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Research Article

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Sequence Stratigraphy and Hydrocarbon Analysis of Coastal Swamp Depobelt, Niger Delta, Nigeria

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Abstract The study area has two recognized depositional sequences, bounded above and below by maximum flooding surfaces (MFS). The maximum flooding surfaces are Uvigerina 8, (9.5ma) and Dodo shale (11 .5ma) and the two sequence boundaries are l0.35ma and l0.6ma. Nonion 4, MFS (l0.4ma) was missing in the section, which could have been as a result of l0.6ma erosion as evidenced from the seismic section. Based on the above, systems tracts were interpreted; High stand systems tract (HST), Low stand system tract (LST) and Transgressive systems tract (TST). The hydrocarbon bearing sand units were analyzed based on systems tracts. The LST had more hydrocarbon bearing sand units, followed by HST, while none was observed for the TST. The average porosity and permeability values for the systems tracts are; for the first HST, 0 = 38%, K = l2O2mD, Second HST, 0 = 36%, K = l52mD, LST 0 = 35%, K = 37n0 and the last HST 0 = 33%, K = 34mD. The reservoirs are more of gas bearing than oil. This is attributed to the source rock type, temperature effect and low permeability values (reduced pore throat).

Keywords Sequence Stratigraphy, Hydrocarbon Analysis

Introduction

Sequence stratigraphy has evolved from an academic concept to valuable tool for oil and gas exploration in the past two decades, but it is under-utilized. The predictions about reservoir potential based on sequence stratigraphy depend on the changes in global sea level, tectonic movements and how they affect lithologic facies and boundaries. The concept of Sequence stratigraphy developed through Seismic stratigraphy, as a recent methodology for stratigraphic interpretation [1]. It was gradually introduced into Nigeria since the early nineties. It was first applied in the Niger Delta where it has since refined the potential for prediction of hydrocarbon habitats [2]. Thereafter, it was tentatively introduced in the Anambra basin and in the carbonates on the Calabar flank [3].

Aim of the Study

To determine the key sequence stratigraphic surfaces and systems tracts of the five wells in the study area within the coastal swamp depobelt in the Niger delta, using wire-line logs, seismic information and biostratigraphic data.

Location of Study Area.

The area of study lies within the coastal swamp depobelt in OML 13 of the eastern part of the Niger delta petroleum province. Five wells named Xl, X2, X3, X4 and X5 were used for this study.

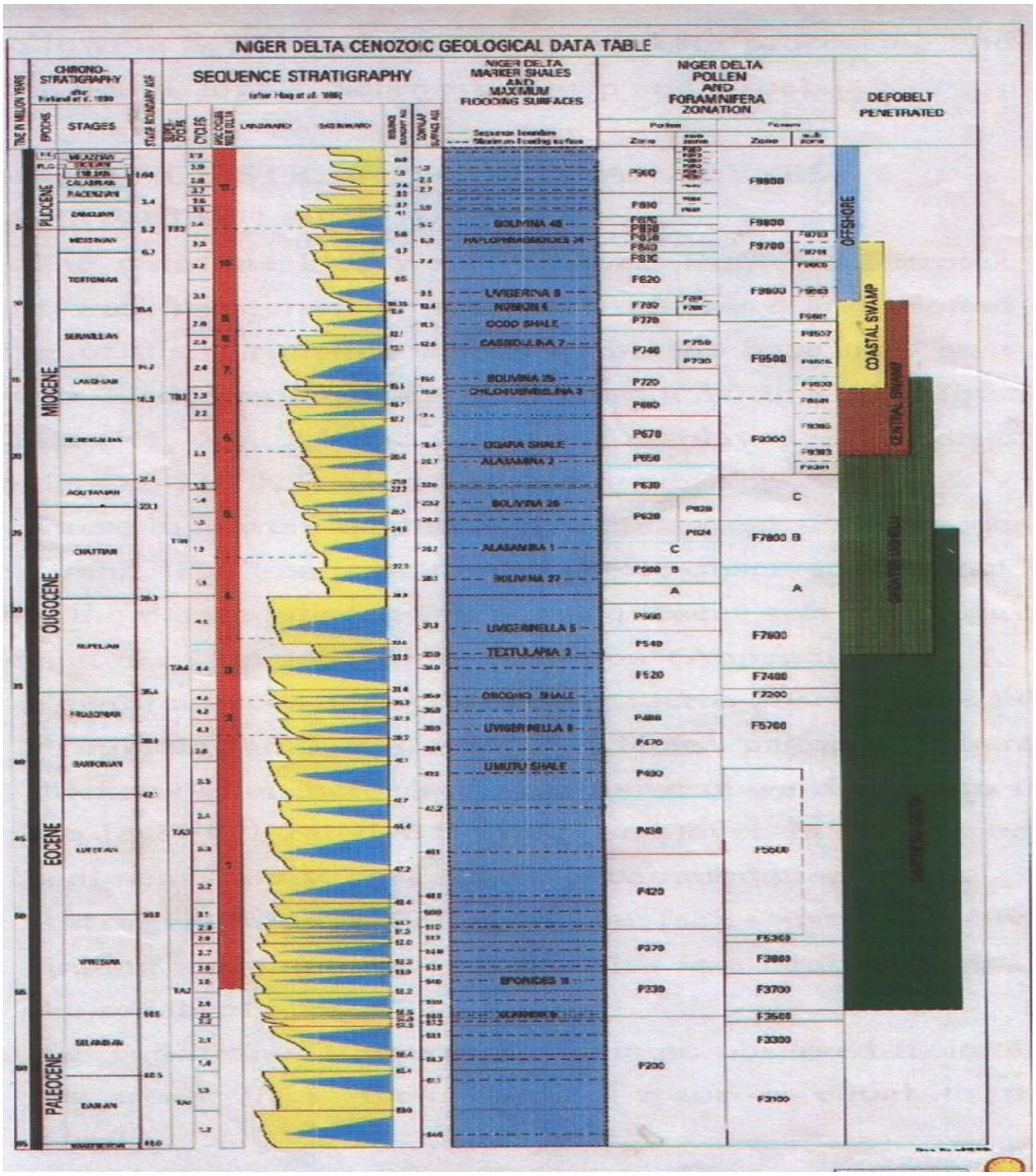

Figure 1: Niger Delta Cenozoic Chronostratigraphic Chart

Data and Method of Study

Data Used for Study

The following data were used for this study: Seismic base map of the field showing all the five wells at their exact positioned locations. Raw numerical data of wire-line logs made up of Gamma Ray log (OR), Spontaneous Potential log (SP), Compensated Bulk Density

Log (CDL), Compensated Neutron Log (CNL), Borehole Compensated Sonic Log (BCSL) and Resistivity log. Biofacies data of well Xl, was used as a control to interprete the other wells, which provided information on fossil abundance and diversity. The indicated sample type used here are side wall cores and ditch cuttings. Side wall core sample description data for three of the wells were used; The chronostratigraphic chart of the Niger Delta was used for the dating of the surfaces (figure 1)

Sequence Stratigraphic Analyses

Wire-line Logs

The wire-line logs were retrieved from the Petrotek data base. It was transferred to the petrel software and plotted out for the building of the correlation panels. With the base map as a control, the logs were loaded in strike and dip directions. In strike direction, four of the wells (Xl, X5, X4 and X3) were displayed, while in dip direction, two wells (X3 and X2) were and displayed..

These logs were displayed at a consistent scale, chosen to enhance the log trend. The trends on the logs were observed for stacking patterns, viewing the parasequences and parasequenees sets which gave an insight on the nature of the depositional patterns [4] and [5].

The three types of depositional patterns observed are as follows:

Progradational Pattern: The facies pattern is characterized by thickening an increase in grain size upward. It is an indication of sea level fall, relative to initial sea level. In this period, the rate of sediment supply, exceeds the accommodation space [6] and [7].

Retrogradational Pattern: The facies pattern show an upward finning and thinning of beds. This is a landward shift in facies asthe sea level rises.

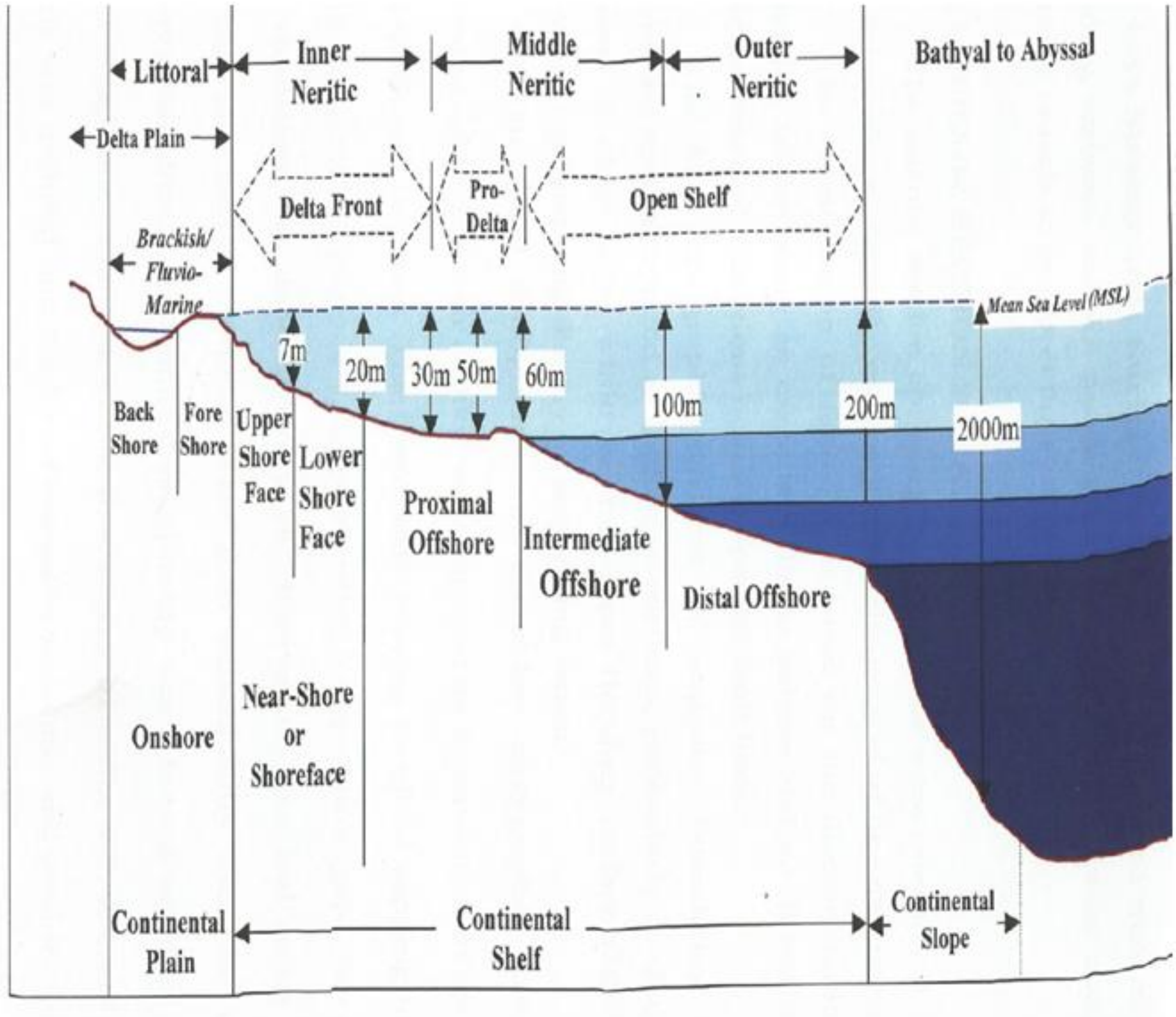

Figure 2: Depositional Enviroments and Bathymetric ranges used in Paleoenviromental interpretation

Aggradational Pattern: There is no observed facie change on the log trend. The Accomodation space is equal to the sediment supply.
Grain size; Abrupt upper contact with shale or siltstone.
This was associated with beach sands, barrier bar sand and the deltaic environment.
Bell shaped: This has a characteristic gradual upward increase in gamma response. It is usually considered as reflecting a decrease in depositional energy, as there is an upward fining of lithologic change from sand to shale. It reflect sand deposited by rivers such as fluvial channel sands, point bars, alluvial and distributary channel sands in the delta plain environment.
Cylindrical/Block shaped: it has a low gamma sharp boundaries and coarsens out, with no internal change in facies. It indicates a massive or thickly bedded sandstone which is lithologically uniform and with none or very few thin non-sandy interbeds. They reflect sands characteristic of tidal channel, bather bars and fluvial channel sands in the outer deltaic parts and turbidites.
Serrated/Irregular shaped: it lacks a character, having a rapid alternation of thin beds of sandstone and shales. They represents aggradation of shales or silts and can occur in several settings.
Depositional environments and bathymetric ranges used in paleoenvironmental interpretations is of key importance at achieving results [8] and [9]. In this work, the biofacies data supplied the fossil abundance and diversity, and as well as paleobathymetry/paleoenvironment. These were critically analysed in relation to the sidewall sample description data. Mineral grains were also noted. For example, the relative abundance of glauconite, calcareous bioclastic grains, and, mica flakes / carbonaceous material is a good relative measure of marine and non- marine influence, respectively.

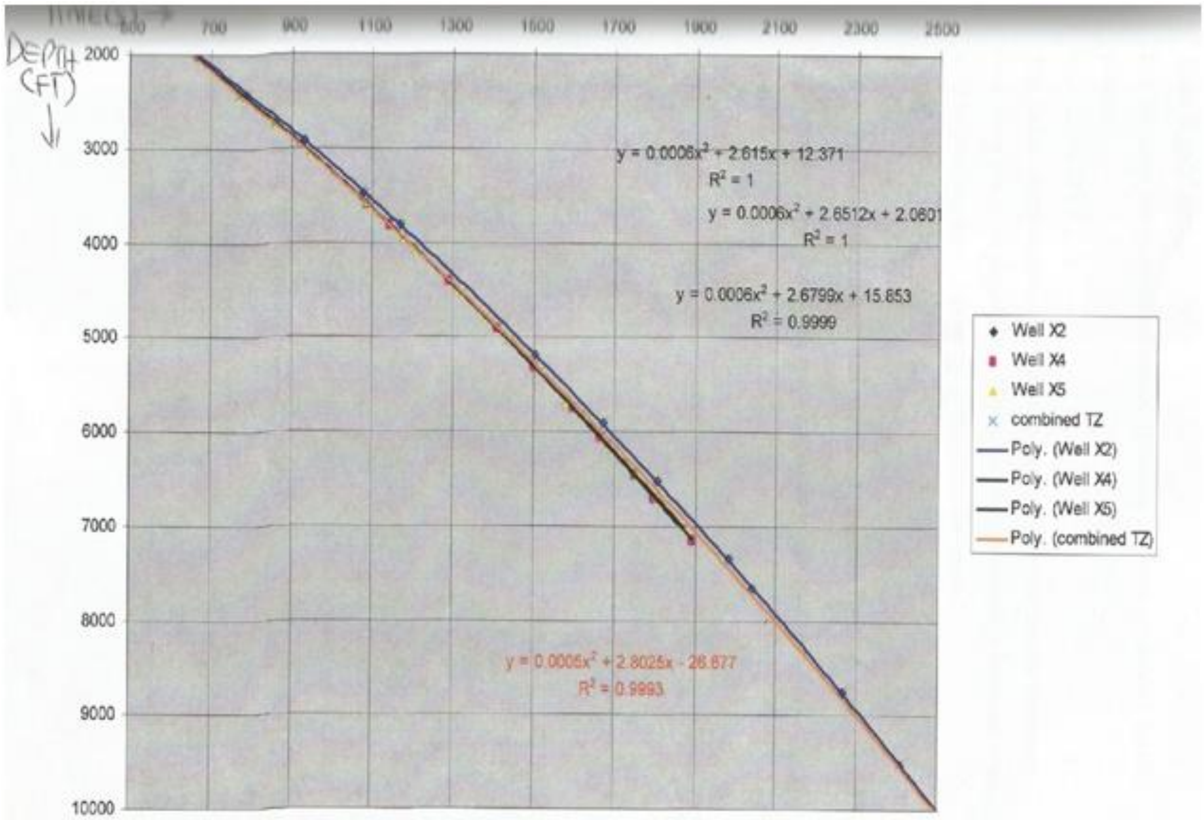

Figure 3: TZ Conversion Plot Using polynomial equation relationship

Seismic Section Data

The seismic section covering the entire area were interpreted from the seisworks workstation on every 16^{th} seismic grid of line and trace.

The identification of faults was based on the discontinuities in reflection falling along an essentially linear pattern and on distortion or disappearance of reflections below suspected fault lines [10].
The key stratigraphic surfaces of sequence boundaries were confirmed and interpreted as truncation surfaces, particularly eroding the topsets of older units, while the maximum flooding surface (MFS) as downlap backstepping display on underlying topsets [11].

Results Presentation and Interpretation

Well Log Sequence Interpretation

The 5th and 4th order parasequences and parasequence sets of depositional system were identified and marked out on the log panel following different successive patterns of progradation, retrogradation and Aggradation [12]. The Lithologic correlation showed that most sand bodies thin out towards the east, an explanation that the eastward part of the field is more proximal to the sea compared to the west. Also, some sand bodies were missing out, inferring an influence of faulting.
The point of convergence of the parasequence sets, suggested a candidate Maximum flooding surface, while the point of divergence suggested a candidate Sequence boundary. However, this was realistic with biofacies interpretation for confirmation.

Biofacies Interpretation

From the biofacies data of well Xl, the F9600 was used to pick out the candidate sequence boundaries (SB) and candidate Maximum flooding surfaces (MFS), while P770 andP800 were used to confirm them. The Dodo shale (11. 5ma) candidate MFS was picked at the depth of 6220ft, within the bathyal environment. It has a faunal diversity/population of 43 and 648, respectively, and a pollen diversity/population of 22 and 374, respectively.
The candidate sequence boundary 10.6ma was picked at a depth of 5404ft within Barren environment. It was barren of both fauna and pollen. A subsequent candidate sequence boundary 10.35ma, was picked at a depth 4400ft within Barren environment. It was clearly observed, especially from the biofacies XY scatter charts that the Nonion 4, (l0.4ma) candidate MFS was missing.
At a depth of 4350ft, the Uvigerina 8, (9.5ma) candidate MFS was picked within Outer Neritic to Bathyal environment. It has a faunal diversity\population of 19 and 189, respectively and a pollen diversity\population of 2 and 15, respectively.

Sequence Stratigraphic Interpretation

Two depositional sequences were observed in this interpretation [6]. The first sequence (depositional sequence 1) is bounded below by Dodo shale, 11.5ma MFS, and above by a supposed Nonion 4, 10.4ma which was missing in the section. In an ideal situation, the Nonion 4, (10.4ma) MFS would be seen within the transgressive system tract lying above the lowstand system tract on sequence boundary l0.6ma. This missing Nonion 4, l0.4ma is attributed most likely to erosion as evidenced also from the seismic section.. The depositional sequence 2 is bounded below by this supposed Nonion 4, l0.4ma MFS, and above by Uvigerina 8, 9.5ma MFS. The Uvigerina 8, 9.5ma is observed within the Afam Clay member.
There is one sequence boundary within each of these depositional sequences. In depositional sequence 1 is the sequence boundary 10.6ma, while in the depositional sequence 2 is the sequence boundary 10.35ma. The sequence boundary 10.3 5ma was picked and confirmed based on the sand tops/bases report data, which marked out the depth for top of Afam Clay formation (TAF) and Base of Afam formation (BAF).

Table 1: Key Stratigraphic Interpreted Log Depths of the Study Area.

Wells	**Xl**	**X5**	**X4**	**X3**	**X2**
Key Stratigraphic Surfaces					
Uvigerina9.5ma Ift)	3886	3730	3780	3650	3752
Sequence Boundary l0.35ma (ft)	3946	3875	3886	3770	3805
Sequence Boundary 1O.6ma(ft)	5488	5380	5565	5230	5200
Dodo—Shale l1.5ma (ft)	6889	6779	7080	6780	6580

The interpreted Key stratigraphic surfaces were marked out across the field at different varying True Vertical Depth Subsea (TVDSS), (Table 1). The maximum flooding surfaces were labeled as 3rd order depositional sequences. The observed depth differences across the field is as a result of sea level changes and faulting. The sea level changes across the field was observed from the trends of parasequence stacking pattern [13]

Depositional Environment Interpretation

The depositional environment were inferred using the log signatures. Available side wall core samples descriptions data were also integrated into the interpretation. Some are extracted from log panel of the study area of interpreted depositional environments.

The log signature between the depth of 2350(ft)-2650(ft) of the upper HST, in well X4, was interpreted as Braided/meandering fluvial channel deposit. Commonly, braided streams grade downstream into meandering (flood plain) rivers.

This signature from well X3, between 5530(ft) –5650(ft) of 5the LST, was interpreted as tidal channel.

Seismic Stratigraphic Interpretation

Horizon (Stratigraphic Surface) Interpretation

Confirmation of the four horizons; Uvigerina 8 (9.5ma) MFS, Sequence boundary 10.35ma, Sequence boundary 10.6ma and Dodo shale (11 .5ma) MFS, were made on the seismic sections. The Key stratigraphic

Table 2: Key Stratigraphic Interpreted Seismic Depths of the Study Area.

Wells	**Xl**	**X5**	**X4**	**X3**	**X2**
Key Stratigraphic Surfaces					
Uvigerina9.5ma Ift)	3880	3734	3776	3653	3757
Sequence Boundary l0.35ma (ft)	3940	3871	3880	3703	3807
Sequence Boundary1O.6ma(ft)	5490	5372	5562	5232	5205
Dodo—Shale l1.5ma (ft)	6890	6780	7072	6764	6566

The little observed depth differences with those on the logs could be as a result of inherent errors in depth conversion.

On the seismic section, between the interpreted Sequence boundaries 10.3 5ma and 10.6ma, suspected erosional zone was identified, in relation to the missing Nonion 4, lO.4ma section. .

Seismic Facies Analyses

Apart from picking out the maximum flooding surfaces and sequence boundaries on the seismic section, the facies were also analysed based on the reflections and amplitudes [14].

Three pronounced seismic facies were picked out, parallel/subparallel, chaotic, and high/low amplitude convergent. The well logs were superimposed on the seismic section for proper analysis of this facies. The parallel-subparallel high reflection amplitude continuity were picked across the section and these were interpreted as suggesting sharp sand/shale altemations of high and low energy environments. The chaotic facies were seen mostly close to sequence boundaries, and in this case, they are suggestive of strata deposited in a variable, relatively high energy setting (channels), while the High/low amplitude convergent facies and were interpreted as suggestive of amalgamated channel complexes and amalgamated layered sheets.

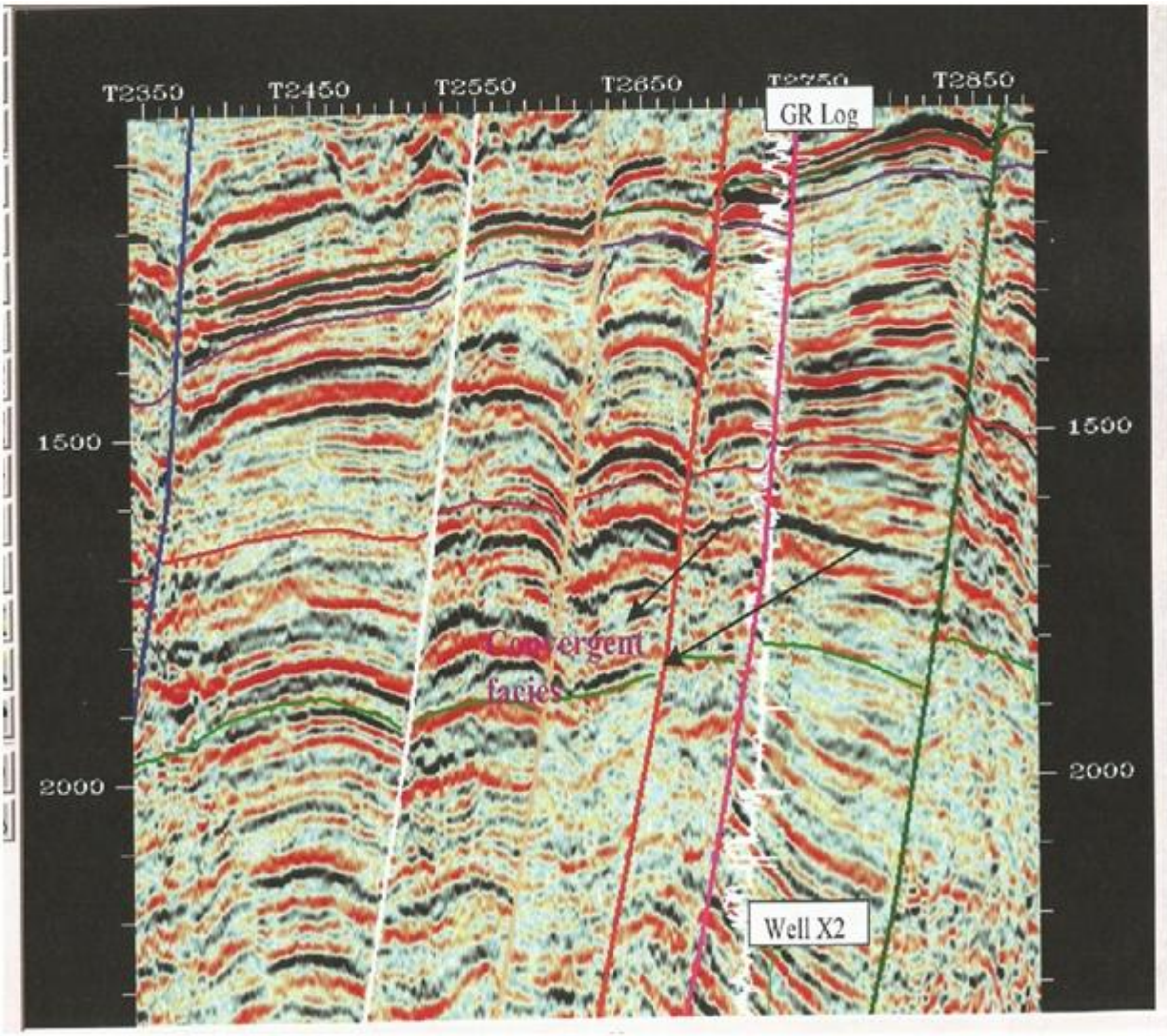

Figure 4: Seismic showing convergent facies

Reservoir Characterization and Interpretation

The studied area has more of gas reservoirs. The LST has 12 hydrocarbon bearing sand bodies, while HST has 7, and none in the TST.

Well Xl has no density nor sonic logs, and so was not analysed for petrophysical parameters. The Well X4 is barren of Hydrocarbon. The key stratigraphic surfaces structural time-depth proved that well X4 was drilled on a synclinal structure, and this likely explains its lack of hydrocarbon. The purpose of this well was to establish some research on appraisal uncertainities. The average porosity (0) and permeability (K) values for the systems tracts calculated are: for the first HST, 0 = 38%, K = 1202mD, Second HST, 0 = 36%, K = l52mD, LST 0 = 35%, K = 37mD and the last HST 0 = 33%, K = 34mD. The TST within the studied area are dominated by shale, without any real sand body

The appreciable high values of average porosity and permeability within the first and second High stand systems tracts, could be associated with the shallow depth and relatively less compaction effects. The lack of any substantial sand body within the TST is probably associated with the rise in sea-level during transgression which favoured dominance.

Table 3: Petrophysical summary sheet of Well X3

Depth	**Sand Name**	**System tracts**	**Hydrocarbon Pore fill**	**Average Porosity (%)**	**Average Permeability (mD)**
2795-3570	X100	HST(Depositional Sequence 2)	-	40	1260
3770-3965	X300	HST (Depositional Sequence 2)	-	37	1210
3987-4050	X400	HST (Depositional Sequence 2)	-	34	90
4050-4360	X500	HST (Depositional Sequence 2)	-	34	50
4545-4585	X600(1)	HST (Depositional Sequence 1)	GAS	35	42
4620-4715	X600(2)	HST (Depositional Sequence 1)	GAS	34	40
4754-4823	X700	LST(Depositional Sequence 1)	GAS	34	39
4940-4960	X800	LST (Depositional Sequence 1)	GAS	33	39
5075-5145	X1000(1)	LST (Depositional Sequence 1)	GAS	32	38
5150-5326	X1000(2)	LST (Depositional Sequence 1)	GAS	32	38
5382-5435	X1200	LST(Depositional Sequence 1)	GAS + OIL	31	34
5530-5653	X1300	HST(Depositional Sequence 1)	GAS	28	34
6030-6190	X1400	HST(Depositional Sequence 1)	-	29	33
6400-6515	X1500	HST(Depositional Sequence 1)	GAS	27	33

The porosity and permeability values within the system tracts were observed to decrease with depth. This decrease of porosity and permeability with depth, is thought to be diagenetical, including compaction, (considering growth faults), cementation and dissolution, which is a function of time, temperature, pressure and fluids.

The studied area was conclusively observed to have low permeability values. Permeability of a rock body can be affected by certain mineralogical changes, arising from the modifications of pore size and shape without necessarily being accompanied by appreciable changes in porosity. Example of such, is in cases where the clay has undergone less dissolution, remaining as grain rims and still blocks pore throats. This significantly reduces permeability, although the porosity may remain high.

The likely source rock (possibly MFS) constituent is of a significant importance in this regard. When combining hydrocarbon distribution with Sequence stratigraphy, it becomes obvious that the MFS(s) also control that particular petroleum system that contains most hydrocarbons. The temperature maturation period also counts. In most of the Western Delta and narrow belt within the Eastern Delta, the hydrocarbon generation at temperatures of 140 — 186°C suggest a predominance of gas source.

Picking the Erosional Interval of the Missing Section

The erosional interval of the missing section was a problematic task to pick on the log, following the depositional processes of the vertical grain size trends.

Standard sequence stratigraphic models for prograding deltaic deposits suggest that a sequence bounding erosion surface should cap a coarsening and shoaling upward succession (forward-stepping parasequences). Thus deposits directly above the sequence boundary are expected to record falling stage and lowstand incision of fluvial channels, and the filling of these valleys with sandy fluvial sediments during subsequent sea level rise. Thus, the erosional interval was determined on the log as represented by an abrupt coarsening of facies which separated the High stand system tract from the Low stand system tract.

On the seismic, it had a characteristic chaotic pattern. This agrees with erosional Interval Interpretations [14].

Sequence Boundary Types

The sequence boundaries; 10.35ma and l0.6ma, within the study area were studied and confirmed to be of the type 1.

This deductions were based on the facts that; for the sequence boundary 10.6ma, it has Lowstand deposits above it, which cannot be seen in a type 2 sequence boundary. And for sequence boundary 10.3 5ma, the Afam clay canyon and other canyons of the Niger delta are interpreted to have formed during sea level Lowstand.

Hydrocarbon System Analysis

The source rock type, temperature effect of source rock maturation and low permeability were considered as contributing factors to the gas saturated reservoirs within the study area.

However, recent research shows that the 9.5ma MFS controls black oil systems. The 10.5ma MFS controls volatile oil with up to about 70% of the oil in place found in reservoirs below this regional seal. The Hydrocarbon system within and below the 11 .5ma MFS and 12.8ma MFS has not been tested yet, but from regional trends, it is conducted to range from volatile oil to gas, up to a hard over pressure zone.

Since hydrocarbon migrates vertically upwards using major faults as migration conduits, it is a probalistic deduction that the major source rock within the study area is likely the Dodo-Shale (1 l.5ma) MFS, and so relating it to the more gas reservoirs.

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