Petrogenesis and qualitative seal assessment of ferruginized Eocene sands, Awkuzu, Southeastern Nigeria

Etimita Osuwake Omini, Beka Francis Thomas, Etu-Efeotor John Ovwata

Abstract— The tidally influenced iron rich sandstones are linear to irregular interbedded layers that compartmentalize the potential reservoir sands in Awkuzu area of southeastern Nigeria. These iron enrichment is probably the product of oxidation and hydration as sediments react with the environment. The ferruginized sandstones are poorly to moderately sorted with quartz and goethite mineral abundance and this reflects in its high SiO_2 and Fe_2O_3 (T) composition. They are derived from intensely altered and weathered sedimentary or metasedimentary rocks which are dominantly of recycled orogenic quartzose and transitional sources from active continental and passive margins. The effectiveness of these ferruginized sandstones as a trap has high uncertainties with respect to regional negligible seal thickness and poor continuity to support the potentially high hydrocarbon accumulations.

Index Terms— Seal, Petrogenesis, Reservoir, Sandstones, Diffraction, Eocene, Ferruginized sand, Trap.

1 INTRODUCTION

Sandstones are ferruginized when iron minerals probably iron oxides and oxihydrooxides fill pore spaces of matrix, thereby increasing the degree of induration. Ferruginized sandstones are evident in the fluvio-tidal sands at Awkuzu and they occur as interbedded layers in the Eocene Nanka Formation [1], [2].

These tidally influenced ferruginized sandstones with estuarine heteroliths interval, dominate the upper sandstone units of Nanka formation [1]. The potential reservoirs sand are compartmentalized by cm-thick elongate ferruginized and lateritic band of sands especially at the lower and middle sandstone units [1]. These ferruginized sandstones are described as potential hydrocarbon trap for Eocene Nanka sands [1]. The understanding of how traps are formed is essential for achieving success in future hydrocarbon exploration based on the presence of adequate petroleum systems [3]. It is very important to include reservoir rock and seal description in hydrocarbon trap evaluation and assessment [4]. The variability in traps, led to further trap classification with emphasis on trap attributes [5], [6].

This study is aimed at inferring the origin of ferruginized sandstones in Awkuzu environ and it further evaluates, the trap potentials using physical sample to outcrop examinations and laboratory analysis.

2 STUDY AREA

The research location is in Anambra State, southeastern Nigeria but stratigraphically, they are part of the outcropping sediments of the Cenozoic Niger Delta [2]. Awkuzu town is located at longitude $6^{0}55'4''$E and latitude $6^{0}14'19''$N in Anambra state (Figure 1). The area is drained by groundwater and surface water with dendritic pattern. The surface water potential is $20x10^{9}$cu.m and groundwater potential is $7.15x10^{9}$cu.m [7]

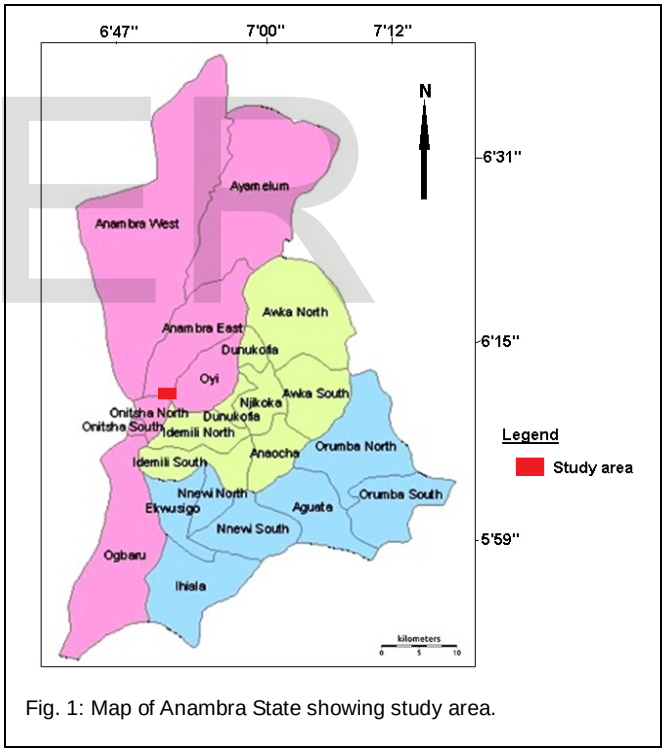


Fig. 1: Map of Anambra State showing study area.

3 MATERIALS AND METHODS

Samples obtained from the field were analysed petrographically using a polarizing microscope and the results were further complemented with X-ray diffraction mineral analysis using Panalytical X'Pert Pro diffractometer, which utilised copper X-ray source and an X'Celerator detector that was operated under standard conditions [8]. The X'Pert HighScore Plus software with the Mineral ICDD database were used in identifying the mineral. The geochemical composition of the ferruginized sand was evaluated using

Fusion-Inductively Coupled Plasma-Mass Spectrometer. Various discriminant plots were used to understand the petrogenesis of this ferruginized sandstone.

4 RESULTS AND DISCUSSION

The ferruginized sandstones occur as linear to irregular interbedded layers (Fig.2) within sands at Awkuzu and they have a dominant thickness that is less than six centimetres (6cm).

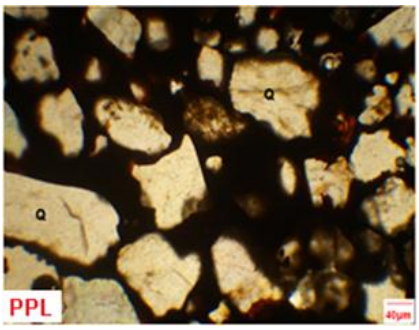
(a) Linear

(b) Irregular

Figure 2: Outcropping forms of ferruginized sandstones at Awkuzu.

Generally, the area of study is undulating with ferruginized sandstones exposed in borrow pits at irregular depths of interval. The surface exposure is limited and consequently, it is difficult to evaluate the lateral extent of these dominantly thin bedded ferruginized sandstones which are products of sands impregnated with iron oxides and oxihydrooxides.

The iron oxide enrichment is probably due to oxidation, hydration and mineralization processes occurring in sediments [9]. In addition, iron precipitation due to lateral groundwater influx [10]. The major mineral constituents of the ferruginized sandstones include quartz and goethite (Fig. 3 and Fig. 4).



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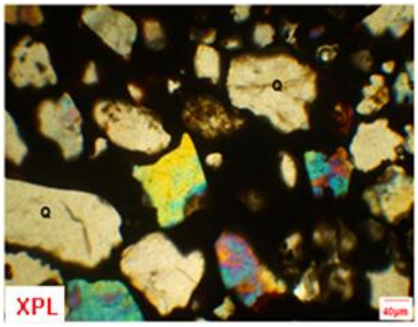

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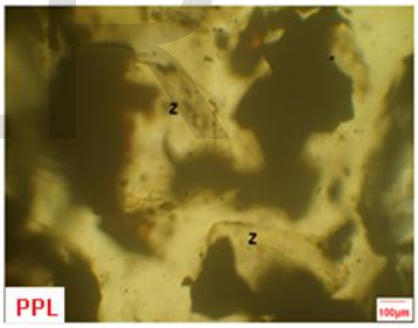

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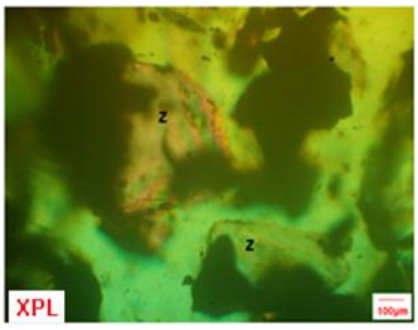

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Figure 3: (a & b) Photomicrograph of ferruginized sandstones. (c & d) Photomicrograph of heavy minerals in ferruginized sandstones in Awkuzu area. (Note: Q=Quartz, Z=Zircon)

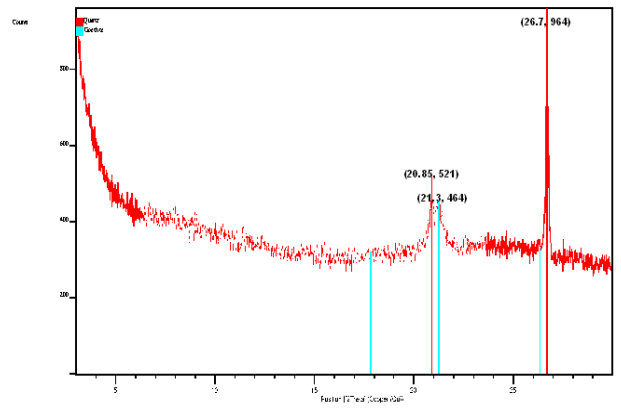


Fig. 4: XRD pattern for minerals identifies in ferruginized sandstones in Awkuzu Environs.

There is no presence of kaolinite in these ferruginized sandstones and the composition of X-ray amorphous minerals is relatively high.

Generally, the sandstone minerals are been altered and replaced by opaque minerals probably iron oxide and/or oxihydrooxides. The pore spaces within the matrix are filled with iron mineral which eventually reduces the effective porosity to insignificant quantities while increasing matrix density.

The degree of replacement is high for the non-opaque heavy mineral like zircon. In addition, the grains are poorly to moderately sorted and they are dominantly subangular with opaque minerals filling and cementing the interparticle spaces.

4.1 Geochemistry

The geochemical composition of these sublitharenitic ferruginized sandstones at Awkuzu shows a high content of SiO_2 and Fe_2O_3 (T) with an average value of 74.86±0.457 and 20.38±0.496, respectively (Table 1).

The degree of alteration, measured using the Chemical Index of Alternation (CIA) is high and the extent of weathering in the sediment source area is intense when evaluated using Chemical Index of Weathering (CIW) [11], [12].

4.2 Petrogenesis

TABLE 1
MAJOR ELEMENT COMPOSITION OF FERRUGINIZED SANDSTONES AT AWKUZU, SE NIGERIA.

		Ferruginized Sandstone Samples						
ANALYSED SYMBOL	UNIT	F1X1	F1X2	F2C	F2C2	FBT	FST	FST
SiO_2	%	74.8	75.21	74.08	75.1	75.1	75.3	74.4
Al_2O_3	%	0.73	0.61	0.63	0.36	0.56	0.52	0.57
Fe_2O_3 (T)	%	21.02	19.69	20.22	20.86	20.22	20.06	20.6
MnO	%	0.006	0.02	0.01	0.02	0.01	0.02	0.03
MgO	%	0.06	0.09	0.06	0.05	0.04	0.03	0.02
CaO	%	0.11	0.14	0.13	0.12	0.14	0.13	0.16
Na_2O	%	0.05	0.05	0.04	0.03	0.03	0.04	0.06
K_2O	%	0.03	0.01	0.02	0.05	0.03	0.01	0.02
TiO_2	%	0.025	0.03	0.026	0.03	0.04	0.02	0.03
P_2O_5	%	0.5	0.69	0.76	0.67	0.64	0.62	0.63
LOI	%	2.39	3.36	3.49	2.68	3.12	3.15	3.16
Total	%	99.721	99.9	99.466	99.97	99.93	99.9	99.68
Log (Fe_2O_3 (T)/K_2O)		2.846	3.294	3.005	2.620	2.829	3.302	3.013
Log (SiO_2/Al_2O_3)		2.011	2.091	2.070	2.319	2.127	2.161	2.116
K_2O/Na_2O		0.600	0.200	0.500	1.667	1.000	0.250	0.333
CIA	%	79.348	75.309	76.829	64.286	73.684	74.286	70.370
CIW	%	82.022	76.250	78.750	70.588	76.712	75.362	72.152

Note: LOI = Loss of Ignition, CIA= Chemical Index of Alteration, CIW= Chemical Index of Weathering.

The ferruginized sandstones are formed from sedimentary and metasedimentary rocks using Na_2O/Al_2O_3-K_2O/Al_2O_3 diagram (Fig. 5).

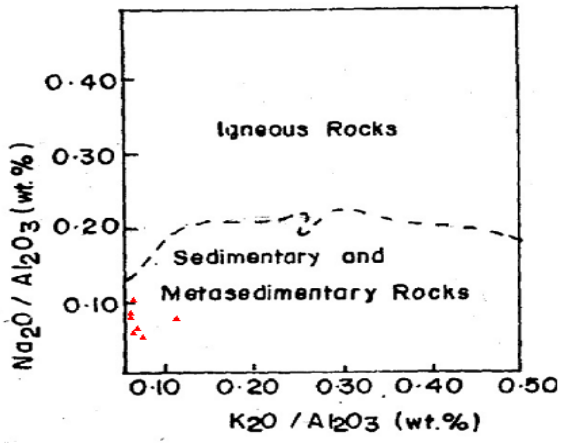


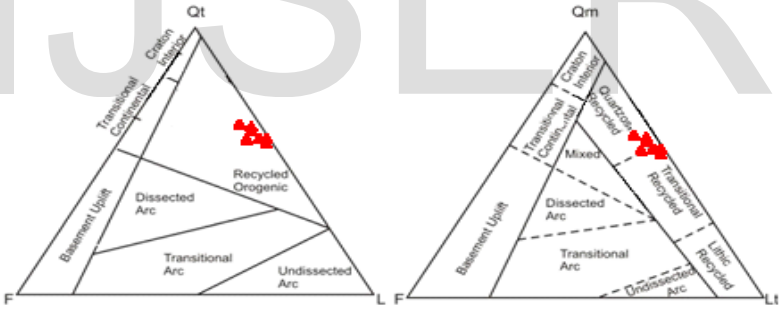
Fig. 5: Na_2O/Al_2O_3-K_2O/Al_2O_3 diagram [13].

These ferruginized sandstones are derived from recycled orogenic sources which are mainly quartzose recycled with imprints of transitional recycled sediments derivations within active continental and passive margins (Fig. 6).

4.3 Trap and Seal Potential

The hydrocarbon trapping potential of these ferruginized sandstones at Awkuzu are associated with products of diagenetic facies changes. These are stratigraphic and geometrically arranged to permit accumulation of potential hydrocarbon in subsurface. These ferruginized sandstones, compartmentalize the potential Nanka reservoir sands [1]. Based on their nature of physical and textural properties evaluated in this study, they can impede migration of hydrocarbon within this potential reservoir.

Generally, the dynamic nature of hydrocarbon trap mechanisms has been defined and classified [3], [4], [5], [6]. Using standard criteria, the effectiveness of ferruginized sandstones in Awkuzu area as potential reservoir hydrocarbon trap has high uncertainties. Though, hydrocarbon presence is a requirement for the economic assessment of a reservoir, but is not a critical component of hydrocarbon trap assessment. The sealing characteristic of ferruginized sandstones of Awkuzu increases its viability as a trap to prevent hydrocarbon flow and this will eventually withhold petroleum column which overtime, may fracture or release hydrocarbon probably due to increased wettability. An effective seal has to be laterally continuous, relatively thick, stratigraphically homogeneous and lack open fractures or faults [16]. The seal potential of ferruginized sandstones at Awkuzu depends on its capacity, geometry and integrity [17].



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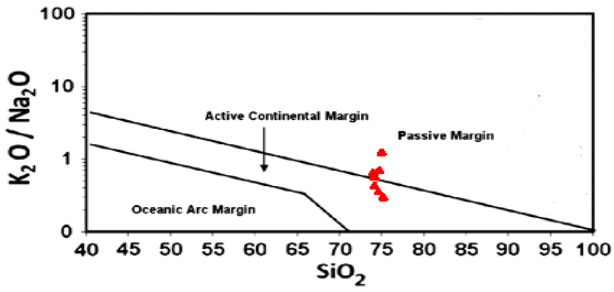

(b)

Fig. 6: Sediment derivation source for ferruginized sandstones at Awkuzu, SE Nigeria (a) QtFL and QmFLt Ternary Diagram [14]. (b) SiO_2 – K_2O/Na_2O Diagram [15].

The seal geometry encompasses the lateral continuity and thickness which is dominantly defined by wireline logs,

seismic, correlation and analogues interpretations [17]. The ferruginized sandstones seal thickness is small, not regional and may dominantly be seismically invisible. There is a high uncertainty that a ferruginized sandstone, that is a less than six centimetres thick will laterally be continuous and with stable lithic characteristics over a sizeable potential reservoir hydrocarbon accumulation.

The process of iron mineral impregnation and induration reduces the throat radius of interconnected pores which increases the seal capacity. The relatively higher wettability and low ductility of these ferruginized sandstones reduce the seal capacity when compared to shales which are the common sealing lithology within the onshore Niger Delta petroleum system. Ferruginized sandstones under conditions of deformation, fracture more easily than clays, shales and anhydrites.

5 CONCLUSION

The fluvio-tidal ferruginized sandstones at Awkuzu are quartzose and transitional recycled sediments from active continental and passive margin. The dominant minerals are quartz and goethite in comparative representative concentrations. The iron oxide minerals increase the level of induration and further enhance its trapping characteristics. This study narrows the knowledge gap on the petrogenesis of ferruginized sandstones and it successfully enumerates qualitatively its hydrocarbon trap potential effectiveness to aid future exploration.

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