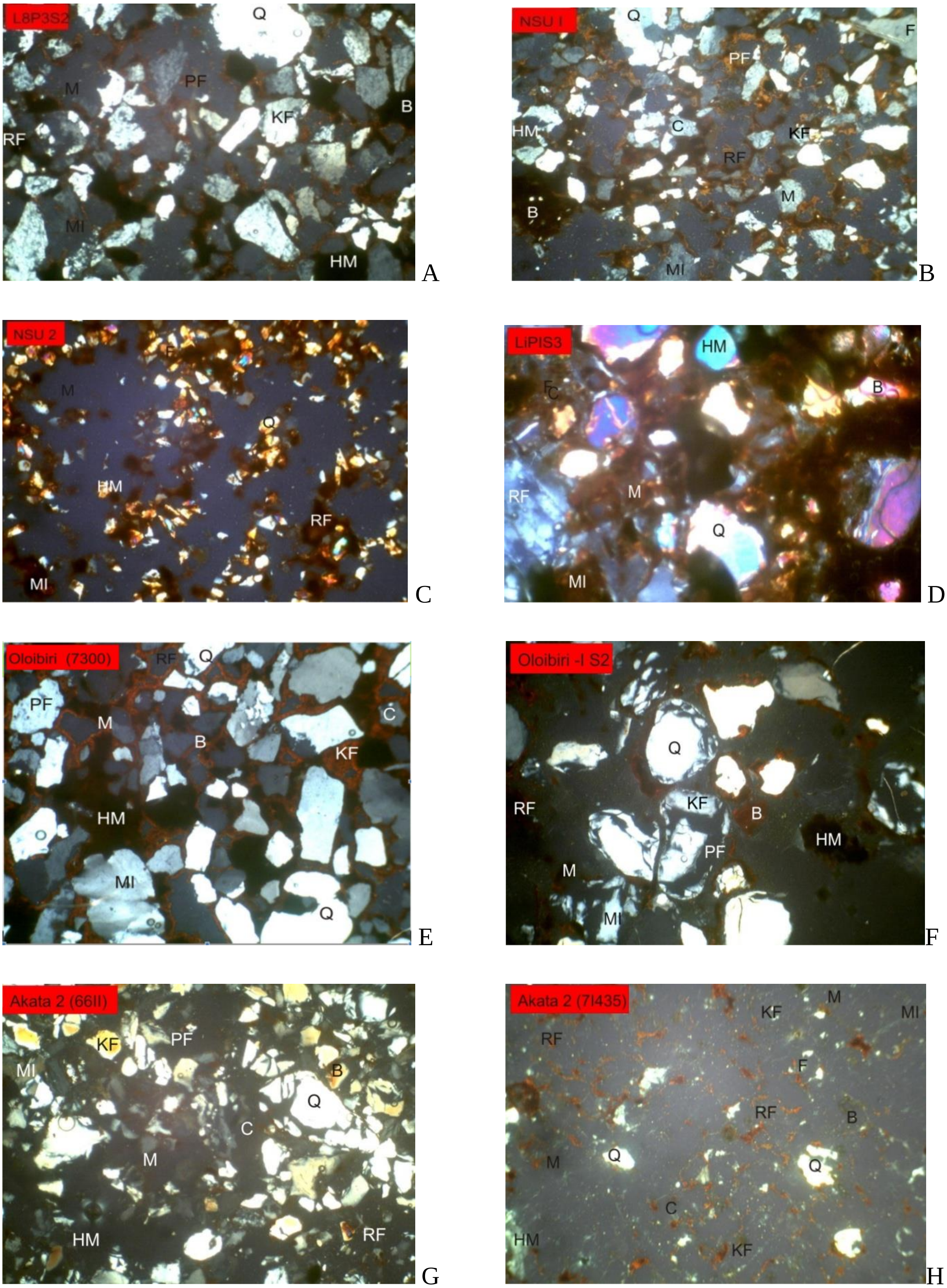
RESULTS

The results of the analyses were summarized in Table 1 and figures (2A-H), showing the elemental and mineralogical composition of the reservoirs.

Magnesium oxide was found to have its highest value in 7.59% in Nanka reservoir Sample and lowest value of 0.05% in Akata-2 well at a depth of 6611feet. On an average, magnesium oxide was 1.88% while iron oxide was 2.63% with its highest value of 7.65% in Nsugbe reservoir samples and its lowest in Oloibiri-1 well at a depth, 7478feet. At a depth of 7478feet, Oloibiri-1 had the highest concentration of calcium oxide with a value of 4.09% and the highest value of magnesium oxide 3.90%; and at this same depth, XRD showed the highest amount of Dolomite. The lowest calcium oxide concentration with a value of 0.03% was found in Akata-2 at 6611feet; while that of magnesium oxide was 0.11% in the same well and at the same depth as the lowest calcium oxide. The average concentrations were 1.4% and 1.88% for calcium and magnesium oxides respectively. The highest sodium oxide concentration was found both in Nanka Formation and the shallow Oloibiri-1 reservoirs at a depth of 7300feet among the analysed samples with a value of 1.88%. However, the least value of 0.11% was found in Akata-2 well at 6661feet. Its average value was 0.83%. The most abundant element which was silicon oxide had its highest concentration of 96.36% in Akata-2 well at a depth 6661feet while it lowest value of 46.9% was found at 6611feet also in Akata-2 well.

Table 1: Chemical Composition of the Reservoirs and their Weathering Indices

WELLS (Depth in Feet)	SiO_2	Al_2O_3	TiO2	Fe_2O_3	CaO	Na_2O	K_2O	MnO	P_2O_5	MgO	LOI	CIA	PIA	CIW	ICV	Qm	Qt	F	L	RF
Akata-2 (6611)	46.90	37.6	0.09	0.88	0.03	0.21	1.6	N/A	0	0.05	9.75	95.33	91.28	99.4	#N/A	20	57	15	3	10
Akata-2 (6661)	96.36	3.04	0.06	0.48	0.19	0.11	0.66	0.01	0.57	0.28	-	75.82	59.19	90.9	0.595	22	64	15	2	8
Akata-2 (7368)	94.00	1.04	0.23	1.24	0.77	0.53	0.68	0.04	0.64	1.36	-	34.44	11.92	44.4	4.663	-	-	-	-	-
Oloibiri-1 (7300)	54.97	25.11	0.01	2.52	0.1	1.88	0.13	0.04	0.22	0.51	9.75	92.25	91.77	92.7	0.207	14	60	14	2	10
Oloibiri-1 (7478)	87.77	2.74	0.06	0.38	4.07	0.6	1.02	0.05	0.63	3.9	-	32.5	20.4	37	3.679	12	57	21	2	10
Oloibiri-1 (7926)	93.55	4.71	0.17	1.12	0.13	0.43	0.88	0.02	0.8	0.53	-	76.7	62.46	89.4	0.692	-	-	-	-	-



Figures 2A-H: Photomicrographs of the studied reservoirs.

DISCUSSION OF FINDINGS

Using the Raw Oxides discriminant plots of Roser and Korsch (1988), deep reservoirs of Akata-2 and Oloibiri-1 wells plotted on the Quartzose sedimentary origin section, this means there are higher quartz concentrations as compared to other rock minerals such as feldspar and lithic fragment. On the contrary, the shallow reservoirs of these wells and those of the outcrop Formations (Nanka and Nsugbe Formations) have Intermediate Igneous origin (Figure 3A) with Nanka Formation also displaying Quartzose Sedimentary provenance like the other surbsurface Agbada Formation. This indicates that the shallow reservoirs have higher lithic fragments and less of quartz as compared to the deep reservoirs; therefore, the deep reservoirs are more mineralogically mature which implies better reservoir qualities.

The Ratio of Oxides Discriminatory Diagram after Roser and Korsch (1988), just like the previous provenance discriminating tool, the deep Agbada Formation reservoirs showed a Quartzose Sedimentary origin, meaning the deep reservoirs have high quartz concentrations compared to feldspar and lithic fragments while others (the shallow reservoirs of these wells and those of the outcrop Formations; Nanka and Nsugbe Formations) were Intermediate Igneous Provenance. Once more, Nanka Formation and the shallow subsurface Agbada Formation reservoirs displayed Quartzose Sedimentary provenance (Figure 3B). This also proves that the deep reservoirs are more mature.

Plotting the reservoir data on Suttner and others (1981), a paleoclimate ternary diagram based on mineralogical composition from petrography analyses; Quartz, Q; Feldspar, F; and rock fragment, RF showed that all the analysed reservoirs fell in Plutonic Humid (Figure 3C). The A-CN-K ternary diagram by Nesbitt and Young (1984) based on Chemical Index of Alteration (CIA); and oxides of aluminium, calcium, sodium and potassium. The trend from shallow to deep series in Akata-2 and Oloibiri-1 wells shows that the CIA reduces, this means weaker weathering. Shallow subsurface reservoirs and the outcrop samples showed Intermediate or moderate paleoweathering. Minerals such as Kaolinite, Chlorite, Gibbsite, Illite, Smectite, Muscovite and Biotite are abundant in the intensive weathering domain, however the deeper reservoirs are expected to have more of Plagioclase, Feldspar, Haematite and clinopyroxene (Figure 3D).

Folk (1974) ternary diagram formulated on petrographic analysis (Figure 3E), grouped all the analysed samples as Lithic Arkose. This implies immaturity. On the contrary, Pettijohn's (1972) chemical classification tool showed that the deep reservoirs of the subsurface wells (Oloibiri-1 and Akata-2 wells) plotted as Quartz Arenite while the shallow reservoirs and the outcrop samples were Lithic Arenite and Subarkose as shown in Figure 3F. While Nanka Formation was both Lithic Arenite and Sub-Arkose, Nsugbe was Sub-Arkose and shallow subsurface Agbada Formation reservoirs encountered at Oloibiri-1 and Akata-2 were Lithic Arenite and Sub-Arkose; showing that Nanka Formation has a lot more similarities to shallow subsurface Agbada Formation reservoirs than Nsugbe Formation. This implies immaturity.

The third is Herron's (1988) bivariate diagram for chemical classification derived from the ratios of silicon, aluminium, iron and potassium oxides which also demonstrated that the deep reservoirs of the subsurface wells (Oloibiri-1 and Akata-2) plotted Quartz Arenite and Sublithic Arenite. However, the shallow reservoirs and the outcropping reservoirs (of Nanka and Nsugbe Formations, the surface equivalence of Agbada Formation) were Lithic Arenite and Iron Sand (as shown in Figure 3G), Nsugbe Formation is Lithic Arenite, Nanka Formation was both Lithic Arenite and Iron Sand while shallow subsurface Agbada Formation reservoirs encountered at Oloibiri-1 and Akata-2 wells were Iron Sand and Lithic Arenite. It also suggests immaturity.

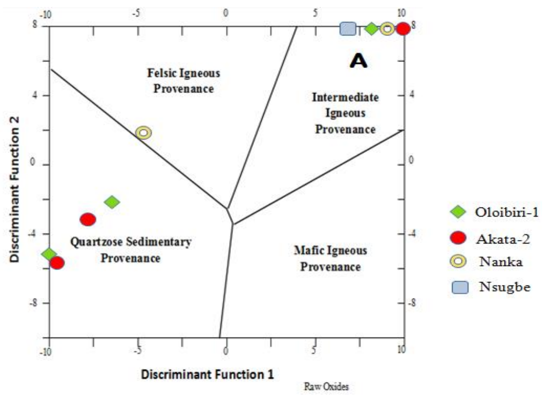


Figure 3A

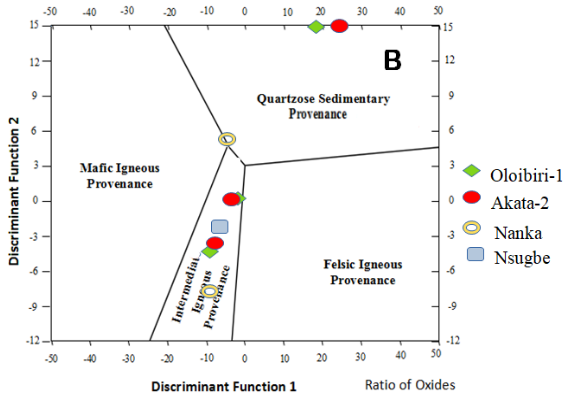


Figure 3B

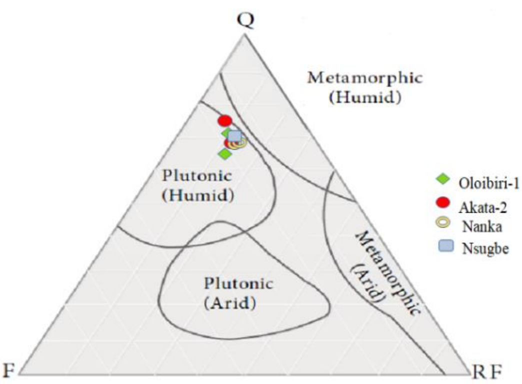


Figure 3C

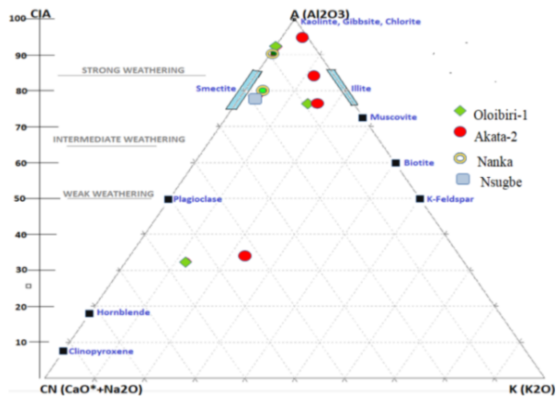


Figure 3D

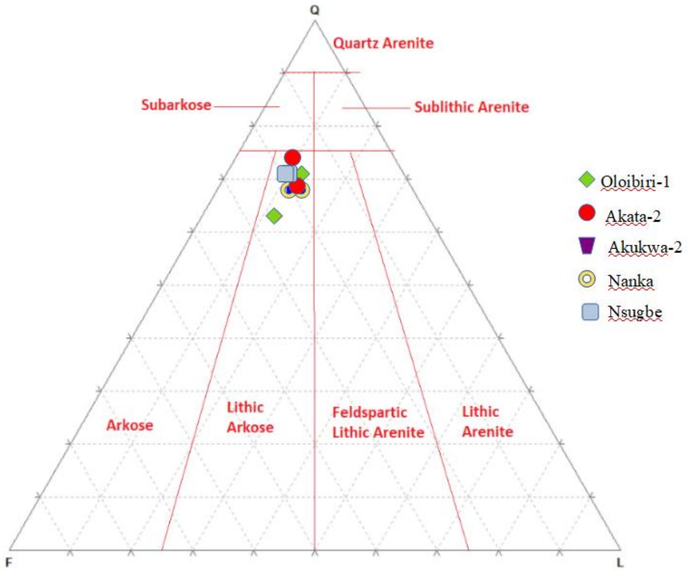


Figure 3E

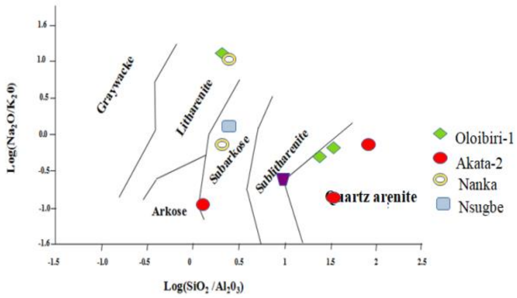


Figure 3F

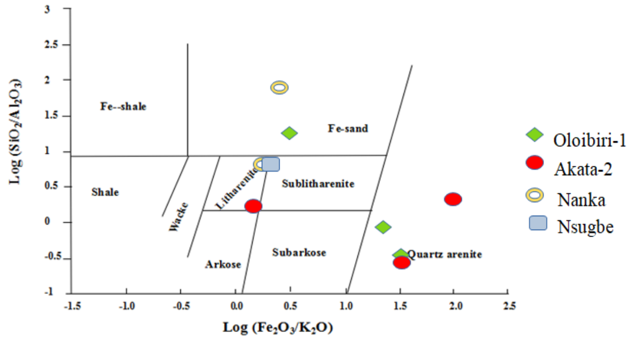


Figure 3G:

Figure 3A: Provenance signatures of the studied samples using raw oxides on Discriminant function diagram (after Roser & Korsch, 1988).

Figure 3B: Provenance signatures of the reservoirs using ratio of oxides on Discriminant function diagram (modified after Roser & Korsch, 1988).

Figure 3C: Q-F-RF Ternary plots for the Paleoclimatic classification of the analysed reservoirs modified after Suttner and others (1981).

Figure 3D: Paleoweathering Al_2O_3 - (CaO+ Na_20) - K_2O Plots for reservoirs on A-CN-K Ternary diagram of Nesbitt and Young (1984).

Figure 3E: QFL Ternary Diagram for the reservoirs chemical classification, modified after Folk (1974).

Figure 3F: Bivariate oxide diagram for chemical classification of the reservoirs (based on AAS and XRF results), Log (Na_2O/K_2O) versus Log (SiO_2/Al_2O_3). Modified after Pettijohn (1972).

Figure 3G: Chemical classification of the reservoirs based on Log (SiO_2/Al_2O_3) against Log (Fe_2O_3/K_2O) diagram by Herron (1988).

One of the effective discriminatory tools used to infer the maturity of the reservoir samples was formulated by Al-Juboury (2007). From the diagram (Figure 4), most samples show immaturity however deep reservoirs of Oloibiri-1 and Akata-2 well show greater maturity. On the basis of the model below (Table 2) by Nwajide and Hoque (1985), almost all the reservoirs analysed proved to be Submature except for the second shallowest depth reservoir of Oloibiri-1 well and one of the Nanka samples which were immature (Table 3).

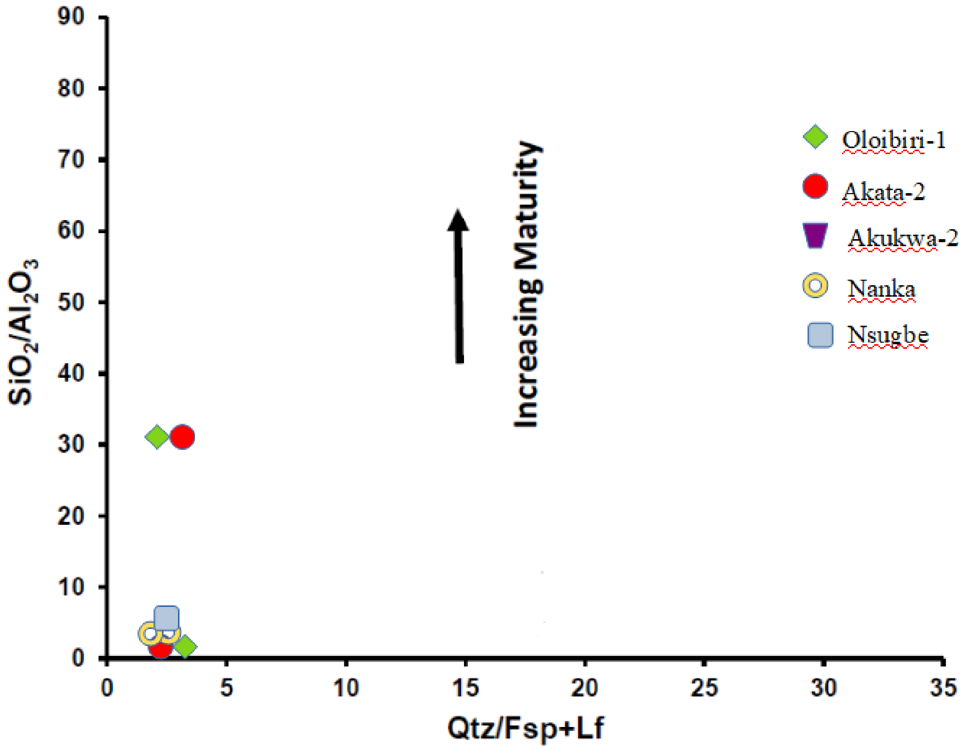


Figure 4: Maturity of the samples using Al-Juboury (2007).

Table 2: Standard Mineral Maturity Index by Nwajide and Hoque, (1985).

Mineralogical Composition	**Maturity Index**
Q=>95 % ; (F+RF)= 5%	MI=> 19 Supermature
Q= 95-90% ; (F+RF)= 5-10%	MI= 19-9.0 Submature
Q= 90-75% ; (F+RF)=10-25 %	MI=9.0-3.0 Submature
Q= 75-50% ; (F+RF)=25-50 %	MI=3.0-1.0 Immature

Q=<50%	MI=<1
(F+RF)=>50%	Extremely Immature

Table 3: Recalculated QFL Mineralogical Composition and Maturity based on Petrography results and Sandstone Compositional maturity after Nwajide and Hoque (1985).

WELLS	Q (%)	F (%)	L (%)	TOTAL	Compositional Maturity
Oloibiri-1 (7300)	79	18	3	100	**Submature**
Oloibiri-1 (7478)	70	27	3	100	**Immature**
Nanka-1	74	22	4	100	**Immature**
Nanka-2	76	20	4	100	**Submature**
Nsugbe-1	77	20	3	100	**Submature**
Nsugbe -2	77	19	4	100	**Submature**
Akata-2 (6611)	76	20	4	100	**Submature**
Akata-2 (7143.5)	79	19	2	100	**Submature**

The summary of the similarities between subsurface Agbada Formation and their outcrop equivalences; Nsugbe and Nanka Formations were summarized and highlighted in Table 4.

WELLS (Depth in Feet)	Formation	Chemical Classification	Paleoclimate	Provenance	Paleoweathering	Maturity	Environment of Deposition
Nsugbe-1	Nsugbe	Lithic Arenite	Semi Humid to Semi Arid	Basement Uplift, Intermediate Igneous	Intermediate	Immature	Non Marine and Deltaic Sandstone
Nanka-1	Nanka	Lithic Arkose	Semi Humid to Semi Arid	Basement Uplift, Intermediate Igneous	Intermediate	Immature	Marine Sandstone
Nanka-2	Nanka	Lithic Arenite	Semi Humid to Semi Arid	Basement Uplift, Quartzose Sedimentary	Strong	N/A	Non Marine and Deltaic Sandstone
Akata-2 (6611)	Agbada	Lithic Arenite	Semi Humid to Semi Arid	Basement Uplift, Intermediate Igneous	Strong	Immature	Non Marine and Deltaic Sandstone
Akata-2 (6661)	Agbada	Quartz Arenite	Semi Humid	Intermediate Igneous to Quartzose Sedimentary	Intermediate	N/A	Non Marine and Deltaic Sandstone
Akata-2 (7368)	Agbada	Quartz Arenite	Semi Humid	Basement Uplift, Quartzose Sedimentary	Weak	Submature	Non Marine and Deltaic Sandstone
Oloibiri-1 (7300)	Agbada	Lithic Arenite	Semi Humid to Semi Arid	Basement Uplift, Intermediate Igneous	Strong	Immature	Marine Sandstone
Oloibiri-1 (7478)	Agbada	Quartz Arenite	Semi Humid	Intermediate Igneous to Quartzose Sedimentary	Weak	N/A	Non Marine and Deltaic Sandstone
Oloibiri-1 (7926)	Agbada	Quartz Arenite	Semi Humid	Basement Uplift, Quartzose Sedimentary	Intermediate	Submature	Non Marine and Deltaic

Table 4: A summary of the geologic history elements of the reservoirs samples.

CONCLUSIONS

All the analysed rocks showed a source with basement uplift characteristics and an inferred depositional environment ranging from Non-Marine and Deltaic to Marine Sandstones. This study has shown that shallow subsurface Agbada Formation reservoirs have a lot of similarities with the outcrop Nanka and Nsugbe Formations than the deep subsurface reservoirs: in terms of their Provenance, Paleoclimate, Maturity and Chemical Classification. Shallow subsurface reservoirs and the sands of Nanka and Nsugbe Formations analysed demonstrated uniform Intermediate Igneous Provenance, Semi Humid to Semi Arid Paleoclimate, immature compositional maturity, and their chemical classification was mostly Lithic Arenite. Whereas, the deep subsurface reservoirs exhibited the characters of Quartzose Sedimentary Provenance, Semi Humid Paleoclimate, mature compositional maturity, and their chemical classification was Quartz Arenite.

REFERENCES

Al-Juboury, A.I. (2007). Petrography and Major Element Geochemistry of Late Triassic. Carpathian Keuper sandstones: Implications for provenance. *Bulletin de l'Institut Scientifique,* Rabat, section Sciences de la Terre, 29(3): 1-14.

Brownfield, M.E., (2016). Geologic Assessment of Undiscovered Hydrocarbon Resources of Subsaharan Africa. Charpter 5. USGS Open File.

Doust, H. and Omatsola, E. (1990). Niger Delta in Edward J.D., and Santogrossi P.A., eds Divergent/Passive Margin Basin. *AAPG Memoirs* 48: Tulsa, AAPG: 201-238.

Folk, R.I. (1974). Petrography of Sedimentary rocks, Austin, Texas. Hemphill Publishing Company.

Genik, G.J. (1993). Petroleum Geology of the Cretaceous-Tertiary Rift Basins in Niger, Chad and Central Africa Republic: *AAPG Bulletin* 73 (8): 153.

Herron, M.M. (1988). Geochemical Classification of Terrigenous Sands and Shales from Core or Log Data. *Journal of Sedimentary Petrology*. 58: 820-829.

Nesbitt, H.W. and Young, G.M. (1984). Prediction of some Weathering Trends of Plutonic and Volcanic Rocks Based on Thermodynamic and Kinetic Considerations. *Geochim Cosmochim Ac* 48:1523–1534.

Nwajide, C.S., (2013). Geology of Nigeria's Sedimentary Basins. First Edition: 277-346.

Nwajide, C.S., and Hoque, M. (1985) Problem of classification and maturity. Evaluation of a diagnostically altered fluvial Sandstone. *Geologic on Nujibouw*, vol.64, p. 67-70.

Pettijohn, F.J., Potter, P.E. and Siever, R. (1972). Sand and Sandstones. 1st ed. New York, NY, USA: *Springer-Verlag*.

Roser, B.P. and Korsch, R.I. (1988). Provenance Signature of Sandstone-Mudstone Suite Determined Using Discriminant Function Analysis of Major Element Data. *Chemical Geology*. 67:119-139.

Stacher, P. (1995). Present Understanding of the Niger Delta Hydrocarbon Habitat in Oti, M.N., and Postma G., eds., Geology of Deltas: Rotterdam, A.A., Balkena: 257-267.

Suttner, L.J., Basu, A. and Mack, G.H. (1981). Climate and the Origin of Quartz Arenites. *Journal of Sedimentary Petrology*. 51:235-246.

Tuttle, M.L., Charpentier, R.R., and Brownfield, M.E., (1999). The Niger Delta Petroleum System: Niger Delta Province Nigeria, Cameroon and Equatorial Guniea, Africa. USGS Open File Report 99-50-H: 1-79.