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# SEISMIC STRATIGRAPHY AND DEPOSITIONAL MODEL FOR THE OLIGOCENE – PLIOCENE SEDIMENT OF THE EASTERN NIGER DELTA, NIGERIA

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## ABSTRACT

Seismic stratigraphic framework and depositional model for the Oligocene – Pliocene strata, Eastern Niger Delta have been established by identifying geologic ages, lithologic characteristics, depositional environments and depositional body types for the seismic units. Majority of the sandstones units were interpreted to be thick, associated with in-situ bathyal mudstones, and contain reworked, older and re-sedimented contemporaneous shallow-water deposits. These probably represent basin floor gravity-flow deposits. The change in condensation through time was interpreted as reflecting avulsion of the shallow marine sediment source in the area. Condensation occurred between Late Oligocene and Earliest–'Mid' Early Miocene, but was predominant in the Lower Miocene. The interpreted MFS's constituted important correlative horizons that are associated with high seismic reflectivity. $MFS_2$ and $MFS_4$ were interpreted and mapped as the regional shale seals to the majority of reservoirs in this field. The resulting analyses of this study were identification of value of fully integrated well-to-well correlations and zonation of reservoirs. A total of eleven reservoir sandbodies with variable net thicknesses ranging from 5-80m in places had been inferred. These reservoir sandbodies consisted principally of one or more of the following genetic types: Deltaic distributary channels and mouth bars, bay fills and fluvial deposits. Six genetic depositional sequences and three systems tracts: Lowstand, Transgressive and Highstand have been delineated and interpreted. Each systems tract has special characteristics useful for recognition and assessment of hydrocarbon plays and prospects in siliciclastics sediments in this field.

## INTRODUCTION

Subsurface work has particularly helped in understanding the way in which facies successions relate to one another and to different types of bounding surfaces. Detailed facies descriptions available for various sub-environments of the Niger Delta Front, and vertical facies sequences have also been described from cored boreholes (Weber, 1971; Oomkens, 1974) (Figure 1).

Thirteen (13) wells had been drilled in the study areas which are located in the eastern Niger Delta and the actual locations of these wells are concealed as result of proprietary factor, three of which were marked as dry wells The reservoirs in the field appear to be producing by a depletion-drive/gas-cap expansion mechanism. Oil and / or gas bearing strata were delineated and characterized as Channel, Distributary mouth bar or barrier bar deposits on the basis of corroborative evidence gathered from the routinely available data. Because of stacked sand/shale alternations, most oil fields in the Niger Delta, of which the study area is an integral part, have multiple reservoir levels, with oil column heights averaging between 15 to 50m. Exceptionally, longer columns (Reijers, 1996) do exist under favorable (fault) sealing conditions and/or in stratigraphic traps.

In this field, sequence stratigraphic concepts were applied to identify and interpret the various depositional facies, linkage between sedimentation patterns, sequences, system tracts, structural framework, and maximum flooding surface hierarchy, depositional environments of genetically related reservoir sand bodies, seal-prone intervals, pay zones as well as migration systems and trapping style. Globally, these methods had been used by numerous authors, research groups and oil industries. The few of them include Portions of the Miocene, Pliocene and Pleistocene plays in the Gulf of Mexico (Vail, 1977; Mitchum et al 1977); Brown and Fisher, (1977); Galloway, (1981), Sangree et al, (1992); Allen (1997), Eocene and Older Channel and Overbank Plays in the North Sea Basin (Gray, (1975); Sarg and Skjold, (1982); Channel and Overbank Sand Plays in several of the California basins, several of more mature basins in Central People's Republic of China: the Neogene Plays in the Offshore Niger Delta, the Nile and the Malay basins. In the same vein, the late Cenozoic deposits of the Niger Delta sedimentary basin had intensively been studied and reported by: Adedokun (1981): Orije and Avbovbo (1982), Amajor and Agbarie, (1989); Ladipo, (1992) and Reijers, (1996).

In this study, we have employed direct hydrocarbon indicators – bright spots, dim spots, flat spots and phase changes – on seismic sections in mapping reservoir area extent. These indicators are valuable mapping tools because they suggest the presence of hydrocarbons directly on seismic sections. The bright spot is a high amplitude reflection caused by the acoustic impedance contrast between the reservoir and the embedding medium (shale). The dim spot is a decrease in amplitude of reflections over a short distance. The reflections appear 'dim' on the seismic sections. They are produced as a result of the contrast between the acoustic impedance of water sand, the embedding medium (shale) and that of the reservoir. The Flat spot is a horizontal reflection that is reflected from fluid to fluid interphases (fluid contact). The flat spot is easily identified by its flatness and unconformability with adjacent reflections (Brown, 2004).

In this study, mapping and interpretations were made to assess:

- The sealing properties of Tertiary growth faults.
- The anticlines associated with these faults otherwise referred to as 'Rollover anticlines'.
- The sheared zones in Well logs using dip log; and
- The correlation of the properties of this sheared zones with their trapping capacity.

## MATERIALS AND METHODOLOGY

The materials used in this study include: Time-Depth curve covering some wells; biostratigraphic/paleobathymetric reports of wells, wireline logs and seismic reflection profiles, caliper and dipmeter logs, and base map (seismic/well situation map-scaled 1/25000) with closely spaced lines.

Log-motif patterns were recognized and delineated using criteria defined by Van Wagoner et al, (1990); for shelfal-facies; Vail and Womardt, 1990; 1991); for slope and basinal facies; and Allen (1997), for deltaic/shelfal facies. A model published by Allen (1997) for sequence boundary delineation and recognition was used for sequence boundary interpretation. Systems tracts defined as subdivisions within each sequence consisting of linked depositional system (Brown and Fisher, 1977) were recognized and delineated by the "Model" of Vail (1989).

The facies expression of the Maximum Flooding Surfaces (MFS's) observed on the correlated wells is that of a maximum shale peak or interval of the inflection between a transgressive and regressive parasequence stacking pattern (MFS's coincide with the highest GR shale peak at the base of regressive sections and could be located with precision on the logs (Allen, 1997). The MFS's were marked, interpreted and named $MFS_1$, $MFS_2$, $MFS_3$, $MFS_4$ and $MFS_5$ and grouped 1st (low), 2nd (medium) and 3rd (high) order MFS's depending on their level of frequencies.

Statistical data on abundance or diversity of fossil taxa provide insight into the rates of sediment accumulation. Fossil abundance and diversity trends were recognized using statistical analysis of quantitative biostratigraphic data (Figure 2) . Abundance events were interpreted to reflect relative slow-rates of sediment accumulation and consequent concentration of fossils per unit volume of sediment was considered condensed section candidates (e.g; Armentrout and Clement, 1990).

| Depth (m) | Bio-Markers | Occurrence | Species Type | Age (Ma) | Sequence Surface Indicated |
|---|---|---|---|---|---|
| | | | | | |
| 700 | M. costata | FDO | Foram Benthic | 2.45 | MFS245 |
| | | | | | |
| 1060 | S. abies | FDO | Nanno | 3.2 | Near SB300 |
| | | | | | |
| 1125 | S. pseudoumbilica | FDO | Nanno | 3.3 | Near MFS340 |
| | | | | | |
| 1760 | U. rustica | FDO | Foram Benthic | 4.2 | SB420 |
| | | | | | |
| 1775 | V. flexilis | FDO | Foram Benthic | 5.0 | MFS500 |
| | T. parvula | FDO | Foram Benthic | 5.0 | MFS500 |
| | | | | | |
| 2230 | D. quinqueramus | FDO | Nanno | 5.6 | Near SB550 |
| | | | | | |

FDO (First Downhole Occurrence) = Local LAD (Local Stratigraphic Last Appearance Datum)

**Figure 2:** Biomarkers recovery for the study wells

The regionally extensive fossil abundance events provide excellent correlation datum if coeval; and these abundance events may be condensed section associated with sediment starvation within the basin. When these abundance peaks correlated with:

- Stratigraphically consistent biochronoevents.
- High Gamma Ray (GR) values or peaks on well logs, and
- Regionally significant down-lap surfaces observed on seismic reflection profile; they were considered to be condensed sections (Loutit et al, 1998); Schafer, 1990); Mudge and Copestake, 1992). The MFS's which mark the point of maximum transgression within each sequence form a good field scale marquers to delimit individual reservoirs – bearing units. Each sequence represents a single episode of deltaic progradation.

Paleo-bathymetric information derived from the biofacies report of wells relates the sediments and their contained microfauna (possible MFS's intervals) to water depths ranging from inner Neritic – Outer Neritic, at the time of deposition.

Logs were first used to define possible SP/GR coarsening – or upward units within fore-stepping, vertically stacked, or back-stepping successions in this field. The recognition of lithofacies, payzones and sequences by the applications of the SP/GR and Resistivity curve shapes discussed in detail by Galloway and Hobday (1983); Pirson, (1970); Goetz et al, (1977), Coleman and Prior, (1982); Asquith and Gibson, (1982);

was utilized. Numerous publications by the authors mentioned above depended on the relationship between log shapes and size trends in sandstone bodies. As interpreted, a sandstone body with a bell-shaped curve indicates a fining-up sequence which may be an Alluvial/Fluvial Channel but also a coarsening-up sequence which may be a deltaic progadation or a shallow marine progradation.The cylindrical SP/GR log curves were used to recognize a fairly uniform grain-sized sand unit which could be braided channel deposits, tidal channel or subaqueous slump deposits.

Reservoir sand bodies/payzones and their bounding surfaces were delineated and labeled I, II, III, IV from bottom to top.These reservoir sandstone bodies/payzones were recognized by the separation of resistivity devices opposite the SP/GR log deflections to the left or by the negative SP, low GR and high resistivity values. Distinguishing oil from gas facies was by combining Neutron logs (NPHI) and bulk density log (RHOB) deflections. The deflection of NPHI to the left and RHOB to the right were used to map and identify oil-bearing reservoir sandstone bodies while the reserve given the gas-bearing zones. Assessment of types of reservoir hydrocarbon (oil/gas) from well log data were acquired by combining neutron-density device that detects low hydrogen concentration and low electron densities cross over in gas reservoirs, and moderate cross over in oil reservoirs. The characteristic neutron-density cross over in conjunction with the overlay of the resistivity device were also used to determine oil/gas and oil/water contacts, locate flooding surfaces and reservoir boundaries for correlations. The studies of reservoir sandbodies, like those described by Leblanc (1977) and others, provided the criteria for recognizing similar genetic types in the subsurface.

The time values of the interpreted horizons were converted to depth with the use of the polynomial function - $Y = 493.36x^2 + 2729.3x + 1.7974$ which was generated from the check-shot data provided. The values obtained were used to produce the structure contour maps.

Seismic analysis and interpretation concentrate on: laying out seismic (dip lines) sections in a sequence to be able to follow the major structure across the area; recognizing or identifying convergence of reflections on the seismic sections; and picking a detailed survey of the sections to interpret and map horizons based on an amplitude extremum. Faults were mapped from trace-to-trace and their cut-outs were interpreted as part of the horizon. Here, six key seismic horizons were mapped and interpreted as $H_6$, $H_5$, $H_4$, $H_3$, $H_2$ and $H_1$ shales due to their continuity and adequate seismic-to-well correlation. Well-to-seismic tie revealed that the hydrocarbon bearing reservoirs are associated with direct hydrocarbon indicators on seismic sections.

After mapping out the faults and horizons, the faults were posted on the already enlarged base map on a tracing paper. The hanging and foot walls of the faults (the throw) were measured with reference to the in-lines. Posting the faults on the map also helped with better identifying, correlating and renaming the faults on the seismic sections. There are both synthetic faults (dipping south) and the antithetic faults (dipping north). The general trend of the faults was NE – SW.

## RESULT AND DISCUSSION

In this study, the results of each phase of interpretation from all the available geological data were objectively appraised and careful mapping was adopted. Sediment patterns in the study area were probably controlled by two fundamental parameters, as clearly pointed out by Allen (1997), and they include:

- The rate of sediment influx and
- Changes in the potential space available for sedimentation.

The interaction between these two parameters determines how the study area was filled with sediments and the stratal geometries that resulted. In addition, a change in the rate in which sediment accommodation increases (or decrease) also controlled the relative abundance of sand/shale ratio and reservoir continuity (Figure 3).

Correlation of cross-sections of logs was prepared using the base of the marine sandstone units as a horizontal datum. Here, it was discovered that the maximum rate of accommodation occurred at a depth corresponding to 2450m (or 8040ft). The marker labeled 'MFS' represent episodes of minimum channel and net to gross sand ratio.

In any given section, it was further ascertained that the higher the rate of accommodation, the more isolated are the channels within floodplain shales; thereby decreasing reservoir connectivity and increasing the potential for stratigraphic seals. In this field of study, the degree of shaliness increases downwards and the formation passes gradually into the Akata (Prodelta) shales. According to Whiteman, (1982); these shales are dark-grey in colour and become silty to sandy upwards. At a depth of 2300m (7550ft), stratigraphic sand markers in wells XW-B and XW-E could be reached in well XW-C.

In the study area, the available reservoirs are made up of one or more of the following genetic sandbody types: barrier bar, deltaic distributary channel and deltaic marine fringe. The resultant stratigraphic units of this field consist of genetically related depositional systems and their component facies and sequences affected by gravity tectonics and crustal response to loading, syn-depositional structural discontinuities.

The assessment of the type of reservoir hydrocarbons from Neutron-Density log data does not always accurately replicate the type of hydrocarbon in the reservoir. For sources not understood many of the sands exhibit poor neutron-density response to gas.

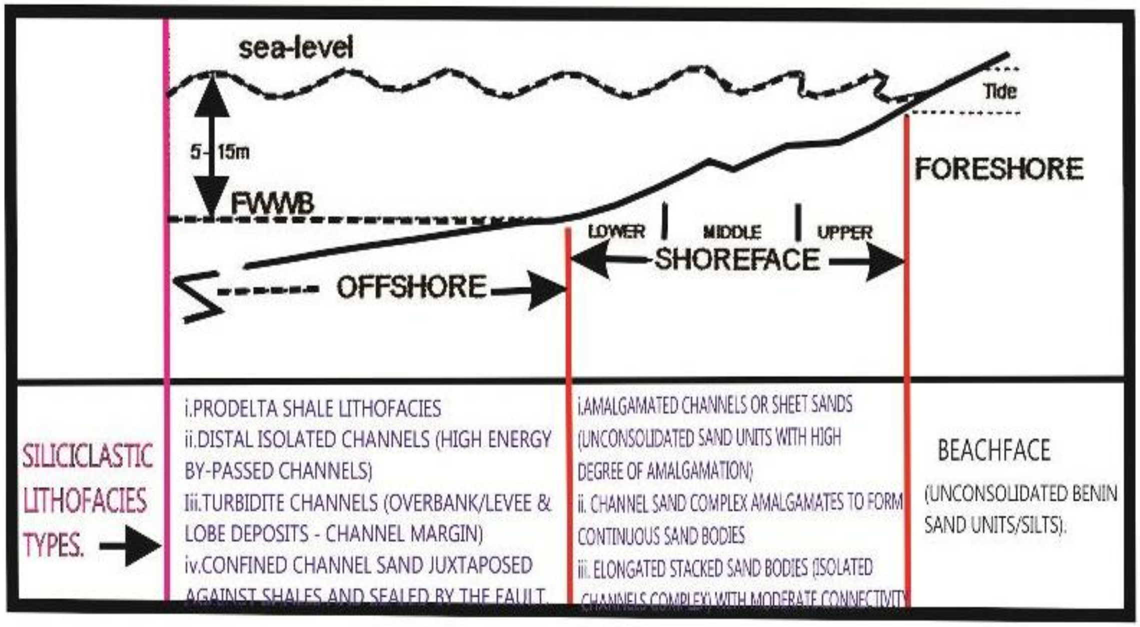


**Figure 3:** The arrangement of siliciclastic lithofacies types in foreshore-shoreface-offshore settings of the study area, Niger Delta

Further drilling of new wells is recommended in some part of the field where structural closures with time-low are related in Tops $H_2$, $H_3$ and $H_4$ subsurface contour maps. These wells should penetrate the top of the Akata formation. Well XW-L corresponding to the dip-line X-82-8 should be drilled further to the level of Top $H_1$ sand because of the seal failure at 1.69 seconds level (or a depth of 1920m (6300ft) or at SP 135 level). This top $H_1$ sand is producing in all the wells located within same structural closure.

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