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Application Of Sequence Stratigraphy For The Enhancement Of Hydrocarbon Reservoir Correlation Of 'ED' Field Offshore Niger Delta, Nigeria

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ABSTRACT
Application of sequence stratigraphy for the enhancement hydrocarbon reservoir correlation of 'ED' Field, offshore Niger Delta. Gamma ray and combination of density and neutron logs was used to interpret lithology. Three hydrocarbon bearing reservoirs labelled as ED-R-1000, ED-R-2000 and ED-R-3000 were delineated. Seismic sequence analysis using reflection terminations were used for the mapping of three depositional sequences on the basis of reflection character analysis. Two major lithologies were delineated. The stratigraphy comprising alternation of sands and shales is typical of Agbada Formation. Three stratigraphic surfaces were used to sub-divide the study field into three (3) depositional sequences and further subdivide the sequences into three system tracts. They are 1154ft(m), 382ft(m) and 738ft(m) thick respectively. Sequence stratigraphic correlation technique aided the local arrangement and geometries of reservoirs within the field and in locating potential reservoirs. The depositional environment of the study field includes distributary channel fill, regressive to transgressive shoreface delta, delta front and storm dominated shelf.
Keywords: Stratigraphy, Depositional sequence, Sequence boundaries, Well logs.

1. INTRODUCTION

According to an article on business day newspaper dated, 3rd of October 2022, Nigerian oil resources may be dwindling faster than expected, with promising fields turning up empty as seen in the latest well on Bonga oilfield, a development that could further compound the challenges in the oil sector together with the fact that a number of dry holes have been drilled in other fields and some reservoirs bypassed due to pit falls in interpretation procedures of some geology principles. An example of such principle is proper well correlation to establish lateral extent and interconnectivity of hydrocarbon reservoirs that are time related. The petroleum industry is facing a future where new technologies, creativity and integration of different disciplines are the core focus for higher exploration success rates and improved oil recovery. This therefore necessitated petroleum exploration activities to move to deep offshore basins as declining productions from mature provinces persist (Ayuk et al 2022). Similarly, according to Pettingill (1998), these deep-water systems may include large volumes of unexplored hydrocarbon in several areas of the world. But characterizing deep-water marine systems can be difficult in the subsurface because most of the reserves in the setting are found in difficult geological settings; such as channel sand, stratigraphy traps, or in thin beds. Also, the settings are often data-poor areas where basin geology is poorly understood, and this makes prospectivity and exploration risks difficult to evaluate. Characterization of reservoirs is an important process to define and optimize the development strategies for prospects in the basin so that maximum economic benefit can be achieved. It helps to determine optimal production strategies and minimize risk. The process requires a synergy of all subsurface disciplines of reservoir engineering, geology, geophysics, petrophysics, and sedimentology. Researchers who have used single or integrated methods in this area, few of them includes; Dutta et al., 2010, Abdel-Fattah and Slatt (2013), Avseth (2000), and Ebere et al. (2016). Approaches of these authors have highlighted the contributions of sequence stratigraphy and rock physics in qualitative and quantitative characterization of seismic data and log. Since the first deep-water project in Niger Delta, further exploration in this basin has been focusing mainly on deep-offshore whose reservoirs are mainly turbidite sands. With the continuation of the exploration in the deep-offshore, there has been an increasing industry concern about reservoir quality and has remained a challenge to the future prospectivity of oil blocks in the ultra-deep offshore basin. To forestall the miseries following a dry well which aims at a perfect bright spot and an unquestionable amplitude variation with offset (AVO) response in this setting necessitates the use of a method which link seismic responses directly with reservoir properties (Ayuk et.al.2022). The deep offshore Niger Delta where the field of investigation is situated is noted for unconsolidated and discontinuous nature of the reservoirs. This made exploration and production of oil and gas in this environment difficult. This research is aimed at solving these problems through the application of sequence stratigraphy for enhancement of hydrocarbon reservoir correlation.

Sequence stratigraphy is a branch of sedimentary stratigraphy that deals with the other, or sequence in which depositionally related strata successions (time-rock) units are laid down in available space called accommodation. Depositional sequence is a stratigraphic sequence bounded by subaerial unconformities or their correlative conformities (Mitchum, 1977). Sequence stratigraphy has been applied in several sedimentary basins of the world leading to the discovery and recovery of more hydrocarbon reserves. The sequence stratigraphic concept was introduced into the Niger Delta Basin exploration, when Durand (1995), Stacher (1995), and Reijers (2011) first applied it in refining the process for prediction of hydrocarbon habitats. Recent developments in the field of sequence stratigraphy (Posamentier and Allen, 1999; Posamentier, 2000; Catuneanu, 2002) offer a definitive approach to stratigraphic analysis of sedimentary strata.

Correlation is the process of establishing which sedimentary strata are of the same age but geographically separated. Stratigraphic correlation is the process of establishing which sedimentary strata are of the same age at distant geographical areas by means of their stratigraphic relationship. In recent years, the geophysical properties of strata have become very important in correlation, particularly in the subsurface. Well-logging uses physical properties of the rock that can be detected by devices pulled through drill holes and it is the primary tool for modern subsurface correlation (Prothero and Schwab 2014).

1.1 Location and Geology of Study Area

The area of study is located in the southeastern part of Niger Delta (Figure 1). It is on the offshore depobelt with Latitude: 04°33'02.368N to 04°49'02.368N and
Longitude: 03°47'42.249E to 04°36'22.239E

Figure 1. Location Map of study area

The Tertiary Niger Delta is geologically divided into three formations representing prograding depositional facies distinguished mostly on the basis of sand-shale ratio (Inyang, N. J. et al 2015; Short, K.C et al 1967; Kulke, H. 1995). These three formations are the Benin Formation or Continental Alluvial Sands, the paralic Agbada Formation and the prodelta marine Akata Formation (Akpabio, I. et al 2014: Agbasi, O. E et al 2017).

2. MATERIAL AND METHODS

The data used for this research was obtained from Nigerian Petroleum Development Company (NPDC) of Benin, with permission from the department of petroleum resources (DPR) Warri. Seismic lines comprised full angle stacked covering an area extent of 397.15 km^2 with crosslines 801 and inlines 501. Well logs from three wells include gamma ray, deep resistivity, density, neutron and sonic. Also check shot survey was also provided for ED-01 well. A base map (Fig. 2) showed the distribution, orientation and relative positions of the wells and seismic lines in the study area. All the data was in digital format which enabled the use of modern software for the analysis. The available computer software which include Petrel™ 2014, and Microsoft office which were used for the interpretation and report writing and a suite of well logs and 3D seismic data. The field is code named "ED" and the wells log (log data in LAS format) are also named ED-01, ED-02, and ED-03 for proprietary reasons. Table 1 shows a summary of the available data set for this study.

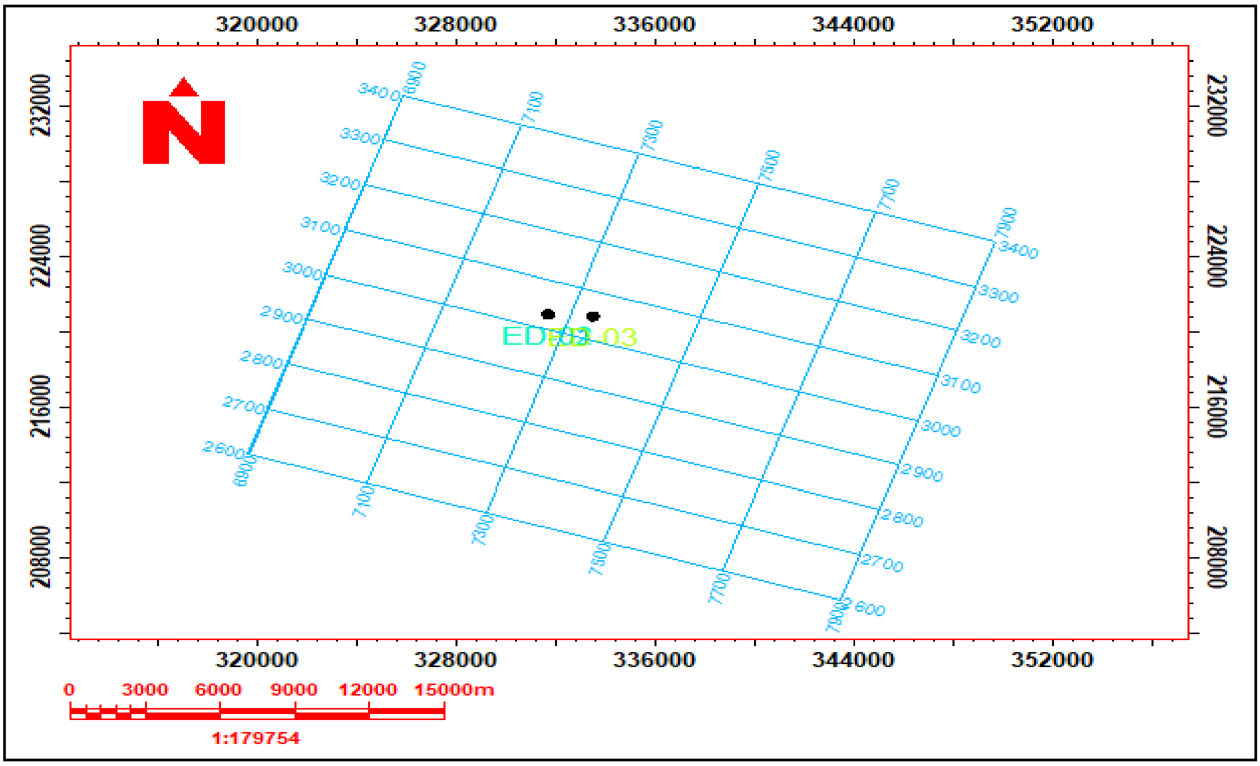


Figure 2**:** Base Map of "ED" Field

Table 1; Available Logs

Name	Start Depth	Stop Depth	GR log	SP log	Cal. log	Res. log	Den log	Neu log	Sonic log	Check shot	X-(m)	Y- (m)	KB(ft)	TVD (ft)	Total TVD Subsea (ft)
ED-01	42.00	13295.00	+	-	+	+	+	+	+	+	331694.48	220995.48	42.00	13295.00	13337.00
Ed-02	46.00	13027.999	+	-	+	+	+	+	+	-	331708.68	220989.98	46.00	13027.999	13073.999
ED-03	0	11070.00	+	-	+	+	+	+	-	-	33512.18	220884.48	43.00	11070.00	11113

Reservoir sands identification was done using the log signatures of both gamma ray (GR) and deep resistivity logs. Zones with low gamma ray log read and high resistivity readings were considered as hydrocarbon bearing sand unit while zones with low resistivity readings and low gamma ray log reading were considered as water-bearing sand units

3. RESULTS AND DISCUSSIONS

The figure 3 below shows that three reservoirs were delineated and named ED-R-1000, ED-R-2000 and ED-R-3000 for which the three reservoirs located at depth between 8730 and 10123ft on ED-01 well. They are located between 9143 and 10643ft on ED-02 well. The reservoirs are located between 8744 and 10234ft on ED-03 and the reservoir ED-R-1000 has oil down through indicated as ODT and the reservoir ED-R-2000 there is an oil-water-contact (OWC) which occurred at 9985m below the surface. The balloon effect displayed by the density-neutron logs shows that there is an associated gas reservoir. Fluid contacts can be gradational in mixed fluid reservoirs but are typically horizontal or nearly so because of the difference in density between gas, oil and water.

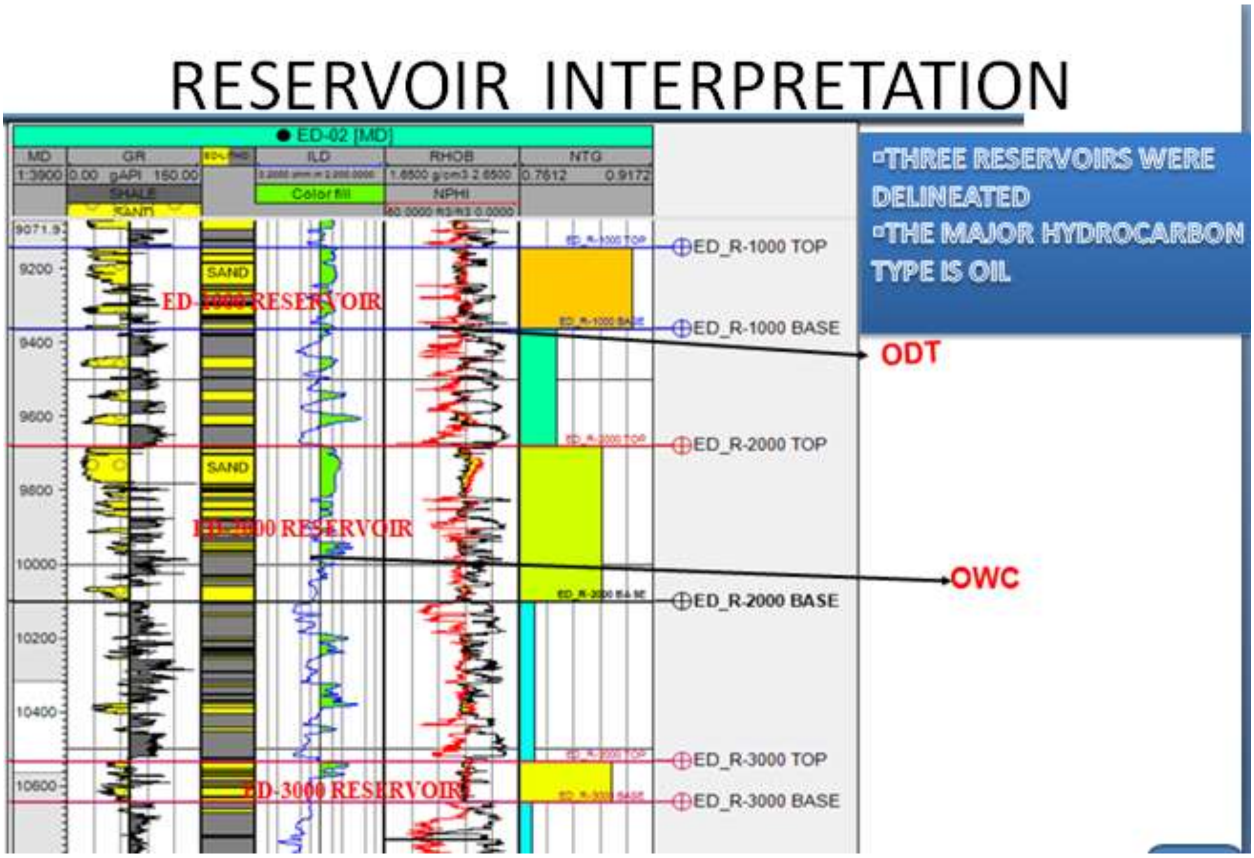


Figure 3. Reservoir Interpretation

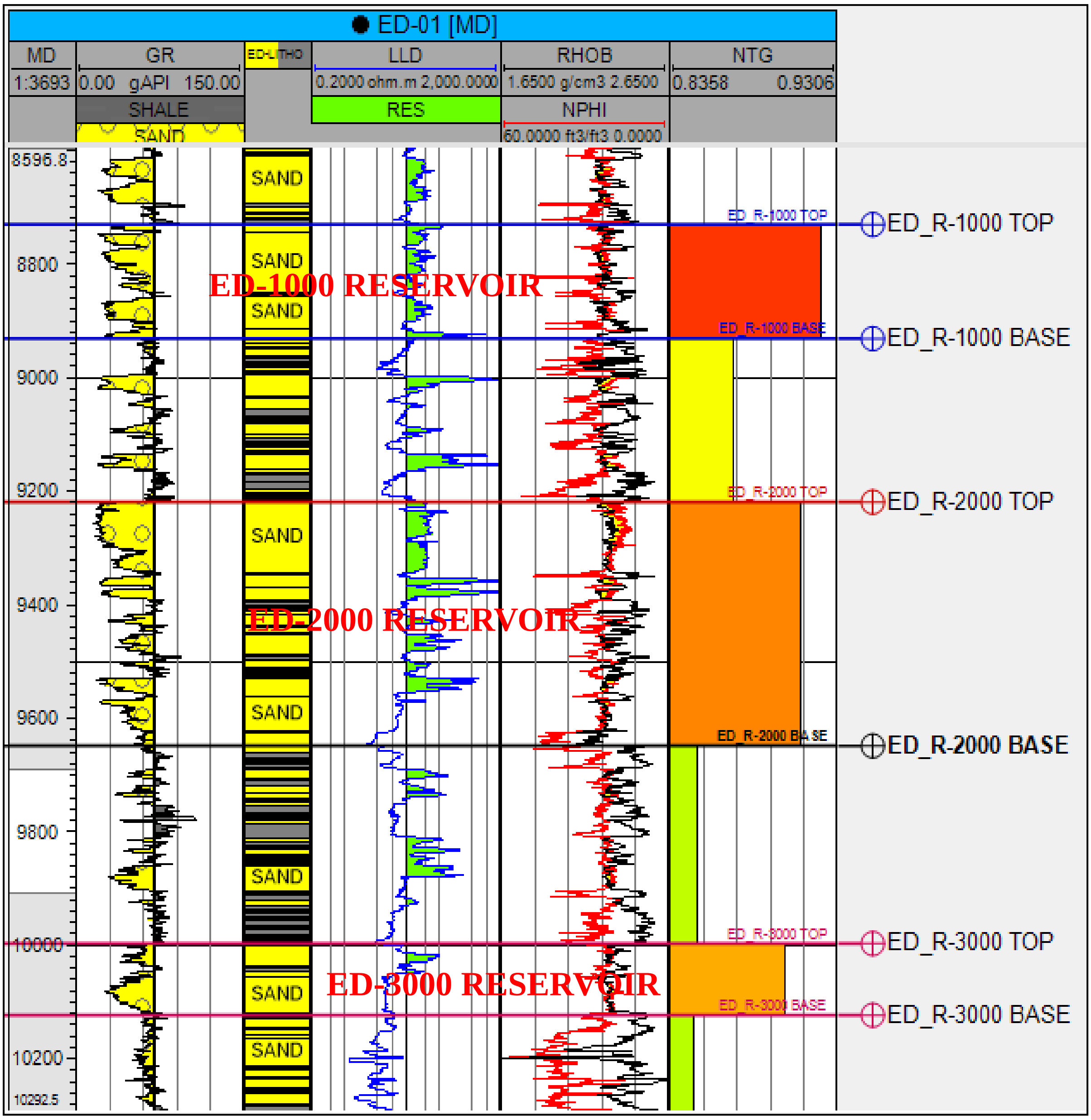


Figure 4: Reservoir Delineation on ED-01 Well

3.1. Log Sequence Interpretation

The gamma ray log motif was used for the determination of key stratigraphic surfaces. The spatial distribution of the recognized constrained stratigraphic surfaces identified include transgressive surfaces (TS), maximum flooding surfaces (MFS) and sequence boundaries (SB). These surfaces were used to subdivide the studied field into three depositional sequences and system tracts. Parasequence stacking pattern including progradational, aggradational and retrogradational was principally used for the log motifs.

3.2. Chronostratigraphic Correlation

Figure 4 shows the chronostratigraphic correlation of the three well within the field of study. The stratigraphic surfaces identified from each of the three wells including maximum flooding surfaces, transgressive surfaces and sequence boundaries as well as system tracts were correlated at different

depths across the wells. There is variation in sediment thickness across the wells, with varied number of systems tracts in each sequence. These subdivided 3 depositional sequences are as discussed below:

The gamma ray log motif was used for the determination of key stratigraphic surfaces. Figures 5 depict sequence stratigraphic analysis of the three wells. The spatial distribution of the recognized constrained stratigraphic surfaces identified include transgressive surfaces (TS), maximum flooding surfaces (MFS) and sequence boundaries (SB). These surfaces were used to subdivide the studied field into three depositional sequences and system tracts. Parasequence stacking pattern including progradational, aggradational and retrogradational was principally used for the log motif.

Then chronostratigraphic correlation of the three well within the field of study was done where stratigraphic surfaces identified from each of the three wells including maximum flooding surfaces, transgressive surfaces and sequence boundaries as well as system tracts were correlated at different depths across the wells. There is variation in sediment thickness across the wells, with varied number of systems tracts in each sequence. These subdivided 3 depositional sequences are as discussed below:

3.3. Depositional Sequence One

Depositional sequence one is the oldest depositional sequence and the deepest in ED-field. It has three stratigraphic surfaces which are sequence boundary (SB), maximum flooding surface (MFS) and trangressive surfaces (TS). It is enclosed by MFS-1 below and MFS-2 above (Figure 5). The depositional sequence is about 1154ft thick. The sediments in this sequence is believed to be deposited as distributary channel in the deltaic depositional environment. Three system tracts are identified within this sequence. The tracts are lowstand, trangressive and highsand System Tracts. Lowstand system tract is predominantly aggradational and progradational stacking pattern, trangressive system tract is retrogradational stacking pattern of fining upward sequence and highstand system tract is progradational stacking pattern of coarsening upward sequence. The highstand system tracts (HST) lies on the MFS-1 and it is about 393 ft. The lowstand system tracts (LST) is then enclosed by the SB below and the TS above. The tract is about 322ft thick. The trangressive system tracts is enclosed by the TS below and the MFS-2 above, the tract is about 130ft thick. The LST and HST are probably potential reservoir rocks while TST is a good sealing rock.

3.4. Depositional Sequence Two

Depositional sequence two directly overlies the depositional sequence one. It also has three stratigraphic surfaces which are sequence boundary, maximum flooding surface and trangressive surfaces. It is enclosed by MFS-2 below and MFS-3 above. The depositional sequence is about 382ft thick. This sequence is also believed to be deposited as pelagic in the deltaic depositional environment. Three system tracts of lowstand, trangressive and highstand System Tracts were also identified with the thickness of each tract being 156ft, 113ft, and 95ft respectively. The HST is enclosed by the MFS-2 below and SB above. The LST is bounded by the SB below and the TS above. The TST is bounded by the TS below and the MFS-3 above. The LST and HST are potential reservoir rocks while TST is a good sealing rock.

3.5. Depositional Sequence Three

Depositional sequence three, directly overlies the depositional sequence two. It also has three stratigraphic surfaces which are sequence boundary, maximum flooding surface and trangressive surfaces. It is enclosed by MFS-3 below and MFS-4 above (Figure 5). The depositional sequence is about 738ft thick. This sequence is also believed to be deposited as shoreface channel in the deltaic depositional environment. Three system tracts of lowstand, trangressive and highstand System Tracts were also identified with the thickness of each tract being 260ft, 443ft, and 49ft respectively. The HST is enclosed by the MFS-3 below and SB above. The LST is bounded by the SB below and the TS above. The TST is bounded by the TS below and the MFS-4 above. The LST and HST are potential reservoir rocks while TST is a good sealing rock.

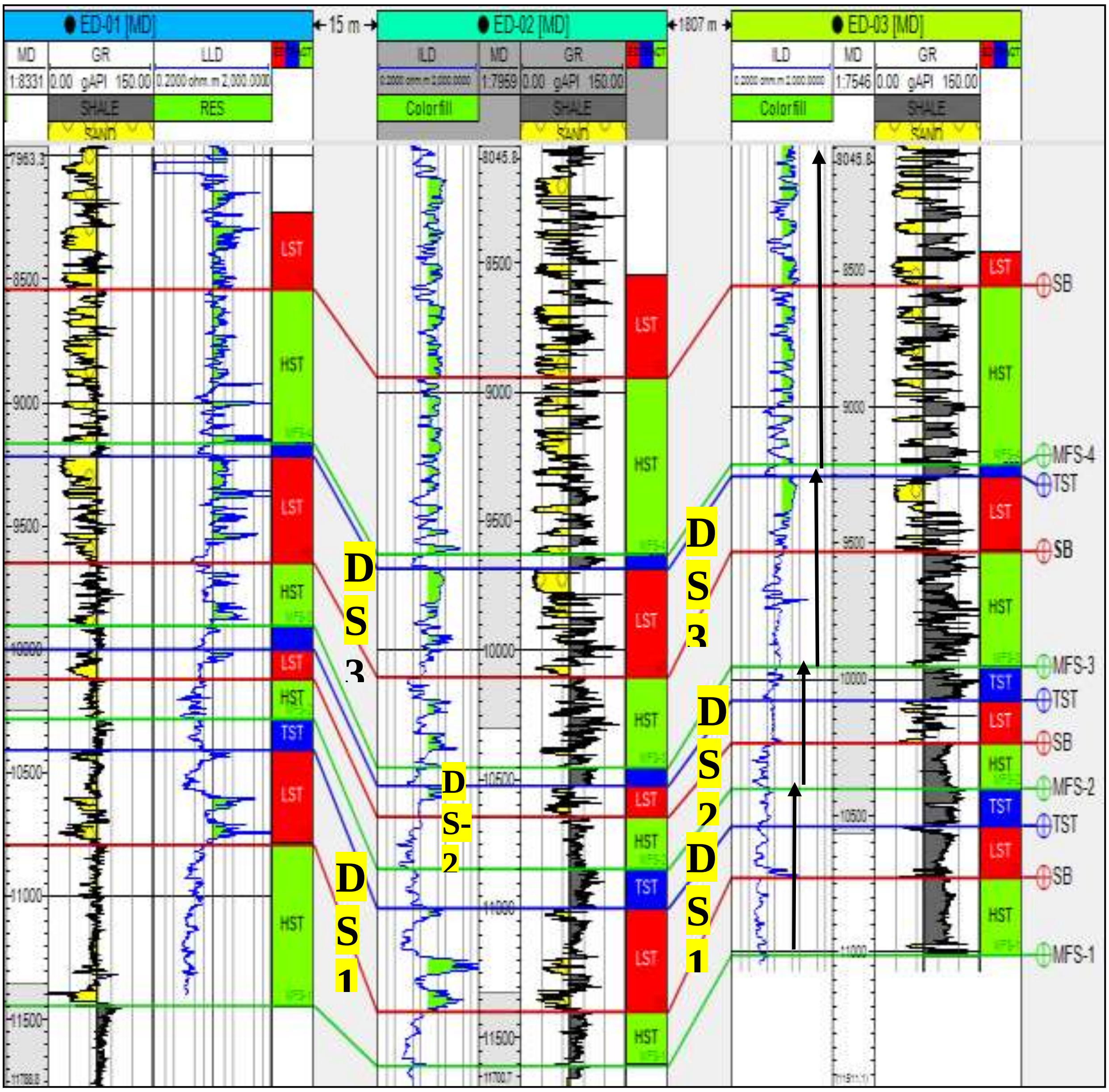


Figure 5:Chronostratigraphic Correlation of the Studied Wells

3.6. Depositional Environment of Sediment

Well Logs and seismic data were used for the delineation of environment of sediment deposition. Log motifs analysis using parasequence stacking patterns of progradational, aggradational, and retrogradational of the studied wells (Table 2.) shows that the depositional environment including distributary channel fill, regressive to transgressive shoreface delta, delta front and storm dominated shelf. The reservoirs are mainly of the lowstand tidally influenced channel and shoreface sands. This suggests that deposition of sediments in the study field took place under varied energies ranging from low to high energy zones. This environment of deposition as defined on log is evident from analysis of sediment facies of reflection patterns. Parallel to subparallel facies are indication of sand-shale interbedding deposited under high energy levels. The probable environment of deposition. This is believed to be deltaic environment in marginal marine settings.

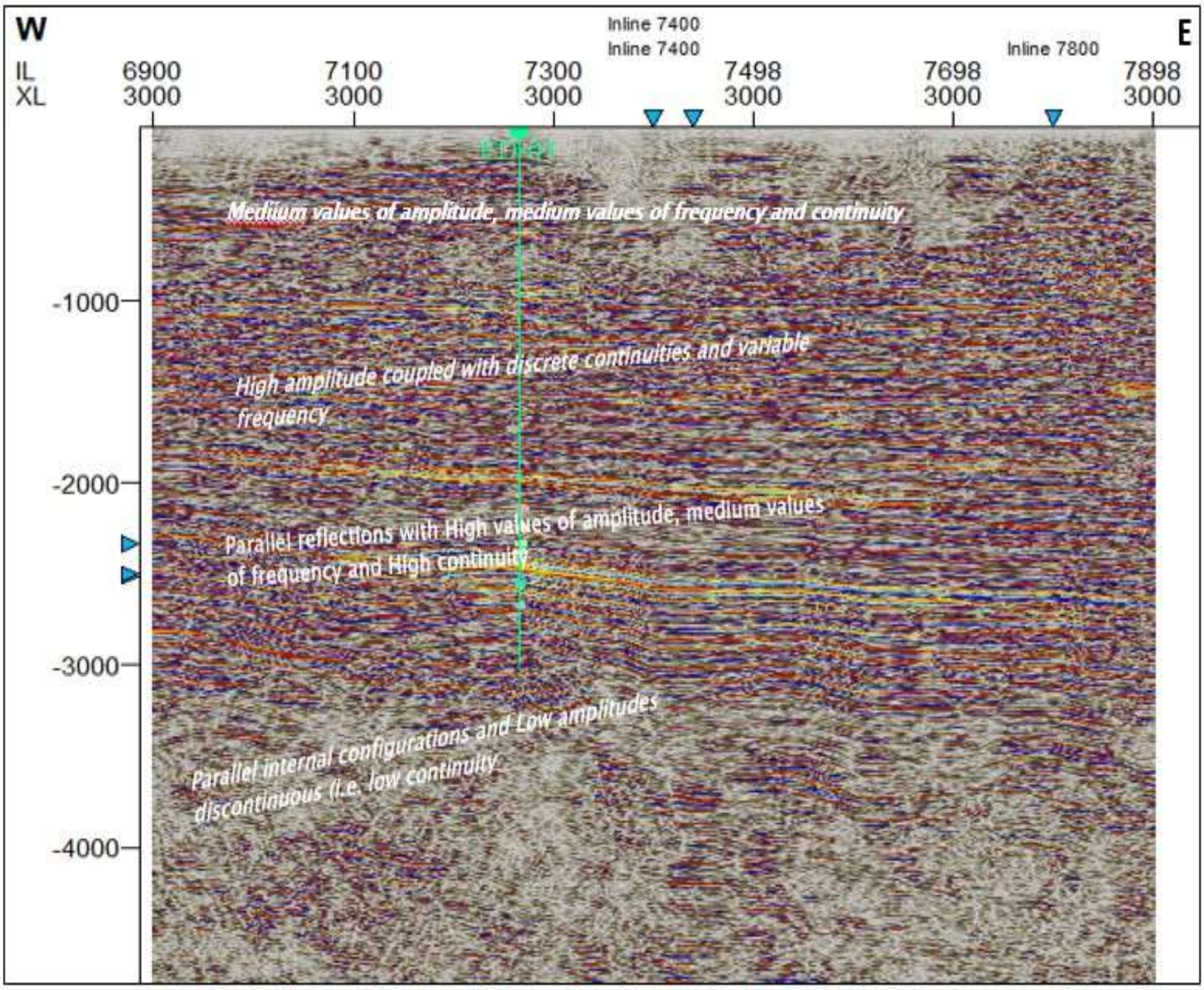


Figure 6: Interpreted Section for Seismic Facies Analysis of 'ED' Field

3.7. Seismic Sequence Interpretation

Seismic facies analysis was done by the analysis of seismic parameters including amplitude, continuity, configuration and frequency. The brief description of each of the seismic facies unit are provided below:

Facies 1: Facies 1 are reflections (Figure 6) showing sub-parallel internal configurations with medium values of amplitudes, discontinuous (i.e. low continuity) with medium frequency.

Facies 2: Facies 2 are reflections (Figure 6) showing sub-parallel internal configuration with high values of amplitudes, discrete continuity and variable frequency.

Facies 3: Facies 3 are reflections (Figure 6) showing parallel internal configurations with high values of amplitudes, continuous (i.e. high continuity) and high frequency values.

Facies 4: Facies 4 are reflections (Figure 6) showing sub-parallel internal configurations with low values of amplitudes, discontinuous (i.e. low continuity) and low frequency values.

Similarly, seismic facies analysis concept was used for the definition of depositional environment of the three analyzed reservoirs. Reservoir ED-R-1000 possesses seismic characters with parallel reflection configuration, continuous high amplitude and high frequency values. This is a typical characteristic of pelagic sediments of deltaic environment. Reservoir ED-R-2000 possesses seismic characters with parallel-to-sub-parallel reflection configuration, continuous high amplitude and high frequency values. It is also a typical characteristic of pelagic sediments of deltaic environment. Reservoir ED-R-3000 possesses seismic characters with sub-parallel reflection configuration, continuous to semi-continuous, medium amplitude and high frequency values. It is a typical characteristics of debris flow sediments of deltaic environment

Table 2: EOD based on Reflection Characters

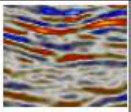
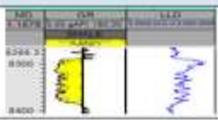
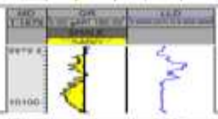
Reservoirs /Seismic Facies	Observed Seismic Signature	Reflection Configuration	Reflection Continuity	Reflection Amplitude	Frequency	Environment of Deposition	Interpretation
ED-R-1000		*Parallel*	Continuous	High	High	Pelagic	Deltaic Chanel
ED-R-3000		*Parallel-Sub-parallel*	Continuous	High	High	Pelagic	Deltaic Channel
ED-R-3000		*Sub-parallel*	Continuous to semi-continuous	Moderate	High	Debris Flow	Shore face Delta

Table 3 : EOD Base on Log Motif/Facies Analysis

Well Log Signature	Well Log Signature	Log Shape Character	Curve Stacking Pattern	EOD Interpretation
		Cylindrical	Aggrading	Distributary Channel fill
		Funnel	Prograding	Delta Front
		Symmetrical	Prograding and Retrograding	Regressive to Transgressive Shoreface Delta
		Serrated	Aggrading	Storm Dominated Shelf

4.0. CONCLUSIONS

The area of study in this research has 3D seismic lines covering 397 square kilometres and a suite of wireline logs from three wells were used to enhance reservoir characterization within 'ED' field, offshore Niger Delta. The gamma ray and combination of density and neutron logs were used for lithologic identification, resistivity log indicated nature of fluids (hydrocarbon and water). Well logs and seismic data were used in the determination of key stratigraphic surfaces and structural interpretation. Two major lithologies were identified within the study field. They are sand and shale units. The sand units comprise of thin shale interbedding which decrease in thickness with depth. The shale layers also increase in thickness with depth. It is a typical of Agbada Formation. Three hydrocarbon bearing reservoirs labelled as ED-R-1000, ED-R-2000 and ED-R-3000 were delineated. The hydrocarbon-type contained in most of the reservoirs is oil. Well log correlation of the three wells revealed the lateral continuity of the sand units.

Log sequence interpretation of the three wells was performed using gamma ray log motifs. Three stratigraphic surfaces namely transgressive surfaces, maximum flooding surfaces and sequence boundaries were identified. These surfaces were used to divide the study field into three (3) depositional sequences and further subdivide the sequences into three system tratcts. The system tract include lowstand, trangressive and highstand system tracts. Lowstand system tract is predominantly aggradational and progardational stacking pattern, trangressive system tract is retrogradational stacking pattern of fining upward sequence and highstand system tract is progardational stacking pattern of coarsening upward sequence. Depositional sequence one is the oldest a depositional sequence and the deepest in ED-field. It is enclosed by MFS-1 below and MFS-2 above. The depositional sequence is about 1154ft thick. Depositional sequence two directly overlies the depositional sequence one. It is enclosed by MFS-2 below and MFS-3 above. The depositional sequence is about 382 ft thick. Depositional sequence three directly overlies the depositional sequence two. It is enclosed by MFS-3 below and MFS-4 above. The depositional sequence is about 738ft thick.

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