SEQUENCE STRATIGRAPHY AND STRUCTURAL ANALYSIS OF THE EMI FIELD, OFFSHORE DEPOBELT, EASTERN NIGER DELTA BASIN, NIGERIA

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ABSTRACT

3D seismic data, wireline logs from six wells, checkshot and biostratigraphic data were used to subdivide the stratigraphic section within the Emi Field, eastern Niger Delta, into packages of sediments bounded by chronostratigraphically significant surfaces. The results revealed two sequence boundaries and three maximum flooding surfaces, which subdivided the stratigraphic succession within the Emi Field into three depositional sequences. Highstand system tract and transgressive system tract were identified within the depositional sequences. Marker shales, characterized by index fossils *Haplophramoides-24* and *Bolivina-46,* were used to date the key bounding surfaces with the aid of the Niger Delta chronostratigraphic chart. Ages assigned to the sequence boundaries were 5.6 Ma and 4.1 Ma. Based on log motifs and biostratigraphic data, the siliciclastic successions penetrated by wells within the Emi Field were inferred to be deposited in a neritic paleoenvironment. Two major faults, F1 and F3, ran across the study area and closures considered as good hydrocarbon prospects were identified and delineated. Analysis of horizons within the sequences and individual system tract revealed that hydrocarbon was hosted both in the transgressive systems tract and highstand systems tract.

INTRODUCTION

Sequence stratigraphic concepts in defining sediment accumulation and preservation trends within basin fills have become a highly successful exploration tool in the search for hydrocarbon resources. Thus, the subdivision of a basin's sedimentary fill into time stratigraphically constrained depositional packages is imperative in unravelling its development and inherent hydrocarbon potentials. Sequence stratigraphic concept is increasingly finding new and unique applications in the regressive siliciclastic sediments of the Niger Delta Basin.

The petroliferous Niger Delta Basin is one of the highest hydrocarbon producing basins with more promising reserves yet to be discovered as exploration proceeds to the deeper waters. The lithostratigraphic subdivision of the Niger Delta sediments cut across time lines and their lateral associations suggest that the sedimentary deposits were strongly influenced by eustacy and tectonics. Sequence stratigraphy thus, facilitates the subdivision of the Niger Delta into packages of sediments that are essentially bounded together by chronostratigraphically significant surfaces. The aim of this research is to subdivide the stratigraphic section within the Emi Field, offshore depobelt, Niger Delta Basin, Southern Nigeria into packages of sediments bounded by chronostratigraphically significant surfaces (condensed sections, their associated maximum flooding surfaces and sequence boundaries).

The area of study, Emi Field, is located in the offshore depobelt, Niger Delta, southern Nigeria (Fig. 1) and covers an area of 58.24 km². The Niger Delta Basin is located on the continental margin of the Gulf of Guinea in the equatorial West Africa and lies between Latitudes 4° and 7° N and Longitudes 3° and 9° E (Whiteman, 1982).

Various works have been carried out in relation to the sequence stratigraphy of different parts of the Niger Delta. These include Bowen *et al.* (1994), who established an integrated geologic framework of the Niger Delta slope, by applying established sequence stratigraphic concepts on a seimic data set of the Niger Delta along with a biostratigraphic data from twenty-six (26) key wells. Stacher (1995) produced a delta wide framework of chronostratigraphic surfaces, and a sequence stratigraphic chart for the Niger Delta using digitallly stored biostratigraphic data, obtained from over eight hundred and fifty (850) wells. Krusi and Idiagbor (1994) linked some types of stratigraphic traps to incised valley

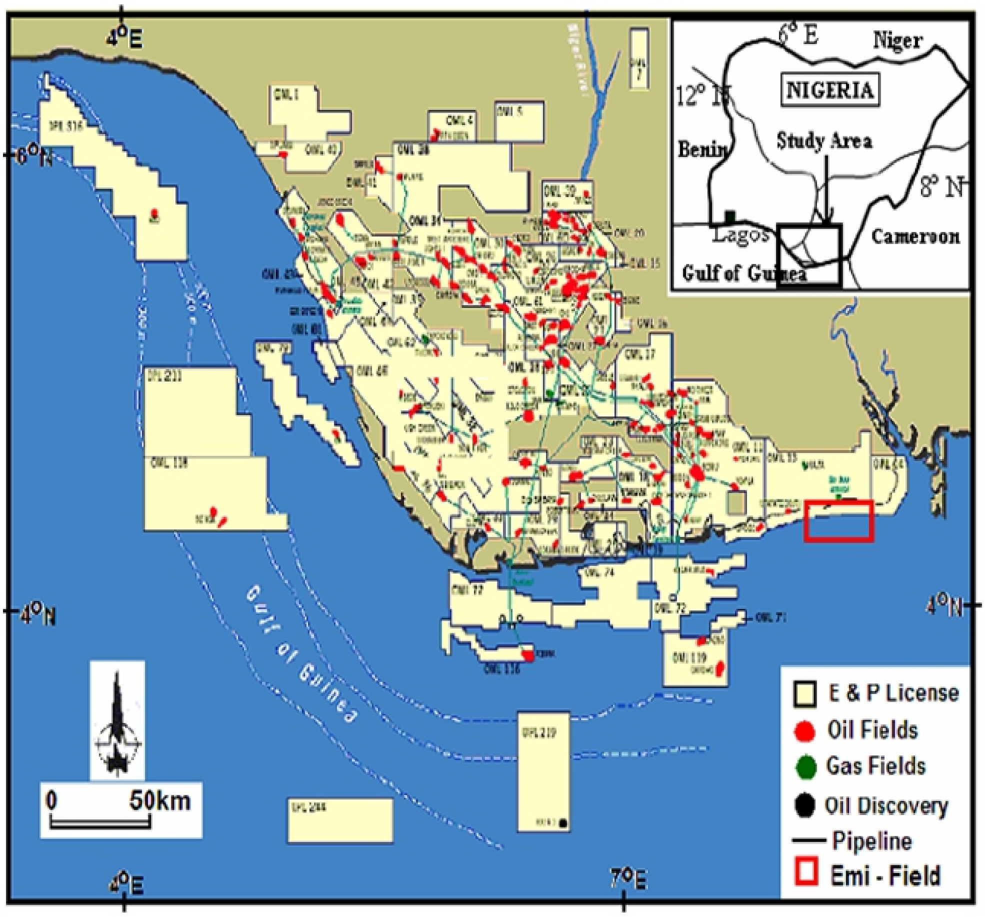

Figure 1: Map of the South-south Nigeria Showing Hydrocarbon Fields and the Location of the Emi Field in the Offshore Eastern Niger Delta (after Nton and Esan, 2010)

fills and lowstand fans. Thus, they were able to improve the identification of stratigraphic plays in the eastern Niger Delta. Ozumba (1999) developed a sequence stratigraphic framework of the western Niger Delta, using foraminifera and wireline log data obtained from four wells drilled in the coastal and central swamp depobelts. He concluded that the late Miocene sequences were thicker than the Middle Miocene sequences.

Nton and Esan (2010) employed the concept of sequence stratigraphy in the Emi Field, offshore eastern Niger Delta. Their study was based on four wells, seismic data and biostratigraphic data. Their results revealed two sequences boundaries and three maximum flooding surfaces. This current study is more extensive and it is based on wire line log data from six wells, 3D seimic data and biostratigraphic data. An evaluation of the fault system within the field was also carried out.

Stratigraphy and Geological Setting

The Niger Delta is a large arcuate Tertiary prograding sedimentary complex deposited under transitional marine, deltaic, and continental environments since Paleocene in the north to Recent in the south. it covers an area of about 75,000 Km² from the Calabar Flank and Abakaliki Trough in eastern Nigeria to the Benin Flank in the west. It opens to the Atlantic Ocean in the south where it protrudes into the Gulf of Guinea as an extension from the Benue Trough and Anambra Basin provinces (Fig. 2). It is characterized by coarsening upward regressive sequences which reaches a maximum thickness of 30,000 to 40,000 feet (Evamy *et al.,* 1978). The overall regressive sequence of clastic sediments was deposited in a series of offlap cycles that were interrupted by periods of sea level change. The structural configuration and the stratigraphy of the Niger Delta have been controlled by the interplay between rates of sediment supply and subsidence (Evamy *et al.*, 1978; Doust and Omatsola, 1990).

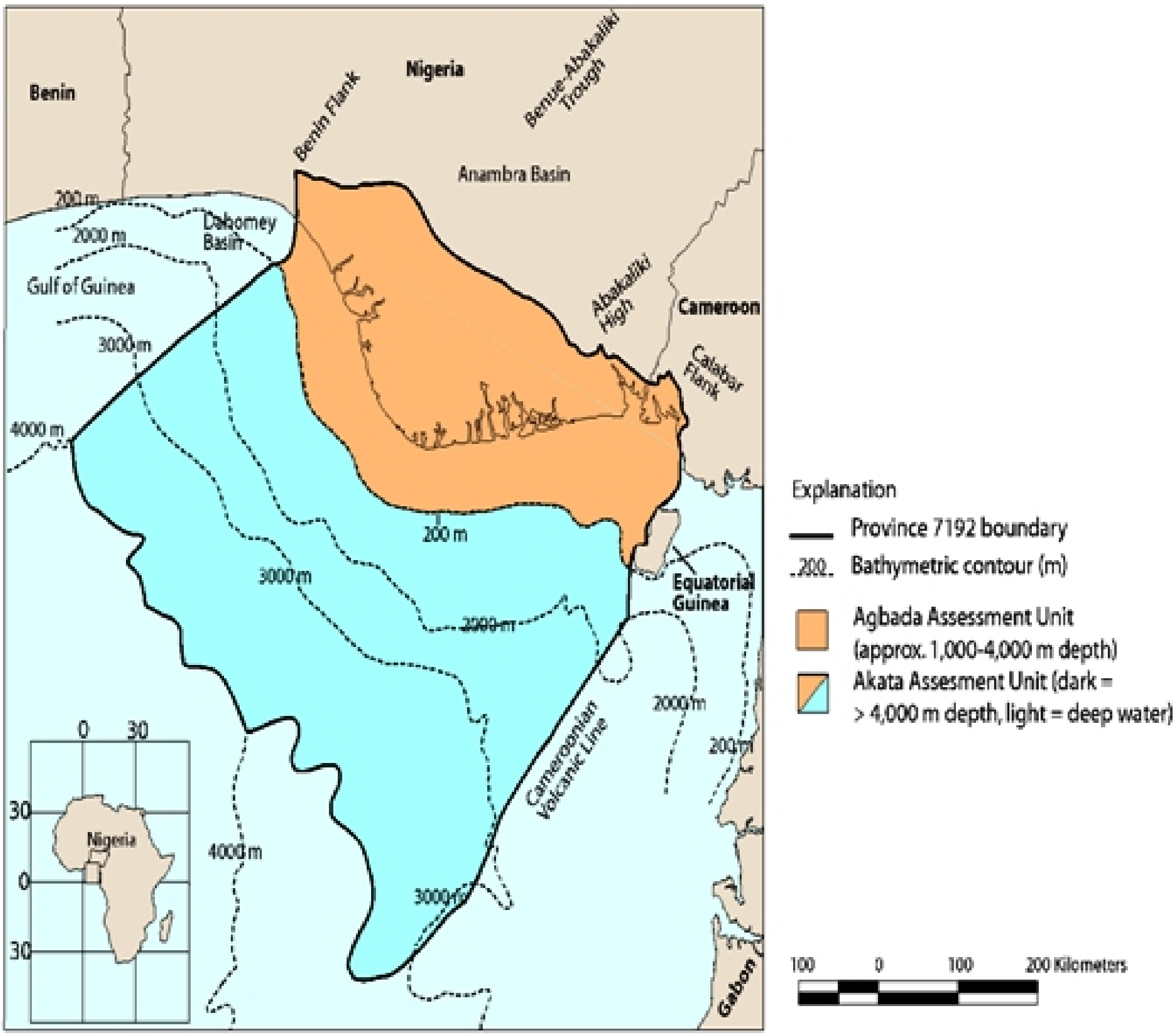

Figure 2: Map Showing Province Outlines and Bounding Structural Features in the Niger Delta Basin (adapted from Tuttle *et al.,* 1999)

This clastic wedge have been divided into three large-scale lithostratigraphic units (Fig. 3); the basal Paleocene to Recent pro-delta facies of the Akata Formation, Eocene to Recent paralic facies of the Agbada Formation and the Oligocene to Recent fluvial facies of the Benin Formation (Short and Stauble, 1967; Evamy *et al.*, 1978; Whiteman, 1982).

MATERIALS AND METHOD

Six (6) exploratory wells and 3D seismic data from within the Emi Field were collected. The wells are as follows: Emi-1, Emi-2, Emi-3, Emi-4, Emi-5, and Emi-6. Well logs including gamma ray, resistivity, sonic, density, neutron etc were also used. The summary of suite of open-hole wireline logs data used for the study is shown in Table 1. SPDC Niger Delta chronostratigraphic chart, an adaptation of the global chronostratigraphic chart of Haq *et al.* (1988) was used along with the biostratigraphic data to assign ages to the key bounding surfaces identified within the Emi Field. This data set created broad constraints on the interpretation of age and depositional environments within the study area. The interactive Sclumberger petrel software package (2009 version) was used for the analysis of the seismic and well log data. A simplified work flow chart of the method adopted in this study is shown in Figure 4.

Table 1: Summary of Suite of Open-hole Wireline Logs Data used for the Study

S/No	Well logs	Emi-1	Emi-2	Emi-3	Emi-4	Emi-5	Emi-6
1	Bulk Volume	✓	✓				
2	Depth	✓	✓	✓	✓	✓	✓
3	Gamma Ray	✓	✓	✓	✓	✓	✓
4	Sonic	✓	✓	✓	✓	✓	✓
6	Shale volume	✓	✓	✓	✓	✓	
7	Neutron Porosity	✓	✓				✓
8	Total Porosity	✓	✓		✓	✓	✓
9	Conductivity	✓	✓	✓			✓
10	Deep Resistivity	✓	✓	✓			✓
11	Caliper	✓	✓	✓	✓	✓	✓
12	Bulk Density						

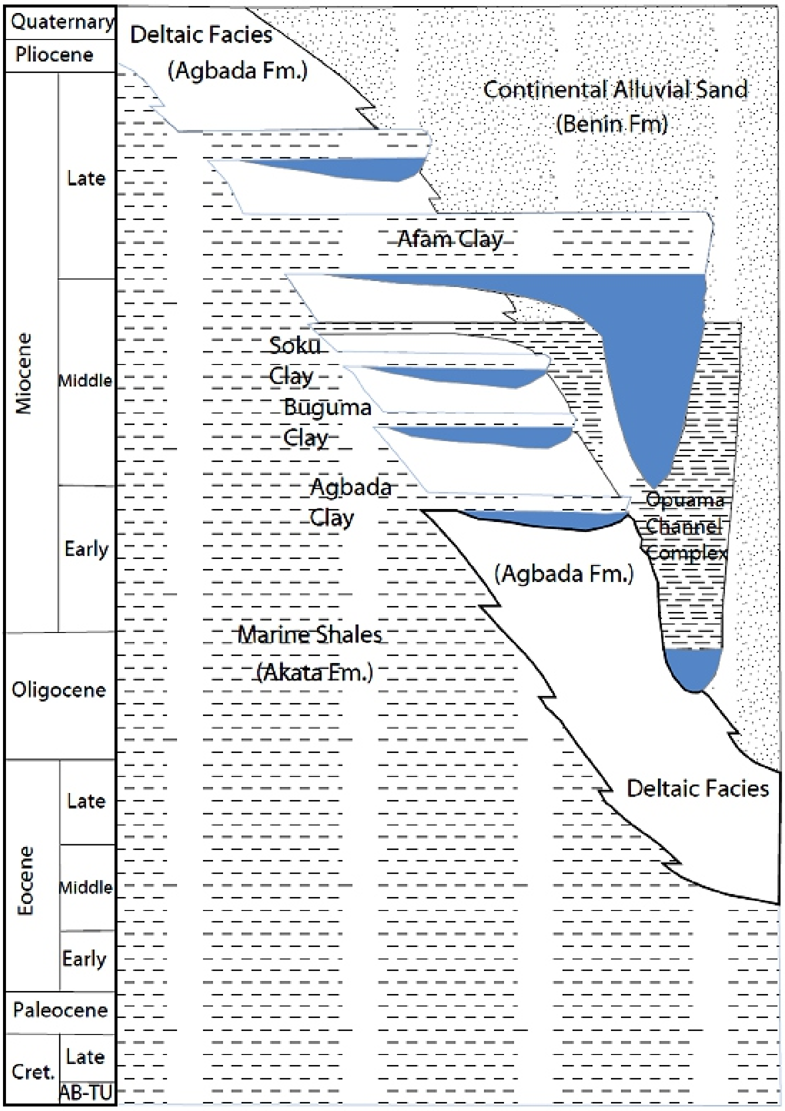

Figure 3: Stratigraphy of the Niger Delta (adapted from Doust and Omatsola, 1990).

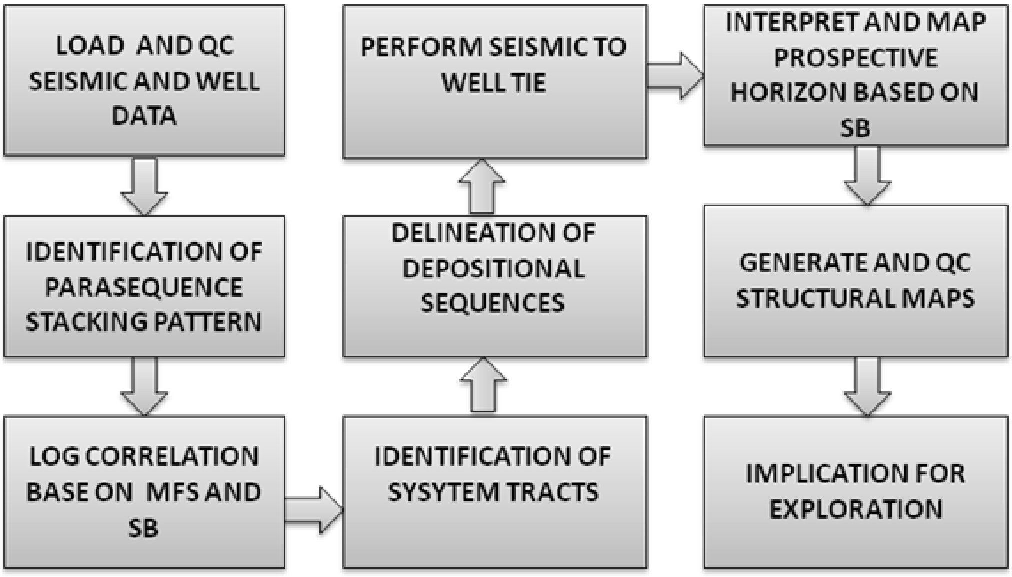

Figure 4: Workflow Chart.

Lithostratigraphy

Lithology was interpreted based on gamma ray log signatures. Detailed observation of gamma ray logs shows progressive alternation of sand and shale. The upper part of the sequences across wells in the Emi Field displays thicker sand intervals than shale and a coarsening upward trend. At the lower part of the wells, shale thickness increases relatively to sand interval. Within the logged intervals, the lithology is dominated by alternating sand and shale with few occurrences of silt occurring approximately in a 65:35 ratio (Fig. 5). Based on the varying proportion of sand and shale with few occurrences of silt and biostratigraphic data of Emi 4 well, one major lithostratigraphic units was identified: the Upper Agbada Formation. The Agbada Formation in the Niger Delta has been the target for drillings of reservoir rocks.

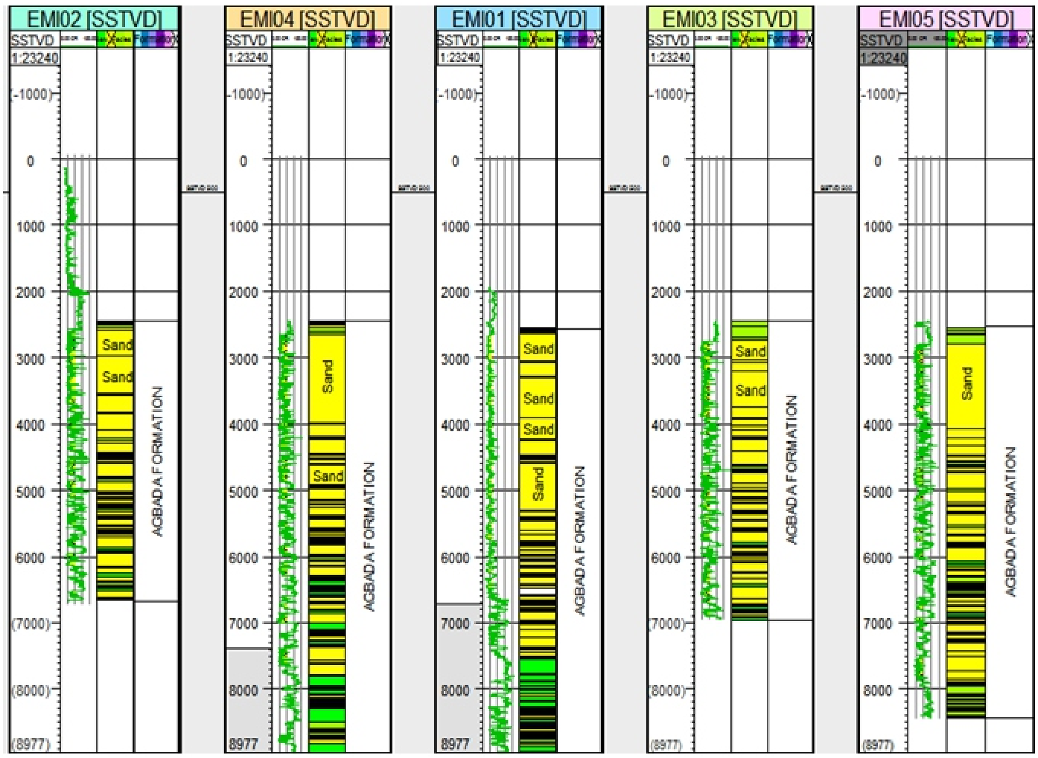

Figure 5: Sand/shale Lithologies Within the Emi Field

Well Correlation

Well correlation for the Emi Field was done after lithological interpretation based on gamma ray log signatures. For correlation, the focus was on mapping sequence boundaries and maximum flooding surfaces. These surfaces were identified based on the abrupt change in well log properties – gamma-ray, resistivity and density among others. The following steps were taken in order to correlate maximum flooding surfaces across the field on well logs:

- Points of highest gamma ray value and lowest shale resistivity values were picked as maximum flooding surface
- Correlation of maximum flooding surfaces in all wells within a background of parasequence and parasequence sets stacking pattern (Van Wagoner *et al.*, 1990; Neal *et al.,* 1993 and Posamentier and George, 1994).

Two sequence boundaries were identified across the wells except in Emi-3 well where only one sequence boundary was identified. Three maximum flooding surfaces were identified across the wells in the Emi Field with the exception of Emi-2 and Emi-3 where only two maximum flooding surfaces were identified (Fig. 6).

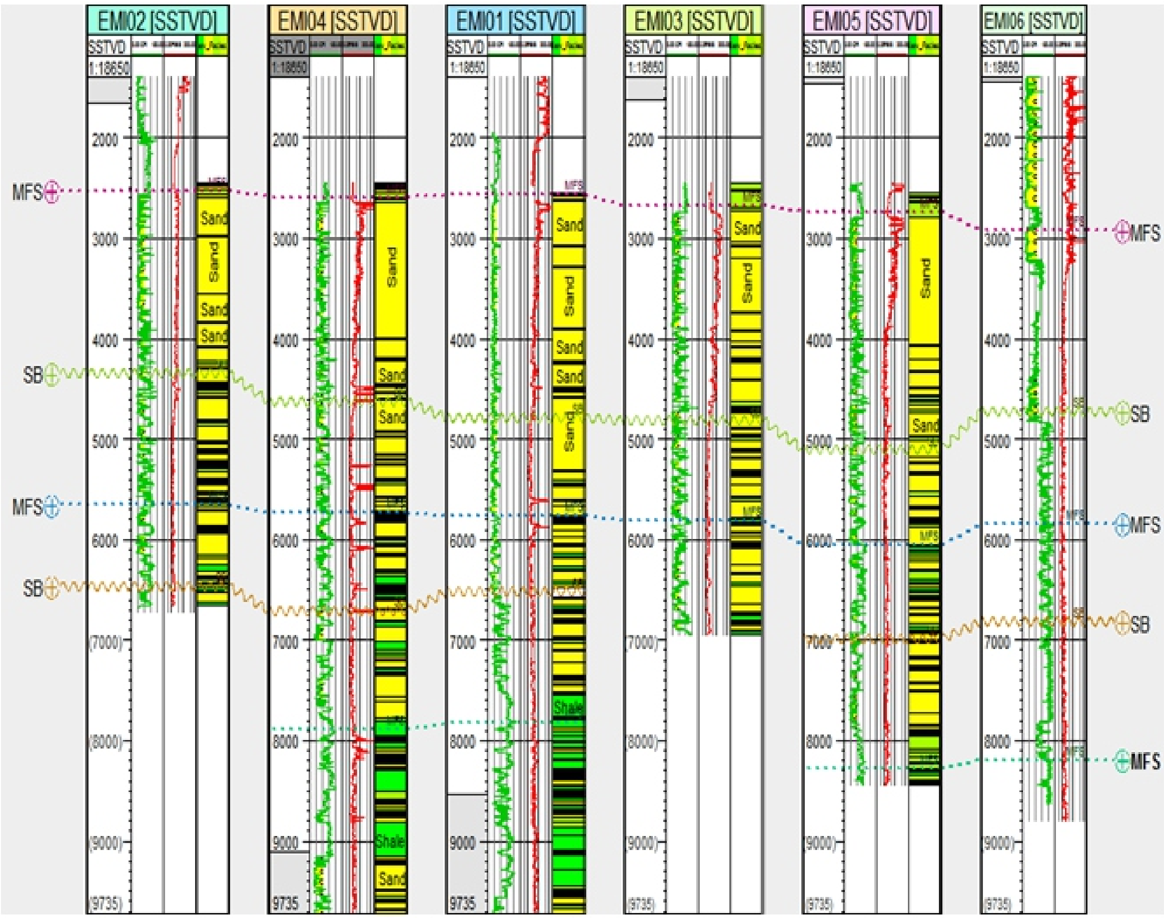

Figure 6: Maximum Flooding Surface and Sequence Boundaries Interpreted on Well Section.

Dating of Key Bounding Surfaces

The key bounding surfaces identified in the study area are the maximum flooding surface (MFS) and sequence boundaries (SB) with their corresponding depths. The biostratigraphic interpretation was focused on the identification of major faunal abundance and diversity peaks, which coincide with MFS within condensed sections, while faunal abundance and diversity minima correspond to SB. The Niger Delta Chronostratigraphic chart aided in this identification and is also used in dating the key bounding surfaces.

The maximum flooding surfaces identified in the study area correspond to the transgressive marker shales of the SPDC Niger Delta chronostratigraphic chart and they are marked by *Haplophragmoides*-24 (6.0 Ma) and *Bolivina*-46 (5.0 Ma). Both marker shales were identified in the Emi 6 well. Two sequence boundaries (SB) were identified and dated with the aid of the SPDC Niger Delta chronostratigraphic chart. The ages assigned to them are 5.6 Ma and 4.1 Ma. The sequence boundaries are represented in all the wells. Table 3 shows the age and depths of the key bounding surfaces as present in all the wells after correlation of all the studied wells.

Table 2: Benthic Foraminiferal Zones Established for Emi-6 Well.

Depth (ft)	Benthic Zones	Age
2000 -6810	Zone I (Valvulina Flexilis)	Pliocene
6810 – 10796	Zone II	Late Miocene

Table 3: Age and Depths of Key Bounding Surfaces

Key Bounding Surfaces	Emi-1 (ft)	Emi-2 (ft)	Emi-3 (ft)	Emi-4 (ft)	Emi-5 (ft)	Emi-6 (ft)
4.1 Ma SB	4795	4331	4811	4628	5093	4712
5.0 Ma MFS (Bolivina- 46)	5711	5655	5804	5721	6053	5820
5.6 Ma SB	6532	6450	_	6715	6980	6831
6.0 MFS (Haplophragmiodes 24)	7824	….	….	7890	8255	8189

Depositional Sequences and System Tract

The study interval was divided into three depositional sequences in Emi-1, Emi-2, Emi-4, Emi-5 and Emi-6 well (Fig. 7). Correlation across the wells in the Emi Field indicates that sequences are not all represented in the wells. Sequence 1 is not represented in Emi-3 well. Sequence thickness increases in sequence 1 and displays reverse thickness trend in sequence 2, implying changes in accommodation space relative to sediment supply, beginning with high rates of accommodation and evolving into low accommodation rates relatively.

Transgressive systems tract (TST) and highstand systems tracts were recognized by stacking patterns and bounding surfaces (maximum flooding surfaces and sequence boundaries). Lowstand systems tract (LST) is absent in the field. This is probably due to erosion of older deltaic complex built up across the shelf during previous LST. System tract displays varying degree of representation across the three identified depositional sequences in Emi-1, Emi-2, Emi-3, Emi-4, Emi-5and Emi-6 well within the Emi Field. The transgressive system tract (TST) is thickest in Emi-1 well in sequence 1 and relatively less thick across the same sequence of other wells. Highstand system tract (HST) is relatively thick in sequence 1 of Emi-1, Emi-4, Emi-3 and Emi-5 (Fig. 7).

Seismic Sequences and Maximum Flooding Surfaces

Analyses of strata termination patterns present on the seismic profile of Emi Field have assisted in the identification of seismic sequences bounded above and below by seismic sequence boundaries (Fig. 9). These sequence boundaries were identified by stacking patterns in well logs and was then transferred onto the seismic (Fig. 8). Generally sequence boundaries are identified by characteristics onlap and erosional truncation patterns. These features are not present on the seismic. Unconformity surface characterised by a downlap at the top and an apparent truncation at the bottom, represents the condensed sections of the depositional sequence. The maximum flooding surface is characterized by dipping strata geometries on seismic section. The highstand system (HST) was identified on the seismic profile by clinoforms downlapping onto the maximum flooding surface (MFS).

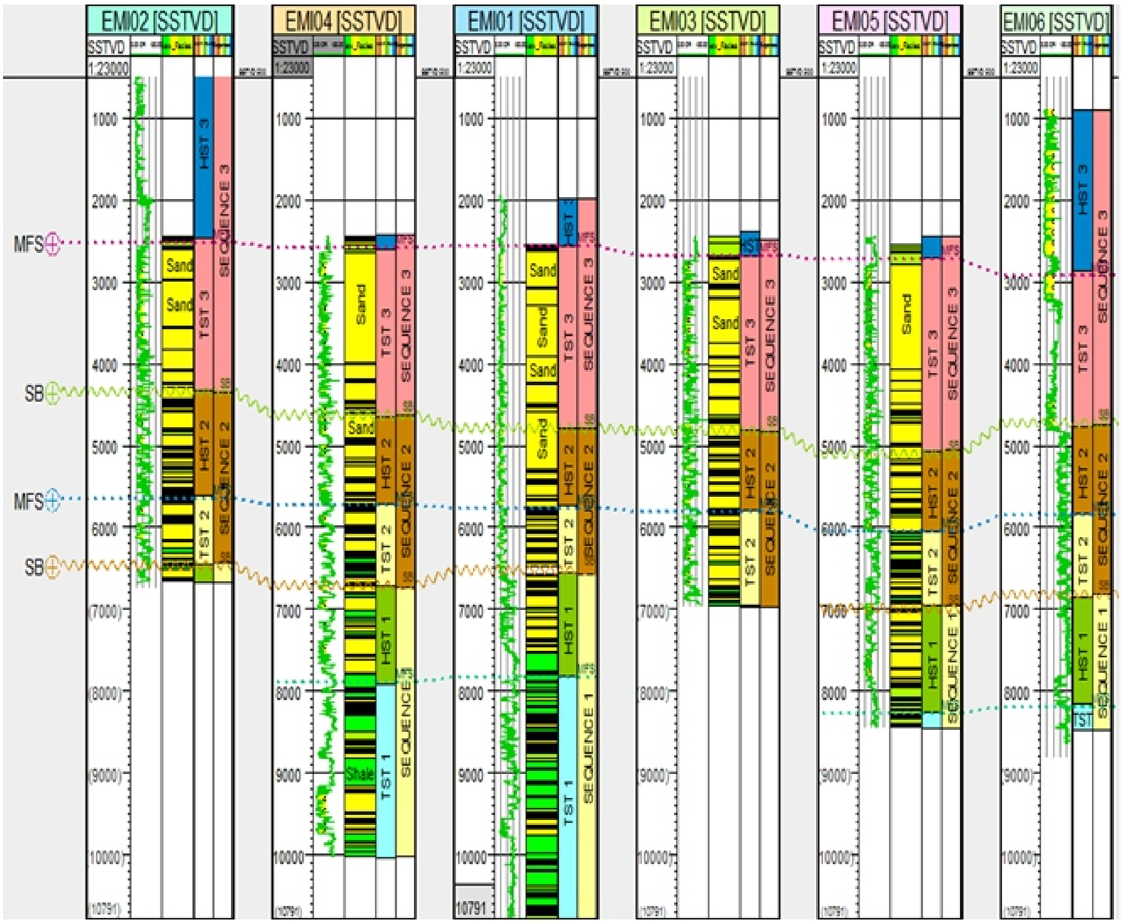

Figure 7: Stratigraphic Correlation Showing all 6 Wells in the Field of Study

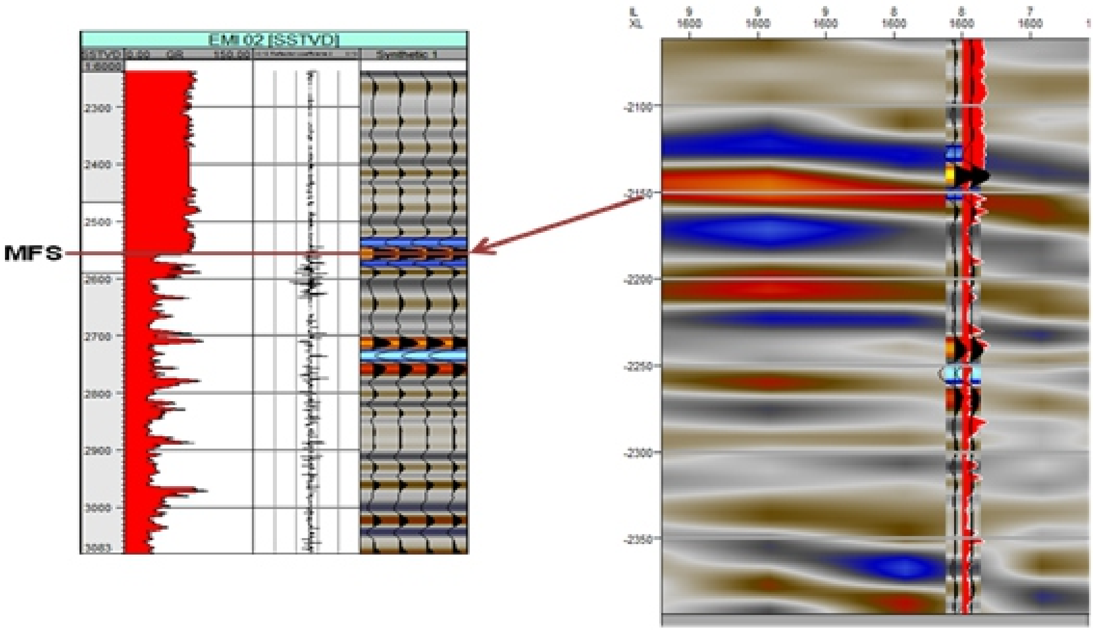

Figure 8: Seismic to Well Tie Shown in Emi-2 Well

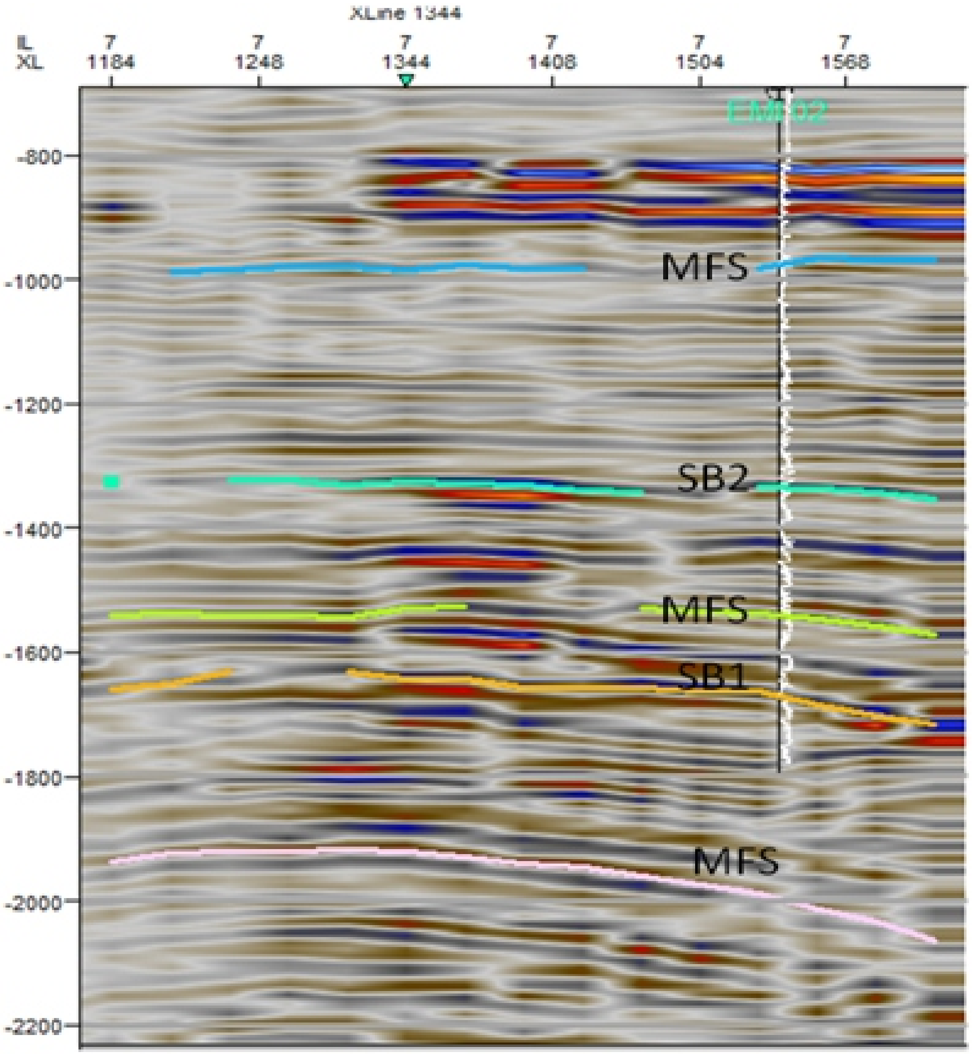

Figure 9: Reflection Pattern, Sequence Boundary and Maximum Flooding Surface Identified on Seismic Cross Sections on Emi-2 Well

Structural Analysis of Seismic Section

There are two major faults (f1 and f3) that run across the study area, these are identified as growth faults (Fig. 10). The growth faults are sub-parallel to one another and trends in the east-west direction. The faults are sealing on the up-thrown side of the fault zone where most of the hydrocarbons could be trapped.

In this study, the seismic section of Emi Field (Fig. 10) shows the effect of growth fault in an expanded fault system, which is in agreement with the work of Mitchum, (1977). All the seismic sections were migrated and this allows for the tying of seismic sections at the intersection point between the cross-lines and in-lines. Most of the major faults picked on the seismic records of the Emi Field are counter regional growth faults which are characteristics of the shelf edge, offshore Niger Delta (Ojo, 1996). Prospect regarded as good hydrocarbon areas have been delineated in the structure contour map (Fig. 11 and 12).

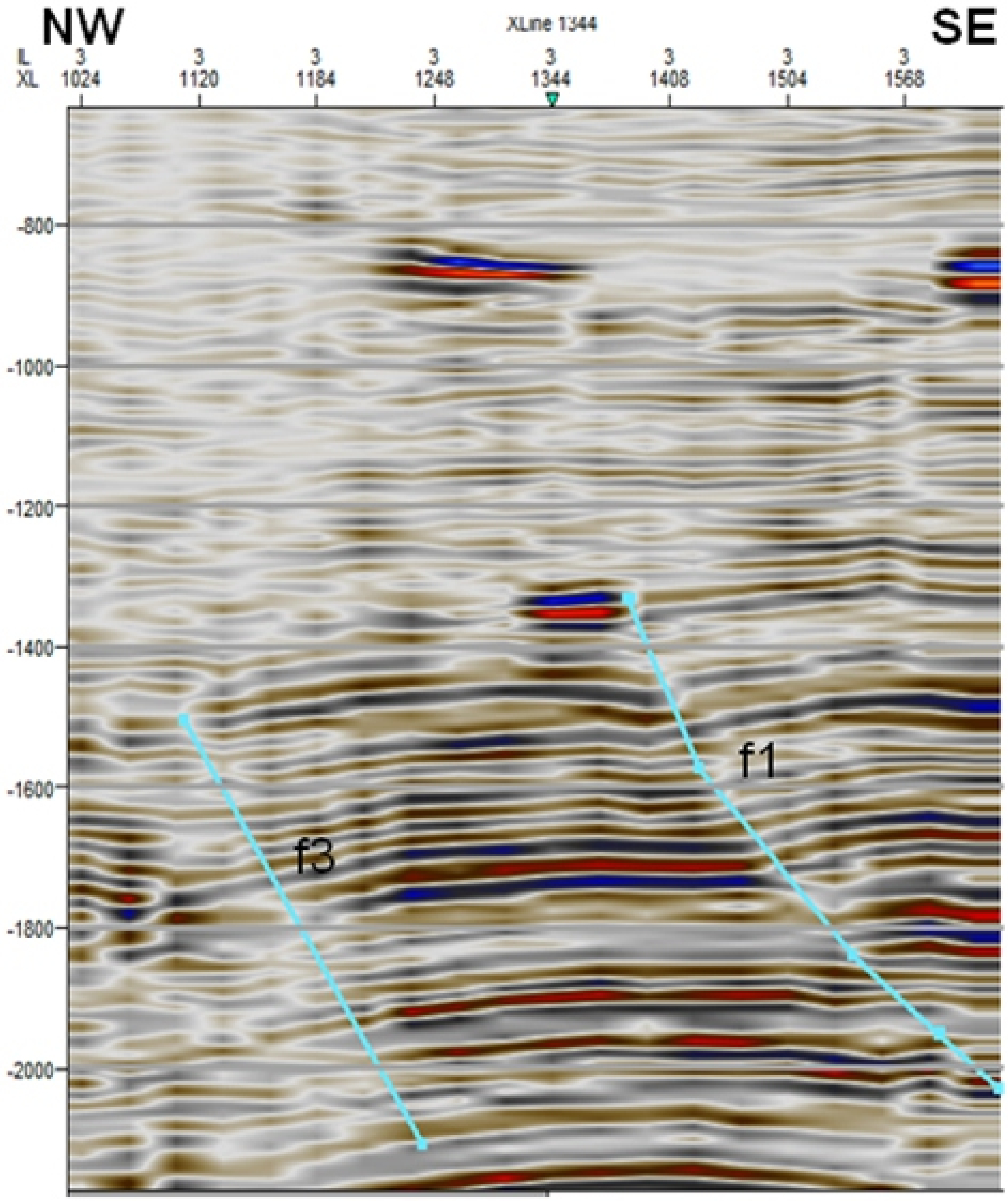

Figure 10: Seismic Cross Section Along Inline 3 Showing Fault f1 and f3

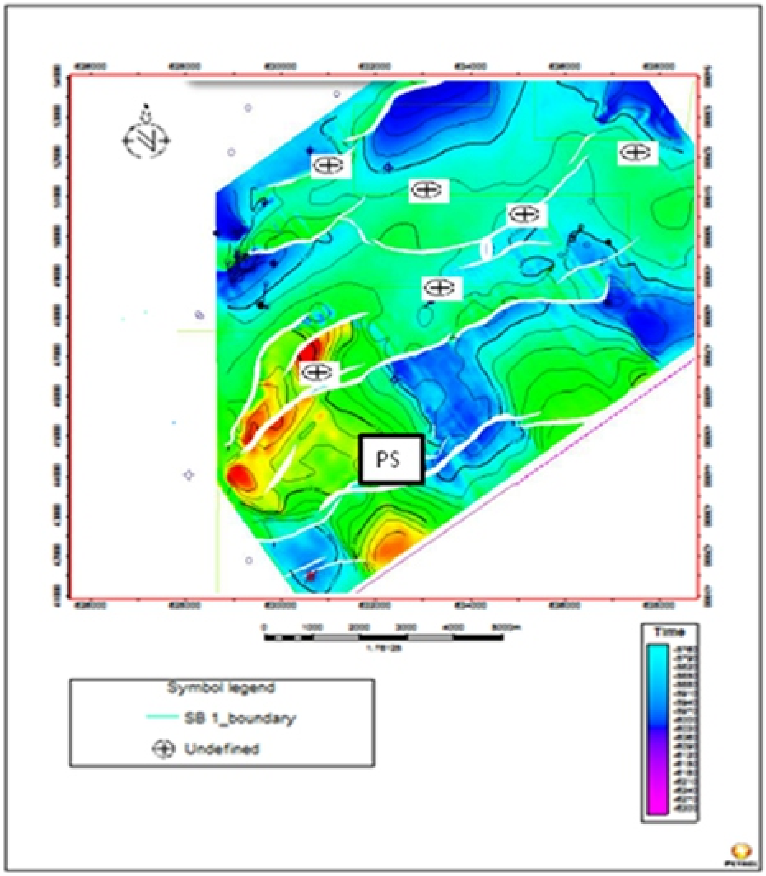

Figure 11: Structural Contour Map of Sequence Boundary 1 Showing Prospect (PS) characterized by Well Developed Fault System in South-western Flank of the Field

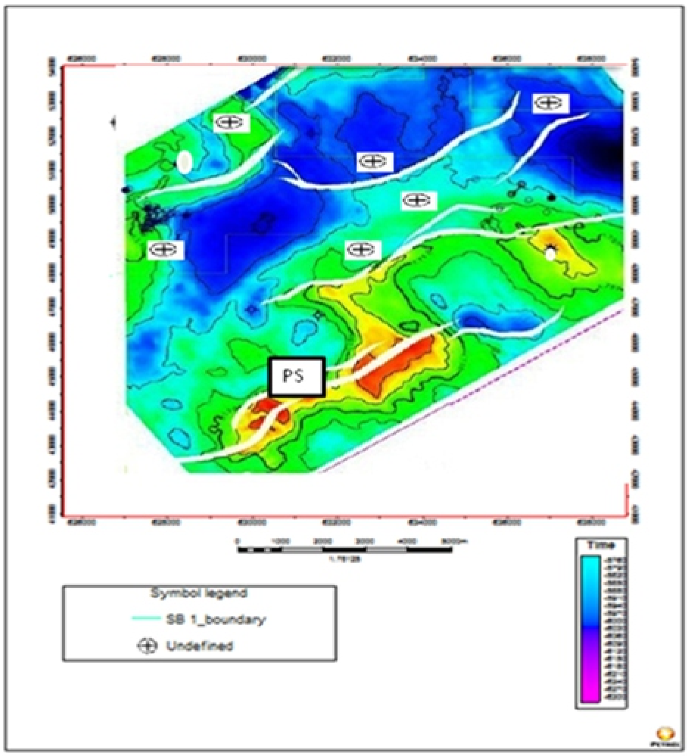

Figure 12: Structural Contour Map of Sequence Boundary 2 Showing Prospect (PS) characterized by Well Developed Fault System and Anticlinal Closure in the South-western Flank of the Field.

Interpretation of Stratigraphic Trends

The Emi Field stratigraphic intervals fall within the Paralic sequence of alternating sand and shale bodies of variable thicknesses. The sand/shale ratios generally decrease with depth suggestive of a fining downward motif. The entire sequence constitutes an overall prograding delta with periods of transgression. Three stacking patterns; progradational, aggradational and retrogradational patterns were identified together with three maximum flooding surfaces. Log trends generally change from thicker, sandier, blocky and upward fining successions to thinner upward-coarsening successions, suggesting a progression from channel deposits to dominantly offshore prograding lobes. This reflects a progression from fluvial depositional settings to pro delta and deltaic shorelines. The Agbada Formation is generally interpreted to contain fluvial deltaic deposits (Weber and Daukoru, 1975).

The maximum flooding surfaces (MFS) delineated in the study area are interpreted to have developed during the highest point of sea level rise and maximum landward incursion of the shoreline. They exhibit pelagic deposition and sediment starvation on the shelf and slope, and separates phase of shoreward retrogradation (transgression) from those of basinward progradation (regression). Three maximum flooding surfaces were delineated across the field and these correspond to the transgressive marker shales of the Niger Delta chronostratographic chart and they are marked by *Haplophragmoides-24* (6.0 Ma) and *Bolivina*-46 (5.5 Ma). Two sequence boundaries (major erosion surface) divides the strata succession in the Emi Field into three sequences, each formed during relative levels of eustacy. Two system tracts were delineated. These are the highstand system tract and transgressive system tract. Lowstand systems tract are absent in the study area and the probable cause is that during transgression, older deltaic complexes, built up and out across the shelf during the previous lowstand system tract phases, which eroded or overstepped the lowstand system tract, a process which extensively redistributes sands as sheet across the shelf.

The highstand systems tract (HST) overlies the transgressive system tract (TST) phase in the study area across the six wells studied. This occurs when the sediment supply rate exceeds the accommodation space, causing parasequence deposition to either aggrade upwards or prograde basinwards. The highstand systems tracts (HST) in the wells are thick with mainly sandy units occurring within its lithological sequence. The sands within the highstand systems tracts HST could serve as good reservoir while growth faults, active in this area, could serve as conduits for upward migration of hydrocarbon. The pelagic shales of the transgressive systems tract could form good cap rocks for the underlying and overlying HST given the right conditions. Stratigraphic correlation across the wells in the Emi Field has shown sequence 3 to be the thickest sequence within the field.

Hydrocarbon Potential

Analysis of horizons within sequences and individual system tract reveal that hydrocarbon is hosted both in the highstand systems tract and transgressive system tract (Table 4). This is further corroborated by the findings of Nton and Esan (2010). Below is a table showing hydrocarbon occurrences with their associated system tract based on well log data interpretation.

Table 4: Hydrocarbon Occurrence and Associated System Tracts from Emi-4

Zone	Top MD(ft)	Base MD(ft)	Gross Int (ft)	Sw pay	Sh Pay	System tract
Zone A	4522.67	4938.28	415.61	0.454	0.546	HST
Zone A1	4586.09	4637.55	51.46	0.351	0.649	HST
Zone A2	4658.13	4714.74	56.61	0.401	0.599	HST
Zone B	5303.08	5332.5	29.42	0.152	0.848	HST
Zone C	5494.46	5606.77	112.31	0.467	0.533	HST
Zone D	5845.9	5902.43	56.53	0.335	0.665	HST
Zone E	6114.82	6177.47	62.65	0.242	0.758	HST
Zone E1	6485.8	6551.41	65.61	0.374	0.626	TST
Zone F	6751.6	6846.72	95.12	0.212	0.788	TST
Zone G	8001.18	8068.18	67	0.212	0.788	HST
Zone H	8112.07	8340.76	228.69	0.212	0.788	TST

CONCLUSION

Two sequence boundaries (major erosion surface) subdivide the stratigraphic succession within the Emi Field into three depositional sequences, each formed during relative levels of eustacy. Ages assigned to the sequence boundaries are 5.6 Ma and 4.1 Ma. The three (3) major depositional sequences were identified in all the wells studied. Three maximum flooding surfaces were delineated across the field and correspond to the transgressive marker shales of the Niger Delta chronostratographic chart and they are marked by *Haplophragmoides-24* (6.0 Ma) and *Bolivina*-46 (5.0 Ma).

Three parasequence stacking patterns; progradational, aggradational and retrogradational patterns were identified in the Emi field. Lateral continuity of facies depended on parasequence associations. Most reservoir units occur between the 4.1 Ma and 5.6 Ma sequence boundaries (SB) as shown in Table 4. The morphology and importance of reservoirs and seals vary between system tracts. The transgressive sands and the highstand sands constitute good (potential) reservoirs. The highstand shales and transgressive shales form seals for the (potential) stratigraphic traps in the Emi Field. Possible migration pathways include carrier beds and faults. The integration of the data sets has facilitated the understanding of the process that generated the vertical stratigraphic succession of sediments which are the characteristic feature of the systems tracts across the Emi Field.

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