



Integration of Seismic Facies and Seismic Sequence analysis for Depositional Environment Reconstruction of nandy Field, Niger Delta

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Abstract

An integrated seismic sequence stratigraphy and facies analysis has been carried out with a view to understanding the depositional environment and stratal stacking pattern of Nandy Field of Niger Delta. Well logs and biostratigraphic information were used to identify the lithologies, stratal stacking patterns, stratigraphic surfaces, system tracts and reservoir potentials of the field. Seismic sequence stratigraphy and seismic reflection patterns were used to identify the seismic facies. Facies-related attributes were employed to identify the continuity and amplitude of seismic events. Three seismic facies packages and three reservoir sands were identified. The environments of deposition of the area consist of marginal marine to continental depositional settings predominantly made of shoreface deposits with few channel sands. The depositional model of the area shows that the deposition went down the axis of fluvial depositional system, which transports sediments through channels down to the shelf into the base of the slope down the basin. The seismic reflection patterns in this field are parallel to divergent reflections, high-continuity and high-amplitude facies, low-amplitude facies, low-continuity and variable-amplitude reflections, chaotic reflections and wavy reflection patterns. The seismic stratigraphic analysis of this field revealed the presence of low stand system tract (LST), high stand system tract (HST) and transgressive system tract (TST). Sands 1 and 2 were delineated within high stand systems tract (HST) while sand 3 was within low stand systems tract (LST). The results of this study show that the Nandy Field was of high hydrocarbon potentials and highlight the importance of using seismic reflection parameters (reflection configuration, amplitude, frequency and continuity) in the division and classification of seismic facies.

Keywords: Facies analysis; Niger Delta; sequence stratigraphy, system tracts

Introduction

Seismic stratigraphy and facies analysis are essential component of the present day exploration and in the development of oil and gas plays. A huge aspect of the value of seismic facies analysis depends however on whether or not local geological factors have been taken into account correctly.

Interpretation of sand-shale depositional facies from seismic reflection data is based on a procedure known as seismic facies analysis [1]. It involves the delineation and interpretation of reflection configuration and other seismic parameters within the seismic-sequence correlation framework. These parameters that are reflection configuration, amplitude, continuity, frequency and interval velocity are interpreted to express certain gross lithologic, stratification, and depositional features of the sediment generating the cycle [1]. Reflection configuration reveals the gross stratification patterns from which depositional processes, erosion and paleotopography can be interpreted. Reflection amplitude contains information on the velocity and density contrasts at individual interfaces and on the extent of

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interbedding. Continuity of reflections is closely associated with continuity of bedding while frequency is primarily a characteristic of the nature of the seismic pulse and it is also related to such geologic factors as the spacing of reflectors or lateral changes in interval velocity [2].

Each of these seismic reflection parameters 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. These units are often interpreted within the chronostratigraphic connotation of the seismic sequence framework.

Seismic reflection configuration is the most obvious and directly analyzed seismic parameter. It is commonly interpreted in terms of environmental setting, depositional processes and lithology estimates of the strata involved. Stratal configuration is interpreted from seismic reflection configuration, and refers to the geometric patterns and relations of strata within a stratigraphic unit. The integration of these seismic reflection elements with all available data other than seismic (e.g. well log, biostratigraphic data, etc) affords a reasonable prediction of depositional environment, lithology and later structural movement.

Synthesis of seismic facies analysis and seismic sequence stratigraphy can help reconstruct basin paleogeography and provide useful insights to a basin's petroleum system.

Nandy Field is located in the onshore Niger Delta. By using the seismic-sequence stratigraphic approach as described by [3], the interpretation of seismic reflection patterns in depositional sequences is done by integrating seismic data, well log data sets and biostratigraphic data. This is done in order to delineate the sequence boundaries (SB), maximum flooding surfaces (MFS), transgressive surface of erosion, the system tracts and also predict the environment of deposition of the sand bodies within the field.

Geology of Niger Delta

The Niger delta, reputed as one of the most prolific petroleum province in the world is found in the Gulf of Guinea on the west coast of Central Africa. It is located at the south-southern part of Nigeria. It is bounded in the south by the Gulf of Guinea and in the North by older (Cretaceous) tectonic elements that include the Anambra Basin, Abakaliki uplift and the Afikpo syncline. In the east and west respectively, the Cameroon volcanic line and the Dahomey Basin mark the bounds of the Delta, Figure-1. The Cenozoic Niger Delta is situated at the intersection of the Benue trough and the South Atlantic Ocean where a triple junction developed during the separation of South America from Africa [4]. The delta is considered one of the most prolific hydrocarbon provinces in the world, and recent giant oil discoveries in the deep water areas suggest that this region will remain a focus of exploration activities [5].

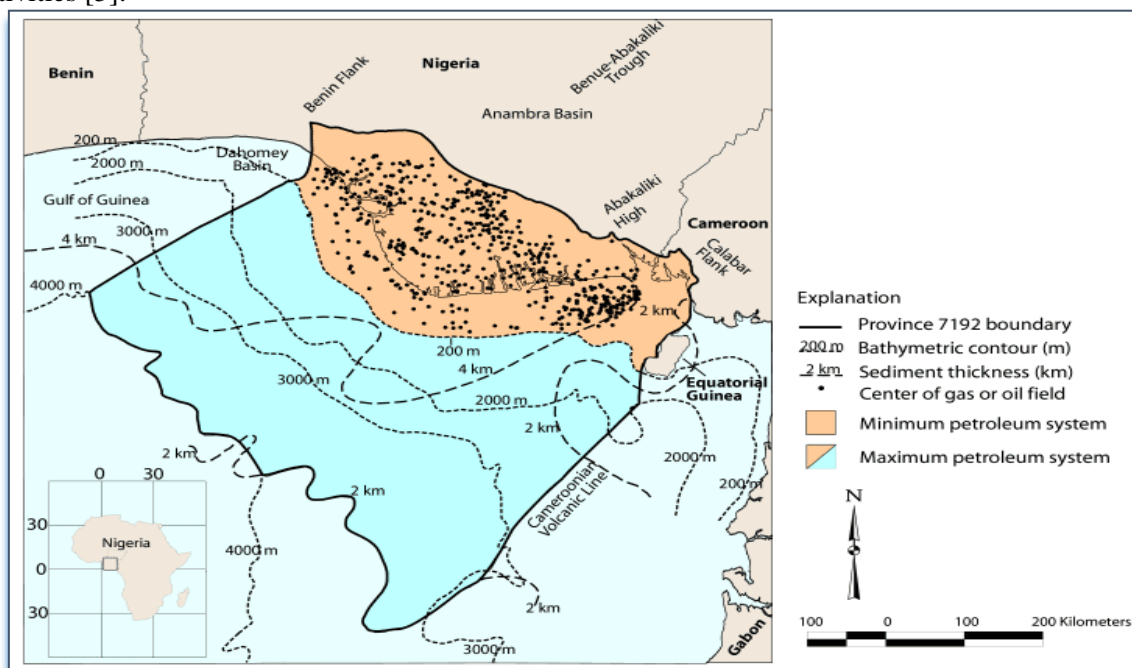


Figure 1-Index Map of Nigeria and Cameroun. Map of the Niger Delta [6]

Materials And Methods

The following datasets were available for this work: base map, well logs (resistivity, gamma ray and sonic logs), check shot and biostratigraphic data. The gamma ray and resistivity logs were used to identify the interfaces between the lithofacies (sand and shale) within Nandy Field and correlated across the Field.

Preliminary estimates of sequences and systems tracts were made by first interpreting the depositional lithofacies on wireline logs. The stratigraphic surfaces were identified and correlated using composite suites of gamma, resistivity and sonic logs. The maximum flooding surfaces (MFS) were delineated by identifying points of high gamma, low resistivity and low sonic on the logs. The result was constrained by the use of biostratigraphic data. The MFS contains the condensed section noted for its high p-wave velocity or low interval transit time. It also contains radioactive shale responsible for high gamma and highly conductive marine-derived glauconite that accounts for the low resistivity of this surface. The column above this surface was taken to be the High Stand Systems Tract (HST) and above the HST was the Low Stand Systems Tract (LST).

Seismic facies were identified by mapping units described by seismic reflection parameters such as reflection configurations, reflection continuity, reflection amplitude, reflection frequency, geometric relations between reflectors and general reflection form.

Depositional environments were delineated by studying the log trends (fining upwards, coarsening upwards) of the well logs and also from the information from biostratigraphic data.

Biostratigraphic data consisting of microfaunal abundance and diversity chart were used in the delineation of the maximum flooding surfaces (MFSs), paleobathymetric interpretation and age determination of some of the surfaces. The age of the surfaces were determined using Niger Delta chronostratigraphic chart [7]. Areas of high Foram abundance and diversity were interpreted as MFS. The synthetic seismogram was generated using density and sonic logs and tied to the seismic data as a control. The well markers were interpreted as sequence boundaries. The events were identified and picked in the identified reservoir within the HST in time along in-line and cross-line using different densities. The loops and sand tops were tied with sands 1 and 2 tops corresponding to peak on the seismic section while sand 3 top corresponds to trough.

Faults were identified and mapped across the seismic section. Fault model was generated in order to have a clear view of the faults in the field. Reflection terminations and seismic reflection patterns were also identified and mapped. The onlap, toplap and other reflection termination patterns were clearly delineated and mapped on the seismic section.

The systems tracts were identified by studying the gamma-ray log, sonic log, resistivity log and biostratigraphic data from the wells. The highstand systems tract, which is characterized by an aggradational to progradational parasequence set, was overlain by a sequence boundary and underlain by maximum flooding surface. The lowstand systems tract, overlain by a transgressive surface and underlain by type 1 sequence boundary is characterized by a progradational to aggradational parasequence set. The transgressive systems tract, characterized by a retrogradational parasequence set is overlain by a maximum flooding surface and underlain by a transgressive surface.

Seismic sequence stratigraphic framework was built by tying the identified stratigraphic surfaces with the seismic section and correlating them across the Nandy Field. The stratal stacking patterns delineated from the well logs were tied to the seismic section and each depositional setting across the section were mapped. Each boundary was demarcated by lines of different colours running through them. Subdividing the seismic section into different depositional setting was done using Possamentier and Allen (1999) model Figure-2. Each depositional setting was coloured and legend developed for their easy recognition.

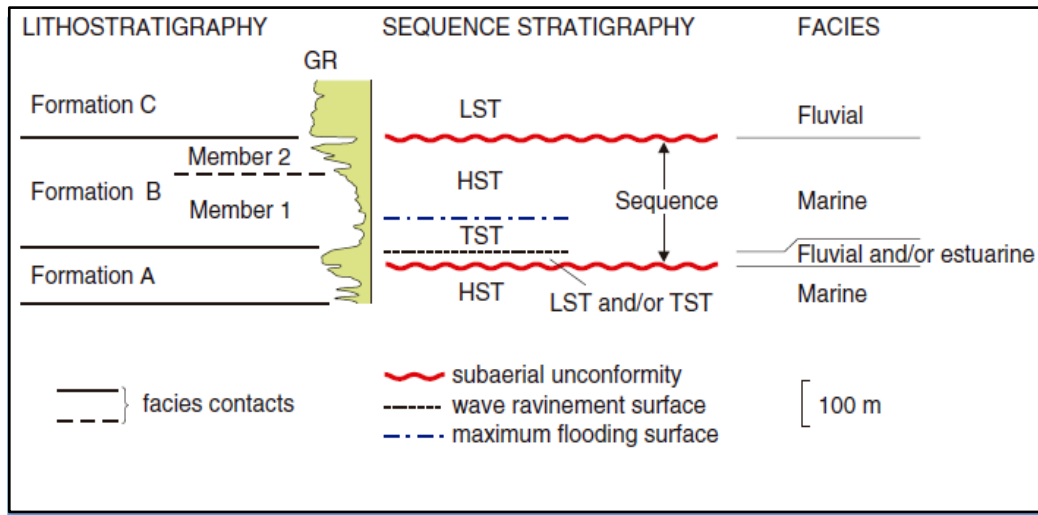


Figure 2-Lithostratigraphic and Sequence Stratigraphic Log Interpretation of a Gamma Ray [8].

Facies and porosity-related seismic attributes were extracted from the seismic data in order to analyze the facies include envelope, instantaneous phase, relative acoustic impedance, and instantaneous frequency which in several work has shown to have relationship with facies and porosity distribution [9].

Each attribute was extracted on the top of the sandstone reservoir map. The time (search) window of extraction of 100ms below the top horizon showed good results.

Results And Discussion

Figure-3 shows the northwest to southeast correlation of the reservoir sands top and base across the four wells using gamma ray, resistivity and neutron/density logs. Sand 1, which is the shallowest reservoir, is located at the depth of about 2560m below the surface and has a thickness of about 80m, sand 2 is located beneath sand 1 at about 2661m and 86m thick while the basal sand 3 is at a depth of 2989m and about 283m thick.

The thickness of shale in each well increases from northwest to southeast direction. This is an indication of basinward movement of facies.

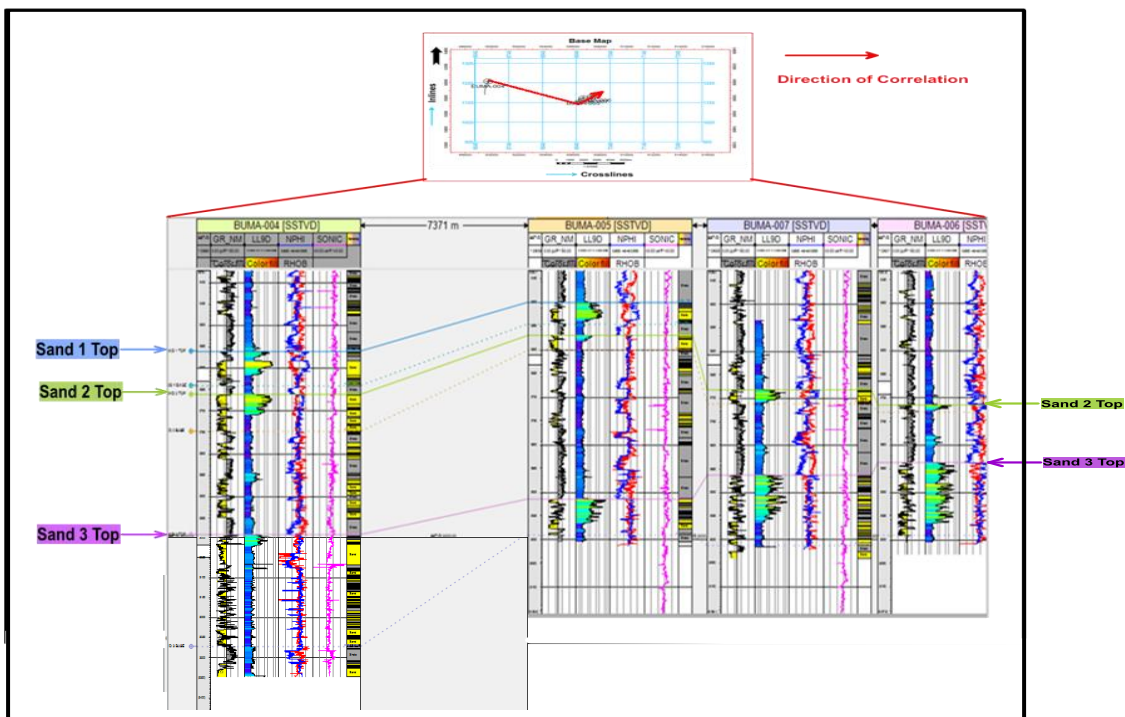


Figure 3-Northwest to Southeast Well Correlation of the Reservoir Sands.

Figure-4 shows key stratigraphic surfaces correlated in the northwest-southeast direction. High gamma ray, low resistivity and low interval transit time (high p-wave velocity) depicts the position of the maximum flooding surfaces (MFS 1, 2 and 3). The high gamma ray of these surfaces is due to high concentration of radioactive elements in shale, low resistivity values are due to the presence of high conductive glauconitic materials while high values of P-wave velocity (low interval transit time) is as a result of high density of the surface. Sequence boundaries 1 and 2 (CSB 1 and 2) mark an abrupt upward change from an aggradational log motif to a progradational log motif. The two transgressive surfaces (CTS 1 and 2) are surfaces between prograding units and overlying retrograding units.

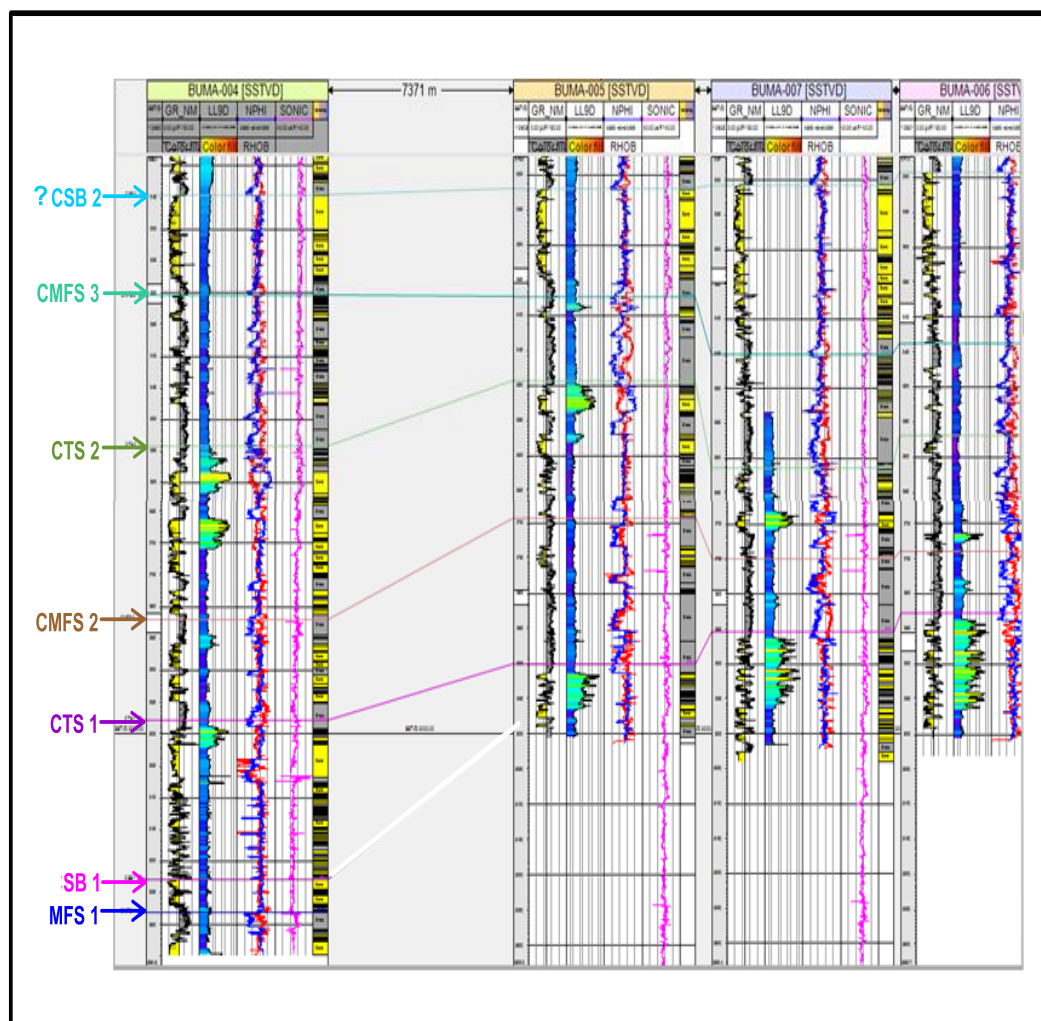


Figure 4-Correlation of the Key Stratigraphic Surfaces in the Northwest-Southeast Direction.

The seismic facies in the Nandy Field of Niger Delta are characterized by layered strong reflector units, weak intervals and irregular chaotic units. The overall seismic section was divided into three seismic facies packages; A, B and C (Figure-5). Seismic facies units A and B were identified on layered seismic facies while unit C occurred on chaotic seismic facies.

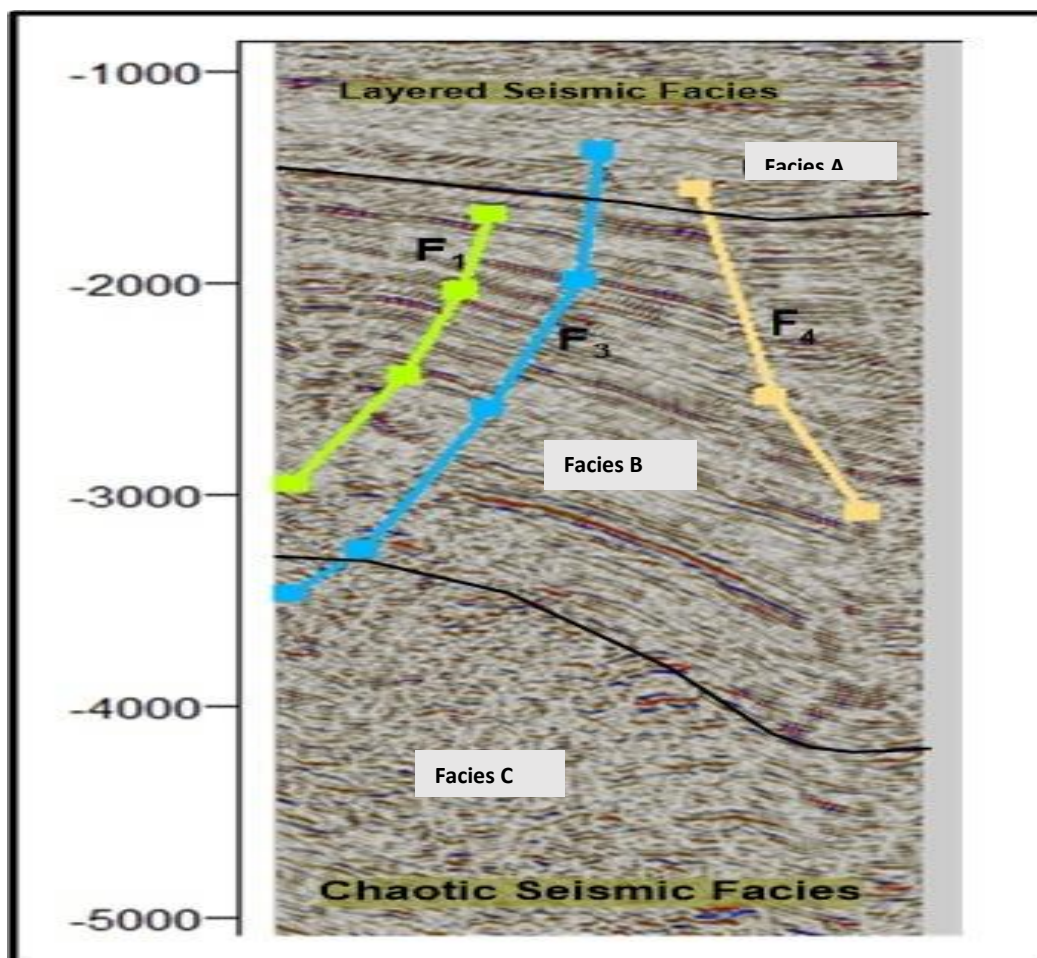


Figure 5-Seismic Line Showing Seismic Facies Packages and Faults Pattern.

Facies A (Table-1) occurred between 6665/1349 and 7315/1349 shot points in 0-1500 ms. It showed parallel to sub-parallel reflection configuration with a generally low continuous reflection continuity. The amplitude (reflection strength) was low landward of the section and moderate basinward of the section. Frequency was relatively variable throughout the seismic facies package. The reflection geometry displayed by this facies is sheet-like external form that is slightly divergent to the south, concordant at the top and downlap at the base. The seismic facies analysis in combination with paleobathymetry data showed channel deposits, distributary channels and shoreface deposits within the marginal marine to continental depositional setting. Facies B lies between 6665/1349 and 6725/1050 in 1500-3300 time window (Table 1). It displayed sub-parallel to divergent reflection configuration. A hummocky reflection pattern was observed towards the far end of the north. It is characterized by continuous reflection, low-to-high amplitude and relatively uniform to high frequency. It is concordant at the top and downlap at the base. The depositional facies is interpreted to be associated with channel deposits, distributary channels and shoreface deposits within the shelf environmental setting.

Facies C extends from 3300ms downwards and it is characterized mainly by an acoustically transparent and chaotic reflection configuration (Table-1). It is characterized by mounded geometry that is discordant at the top. The reflection continuity is highly discontinuous with a highly variable amplitude from high to low and a very low reflection frequency. The interpreted facies indicate channel deposits, distributary channels and shoreface deposits within the shelf environmental setting. Shelf seismic facies characterised by reflections having poor lateral continuity and bursts of high amplitude are typically non-marine sediment types.

Table 1-Seismic Characteristics and Depositional Facies Interpretation for Nandy Field.

Seismic Facies	Reflection Configuration	Reflection Geometry	Reflection Continuity	Amplitude	Frequency	Depositional Facies	Depositional Environment
Facies A	Parallel to sub-parallel	Sheet-like external form, Concordant at the top, downlap at the base	Low continuity	Variable	Relatively uniform and high	Channels, over-bank deposits and distributary channels	Marginal marine to continental depositional Setting
Facies B	Sub-parallel to divergent and Hummocky and fairly chaotic towards the base	Sheet drape, concordant at the top, downlap at the base	Relatively continuous	Generally low to high	Fairly uniform and moderate	Channel and over-bank deposits, distributary channels and Shoreface deposits	Shelf
Facies C	Chaotic reflection	Mounded and discordant at the top	Highly discontinuous	Highly variable, from high to low	Very low	Channel and over-bank deposits, distributary channels and Shoreface deposits	Shelf

Depositional environments were interpreted after comparing log signatures within sequences, parasequences and parasequence sets and their stacking patterns with the stacking patterns and depositional environments. The environment is predominantly made of shoreface deposits with few channel sands on top (at a shallow depth). The channel sands were evident on the blocky or cylindrical log character of sands 1 and 2 depicting uniform deposition Figure-3. Sand 3 reservoir was deposited in a predominantly shoreface environment which was seen on the log as a funnel shaped log character representing a coarsening upward unit Figure-3. The serrated coarsening upward parasequence sets located in the lower parts of sand 3 infers a storm dominated lower shoreface environment while the upper unit which is cleaner indicate upper shoreface environment.

As a whole, the stratigraphic successions within the field is a mixture of progradational and retrogradational succession of clastic sediments (Table-2) which are characterised by coarsening upward and fining upward sequences of sediments deposited during periods of relative sea level fall and rise which resulted to basinward and landward movement of the shoreline.

Table 2-Gamma-ray Facies Association, Seismic Facies Packages, Sequence Stratigraphic Framework and Depositional Systems of Nandy Field

Well-log Signature	Gamma-ray Facies and Depositional Systems	Seismic Facies Packages	Sequence-Stratigraphic Framework
Blocky (cylindrical) and Funnel shape (coarsening upward)	Fluvial channel and Distributary channels	Layered seismic facies with parallel to sub-parallel reflections	Progradation
Blocky (cylindrical) and bell shape (Finning upward)	Tidal channels and transgressive shelf	Layered seismic facies with sub-parallel to divergent reflection	Transgression
Funnel shape (coarsening upward)	Shore-face deposits	Layered seismic facies with sub-parallel to divergent reflection	Progradation

The identified maximum flooding surfaces (MFS), sequence boundaries and transgressive surfaces are shown in Figure-6. Finning upward sequence, which is associated with transgressive system tract, is represented by blue arrow while coarsening upward sequence and blocky log signature associated with low stand and high stand systems tracts are represented by red and green arrows. There are two inferred sequences, sequence 1 and 2, with no LST in sequence 2. This is because there was no clear indication of a sequence boundary (SB) after the first sequence and also due to the fact that the facies were moving landward. Sequence 1 consists of Low Stand Systems Tract (LST), High Stand Systems Tract (HST), and Transgressive Systems Tract (TST) while sequence 2 contains only TST and HST. The reservoir sands 1 and 2 occurred within the HST while sand 3 occurred within LST. The three reservoir sands, their depths of occurrence, thicknesses, porosities, associated systems tracts and their stacking patterns are shown in Table-3.

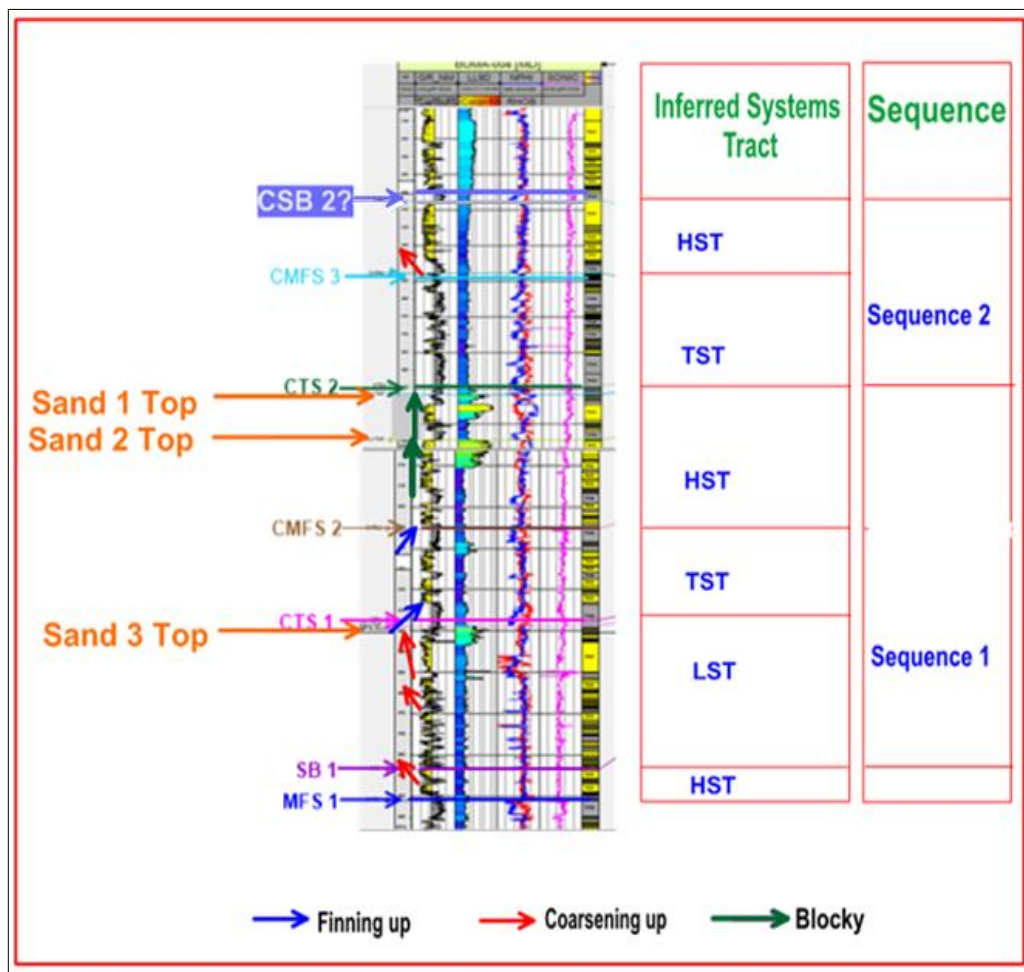


Figure 6-Identified Systems Tracts, Sequences and their Corresponding Key Surfaces.

Table 3- Hydrocarbon Occurrence and Associated Systems Tracts.

Reservoirs	Depth Interval (m)	Thickness (m)	Porosity	Water Saturation	System Tract	Stacking Patterns
Sand 1	2560-2640	80	0.27	0.16	HST	Aggradational/Progradational
Sand 2	2661-2747	86	0.25	0.17	HST	Aggradational/Progradational
Sand 3	2989-3271	283	0.25	0.20	LST	Progradational

The synthetic seismogram used to recognize event marking the top and base showed sand 1 top and base to be a peak Figure-7. Well-to-seismic tie was done by placing the well logs on the seismic section Figure-7(a, b). Figure-8 shows the seismic section with the delineated surfaces and systems tracts

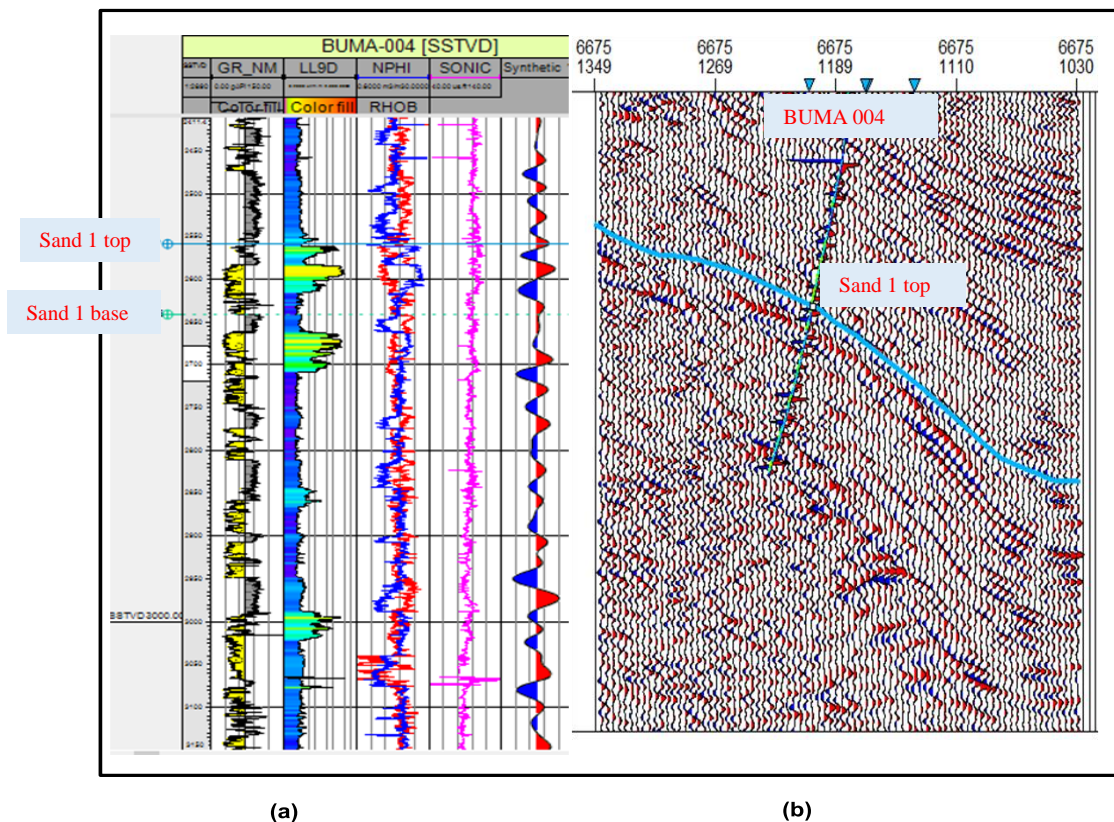


Figure 7- (a) Synthetic Seismogram Indicating Sand 1 Top and Base (b) Well-to-Seismic Tie showing Sand 1 Horizon (blue line) with Synthetic Seismogram.

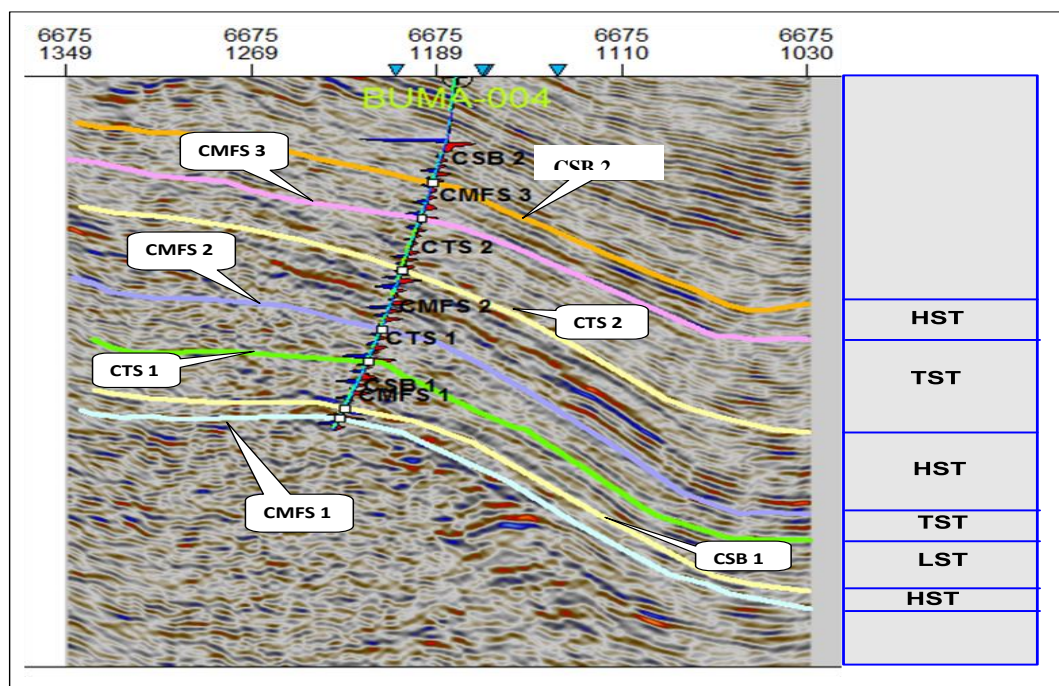


Figure 8-Seismic Section with Synthetic Seismogram Showing the Delineated Surfaces and Systems Tracts

Figure-9 shows the mapped faults and the delineated seismic reflection patterns. All the faults are listric faults that were caused by differential loading of sediments and subsequent movement of the diapiric Akata Formation of Niger Delta Basin. The reflection patterns are downlap, onlap and chaotic reflections. The mobile shale of the Akata Formation gave rise to the chaotic reflections. The reflection pattern is gently dipping at some points indicating partial tilting of the initially horizontal beds while in some parts, it is almost horizontal reflecting the presence of aggradation in transgressive system tract which was observed from the well logs. The clinoforms are not well developed because the area of study is a shelf environment.

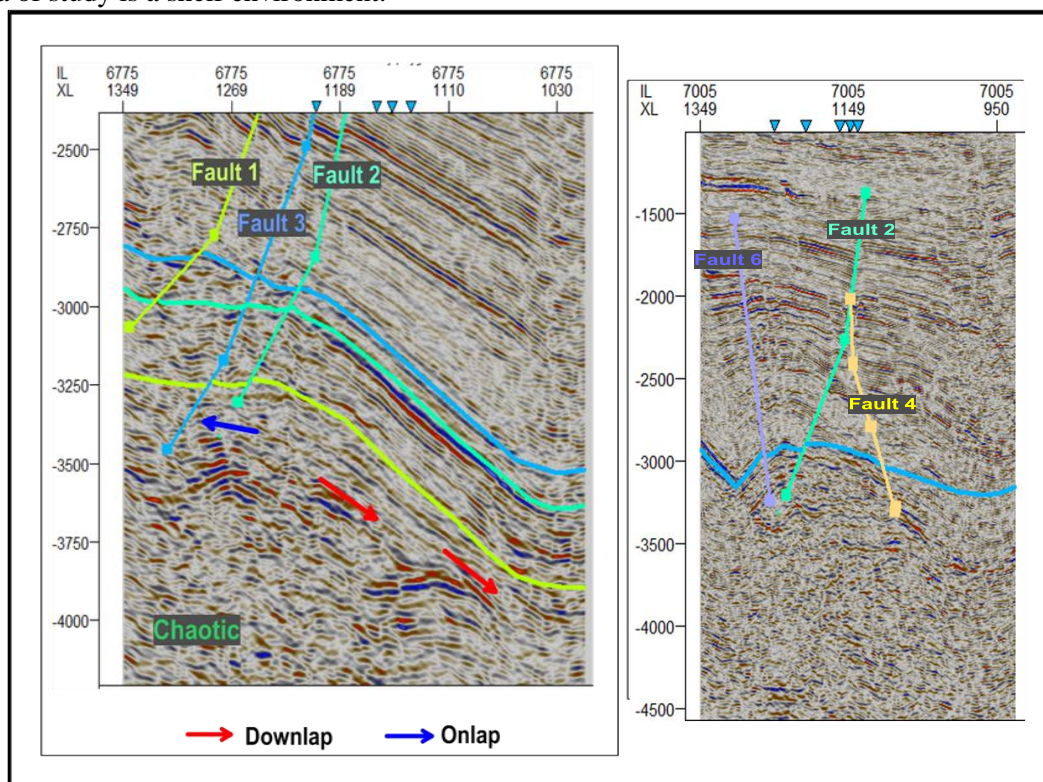


Figure 9- Interpreted Faults 1, 2, 3, 4 and 6 and Reflection Terminations.

The listric faults, (faults 1, 2, 3 and 6) viewed in 3D are shown in Figure-10. Faults 2, 1 and 3 dip to the northern direction while fault 6 dips to the south.

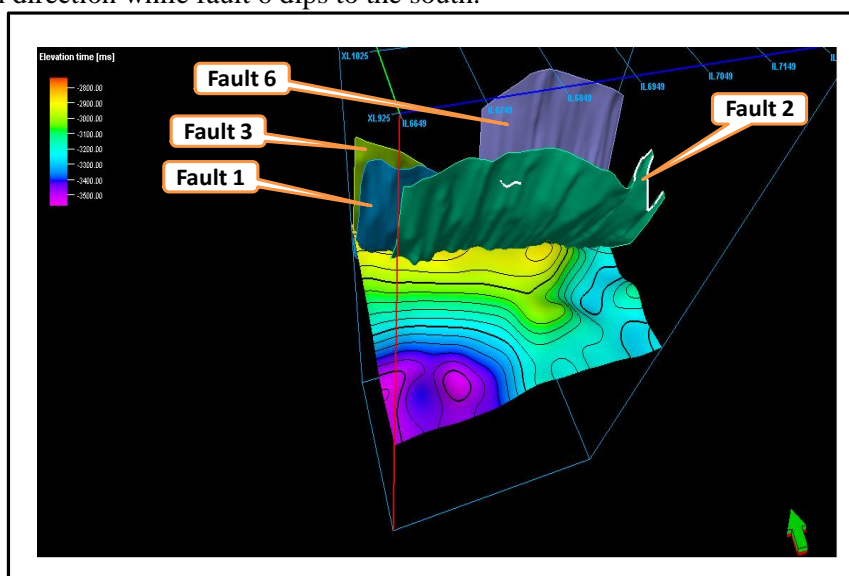


Figure 10-3D View of the Listric Faults with the Major Fault, Fault 2, Faults 1 and 3 Dipping to the North.

The seismic sequence stratigraphic framework showing the delineated surfaces, systems tracts and their corresponding well logs are shown in Figure-11. Three maximum flooding surfaces (two of which are candidate maximum flooding surfaces, CMFS), two candidate transgressive surfaces (CTS) and two sequence boundaries (one of which is a candidate sequence boundary, CSB) were identified in the field. The first MFS dated 11.5Ma during the Miocene on the Niger Delta cycle chart inferred at 3290m (10793ft) in well 04 is at P770 zone (at the top of P740 and below P780). This was only identified in this well because well 04 is deeper than all other wells. CMFS 2 and CMFS 3 were located in well 04 at depth 2820m and 2304m respectively. These were correlated to 2693m and 2380m in well 05, 2748 and 2450m in well 07 and 2732m and 2440m in well 06 respectively. The CTS 1 and CTS 2 were located at depth 2978m and 2542m in well 04 respectively while in well 05, they are at depths 2897m and 2496m, well 07, at 2853m and 2614m depth and in well 06 they are at depths 2827m and 2570m. SB 1, dated 10.6Ma also during the Miocene was identified at depth 3287m (10784ft) in well 04 only because other wells did not penetrate to this depth. CSB 2 was located at the depth of 2280m, 2337m, 2418m and 2354 in wells 04, 05, 07 and 06 respectively.

There are three systems tract available in the field, LST, TST and HST. The first two reservoirs, Sand 1 and Sand 2 fall within the HST while Sand 3 fall within the LST.

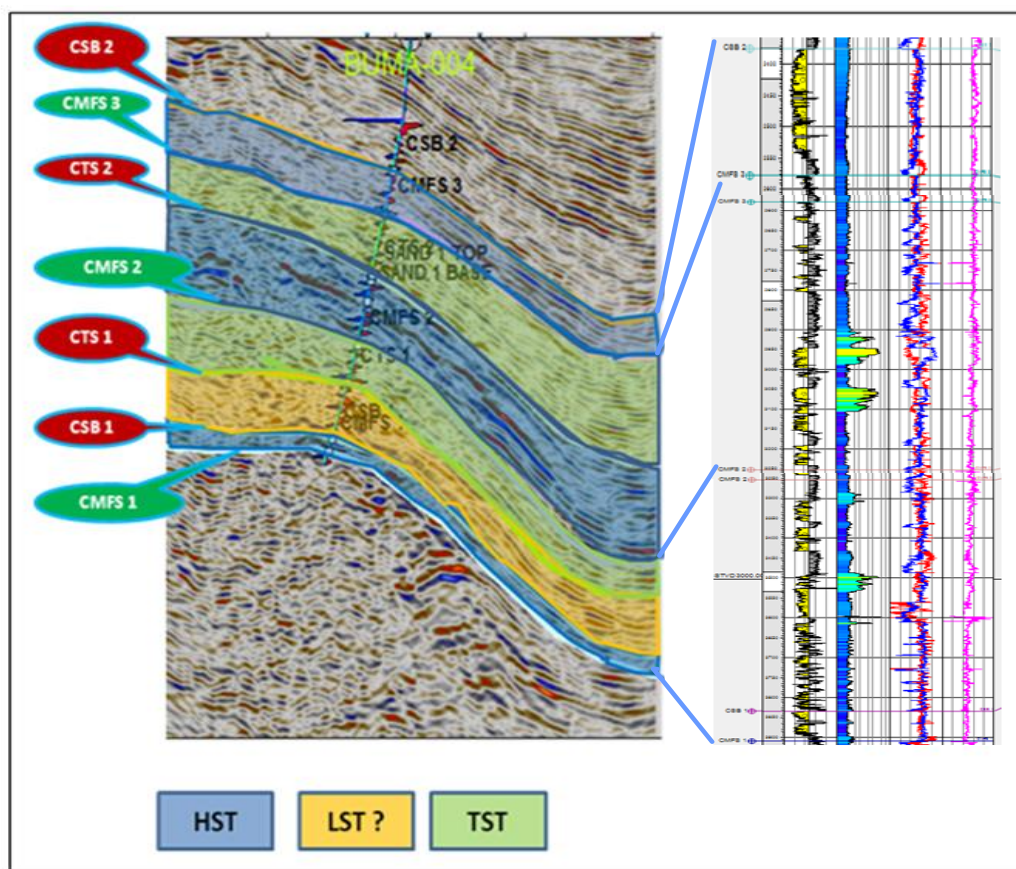


Figure 11-Seismic Sequence Stratigraphic Framework (Seismic Section Indicating the Delineated Surfaces, Systems Tracts and their Corresponding Gamma Ray Log).

Conclusion

This study shows that the depositional pattern of the Nandy Field of Niger Delta formed as a result of variation in channel behaviour along the shelf and slope channel systems. The environment is predominantly made of shoreface deposits with sandy channels. This is characterized by deposition within the neritic and inner neritic settings that were dominated by levee channels. The sediments were deposited in shelf-slope environment.

Reflection configurations were observed as layered (parallel and divergent) and chaotic reflections. The facies were interpreted as high-continuity and high-amplitude facies, low-amplitude facies and low-continuity/variable-amplitude facies. Examination of instantaneous phase attribute shows continuity and discontinuity of events while reflection strength attribute shows areas of high and low amplitudes.

The presence of structures such as growth faults and roll over anticline in the field as well as discontinuous nature of sand bodies favours the formation of combined structural and stratigraphic traps in the field. This will help in the prediction of well locations in the area.

Three MFSs, two SBs and two transgressive surfaces (TS) were identified. These stratigraphic surfaces aided in the subdivision of intervals into sequences and systems tracts. Two sequences and three systems tracts were identified. The systems tracts are high stand system tract, low stand system tract and transgressive system tract. Sequence 1 consisted of lowstand systems tracts (LST), transgressive systems tracts (TST) and highstand systems tracts (HST), while sequence 2 comprises of only TST and HST. Two reservoirs were identified in the HST, while the third reservoir was seen in LST. The transgressive system shales serve as the seals, while the HST sands and the massive LST sand are the potential reservoirs.

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