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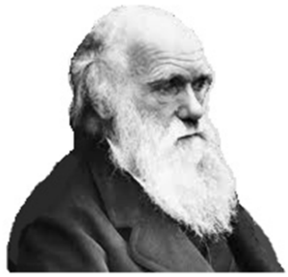

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Structural and seismic sequence stratigraphy analysis of seismic and biostratigraphy data from an onshore field, Niger Delta, Nigeria

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ABSTRACT

The structural and sequence stratigraphy of a Niger Delta onshore field has been analysed from seismic and biostratigraphy data in order to assess the hydrocarbon potential of the area. Seven faults F1, F2, F3, F4, F5, F6 and F7 were delineated in the seismic sections. The faults, F1, F4, F6 and F7 are synthetic faults, while F2, F3 and F5 are antithetic. Two horizons H1 and H2 were identified in the seismic sections within the time window of 2200-2600 ms. The seismic sequence stratigraphy analysis revealed five sequence boundaries S1, S2, S3, S4 and S5, which represent four depositional sequences. Four maximum flooding surfaces (MFS) were also delineated in the seismic data. The analysis of the biostratigraphy data thus revealed four sequence boundaries (S1, S2, S3, S4) and three maximum surfaces (MFS1, MFS2 and MF3). The age of the sequence boundary ranges from 13.1Ma to 8.3 Ma. The age of the observed maximum flooding surfaces ranges from 12.8 Ma to 9.4 Ma. In vertical succession, the depositional sequences were identified by the order; sequence boundary, lowstand system tract (LST), Transgressive system tract (TST), Maximum flooding surface (MFS), and Highstand system tract (HST). The lowstand system tract is made up of stacking pattern of sand, while the transgressive system tract thinned into the condense section.

Keywords: Sequence stratigraphy, faults, seismic, horzons, Niger Delta

1. INTRODUCTION

Hydrocarbon exploration and production have been on for almost sixty years now in the Niger Delta sedimentary basin, Nigeria. The Niger Delta sedimentary basin, which consists of

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offshore and onshore regions is a passive continental margin. It is one of the world major hydrocarbon basins. Understanding of the structural and stratigraphy of the region is crucial to the hydrocarbon exploitation of the basin.

Sequence stratigraphy is a technique of hydrocarbon exploration used for explaining accumulation and preservation trends of sediments. It involves the subdivision of basin fills into beds, bed-sets, parasequences and sequences bounded by chronostratigraphically surfaces of erosion, non-deposition surfaces and their correlative surfaces. Sequence stratigraphy also involves an understanding of the depositional processes and the factors such as sea level changes, subsidence rates, sediment supply, climate condition and basin geometry that influenced them. It enables us to describe and predict the occurrence, extent, geometry and economic importance of sedimentary facies.

The sequence stratigraphy of a basin fills can be obtained from seismic, well logs, core and biostratigraphic data or from their integration. The core and well logs provide access to a detailed vertical resolution of sedimentary sections while seismic and outcrop studies provide the lateral continuity of the sequence stratigraphic framework. The biostratigraphy data provides the time constraints for the other data.

A lot of work has been done on the structural and sequence stratigraphy of some parts of the Niger Delta. Some of these works include the chronostratigraphic surfaces, sequence stratigraphiy and structural analysis of the Niger Delta. The objective of this research work is to delineate the various structures, sequences, bounding surfaces and system tracts in the study area and evaluate its significance in hydrocarbon exploration [1-16].

2. GEOLOGY OF THE STUDY AREA

Figure 1. Map of Niger Delta showing the Study Area

The study area (Fig. 1) is located within the Niger Delta in the Gulf of Guinea, West Africa. Although the modern Niger Delta formed in the Early Tertiary, sediments began to accumulate during the Mesozoic rifting which is associated with separation of the Africa and South American continents.

The Tertiary Niger Delta deposit is characterized by a series of depobelts that strike northwest- southeast, sub- parallel to the present day shoreline. Depobelts become successively younger basinward, ranging in age from Eocene in the north to Pliocene offshore of the present shoreline. Depobelts, tens of kilometers wide, are bounded by a growth fault to the north and a counter regional faults seaward. Each sub-basin contains a distinct shallowing upward depositional cycle with its own tripartite assemblage of marine, paralic, and continental deposits. Depobelts expresses a series of breaks in the progradation of the deltaic system and as the deltaic sediment loads increase, underlying delta front and prodelta marine shale start to move upward and basinward.

The Formations within the Niger Delta clastic wedge have been defined based on sand/shale ratios estimated from subsurface well logs. The three major lithostratigraphic units defined in the subsurface of Niger Delta Akata, Agbada and Benin Formations, reflect a gross upward-coarsening clastic wedge. These Formations were deposited in dominantly marine, deltaic and fluvial environments, respectively. Stratigraphically equivalent units to these three formations are exposed in the southern Nigerian.

The Akata Formation consists of prodeltaic dark shales and silts and it is about 6,400 m thick. The age ranges from Paleocene to Recent. These shales are exposed onshore in the northeastern part of the delta, where they are known as the Imo shale. This formation also crops out offshore in diapers along the continental slopes, where deeply buried, Akata shales are typically overpressured. Akata shales have been interpreted to be prodelta and deeper water deposits that shoal vertically into the Agbada Formation. It is the main hydrocarbon source rock of the Niger delta complex.

The Agbada Formation consists of paralic sequence of shale and sand interbeds and it has amaximum thickness of about 3,900 m. The Agbada Formation ranges from Eocene to Pleistocene in age. The Agbada formation is interpreted to have formed in fluvial-deltaic environments.

The Benin Formation, which lies on top of the Agbada Formation is made up of interbedded fluvio-marine sands, sandstones and siltstone. The age of the Benin formation ranges from Oligocene to Recent. The formation thins basinward and ends near the shelf edge. It is mainly continental in origin and it is made up of sandstones. The thickness ranges from 0 -2100 m.

The Benin formation is the fresh water-bearing continental sands in the Niger Delta. Most Niger Delta faulting is due to extensional deformation. The exception is in the distal section, where overthrust faults form in the toe of the proto-Niger delta. These extensional faults are normal and are listric, comprising syndepositional growth faults and crustal tensional faults. These faults are synthetic or antithetic, running sub-parallel to the strike of the basins. These synsedimentary faults exhibit growth strata above the down thrown block, as well as anticlinal (rollover) closures.

Most hydrocarbon bearing structures in Niger Delta deposits are enclosed in these structure-building faults. Growth faults and antithetic faults play an essential role in the hydrocarbon trap configuration.

3. MATERIALS AND METHODS

The basic data used in this research work are seismic and biostratigraphy data from a deep borehole in the area. The SEG-Y seismic data was imported and loaded into Shlumberger Petrel software 2009.1™ platform. Both structural and sequence seismic stratigraphy interpretations were carried out on the seismic data.

3. 1. Delineation of Faults and Horizons

The structural interpretation involves faults and horizon identification and delineation. Fault identification on the seismic sections was based on analysis of vertical displacement of reflection, reflection surface discontinuity and truncation/termination of reflection events. Horizon is a geological time surface that is isochronous. It is usually associated with region-wide reflections at the interfaces between two different layers.

3. 2. Determination of Bounding Surfaces

The sequence stratigraphy analysis of the seismic data involves identification and delineation of significant surfaces such as the sequence stratigraphic or bounding surfaces. The surfaces include Sequence Boundary (SBs), Maximum Flooding Surfaces (MFSs) and Transgressive Surfaces (TSs).

The Maximum Flooding surfaces are recognized in the seismic sections by condensed sections and laterally continuous burrowed zones. The Sequence Boundaries are identified in the seismic sections by an abrupt basinward shift in the facies. Erosional truncation is evidence of subaerial exposure. The Transgressive Surface which is the first major flooding surface to accompany the sequence boundary was identified on the seismic data by facies discontinuity characterized by abrupt deepening across the boundary.

The biostratigraphy data and chrostratigraphic chart of Niger Delta prepared by the Shell Petroleum Development Company were used to assign ages to the delineated bounding surfaces in the seismic sections.

3. 3. Determination of Strata Terminations.

The various strata terminations include truncation, toplap, downlap and offlap. Truncation is the termination of the strata against an overlying erosional surface. It is delineated at the top of depositional sequence and at the base of incised valley. It is an indication of sequence boundary. Toplap normally occurs at the top of depositional sequence and it is the termination of strata against overlying younger strata.

The Downlap is a downdip termination of initially incline younger strata against older strata. The seismic sequence is a package of sediments that are bounded by discontinuities (usually unconformities), using the continuity of reflections and the patterns of reflection terminations. Seismic boundaries are defined in seismic sections by delineating the termination of seismic reflectors at the unconformity surfaces.

The terminations can occur below a discontinuity or above the discontinuity.

The terminations at the upper sequence boundary are toplap and truncation while the termination at the lower sequence boundary are the onlap and downlap.

3. 4. Determination of Depositional Sequence.

Depositional sequence is obtained from the record of cycle of relative sea level and can be identified in the seismic section by sequence boundary (SB1), Lowstand System Tract (LST), Transgressive System Tract (TST), Maximum flooding Surface (MFS), Highstand System Tract and Sequence Boundary (SB II) in a vertical succession. The seismic sequence boundary is dileneated by characteistics onlap and erosional truncation patterns. The maximum flooding surface is usually associated with dipping strata on the seismic data while clinoforms downlapping onto the maximum flooding surface in a seismic section is used for delineating highstand system tract.

4. RESULTS AND DISCUSSION

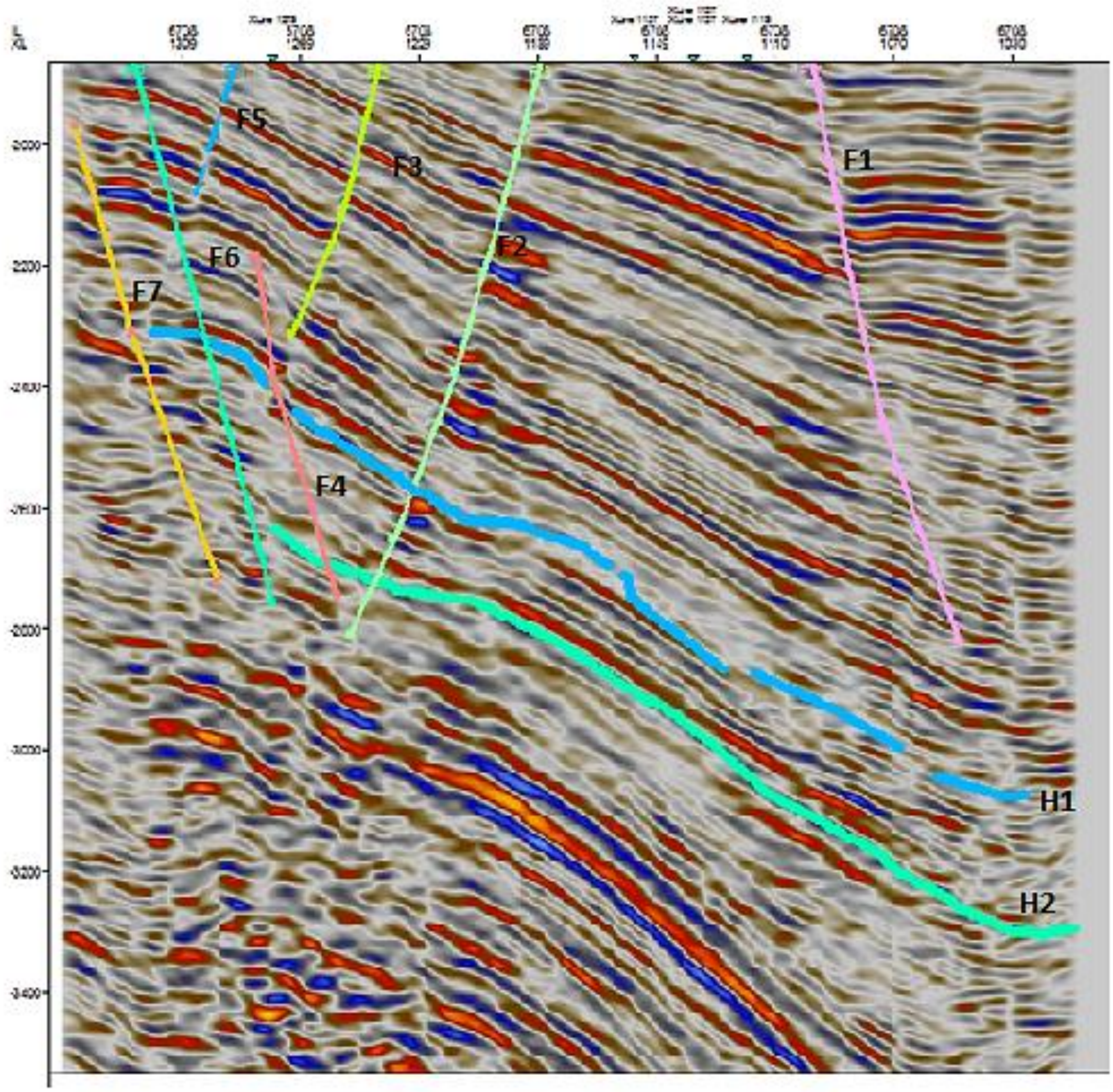

Figure 2. Structural interpretation of seismic data from the study area.

The result of the structural interpretation of the seismic data is shown in Fig. 2. Seven faults F1, F2, F3, F4, F5, F6 and F7 were delineated in the study area. The faults, F1, F4, F6 and F7 are synthetic faults while F2, F3 and F5 are antithetic. The faults were identified based on the break in reflection events. These faults could act as a migration pathway for hydrocarbon. The structural patterns vary across the seismic dipping downward from northwest to southeast. Two horizons H1 and H2 were identified within the time window of 2200-2600 ms. These horizons represent the top of reservoirs in the area.

The sequence bounding surface interpretation result is presented in Fig. 3. Five sequence boundaries S1, S2, S3, S4 and S5 which represent four depositional sequences S1, S2, S3 and S4 were delineated in the seismic section. The sequences were delineated from the discordant relationship of rock units at the sequence boundaries. The sequence boundaries are laterally extensive and conformable in stratigraphic order from the oldest (SB1) to the youngest (SB5).

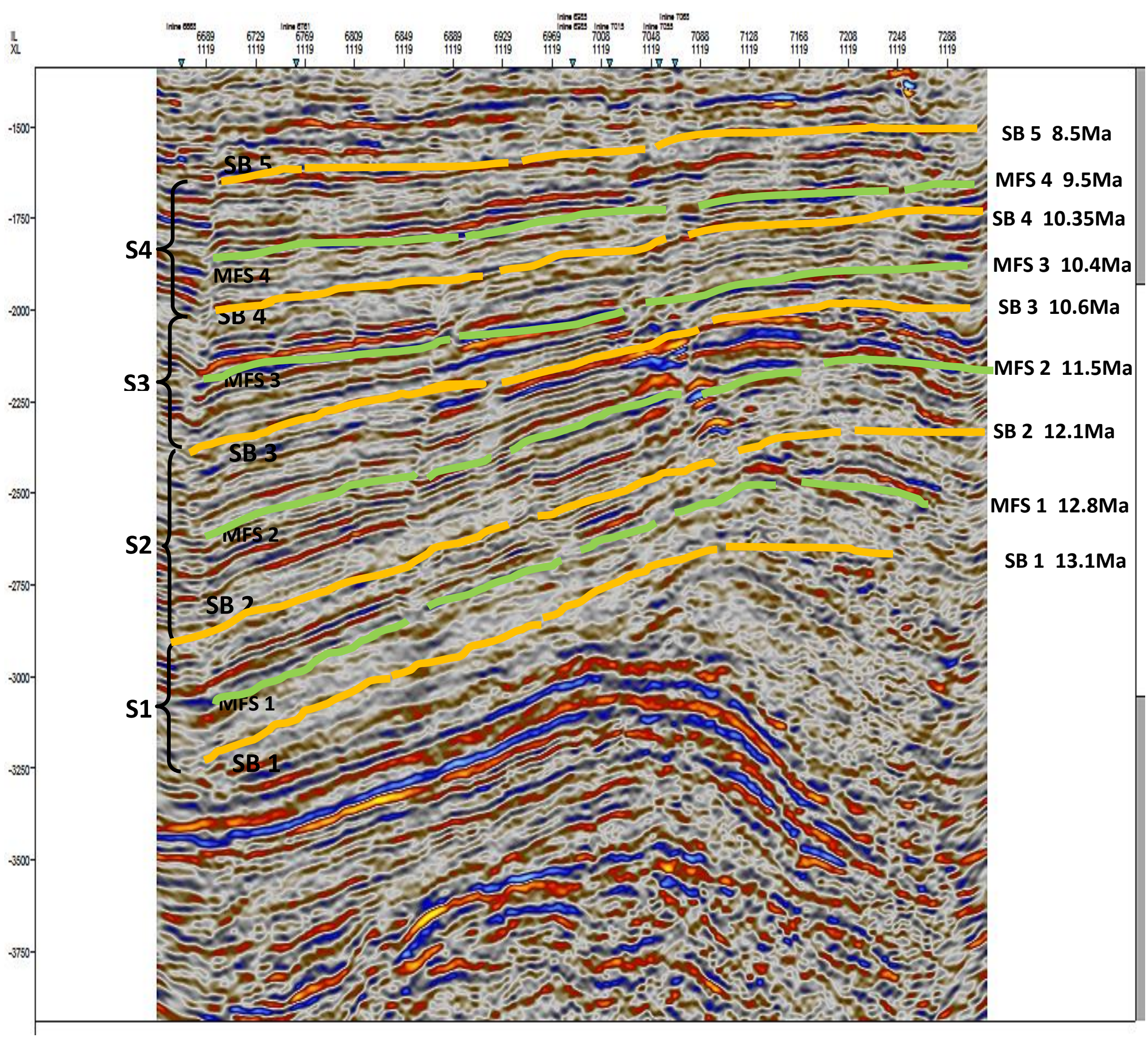

Figure 3. Interpretation of sequence bounding surfaces

The oldest sequence (S1) is assumed to overlie the top of the Akata Formation throughout the study area indicating that the sequence boundary is a regional unconformity that truncates steeply dipping Akata reflection. Four maximum flooding surfaces (MFS) were delineated in the area. The age range of the oldest sequence boundary to the youngest is from 13.1Ma to 8.3 Ma. The observed maximum flooding surfaces age ranges from 12.8Ma to 9.4 Ma. The maximum flooding surface is due to the presence of an extensive shale that lacked terrigenous material. It is an indication of a retrogradational complex. The maximum flooding surface develops during the period of highest sea level rise and maximum incursion of shoreline into land. The strata terminations observed in the seismic section are shown in Fig, 4. Both onlap, downlap and toplap were delineated and are represented with different colour codes.

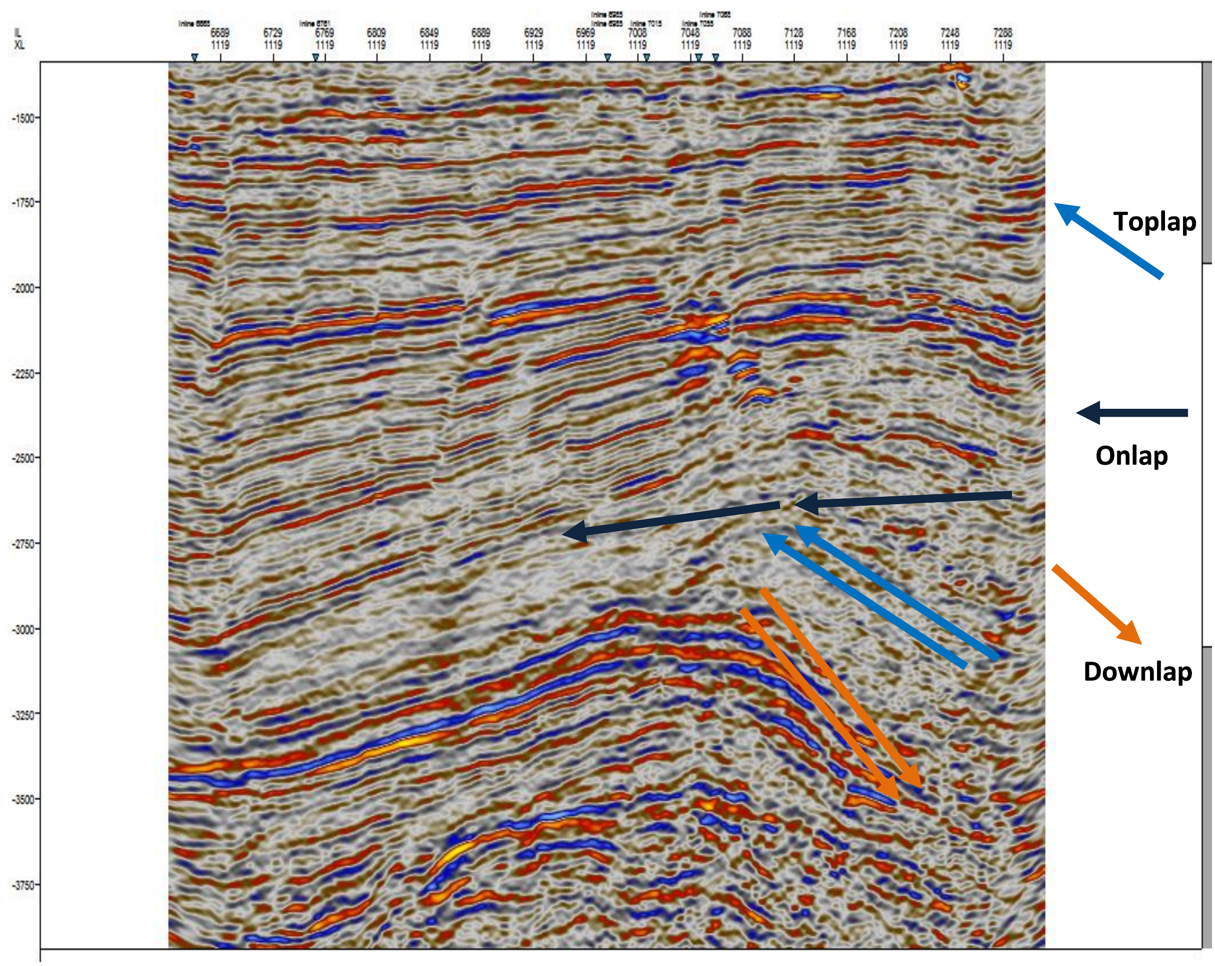

Figure 4. Delineated seismic strata termination

4. 1. Depositional Sequence

In vertical succession the depositional sequences were identified by the order; sequence boundary, lowstand system tract (LST), Transgressive system tract (TST), Maximum flooding surface (MFS), and Highstand system tract (HST). The lowstand system tract is made up of a stacking pattern of sand while the transgressive system tract thinned into the condense section

(MFS). Above the maximum flooding surface is the highstand system tract. The highstand system tract is made up of mostly sand interbedded by thinned shales. The highstand system tract is usually terminated by sequence boundary.

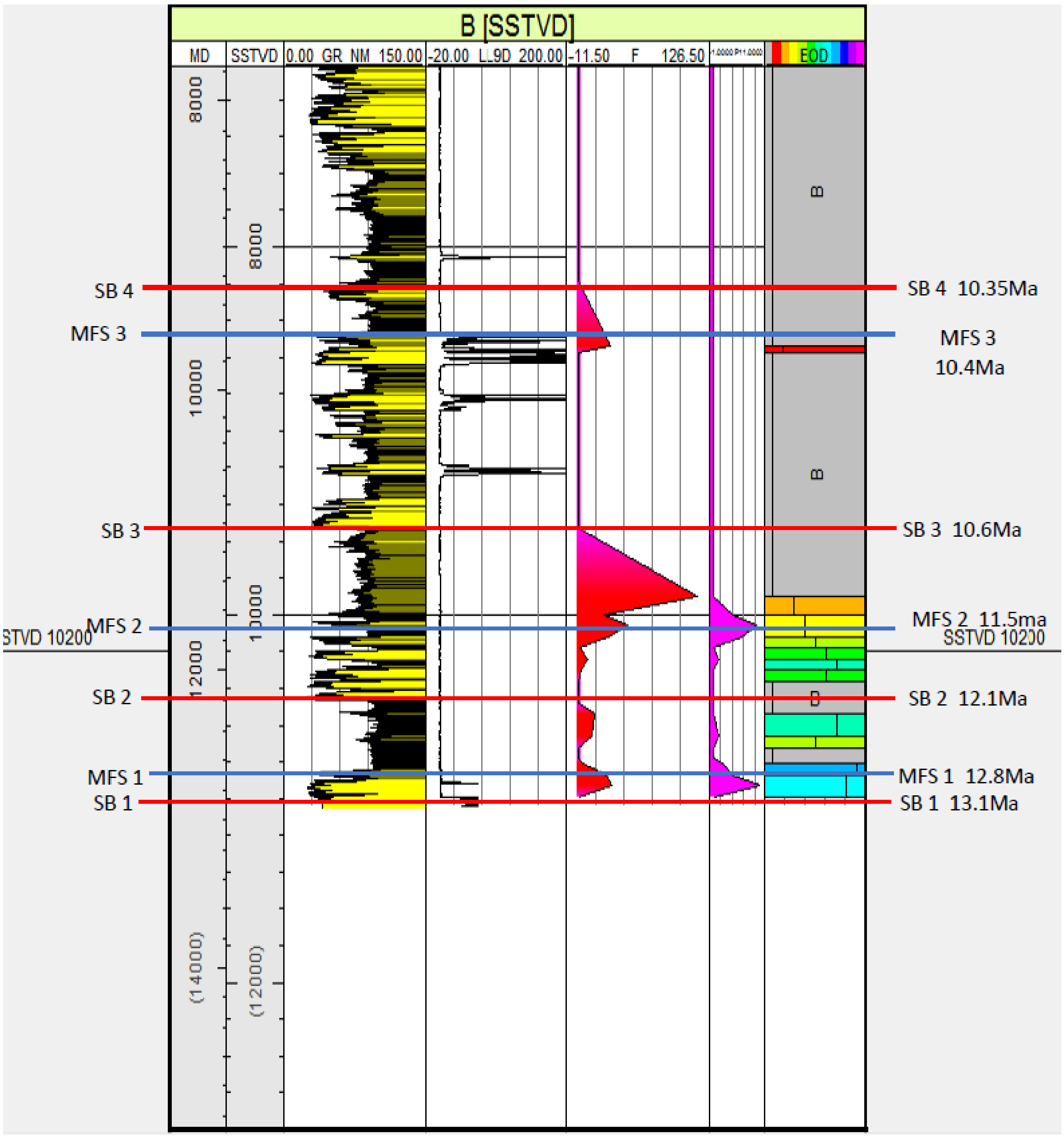

Figure 5. Interpreted biostratigraphy data from a well in the study area

4. 2. Seismic Facies

The seismic facies is characterized by parallel and wavy, discontinuous and high amplitude reflection patterns. They are chaotic, discontinuous reflection of variable amplitude ranging from medium to high amplitude patterns. Discontinuous and parallel reflections dominate the northwestern section between a time window of 1500 and 2750 ms. The parallel wavy, high amplitude discontinuous reflection patterns are present in the southern section within a time window of 3250 to 4000 ms indicating the presence of an anticline. The southwest end of the study area is characterized by low amplitude, discontinuous, parallel reflection typical of synclinal stratigraphic trap covering a time window of 3100 to 3900 ms. The divergent, medium to high amplitude reflection patterns occur at the northeastern end between a time of 2000 and 2400 ms. On the other hand, chaotic, discontinuous discordant reflection of variable amplitude is predominant at the centre within a time window of 2500 to 3250 ms, indicating the presence of deformed over pressured shales resulting from improper dewatering during rapid burial of the sediments.

4. 3. Biostratigraphic Analysis

The interpreted biostratigraphy data from a deep oil well in the field is shown in Figure 5. The biostratigraphy data were used for constraining the age of the sequence boundaries and the maximum flooding surfaces observed in the seismic data. The biostratigraphy data gave information about the fauna, flora diversity and population and bathymetry of the study area. The maximum flooding surface is usually associated with high abundance and diversity peaks.

Four sequence boundaries (SBs) namely SB1, SB2, SB3 and SB4 were identified and three maximum surfaces (MFS1, MFS2 and MF3) were observed in the well. The sequence boundaries SB1, SB2, SB3 and SB4 were dated 13.1 Ma, 12.1Ma, 10.6Ma and 10.35Ma respectively. Three maximum flooding surfaces MFS1, MFS2 and MF3 dated 12.8Ma, 11,5Ma and 10.24 respectively were also delineated in the data. The stratigraphic analysis of the study area showed that the Maximum Flooding Surfaces correspond to the major shale break (high shale content)

5. CONCLUSIONS

Seismic sequence stratigraphy and structural analysis of the study area revealed two sequence boundaries, a maximum flooding surface, two highstand system tracts, two lowstand system tracts and one transgressive system tract. The cyclic pattern of the system tracts in field X provides a good hydrocarbon trapping system. And the petrophysical calculation indicates that the Lowstand system tract and Highstand system tract consist of potential reservoirs. The sequence stratigraphic analysis two bounding surfaces, namely Sequence boundaries (SBs) and Maximum flooding surfaces (MFSs) in the study area. Five sequence boundaries and four maximum flooding surfaces were observed in the seismic sections. This study proves that with a high quality seismic and biostratigraphy data, can be efficiently applied for hydrocarbon exploration in the Niger Delta.

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