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Bioturbation Controls on Reservoir Porosity and Permeability of Xena-14, Onshore, Central Swamp Depobelt of Niger Delta

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ABSTRACT

The controls of bioturbation on reservoir porosity and permeability of onshore, Xena-14, Niger Delta reservoir rock was conducted. Study revealed a spread of Cruziana to Skolithosichnofacies with average porosity of 23.3% and permeability of 328.8mD over all the study interval covering all the eleven (11) recognized sandstone and heterolithic lithofacies intervals. An average porosity of 23.44% and permeability of 444.6mDwas recorded for the bioturbated sandstone intervals while average values of 23.3% and 322.9mD was deduced for the unbioturbated sandstone facies excluding the heterolithic intervals. The samples generally displayedmoderate to sparse bioturbation (0-30%) andintensity of 2(BI) with the more bioturbated facies intervals displayingboosted porosity and permeability values indicating that bioturbation as much as the grain dispositionof thehigh energy onshore settings positively controls reservoir quality and consequently be applied in exploration and identification of prospective reservoirs.

INTRODUCTION

Bioturbationoccursduring and after sediments deposition owing tosediment and organismsinteractions (Pemberton *et al*., 2001).Bioturbation modifies textural attributes, grain arrangement and orientation that greatly influences the porosity and permeability distribution pattern of sedimentary reservoir rocks by introducing clay rich matrix within the pore spaces of larger grains which resultsto restructuring of original sedimentary grains and fabric (Gingras *et al.*, 2004; Meysman and Boudreau, 2003).

The development of trace fossils and other associatedbiogenic sedimentary structures from bioturbation processesreflects sedimentary responses to environmental, sedimentological and bathymetric variations. (Pemberton *et al*., 1992). Trace fossils such as the *Macaronichnus*were produced by organisms capable of dwellingwithin high energy hydrodynamicenvironments (Goldring, 1995). Organisms that dwell within the high energy environments are known to create simple vertical to U-shaped burrows,categorized as *Skolithos* ichnofacies assemblageusually pellet lined to protect and keep their burrow walls stable from the inimical environmental conditions.

Studies have shown that core samples from the Niger Delta sedimentary basinare commonly bioturbated with varieties of both vertical and horizontal trace structures with thoroughly-sparsely bioturbated facies (Jackson *et al*., 2013; Odelugo *et.al.* 2016). Pollard *et al.* (1993) revealed that the renowned pellet lined *Ophiomorpha* burrows of the *Skolithos* assemblage is observed to occur inNear-shore environment wherever the sediment is primarily of sand sizedgrains.The type of sediment in which *Ophiomorpha*trace is found can be used to

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differentiate between the offshore, shoreface and the estuarine sedimentary environments (Pollard *et al*. (1993).

Studiesindicated that the greatest population and diversity of trace fossil assemblages are observed within the lower shoreface to upper offshore depositional settings with fewer and simpler vertical traces observed within the delta top while the more complex three dimensional spread of facies are recognized in the deeper marine environmental setting making trace fossils important paleoecological indicators (Core Lab (1996), Odelugo *et al*, 2016).

STUDY LOCATION:
The study well is situated in the Central swamp-1 depositional setting within latitude 40N and longitudes 60E-70E of the Niger Delta sedimentary basin (Knox and Omatsola, 1989) as shown in Figure 1.0.)

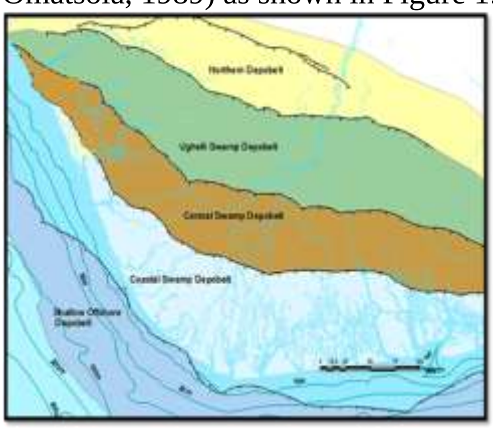


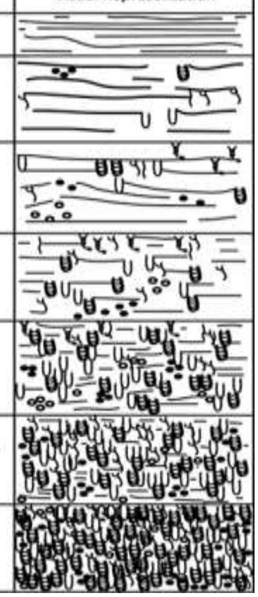
Figure 1.0: Study location (Modified from Knox and Omatsola, 1989)

STUDY METHODOLOGY:
Different investigative procedures were appliedbut the keyanalytical process involveddetailed sedimentological and ichnological evaluationof the core samples to define and interpret the encountered lithologies, textural and structural features as observed.

Bioturbation intensity was evaluated adopting Howard & Reineck, 1972bioturbation quantification scheme(Tables 1.0) where the higher grades reflects high bioturbation intensities and the lower grades define lower intensities of bioturbation activities and traces occurrence with better preserved primary structures as shown in Table 1.0.

Table 1.0: Bioturbation Quantification Scheme (Howard & Reineck,1972)

Grade	Classification	Visual Representation
0	Bioturbation Absent	
1	Sparse bioturbation, bedding distinct, few discrete traces	
2	Uncommon bioturbation, bedding distinct, low trace density	
3	Moderate bioturbation, bedding boundaries sharp, traces discrete, overlap rare	
4	Common bioturbation, bedding boundaries indistinct, high trace density with common overlap	
5	Abundant bioturbation, bedding completely disturbed (just visible)	
6	Complete bioturbation, total biogenic homogenization of sediment	



RESULT AND INTERPRETATIONS: LITHOFACIE ANALYSIS:
Implementing Reijers *et al*. (1993) lithofacies classification scheme, the study core Xena-14 was grouped into Eleven (11) lithofacies assemblages (Table 2.0); cross-bedded medium-fine grained sandstones (Sx), Bioturbated cross bedded wave-rippled medium to fine sandstones (Swxb), Bioturbated cross bedded coarse pebbly sandstones (S4xb), Cross bedded coarse

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pebbly sandstones (S4x), Parallel-laminated sandstones (Sp), Bioturbated Parallel-laminated sandstones (Spb), Cross bedded wave-rippled sandstones (Swx), cross bedded wave-rippled sand-rich heteroliths (Hswx), Parallel-laminated sand-rich heteroliths (Hsp), Wave-rippled Mudstone (Mw) and parallel laminated mudstone (Mp) as shown on Plates 1.0.

The Xena-14 lithofacies showed dominance of sand-rich facies (81.8%) over the heterolithic facies (18.1%). All the lithofacies identified in Xena-14 showed

Plates 1.0: Lithofacies identified in the Xena-14 study cores samples

moderate to sparse bioturbation occurrence (0-30%) with intensities of 2-BI suggestive of a high energy, high hydrodynamic activities-stressed environment.

PETROPHYSICAL ANALYSIS:

The porosity and permeability per facies (Table 3.0) distribution table revealed that the Xena-14 petrophysical data showed an average porosity of 23.3% and permeability of 328.8mD overall indicative of a very good reservoir attribute while the intervals with values above average is the bioturbated sandstone intervals while that with values below average corresponds to the heterolithic intervals (Figure 2.0).

Table 2.0: Xena-14 Lithofacies Analysis distribution table

Facies Group	Facies No	Lithofacies Description	Facies code
Sandstone	1	*Cross-bedded medium-fine sandstone*	Sx
	2	*Cross-bedded coarse pebbly sandstone*	S4x
	3	*Bioturbated cross-bedded coarse pebbly sandstone*	S4xb
	4	*Cross bedded wave-rippled medium to fine sandstones*	Swx
	5	*Cross bedded wave- rippled medium to fine sandstones*	Swxb
	6	*Bioturbated Parallel laminated sandstones*	Spb
	7	*Parallel laminated medium to fine sandstones*	Sp
Heteroliths	8	*Cross bedded wave-rippled sand-rich heteroliths*	Hswx
	9	*Parallel- laminated sand-rich heteroliths*	Hsp
	10	*Parallel-laminated mudstone*	Mp
Mudstone	11	*Wave-rippled mudstone*	Mw

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Table 3.0: Xena-14 Petrophysical distribution table

Plug ID	Depth (ft.)	Predominant Lithology	Facies Association Code	Porosity (%)	Permeability (mD)
1	8939.00	Sandstone	Swxb	23.6	302
2	8946.00	Sandstone	Spb	25.6	1460
3	8949.00	Sandstone	S4xb	21.6	307
4	8955.00	Sandstone	Swxb	21.2	390
5	8961.00	Sandstone	Sx	24.8	1070
6	8967.10	Sandstone	Sp	19.6	258
7	8970.00	Sandstone	Sp	24.4	676
8	8976.00	Sid/Sandstone	Swx	23.2	210
9	8982.00	Sandstone	Sx	24.0	1395
10	8991.00	Sandstone	S4xb	25.2	1755
11	8997.50	Sandstone	Sx	23.6	326
12	9004.24	Sandstone	Sx	23.6	335
13	9010.60	Heteroliths	Hsp	23.2	338
14	9015.00	Heteroliths	Hswx	21.6	132
15	9017.14	Heteroliths	Hswx	23.6	289

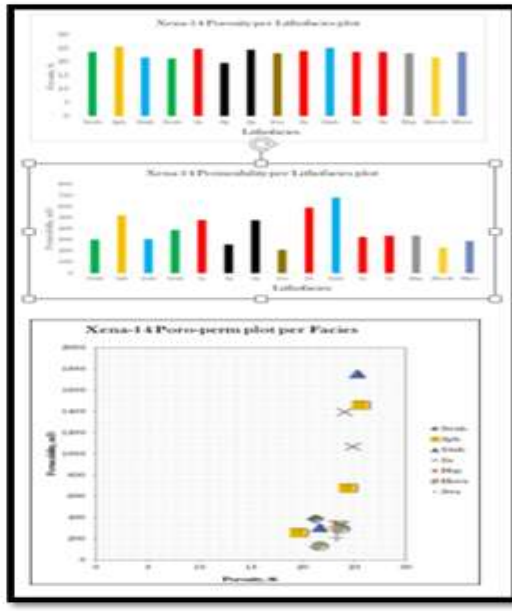

Figure 2.0: Petrophysical Analysis display

ICHNOFACIES ANALYSIS

The Xena-14 study sample is characterized by moderate to no bioturbation intensity (0-30%) adopting Droser & Bottjer, (1991) bioturbation index scheme of defining bioturbation intensity (Figure 3.0). The most observed fossils observed are elongated, disc and tube shaped burrows with well to poorly developed outer linings vertical to slightly inclined (Table 4.0; Plates 2.0) interpreted as *Ophiomorpha, Palaeophycus, Cruziana, Rosselia, Diplocraterion and Teichichnus* trace fossils. These ichnofacies assemblage falls essentially within the *Skolithos* and *Cruziana*ichnofacies assemblages normally occurring from the marginal to shallow marine environments (MacEachern *et al.* (2005).

Considering the ichnofacies we have that the sand-rich facies demonstrated sparse or no bioturbation with less intensity while the finer grained sediments of the lower shore face and showed more bioturbation with greater intensity.

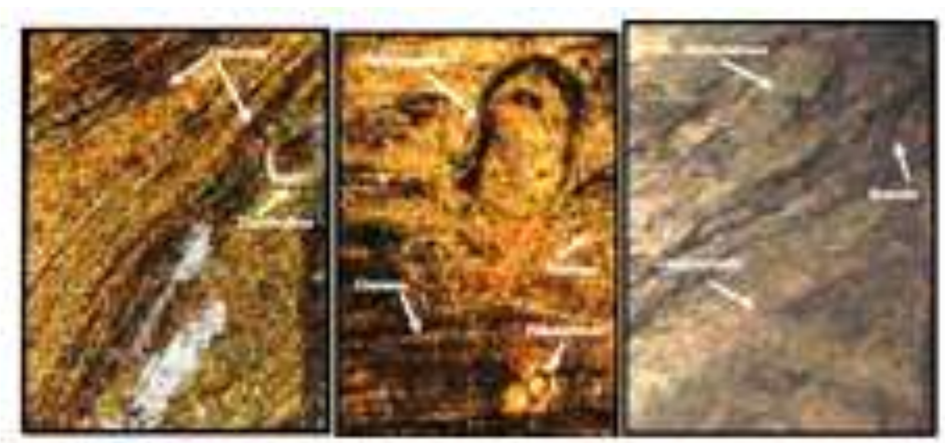

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Plate 2.0: Trace fossils as observed in Xena-14

Table 4.0: Ichnofacies Analysis:

Core cut	Depth (ft.)	Bioturbation percentage & Intensity (BI)	Ichnological description	Ichnofacies
ONE	8938.00-8945.50	1-4% (1-BI)	*Lowly bioturbated cross bedded dominantly medium-grains, rounded -sub-angular and well-moderately sorted with occurences of Ophiomorpha, Diplocraterion and Rosselia*	*Skolithos /Cruziana*
	8945.50-8954.40	0	*Wavy cross bedded coarse-grained, sub-angular/sub-rounded and very well sorted sandstone. No bioturbation*	
	8954.40-8992.00	5-30% (2-BI)	*Lowly bioturbated wavy cross bedded coarse-grained ,pebbly; sub-angular/sub-rounded and well sorted with occasional dark grey mudstone with occurence of Ophiomorpha,Teichnus, Cruziana and Palaeophycus*	*Skolithos /Cruziana*
	8992.00-9009.20	0	*Cross bedded medium grained sub-angular/sub-rounded and moderately sorted with coal fragments, mud clasts at the base. No bioturbation*	
	9009.20-9022.25	0	*Wavy fine muddy sandstone to Silty Mudstone highly fissile angular / sub-angular and very well sorted. No bioturbation*	

BIOTURBATION CONTROLS ON RESERVOIR QUALITY:

The top reservoir quality observed within the study interval wasunderstood to be associated with the sandstonebioturbated facies intervals exhibiting an average porosity of 23.44% and permeability of 444.6mD compared to the average porosity of the unbioturbated sandstone intervals; 23.3% and permeability of 322.9mD

The study samples generally showed moderate to sparse bioturbation (0-30%) and intensity of 2(BI) with the more bioturbated facies intervals displaying boosted porosity and permeability values indicating that bioturbation as much as the grain disposition of the high energy onshore settings impacts positively on the reservoir quality.

The intervals with the very best petrophysical attributes was recognized within thebioturbated coarse-grained, cross-bedded, and parallel bedded sand-rich intervals interpreted as high energy shore face deposits followed by the unbioturbated sandstone interval and sandstone-rich heterolithicintervals. The heterolithic faciesintervalsrevealed slightly reduced reservoir valuesprobably due to the presence of clay matrix within their pore spaces together and its concomitant cementation impacts.

CONCLUSIONS

In integrating key petrophysical parameter (porosity and permeability) with lithofacies and ichnofacies observed in the study samples, it was demonstrated that bioturbation controls reservoirqualityas much as other textural attributes.

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