ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-2893 (Print)
ISSN: 2521-2907 (Online)
CODEN: ESPADC

Earth Sciences Pakistan (ESP)

DOI: http://doi.org/10.26480/esp.01.2023.11.16

CrossMark

RESEARCH ARTICLE

DEPOSITIONAL SEQUENCES IN THE OFFSHORE WABI FIELD IN THE NIGER DELTA NIGERIA

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ARTICLE DETAILS

Article History:

Received 04 January 2023
Revised 15 February 2023
Accepted 21 March 2023
Available online 28 March 2023

ABSTRACT

Well-log, biostratigraphic, chronological chart and seismic data from offshore Wabi Field in the Niger Delta were used to delineate depositional sequences, stratigraphy, systems tracts and flooding surfaces. Geologic faults, horizons systems tracts were detected in seismic section. The faulting patterns ware boundary, synthetic, antithetic, and roll-over faults in N-W to S-E trending. Hydrocarbons are encountered between 9,560 and 12,750ftss in 3-stacked B, O, and R1 reservoirs in crestally collapsed rollover anticlines, which are predominantly shore face. Reservoir R1 was the thickest (320ft) sand unit; Reservoir B was the thinnest (50ft) sand unit. The thinning of the sand sequences at greater depths is indicative of bulk density being increased as the sediment compacted. Sequence Stratigraphic Analysis reveals Onlap is generally associated with marine transgression; Toplap which terminates below the surface, lap out in the landward direction. Three (3) maximum flooding surfaces (MFS) of 20.4Ma, 16.7Ma and 15.9Ma were inferred. The field was deposited during lower to upper Miocene Epoch using the Niger Delta Cenozoic Geologic Data. The reservoirs of interest fall within the following system tracts: B Sand is a Low Stand System Tract (LST), O Sand is a High Stand System Tract (HST) and R1 Sand is a Transgressive System Tract (TST). Two types of facies of channel (blocky signatures) and shoreface (coarsening upward) sand deposits with traces of heterolithic sand, silty sand (serrated motif) and marine shale are inferred. Wabi field is dominantly fluvial (channel deposits) environment as shown by the major blocky log signature. The results could help identify depositional sequences, systems tracts on seismic sections by interpreting the location of their boundaries and flooding surfaces. Moreover, delineation of subsurface structures, reservoir quality and lateral extents are of key importance in the determination of economic viability of Fields and exploration opportunities.

KEYWORDS

Depositional Sequences, Well-Logs, Biostratigraphy, Chronological Data, Seismic Data, Flooding Surfaces, Stratigraphy, Niger Delta Basin.

1. INTRODUCTION

A depositional sequence represents a complete cycle of deposition bounded above and below by erosional unconformities. The sequence has a maximum duration, which is measured between the correlative conformities to the bounding unconformities. Thus, the duration of the sequence is determined by the event controlling the creation and destruction of accommodation i.e. tectonic subsidence and/or eustacy (Embry and Johannessen, 2017). Several workers have contributed to the better understanding of the Niger Delta depositional sequence stratigraphy; most of them used only well-logs or biostratigraphic data or both. Magbagbeola and Willis studied the depositional sequence of the Niger Delta and found that Tertiary Niger Delta deposits are characterized by a series of depobelts that strike northwest, southeast, and sub-parallel to the present day shoreline (Magbagbeola and Willis, 2007). He also observed that depobelts become successively younger basin ward, ranging in age from Eocene in the north to Pliocene offshore of the present shoreline.

A group researchers use well-log data to delineate the six stratigraphic units and system tracks in the XYZ Field of the Niger Delta (Ekeh et al., 2019). In other study, researchers delineated northeast-southwest bounding fault between 200 and 400ft (Umunna et al., 2019). The subsurface structures delineation of Toja Field southwest Niger Delta using well-log and seismic data. A group researchers mapped highly synthetic and antithetic faults which are in line with faults trends identified in the Niger Delta (Ochoma et al., 2020b; Anyiam and Mode, 2008). Seismic reflection amplitude contains information of stratigraphic significance. These parameters are mapped as seismic facies units that are three-dimensional groups of reflections whose elements differ from those of adjacent facies units (Sangree, and Widmier, 1977). These units are often interpreted by integrating chronostratigraphic with seismic sequence framework. Synthesis of seismic facies analysis and seismic sequence stratigraphy can help reconstruct basin paleogeography and provide useful insights to a basin's petroleum system.

In this present research, the aim is to interpret the depositional environments, systems tracts and stratigraphy by integrating seismic data with the conventional well-log and biostratigraphic information. The advantage of seismic data lies in interpreting stratigraphic boundaries (Vail and Mitchum, 1977; Vail et al., 1977; Amakiri et al., 2023). Moreover, the use of seismic with well-log and biostratigraphic data reduces uncertainty in the identification and classification of some subsurface structures (Swan, 1991; Dong, 1996; Mahob et al., 1999; Larsen et al., 1999; Kelly et al., 2000; Jin et al., 2000). The results of this work can lead to the discovery and identification of more bypassed stratigraphic traps which earlier workers, due to preference for dominant structural traps,

Quick Response Code	Access this article online	
	Website: www.earthsciencespakistan.com	**DOI:** 10.26480/esp.01.2023.11.16

Cite the Article: Amakiri, S., Uko, E. D., Tamunobereton-ari, I., Amakiri, A.R.C., Amonieah, J. (2023). Depositional Sequences in the Offshore Wabi Field in The Niger Delta Nigeria. *Earth Sciences Pakistan, 7(1): 11-16.*

did not give enough consideration by previous workers. This in essence would considerably increase the discovery of more hydrocarbon potential in the area of study.

2. Study Area and Its Geology

The study area lies between latitudes 4°N and 6°N and longitudes 3°E and 9°E (Klett et al., 1997). The Niger Delta evolved in the early Tertiary times when classic rivers input increased (Whiteman, 1982; Doust and Omatsola, 1989; Tuttle et al., 1999).

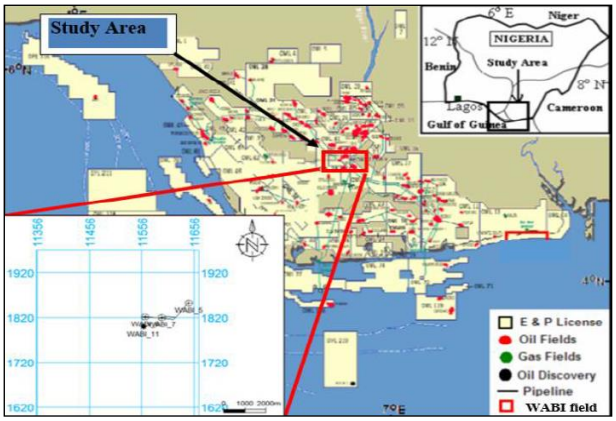


Figure 1: Map of Nigeria showing Wabi Field

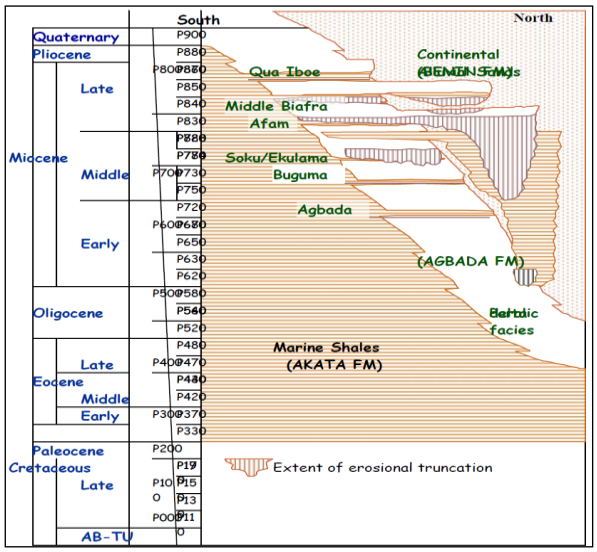


Figure 2: Stratigraphic Column Showing theNiger Delta, NigeriaThree Formations of the Niger Delta (Doust and Omatsola, 1990)

The Niger Delta is made up stratigraphically by these units: Akata formation, Agbada formation, Benin formations (Figure 2) (Reyment, 1965). Akata Formation is made up of an open marine facies unit of age from Palaeocene to Eocene and has a thickness of about 6500m (Whiteman, 1982; Corredor et al., 2001). This formation is the oldest stratigraphic unit and has been generally regarded as the main source rock for oil in the delta (Short and Stauble, 1967). Agbada Formation is between Benin formation and Akata formation. It is Eocene to Oligocene in age and thickness that ia more than 3500m thick (Corredor et al., 2001). It has micro fauna at the top while the base is characterized by a body of sandstone. This formation serves as the main hydrocarbon reservoir (Ejedawe, 1981). Benin Formation is the youngest unit in the Niger Delta. It is continental and consists of coastal plain sands, gravel with a few clay intercalations. It is of late Eocene to recent deposits of alluvial and upper coastal plain deposits that are up to about 2000m thick (Avborbo, 1978; Whiteman, 1982).

3. Materials and Methods

3.1 Data Acquisition and Quality Control

Data sets for this study were provided by Total Exploration and Production (E&P) Nigeria Limited with the assistance of the Department of Petroleum Resources (DPR). Seismic data consists of interpreted seismic sections. Figure 3 shows the plan view of the 3-D seismic data coverage. Well-log, check shots and Biostratigraphic data were also provided. The data were assembled, quality checked (Weber et al., 1971). The well logs were edited, normalized, and interpreted before they were used in a reservoir study.

3.2 Wells Correlation

The Spontaneous Potential (SP) and Gamma Ray (GR) were used for well correlation - by describing and linking similar lithology, picking top and base of sand-bodies, fluid trends (Figure 4).

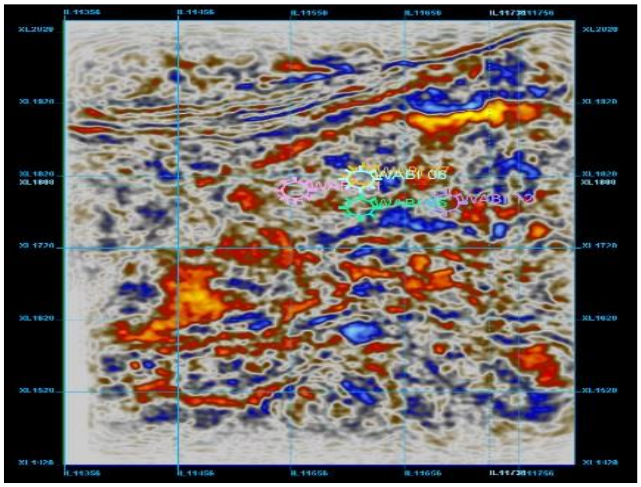


Figure 3: Seismic Data Coverage of the study area

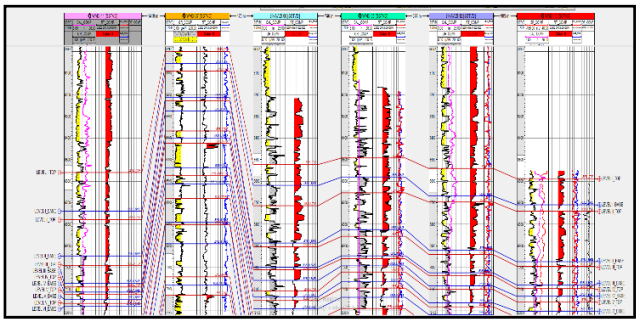


Figure 4: Wells correlation Identification across Wabi Field

3.3 Determination of Environment of Deposition, Sequence Stratigraphy and Maximum Flooding Surfaces

Using gamma ray and resistivity logs responses, depositional energy trends were delineated and compared with the trends (Figure 5) (Emery Emery-Myers, 1996). The GR enables shapes such as funnel, blocky, cylindrical and bell shapes to be identified. Well logs for wells Wabi-5, -6, -7, -10, -11 and -12 were placed side by side and correlated with Emery-Myers trends to determine stratigraphic units that are equivalent in time, age or stratigraphic position (Emery-Myers, 1996). Lithology correlation was carried out across the six well (Figure 6). The log shapes and responses identified system tracts, sequence boundaries and maximum flooding surface based on the criteria discussed by (Vail and Wornardt, 1992; Okpala et al., 2021).

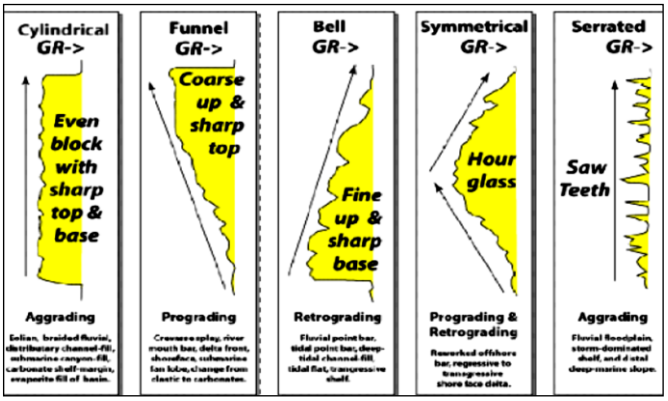


Figure 5: Emery-Myers response Shapes (Emery and Myers, 1996)

The sequence stratigraphic interpretation of the field was carried out based on the biostratigraphic data from Well Wabi-10. This was extrapolated to other wells by shale correlation and other visual interpretations. The biostratigraphic data were integrated with the log signatures to determine the depositional sequences, sequence boundaries, depobelt, the age of the field and the epoch at which the field was deposited. The age of deposition was verified using the Niger Delta Chronological chart (Figure 7). Maximum flooding surfaces were identified as shaliest part of the well log defined by high-gamma-ray value intervals that separate overall fining upward from coarsening upward intervals within sequences (Vail et al., 1977). This is also associated with low resistivity values. In most cases this was used to define the top of the transgressive system tract.

To determine Maximum Flooding Surface (MFS) across the wells, GR log values and Neutron-Density log separations were used to ascertain zones with the highest GR value and widest separations respectively across the other five wells that did not have biostratigraphic data and also, to validate the biostratigraphic information from well Wabi-10. The separate well and seismic interpretations of the sequence boundaries, MFSs and Systems Tracts were subsequently integrated with help of the synthetic seismogram. The two interpretations were compared and checked to make sure that good matching is achieved. Sequential-stratigraphic section in depth in which the MFSs, Sequence Boundaries and Systems Tracts from well to well with the stratigraphic section was prepared.

Resistivity log was also used to buttress the picking of candidates Maximum Flooding Surfaces (MFS) identified from the log motifs. Marker-beds were identified using SP, Gamma Ray and Resistivity logs. This phase involves the identification and comparison of characteristic log patterns such as fining upward or coarsening upward cycles. High resolution Biostratigraphic data and Niger Delta Chronological Chart was integrated into the wireline logs for proper delineation of the Condensed Sections (CS) with the associated Maximum Flooding Surfaces (MFS) [Figures 6 and 7] (Nwaamaka, 2015). The faunal abundance peaks in the high resolution Biostratigraphic data used in the study confirmed the MFS identified on well logs. Therefore candidates MFS were identified on the well logs with the help of high resolution biostratigraphy.

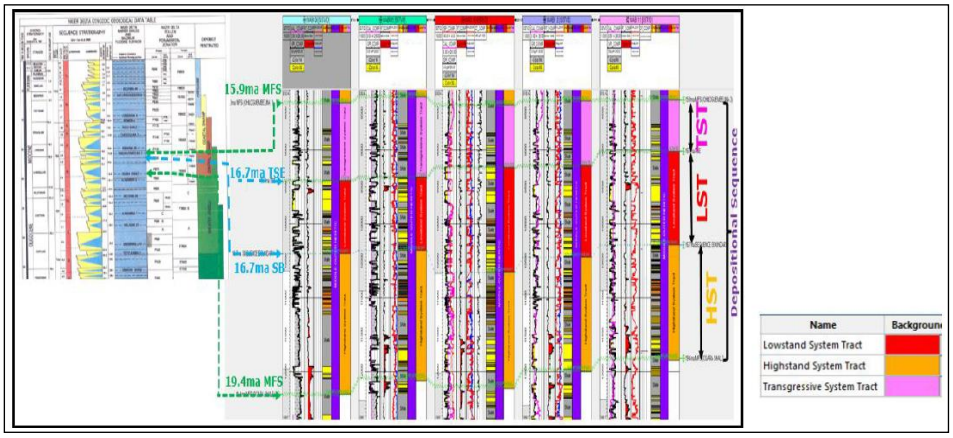


Figure 6: Correlation of High Resolution Biostratigraphic data and Niger Delta Chronological Chart

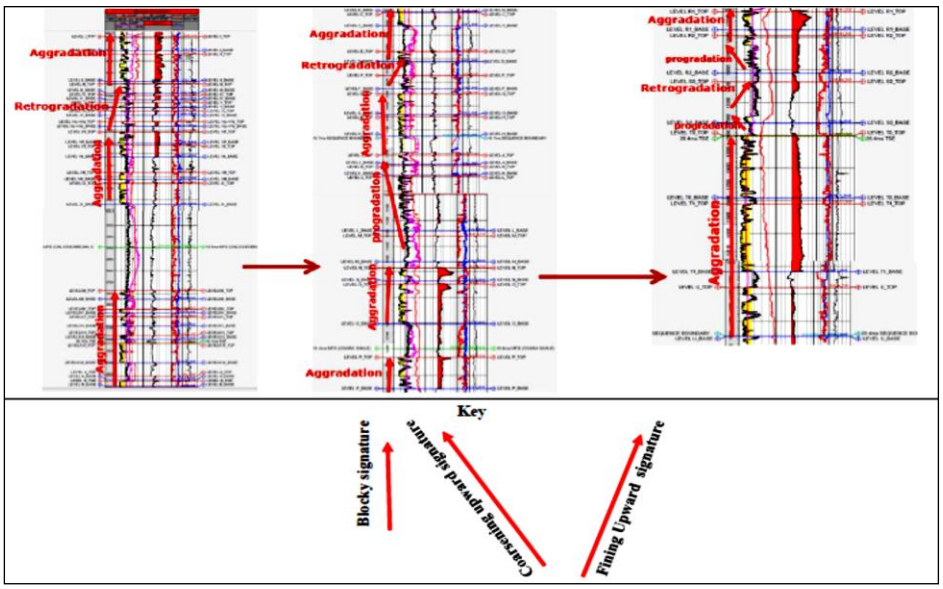


Figure 7: System Stratigraphy of Well Wabi-10, example

4. Results and Discussion

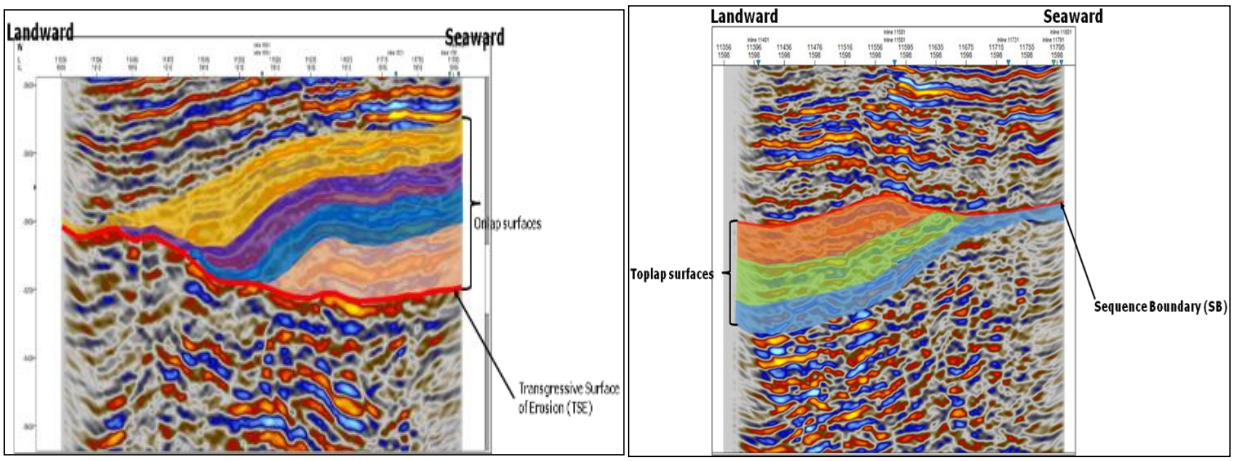
4.1 Results

The results as presented in Figures 8 - 12, Tables 1 and 2.

4.1.1 Interpretation of Seismo-Stratigraphy

Results from the sequence stratigraphic interpretation on the seismic (Seismo-stratigraphy) shows evidence of truncation and channelization (Figure 8). Figure 8a is onlap surface because the stratigraphic terminations are above the surface. The loops coming out die out where the sediments are dying into which is the transgressive surface of erosion (TSE). Onlap is generally associated with marine transgression (Vail et al., 1977a). The trajectory is often landward and the termination is up dip. The strata and the surface often dip in opposite direction. Figure 8b is the toplap, termination is below the surface. The termination of strata, or seismic marker against an overlying surface mainly resulting from non-deposition with perhaps only minor erosion (Vail et al., 1977b). The strata lap out in the landward direction but the successive termination lie progressively seaward.

From the biostratigraphic data, three maximum flooding surfaces (MFS) of 20.4Ma, 16.7 and 15.9Ma were inferred corresponding to Sequence-1 (HST), Sequence-2 (LST) and Sequence-3 (TST) respectively. The field was inferred to have been deposited during Lower to Upper Miocene Epoch using the Niger Delta Cenozoic Geologic Data. Reservoirs B Sand is a Low Stand System Tract (LST), O Sand is a High Stand System Tract (HST) and R1 Sand is a Transgressive System Tract (TST), Figure 9.



(a) Onlap **(b) Toplap**

Figure 8: Seismo-Stratigraphic Interpretation

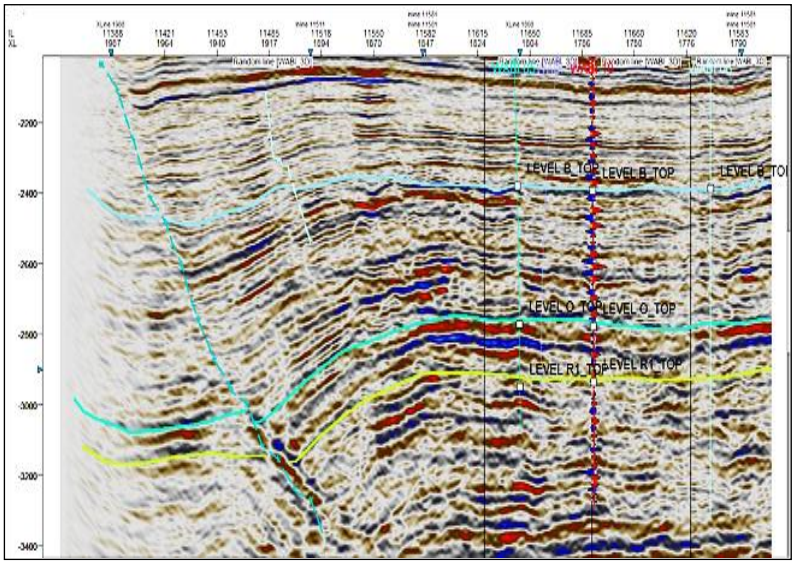


Figure 9: Mapping of Horizons and Faults, NW-SE

The detailed delineation of the MFSs is shown in Figure 6 for Well Wabi-10 which has penetrated all the sand units in the Field. From the log signatures, the predominately Aggradation (Blocky Signature) infers channels (fluvial) sand while the intermittent presence of progradation (coarsening upward) signature suggests shoreface sand. The Retrogradation (fining upward) signature infers as Channels or Tidal sand units. Owing to the absence of biostratigraphic and core data, the blocky and fining upward signatures are interpreted as channels (fluvial) sand units while coarsening upward signatures as Shoreface Sand Units.

Well Wabi-10 composite log is blown it up for the signatures to be seen very clearly. From the Well Wabi-10 type-log (Figure 7; Table 1):

(i) Wabi field is dominantly Aggradation Fluvial (Channel Deposits) environment as shown by the major blocky log signature;

(ii) There could be other minor Retrogradation depositional (Channels or Tidal Sand) environment evidences as shown by few fining upward and coarsening upward log signatures. This is expected within parallic/marginal marine environment;

(iii) The sand bodies are well developed at the deeper depth while in-between to shallow depth showed poor to average sand development;

(iv) In-between these 2 major depositional sequences we have minor sequences (para-sequences;

(v) Three (3) MFSs are identified (Figure 9; Table 2); with the seismic data and available biostratigraphic information, regional seismo-stratigraphic section is presented in Figure 8.

Table 1: Major and Para- Sequences

Process	Depth Range (ft)		Thickness (ft)
Aggradation	0	6610	6610
	6610	7000	390
	7770	8040	270
	8830	9010	180
	9230	9400	170
	9550	9720	170
	9920	10020	100
	10300	10650	350
	11526	12000	474
	12260	12500	240
	13400	13780	380
	13820	14270	450
	14350	14690	340
Retrogration	7000	7200	200
	7314	7630	316
	10140	10240	100
	11330	10520	810
Progradation	9010	9090	80
	10780	11280	500
	12560	12640	80

Table 2: Thickness and Age of Maximum Flooding Surfaces (MFSs)

MFS	Depth Range (ft)		Thickness (ft)	Age (Ma)
MFS1 (TST)	8400	9230	830	15.9
MFS2 (LST)	9230	10650	1420	16.7
MFS3 (HST)	10650	14720	4070	20.4

4.1.2 Facies Interpretation

The results of Well log signatures show majorly two types of facies. They are the Channel (blocky signatures) and Shoreface (coarsening upward) sand deposits with traces of heterolithic sand, silty sand (serrated motif) and marine shale. Wabi field is dominantly fluvial (channel deposits) environment as shown by the major blocky log signature. There could be other minor depositional environment evidences as shown by few fining upward and coarsening upward log signatures. This is expected within parallic/marginal marine environment. A major shale separates two depositional sequence was inferred from the log. In-between these 2 major depositional sequences there are minor sequences (para-sequences).

5. Conclusion

5.1 Seismic Interpretation

(i) Sand sequences thinning at greater depths is indicative of bulk density increasing as the sediment compacts at depth.

(ii) Sequence stratigraphic interpretation on the seismic (Seismo-stratigraphy) shows evidence of truncation and channelization. Onlap surface is encountered because the stratigraphic terminations are above the surface. The loops coming out die out where the sediments are dying into which is the transgressive surface of erosion (TSE). Toplap is also interpreted, termination is below the surface. The termination of strata, or seismic marker against an overlying surface mainly resulting from non-deposition with perhaps only minor erosion. The strata lap out in the landward direction but the successive termination lie progressively seaward.

5.2 Sequence Stratigraphic Analysis

(i) Onlap is generally associated with marine transgression.

(ii) Toplap which terminates below the surface, lap out in the landward direction.

(iii) Three (3) maximum flooding surfaces (MFS) of 20.4Ma, 16.7Ma and 15.9Ma were inferred.

(iv) The field was deposited during lower to Upper Miocene Epoch using the Niger Delta Cenozoic Geologic Data.

(v) The reservoirs of interest fall within the following system tracts: B Sand is a Low Stand System Tract (LST), O Sand is a High Stand System Tract (HST) and R1 Sand is a Transgressive System Tract (TST).

5.3 Facies Deposition

(i) Two types of facies: channel (blocky signatures) and shoreface (coarsening upward) sand deposits with traces of heterolithic sand, silty sand (serrated motif) and marine shale.

(ii) Wabi field is dominantly fluvial (channel deposits) environment as shown by the major blocky log signature.

Acknowledgements

Authors are very grateful to Total Exploration and Production (E&P) Nigeria Limited with the assistance of the Department of Petroleum Resources (DPR), a Subsidiary of Nigeria National Petroleum Corporation (NNPC) for approval and release of data.

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