

Stratigraphic Interpretation using Seismic and Well Log Data of 'OGEY' Field, Niger Delta

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ABSTRACT

The stratigraphic interpretation of 'OGEY' Field, deep offshore Niger Delta was carried out with a view of correlating the subsurface facies and deducing the environments of deposition of the field. This was done by using the concept of sequence and seismic stratigraphy. The data available and used for this study include digital 3-D seismic, well logs, biostratigraphic information and check shot data. Petrel software was used to analyse the data. The interpretation procedure involves data quality check, qualitative interpretation, well log interpretations, sequence stratigraphic interpretation, seismic to well tie, facies interpretation, and depositional environment interpretation. Lithological identification was done with the aim of differentiating the shale and sandstone lithological units. This process was carried out using the gamma ray and resistivity logs. Sequence stratigraphic interpretation was established by integrating biostratigraphic information and well log data. Sequence stratigraphy interpretation was carried out using the data sets available (i.e., biostratigraphic information, well logs and seismic data).

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The reservoir sands were later correlated across the wells after defining the reservoirs depositional environment to monitor their lateral continuity and probable structures within the well coverage area. The well log data was also tied with seismic sections for accurate geologic interpretation. Seismic facies analysis was done by combining the geometric information with the seismic attributes. The lithologies identified are sand, sandy shale and shale respectively. The sequence boundaries identified were dated 20.4Ma, 17.7Ma, 15.50Ma, 12.10Ma and 10.35Ma while the Maximum Flooding surfaces were dated 19.4Ma, 15.9Ma, 12.80Ma, 10.4Ma, and 9.6Ma

respectively. The result revealed three system tracts which are LST, TST and HST which indicated five depositional sequences. Four seismic sequences were observed in this field and they are SF1, SF2, SF3, and SF4. The environment of deposition for the field is deep offshore with depositional units ranging from turbidite sand to sheet sands, channel levee and overbank complex, canyon fills and mass transport deposits.

Keyword: seismic attributes, facies analysis, depositional environment, sequence stratigraphy

1. INTRODUCTION

Stratigraphy is well known as the science of the layers characters of rocks (Davies, 2007). Seismic stratigraphy uses seismic reflection patterns to identify depositional sequences to predict the lithology of seismic facies by interpreting depositional processes and environmental settings, and to analyse relative changes in sea level as recorded in the stratigraphic records (Mitchum, 1977). The use of seismic stratigraphy for identifying exploration targets has been the focus of several studies (Galloway, 1975; Brown and Fisher 1977; Mitchum 1977; Payton 1977, Armentrout and Perkins, 1991; Miall, 1991; Posamentier and George, 1994; Galloway 1998; Davies 2004; Catuneanu 2006). These studies have shown that seismic stratigraphic principles can help to improve seismic interpretations. Stratigraphic interpretations, such as geologic time correlations, the definition of genetic depositional units, and thickness and depositional environment of genetic units can be achieved using seismic stratigraphy (Mitchum *et al.*, 1977; Catuneanu, 2006). Generally, application of seismic stratigraphic techniques has become an important component of standard seismic interpretation workflows. The method has continued to enhance the identification of drill well opportunities with reduced risks and uncertainties in business decisions, especially where there are well controls. Also, as exploration continues to move into frontier regions and into deeper parts of sedimentary basins where well control is limited or lacking, fundamental to delineating drilling

targets is interpreting stratigraphy, sedimentary facies, and geologic history from seismic reflection data (Galloway, 1976; Cross and Lessenger, 1988; Paumard, 2019; Cawthra, 2020). Seismic reflection profiles form an important source of data for the interpretation of subsurface stratigraphy and depositional systems. (Veeken, 2007) reported that four major groups of systematic reflections are distinguished on seismic sections: sedimentary reflections representing bedding planes; unconformities or discontinuities in the geological record; artefacts like diffractions and multiples; and non-sedimentary reflections like fault planes and fluid contacts. One of the standard operations in seismic interpretation for hydrocarbon exploration is the ability to identify and distinguish the various subsurface features that fall under these aforementioned categories from the seismic data. These features are subsequently evaluated for their possible implications for hydrocarbon accumulations, if any, in the area of interest. Generally, to delineate geological features and potential areas of commercial oil and gas accumulations, the seismic reflection data must be interpreted in a geological meaningful manner using various interpretation techniques, one of which is seismic stratigraphy.

1. GEOLOGY OF THE AREA

The Niger Delta occurs at the southern end of a major series of rifts extending from what is now the Atlantic Ocean to the modern Mediterranean and hosts the largest petroleum province of Africa. These rifts are of Cretaceous age and at one time allowed a continuous seaway to extend across the continent (Selley and Van der Spuy, 2016). The Niger Delta Basin is located within the peri-oceanic section of the Abakaliki–Benue suture zone of the much larger southern Nigerian basin. On the west, it is separated from the Dahomey (or Benin) basin by the Okitipupa basement high, and on the east it is bounded by the Cameroonian volcanic line. Its northern margin transects several older tectonic elements: the Anambra basin, Abakaliki uplift, Afikpo syncline and Calabar Flank (Nwaezeapu *et al.*,

2018). The Niger Delta is the youngest sedimentary basin within the Benue Trough system (Emujakporue et al., 2009). The Niger and Benue Rivers are the main supplier of sediments.

The Cenozoic section of the Niger Delta is divided into three formations which includes Akata, Agbada and Benin Formation representing prograding depositional environments (Short and Stauble, 1967). The delta is 75000 km² in size and reaches a maximum of 12km in the centre of the basin (Whiteman, 1982). The basal Akata Formation which is predominantly marine prodelta shale is overlain by the paralic sand/shale sequence of the Agbada Formation. The topmost section is the continental upper deltaic plain sands known as the Benin Formation. Virtually all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstones of Agbada Formation where they are trapped by rollover anticlines (Ekweozor and Dankoru, 1994; Michele et al., 1999; Uko, 1996). Akata Formation is about 6400 m thick at the center of the clastic wedge; the lithologies include dark gray shale and silts, having streaks of sand which their origin could be from turbidite flow. This Akata Formation grades vertically into the Agbada Formation with abundant plant remains and micas in the transition zone (Doust and Omatsola 1990; Figure 2). The age of this Formation ranges from Miocene to Recent.

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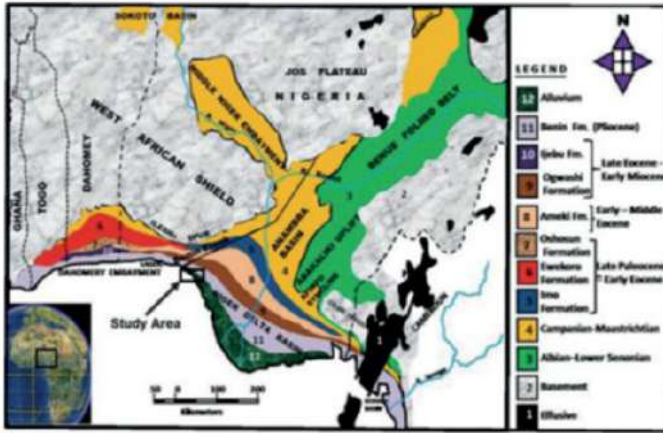


Fig. 1. Geological Map of Nigeria showing the Location of the Study Area (Niger Delta) (modified after Murat, 1972)

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AGE	FORMATION	LITHOLOGY	THICKNESS	SEDIMENTARY CYCLE	ENVIRONMENT
HOLOCENE	BENIN	[Symbol: dots]	max 2100m	DELTA	CONTINENTAL
PLEISTOCENE					
NEOGENE					
PLIOCENE	AGBADA	[Symbol: horizontal dashes]	3000m	REGRESSION	TRANSITIONAL TO MARINE
MIOCENE					
OLIGOCENE	AKATA	[Symbol: vertical dashes]	600 - 6000m	MODERN NIGER	MARINE
EOCENE					
PALEOCENE					

Fig. 2. Generalized Lithostratigraphy of Niger Delta (Nwangwu, 1990)

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While Agbada Formation extends throughout Niger Delta clastic wedge and has a maximum thickness of about 3962 m. The lithologies of this Formation include alternating sands, silts and

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shales. Strata in the Agbada Formation are believed to have been produced in fluvial–deltaic environment. Agbada Formation ranges from Eocene to Recent in age (Sanuade et al, 2017). But the Benin Formation is the top of the clastic wedge Niger Delta. The top of this Formation consists of the recent sub aerially exposed delta top surface. The shallow part of Benin Formation is made up of non-marine sands that were deposited in either upper coastal plain or alluvial depositional environments (Doust and Omatsola, 1990). Benin Formation ranges from Paleocene to Recent in age (Short and Stauble, 1967).

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The Niger Delta Depobelts represent successive phases of delta growth. They are composed of bands of sediments about 30–60 km wide with lengths of up to 300 km, (Stacher, 1995). They form when paths of sediment supply are restricted by structural deformation, focusing sediment accumulation into restricted areas on the delta. Depobelts can eventually change location when local accommodation gets filled and the locus of deposition will shift basinward (Doust and Omatsola, 1990).

2. METHODS AND DATA

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The data available and used for this study include digital 3-D seismic data, well logs data and well header, biostratigraphic data and check shot data. The base map of OGEY field (Figure 3) reveals certain information about the field including the location of shot points, the location of wells within the field and coordinates of field borders with the locations of the four wells(OGEY1, OGEY2, OGEY3 and OGEY4) used for this study.

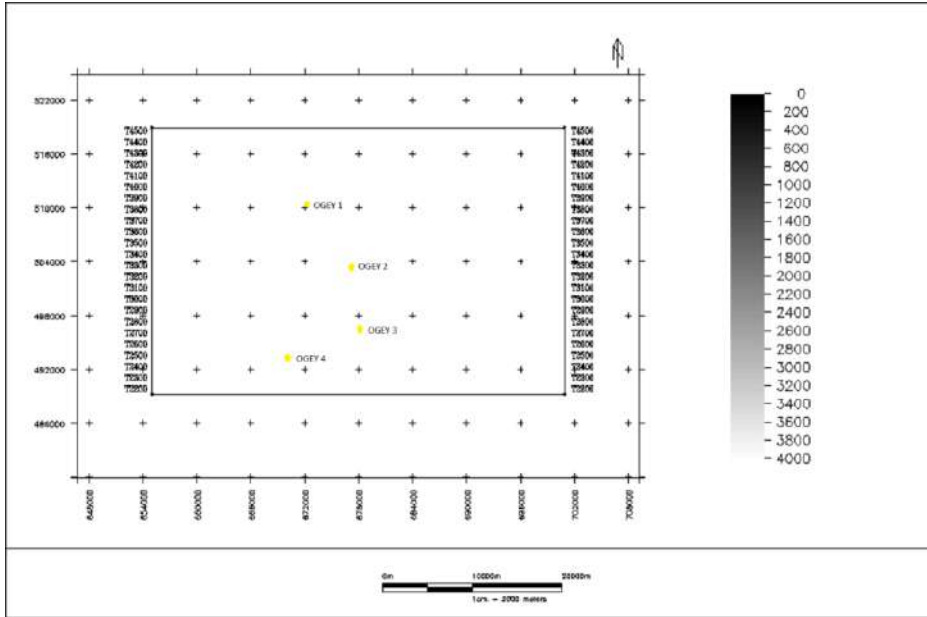


Fig. 3. Base map of OGEY Field.

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The Post-stacked 3D seismic data (SEG-Y format). Each seismic section is displayed with a linear scale of two-way travel times in milli-seconds which increases downward. The horizontal axis is distance (km). Table 1 shows the summary of the well log data sets from four wells. It was used to facilitate the identification of geologic formation, fluids, correlation between wells, facies relationship and depositional environment of sediment. The well log data was also correlated with seismic sections for accurate geologic interpretation. The Biostratigraphic data was available for Ogey-001 well (Table 1). It was used to validate sequence stratigraphic interpretation from both seismic sections and wireline logs. Also the Checkshot survey information was available for the four wells (Table 1). It was used to produce time-depth plots of the wells. The time-depth plots were used for the seismic to well ties to enhance structural and stratigraphic interpretation.

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Table 1. Table Showing Logs and Biofacies Data Present in the Wells.

LOG/WELLS	Ogey _001	Ogey _002	Ogey _003	Ogey _004
Caliper	x	x	x	X
Gamma Ray
Deep Res
Density
Neutron
Sonic
Check shot
Biostratigraphic data	.	X	x	X

.	Available
x	Not available

Key

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Ogey_001 or OGAY1

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The methodology workflow that was adopted for this research work starts from the data analysis and interpretation which includes data loading and quality control, chronostratigraphic correlation, well log interpretation, seismic to well tie, seismic data interpretation and environment of sediment deposition definition then finally stratigraphic interpretation. Lithological identification was done with the aim of differentiating the shale and sandstone lithological units. This process was carried out using the gamma ray log. The guiding principle used is by considering the response of the gamma ray log to radioactive elements. Shales generally have higher proportion of radioactive

elements when compared to sandstone. In well logging, properties of the formation drilled are measured such as lithology of the formation, porosity of the formation and resistivity of the formation amongst others. They are normally arranged according to triple Combo logs such that they into three different tracks representing lithology, resistivity and porosity. The gamma ray and deep resistivity logs were principally used for the delineation of hydrocarbon and water bearing zones. The resistivity log is set at a logarithm scale of 0.2 – 2000 ohm-meters. At reservoir zones, gamma ray response is expected to be low, and the resistivity is expected to be high since hydrocarbons are highly resistive. This was employed for the qualitative delineation of hydrocarbon bearing sand intervals. The reservoir sands were later correlated across the wells after defining the reservoirs depositional environment to monitor their lateral continuity and probable structures within the well coverage area. Sequence stratigraphic interpretation was established by integrating lithofacies and well log data. Sequence stratigraphy interpretation was carried out using the data sets available (i.e. biofacies, well logs and seismic data). The Epoch and the ages of the key surfaces from biofacies data was then determined by corresponding the bio-zones information with the SPDC Niger Delta chronostratigraphic chart (Figure 4) defined by Armentrout, (1987), Armentrout and Clement (1991), Stacher. (1995). The stratigraphic markers identified through interpretation of biofacies is imported into petrel and then integrated into the well section as well top markers, based on the information gotten from the biofacies data. The system tracts (HST, LST, and TST) were identified on the biofacies data based on their depositional setting with their respective depth values. Then it's correlated with well log signature building sequence based on distinctive characteristics of parasequences stacking pattern. They include: the maximum flooding surfaces (MFS) and the sequence boundary (SB). The maximum flooding surfaces correspond to where there is abundance of fauna deposition while the sequence boundary correspond to where there is low deposition. One

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the well logs regions with MFS should also high radioactive reading on the Gamma ray log, coupled with high density readings. SB should show evidence of erosion or truncations on well logs. For more detailed stratigraphic work, one could attempt to do a seismic sequence analysis. The result of the seismic sequence analysis is compared to that gotten from well logs and biofacies data, both information is integrated to get a more detailed stratigraphic information. A well tie is used in generating a synthetic which is compared with the original seismic to properly tie well top markers to a particular event on the seismic profile. This involves using the sonic log (when inverted yields velocity) and density log to generate an acoustic impedance log, a reflection coefficient series is then generated from each of the acoustic impedance boundary using the zero offset reflectivity formula. The synthetic seismogram (figure 5) was generated by the convolution of the reflection coefficient of each lithological unit with a Ricker wavelet containing a frequency of 30Hz which is within the frequency range of the base seismic data. It was observed that at this frequency, the 3-D base seismic data was at zero- phase. At the zero-phase wavelet, the maximum amplitude coincides with the spike of the reflector and the pattern of the wavelet becomes symmetrical. From the seismic-well tie, it was also observed that there was a perfect match between the seismic and the synthetic seismogram.

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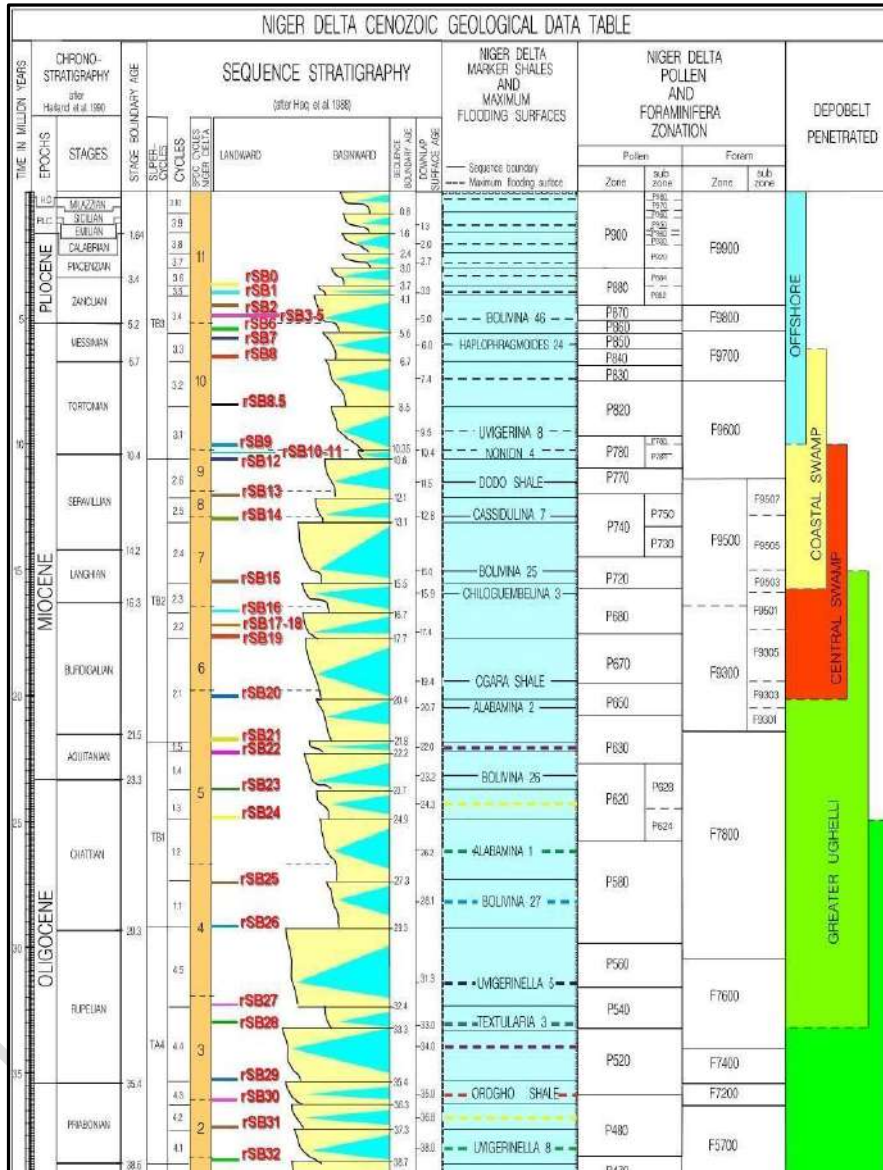


Fig. 4. SPDC Chronostratigraphic Chart of Niger-Delta (Emery and Myers1996).

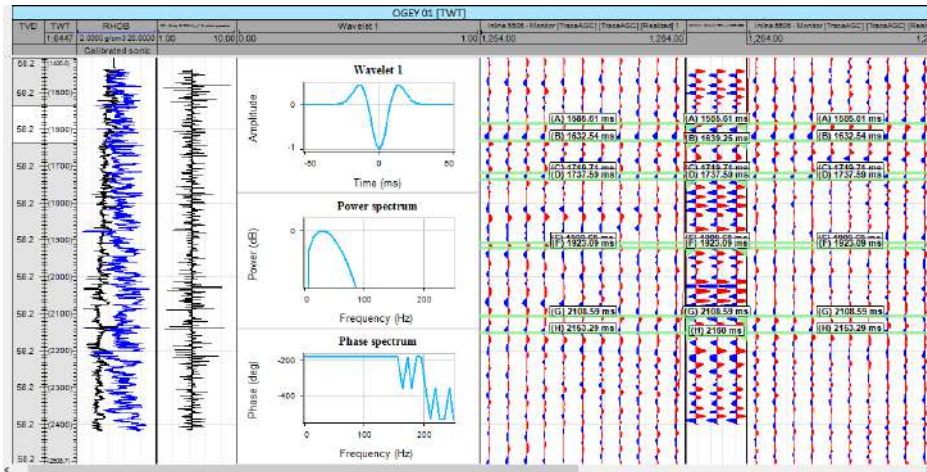


Fig. 5. Synthetic Seismogram generated from the convolution of the reflectivity series and a wavelet.

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The log motive approach was used in establishing the sedimentary facies, their successions and environments of deposition in this field. This was based on the fact that mechanism of sediment deposition varies from one deposition setting to the other (Asqith and Gibson 1982, Wagoner *et al.*, 1990). This results to difference on vertical facies succession. Log signature may be associated with wide range of depositional environment.

The facies is the sum of characteristics of a rock including its chemical, physical and biological features that distinguishes it from adjacent rock, seismic facies are therefore defined as seismically defined bodies that exhibit similar patterns, attributes and reflection. Seismic facies unit is a mapped, three dimensional seismic unit and there are four major types of features used to define separate facies unit which are; Seismic amplitude, Reflection geometry. Reflection continuity and Wavelet frequency.

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3. RESULTS AND DISCUSSION

Focusing on the stratigraphic interpretation 'OGEY' field, the lithology identified within the field are sand, sandy shale and shale respectively. The sequence boundaries identified were dated 20.4Ma, 17.7Ma, 15.50Ma, 12.10Ma and 10.35Ma while the Maximum Flooding surfaces were dated 19.4Ma, 15.9Ma, 12.80Ma, 10.4Ma, and 9.6Ma respectively. The result revealed three system tracts which are LST, TST and HST which indicated five depositional sequences (Figure 6). Four seismic sequences were observed in this field and they are SF1, SF2, SF3, and SF4. The first Maximum Flooding Surface recognized in the OGEY 01 well was dated 19.4Ma at a depth of 10800ft characterized by the Ogara shale marker on the chronostratigraphic chart. The 20.4Ma SB, 19.4 Ma MFS and 17.7Ma SB occurred within the SPDC foram F9300 zone. The second Maximum Flooding Surface was dated 15.9Ma characterized by the Chiloguembelina 3 shale at a depth of 10050ft, the third Maximum Flooding Surface was dated 12.80Ma characterized by the Casidulina 7 at a depth of 9450ft. The 15.9Ma MFS, 15.5Ma SB, 12.80Ma MFS and 12.1Ma SB are within the F9500 zone. The F9300 zone to F9500 zone indicates that sediments are within the middle Miocene Epoch (Table 2). The fourth Maximum Flooding Surface was dated 10.4Ma characterized by Nonion 4 shale marker at a depth of 8370ft and the fifth Maximum Flooding Surface was dated 9.6Ma characterized by the Uvigerina 8 shale marker at a depth of 7370ft. The 10.4Ma MFS, 10.35Ma SB, and 9.6Ma MFS are defined in the F9600 Zone indicating Late Miocene Epoch. For the paleoenvironment interpretation, it is observed that there is a high proportion of shale (90%) over the well section is indicative of dominance of low-energy depositional conditions. The lower part of the well section (11330 – 7890ft) is dominated by rich and diverse deep water calcareous benthics. Since the abundance calcareous are indicative of lower bathyal environments and abundance of arenaceous are indicative of upper bathyal environments, the analysis of the data

shows that the above foraminiferal association is indicative of sediment deposition in a lower to upper Bathyal environments.

Table 2. Summary of Biostratigraphic studies, showing determined key surfaces, depth of occurrence, foram zones and their Epoch

KEY SURFACES AGE	MD (FT)	F-ZONE	EPOCH
9.6Ma MFS	7370	F-9600	LATE MIOCENE
10.35Ma SB	8156		
10.4Ma MFS	8370		
12.10Ma SB	9300	F-9500	MIDDLE MIOCENE
12.80Ma MFS	9450		
15.50Ma SB	9970		
15.9Ma MFS	10050		
17.7Ma SB	10330	F-9300	
19.4 Ma MFS	10800		
20.4Ma SB	11310		

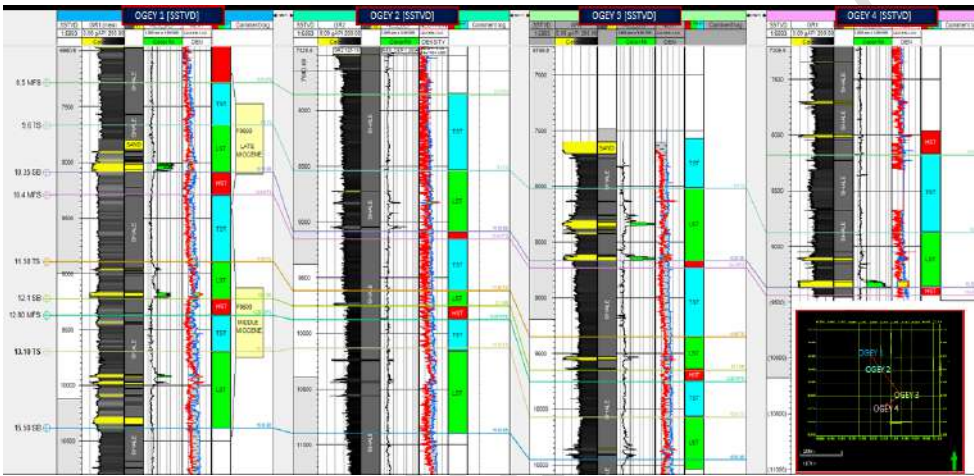


Fig. 6. Depositional Sequences of 'OGEY' Field Interpreted on Wireline Log and Correlation Supported with Biostratigraphic Information

3.1 Seismic Interpretation

The 3-D Seismic Interpretation approach when integrated with the well logs by comparing marker beds or other correlation points picked on well logs with major reflections on the seismic section can improve the interpretations of the data laterally and vertically. This section describes results from seismic-to-well tie, fault mapping, horizon mapping and time-depth conversion as shown in Figures 7-9.

3.2 Seismic Sequence Analysis and Facies Unit

Four (4) major sequences (Figure 10a and 10b) were observed in this field by analyses of the reflection terminations (amplitude, continuity, toplap, and truncation) and observation of seismic parameters (amplitude, continuity, configuration and frequency) and external geometries (tabular, lenticular, mounded, wedge etc.), each of these seismic sequences is then further sub-divided into two seismic facies after analyzing the characteristics. Brief description of each of them are provided below: Seismic Sequence 1: This interval is the bottom part of the seismic data (Figure 10a) to a range of about -3252 milliseconds (i.e., from the bottom part to the blue line on Figure 10a, it is also represented on Figure 10b from the bottom to the brown line), this is controlled by post deformations as a result of mobile shale diapirism. Reflection in this sequence display parallel internal configurations being concordant to the sequence boundaries. This sort of configuration indicates unique form sedimentation conditions for an infill or a sequence on top of subsidising substraction (Veeken et al., 2006).

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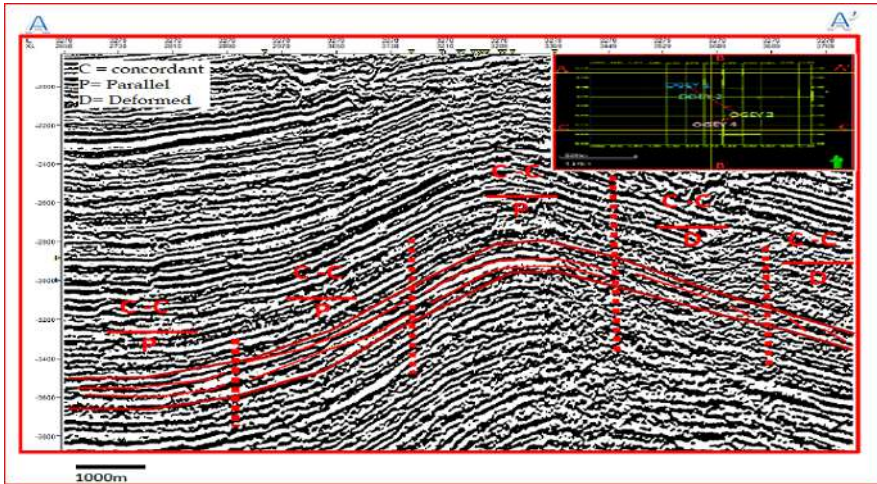


Fig. 7. Geometric Capturing Approximately along West to East (A to A') of 'OGEY' Field on inline 3270

Field on inline 3270

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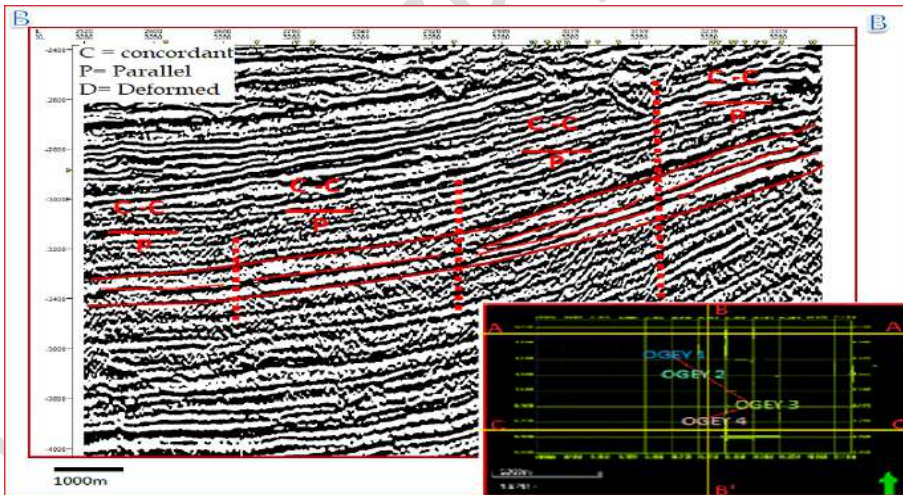


Fig. 8. Geometric Capturing Approximately along North to South (B to B') OF 'OGEY' Field on Crossline 3280

'OGEY' Field on Crossline 3280

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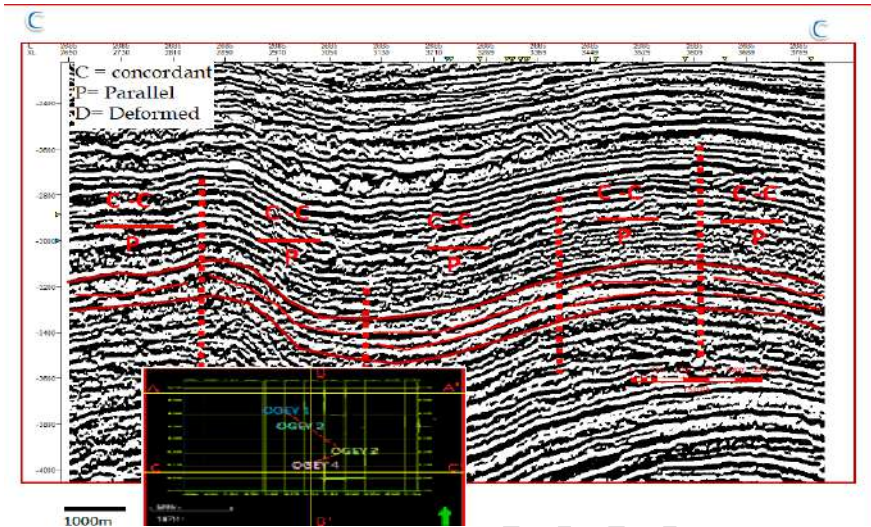


Fig. 9. Geometric Capturing Approximately along West to East (C to C') of 'OGEY' Field on inline 2665

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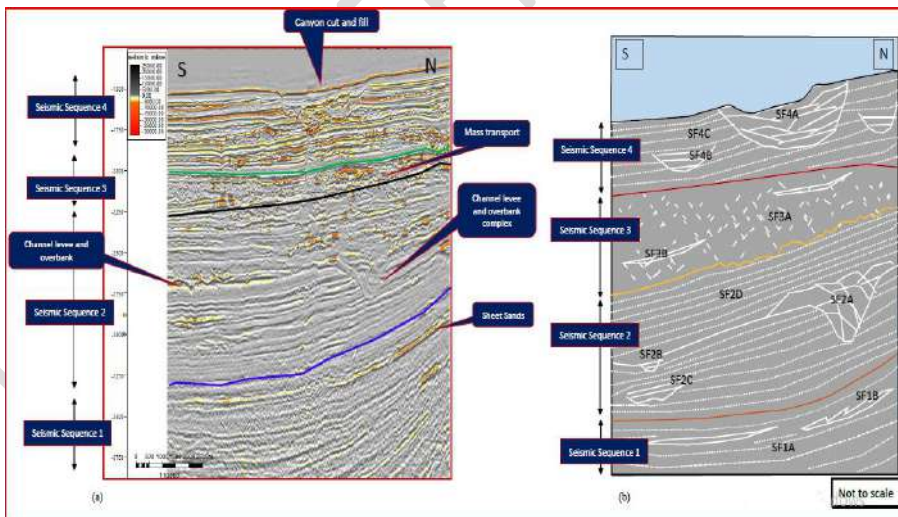


Fig. 10. Seismic facies interpretation on inline 3480 (a) Interpreted Section for Seismic Sequence Analysis of 'OGEY' Field. (b) Schematic Image Illustration Facies Unit Identified Within Each Sequence.

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3.3 Environment of Deposition Definition

The results defined from the Integration of well logs, biofacies, and seismic data confirms that the environment of deposition for the field is deep offshore with depositional units ranging from Turbidite sand to Sheet sands, Channel Levee and Overbank Complex, Canyon Fills and Mass transport Deposits (Figure 10).

4. CONCLUSION

The stratigraphy of 'OGEY' field, deep offshore Niger Delta has been interpreted using the concept of sequence and seismic stratigraphy. This was done by integrating wireline log, biofacies and 3D poststack seismic data. Five Maximum Flooding surface and Five Sequence Boundaries were identified and utilized to subdivide the stratigraphic succession into five depositional sequence and their corresponding system tracts. Three system tracts are present in each depositional sequence. These are the Lowstand System Tracts, Transgressive Stage System Tracts and the Highstand System tracts. Seismically, 'OGEY' field comprises four seismic sequences with their Facies unit identified. The seismic sequence one contains two Facies units: SF1A (reflections with low medium values of amplitude, medium values of frequency and continuity) and SF1B (high amplitudes discontinuous (i.e., low continuity) with medium frequency). The external geometry observed within the seismic sequence one was sheet forms and interpreted to be possibly either distributary channel sands or weakly confined channels, the other depositional sequences have their peculiar characters relative to sequence one.

5. RECOMMENDATIONS

Further interpretation on Spectral Decomposition should be done to properly image the boundaries of channel axes, margins and splays. This would greatly contribute to accuracy of assigning wells to be drilled in the study area. Also, wells assigned closer the channel axis. This is

because the axis contains more potential holding capacity for hydrocarbon storage. More wells drilled can also help to understand the nature of connectivity and quality of the reservoirs.

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