International Journal of Scientific & Engineering Research, Volume 10, Issue 12, December-2019
ISSN 2229-551

Sequence Stratigraphy of Emi Field, South-Eastern Niger Delta, Nigeria

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Abstract - Detailed seismic facies and well-log characteristics analyses combined with biostratigraphic and lithologic data, seismic reflection profiles and sequence stratigraphic techniques, provided the framework to unravel the sequence stratigraphy of Emi Field, South-Eastern Niger Delta, Nigeria. The study was initiated to identify, map and interpret the shallow clastic depositional sequences, attempt to establish the stratigraphic relationships associated with the stratigraphic units, and use the results to assess the stratigraphic plays, in the study area for future exploration activities. Fourteen (14) and thirteen (13) higher-order candidates for sequence boundary and sequence respectively, were delineated and interpreted across the study area. Correlation at the higher-order scale was good and showed improvement over the 3rd-order (regional) scale. The thirteen higher-order sequence candidates were grouped into two 3rd-order sequence candidates using objective criteria. Toplap, downlap, onlap, truncation and concordance relationships existed between the stratigraphic units and boundaries of the sequence candidates. Updip portions of the truncations and toplapping stratigraphic units as well as onlapping stratigraphic units in the area, are predictably good exploration targets. The thick lowstand systems with high net sandstone percentage are predictably excellent reservoirs. The shales of the Transgressive Systems Tracts (TST) overlying the Lowstand Systems Tracts (LST) are potential sources of excellent cap rock/seal for the underlying lowstand prospects.

Keywords: *Sequence boundary, sequence, toplap, truncation, downlap, concordance, onlap, Lowstand Systems Tracts, Highstand Systems Tracts, Transgress Systems Tracts*

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1.0 INTRODUCTION

It is on record that over 80% of Nigeria's revenue comes from oil and gas, with the Niger Delta basin being the major Petroleum province. Currently, most of this petroleum are in fields that are onshore and the continental shelf (in waters less than 200 meters deep), though large discoveries are undergoing development and exploitation in deeper sections. These discoveries are primarily in geological structures such as rollover anticlines and faults. The Niger Delta province is the twelfth richest in petroleum resources, with 2.2% of the world's discovered oil and 1.4% of the world's discovered gas.

It was necessary to improve the existing geological knowledge of the Niger Delta region through the application of modern concepts of sequence stratigraphy in a bid to satisfy the increasing demand for production of the vast hydrocarbon resources. The growing call for hydrocarbon prospecting, however, justifies the use of the concept of sequence stratigraphy to develop the framework and stratigraphic play concepts of Emi Field.

1.1 GEOLOGICAL SETTING

The study area is in offshore waters and belongs to Mobil Producing Nigeria Unlimited. It is about 23 kilometers southwest of Qua Iboe Terminal. The study area is in the southeastern part of the Niger Delta on the continental margin of Gulf of Guinea in the West Coast of Africa and, lies between latitudes 3^0 and 6^0 N and longitudes 5^0 and 8^0 E (figure 1).

From the Eocene to the present times, the delta prograded southwestwards, forming depobelts representing the most active portion of the delta at each stage of its development [4]. In the region of the Niger Delta, rifting diminished altogether in the Late Cretaceous [5]. After rifting ceased, gravity tectonism became the primary deformational process.

Sequence stratigraphy is the study of the relationships between stratigraphic units within a time-stratigraphic framework. The stratigraphic record consists of sequences, which are genetically related units of strata, separated from one another by surfaces of unconformity, or correlative conformities (Armentrout, 2000). The stratigraphic units are deposited in sequence on/or adjacent to marine basin margins, which are characterized by repetitive episodes of progradation with intermittent periods of transgression and submergence of depositional platform. These stratigraphic units which are the depositional sequences, are the fundamental units of sequence stratigraphy (Vail et. al., 1977; Armentrout, 2000).

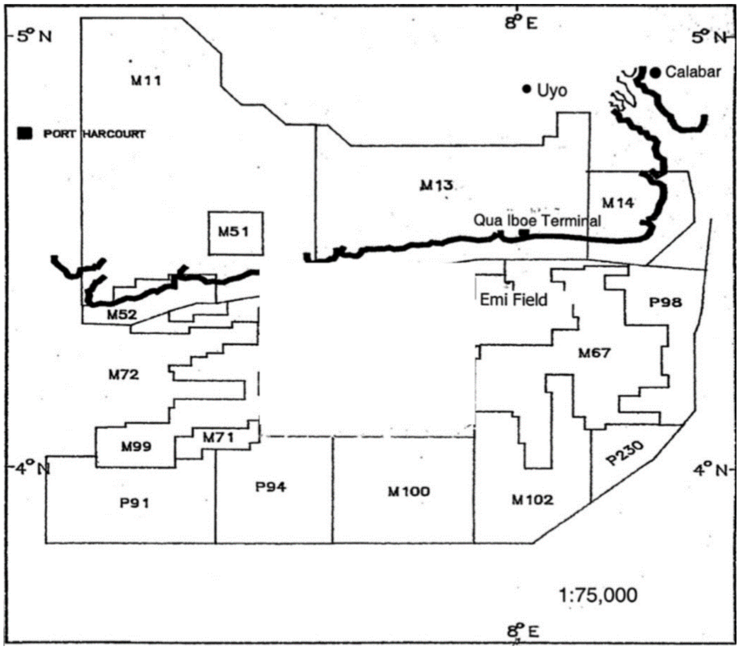

Figure 1. Niger Delta map showing location of Emi Field

2.0 Materials and Methods

2.1 Materials: The datasets for the study included geophysical well-logs (gamma ray, self potential, resistivity, sonic, density and neutron logs), 3-D seismic data covering the entire study area, biostratigraphic and lithologic data, check-shot survey data and basemap of the area.

2.2 Methods: Sequence stratigraphy concepts and techniques developed by Armentrout, (2000), Cox, (1996), Houseknecht, (2004), Hoy and Ridway, (2003), Vail *et. al*., (1977), Vail, (1987), Vail and Wornardt, (1991), and Zeng and Hentz, (2004) were utilized in this study. The techniques include the following: delineation of candidates for sequence boundary, depositional sequence, transgressive and maximum flooding surfaces from seismic and well data where possible; delineation of systems tract candidates from well data; sandstone count analysis; seismic-log integrated correlation; seismic facies analysis and integrated sequence stratigraphic interpretation of well and seismic data. The sequence of interpretation in the study was from well data to seismic data.

2.2. 1 Depositional Sequences and Sequence Boundaries: On well-logs, candidates for sequence boundary were identified where there was a significant change in facies (log characteristics) (figure 2). This occurred at the following positions: upward coarsening log pattern between maximum flooding surfaces (maximum gamma ray count, fastest sonic velocity and lowest resistivity); upward coarsening log pattern changing to upward fining log pattern; blocky (aggradational) log pattern overlying an interbedded log pattern and where there is abrupt increase in silt and sand content (interbedded log pattern) over hemipelagic shale (back-stepping log pattern).

From biostratigraphic data, candidates for sequence boundary were delineated at points of maximum abundance and minimum diversity in the faunal and floral checklists, with the sequence boundaries located somewhat above the next downhole major increase in fossil abundance. Interval of significant shift in biofacies assemblage in the fossil distribution, were also used to infer possible sequence boundary candidates. From seismic data, the surfaces characterized by regional onlaps of seismic reflections above, and erosional truncations of seismic reflections below, were identified and used to delineate sequence boundary candidates in the study area (figure 3). The units within two successive sequence boundaries formed the depositional sequence candidate.

2.2.2 Transgressive Surfaces (TS): On well-logs, candidates for transgressive surface were identified and delineated by the first significant flooding surface above the progradational to aggradational log pattern parasequence set of the lowstand systems tract (figure 4). It was not easy to delineate the transgressive surfaces from available biostratigraphic data. However, where the first significant increase in abundance and diversity of fossils above the sequence boundary occurred, candidates for transgressive surface were suspected and interpreted for this study. From seismic data, candidates for transgressive surface were identified at the point of first significant marine-flooding surface across the shelf (beyond the shelf-slope boundary) within the depositional sequence.

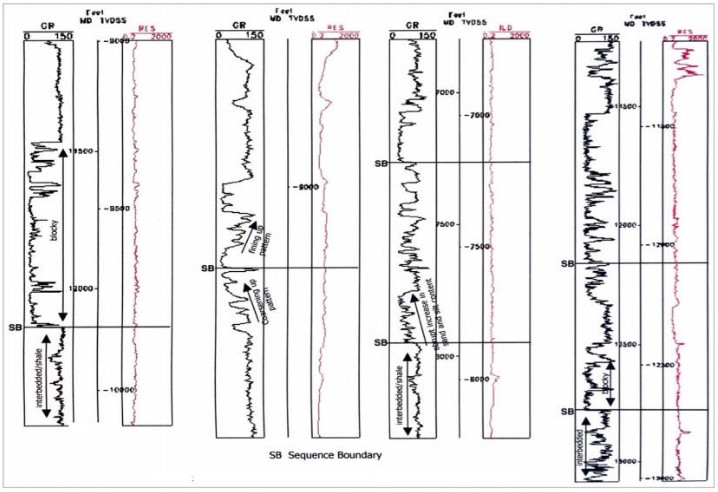

Figure 2. Well-log criteria for delineating Sequence Boundary candidates

2.2.3 Maximum Flooding Surfaces (MFS): On well-logs, candidates for maximum flooding surface were identified by maximum gamma ray counts (shaliest portion), lowest resistivity and fastest sonic velocity (figure 4). From biostratigraphic data, candidates for maximum flooding surface were associated with intervals of faunal and floral abundance and diversity maximum. Candidates for condensed section were most importantly marked by fossil abundance and diversity peaks and, often but not always associated with maximum flooding surfaces. They were shale-prone sections with characteristic back-stepping log pattern, marked by large increases in diversity and abundance of fossils. The distinctive signature in log curves over candidates for condensed section helped in locating candidates for maximum flooding surfaces much more confidently in this study. On seismic data, the non-conformity surfaces characterized by a downlap of reflections at the top, and by apparent truncation of reflections at the bottom, were used to delineate the candidates for maximum flooding surface in this study.

2.2.4 Lowstand Systems Tract (LST): Candidates for lowstand systems tract in the study area were identified by their generally blocky/cylindrical and crescentric shape of the of log motifs in addition to their progradational to aggradational stacking patterns of the parasequences and parasequence sets. The top of the lowstand systems tract was usually the transgressive surface and the base of the it, the upper boundary of the sequence below.
From available biostratigraphic data, it was difficult to delineate the lowstand systems tracts. However, at intervals of low abundance pattern of fossils, near-absence of insitu fossils and occurrence of reworked fossils, lowstand systems tract candidates were suspected for this study.

2.2.5 Transgressive Systems Tract (TST): Candidates for TST in the study area were delineated based on their characteristic stacked bell-shaped log pattern, thinning and fining upward of the parasequences and parasequence sets with a retrogradational stacking pattern of the parasequence sets. From biostratigraphic data, TST candidates were delineated where there was upward increase in abundance of fossils (where possible). The top of the TST is the maximum flooding surface and its base is the transgressive surface.

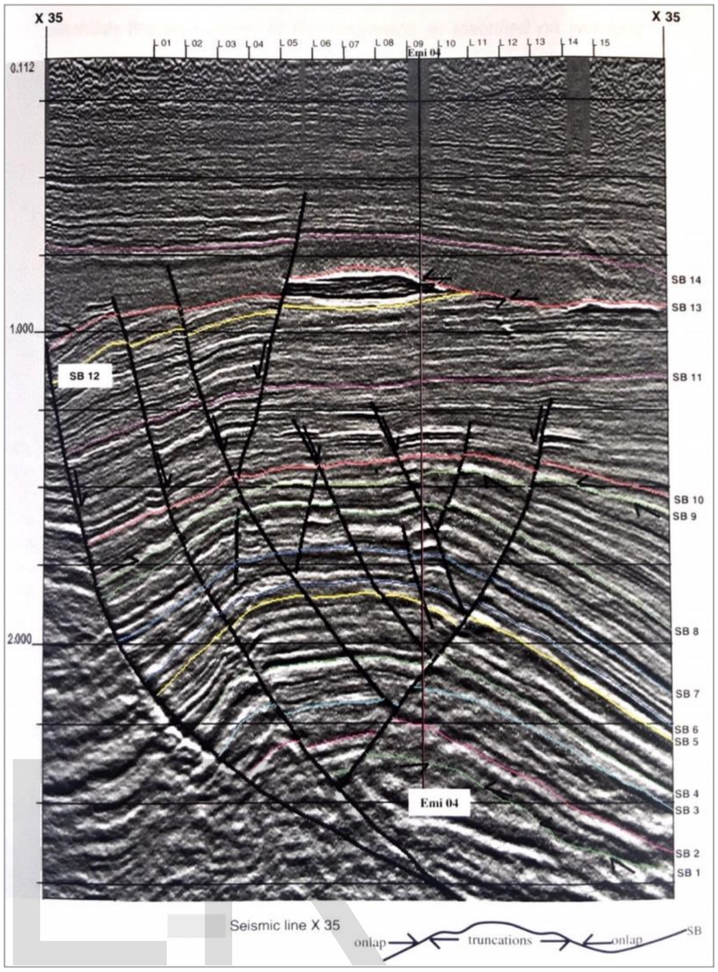

Figure 3. Seismic line X 35 showing interpretation of sequence boundaries and seismic facies

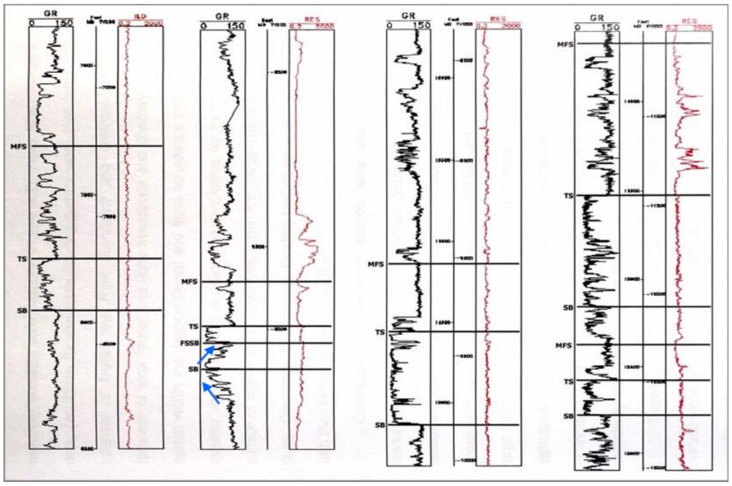

Figure 4. Well-log criteria for delineating candidates for Sequence Boundary (SB), Transgressive and Maximum/Minor Flooding Surfaces (TS and MFS)

2.2.6 Highstand Systems Tract (HST): The highstand systems tracts were delineated based on their characteristic stacked funnel-shaped log patterns that thicken and coarsen upward. The stacking pattern of the parasequences and parasequence sets is aggradational to progradational. The top of the HST is usually a sequence boundary and the base is the maximum flooding surface. From biostratigraphic data, the possible candidates for HST were recognized by low and upward decreasing fossil abundance and discontinuity.

2.2.7 Sandstone Count Analysis: This was carried out separately in each of the sequences and associated systems tracts, in the study area. The analysis was done by picking sand base-line at the thickest and cleanest sand, and shale base-line at the cleanest and most continuous shale in the entire log section. The mid-point of the two baselines was used as the cut-off point for delineation of sandstone and shale lithologies for each sequence and its associated systems tracts, in the study area. Thickness of the interval to the left of the cut-off point was taken as net sand thickness and, that to the right taken as shale thickness. The summation of the thickness of the net sand and shale intercalations within the interval for analysis, was taken as gross sand thickness for each sequence and its associated systems tracts. Net sand thickness for each sequence was expressed as a percentage of the gross sand thickness to determine the net sand percentage within each sequence. The same method was used to determine net sand percentage in each of the systems tracts.

2.2.8 Seismic Log Integrated Correlation (SLIC): Seismic log integrated correlation process was achieved using checkshot survey data from all the wells in the study area. Time and depth values from all the wells in the study area were plotted together as a composite (figure 5) and line of best fit taken to obtain a velocity function for depth conversion in the area. The procedure enhanced seismic-to-well tie for meaningful sequence stratigraphic interpretation.

2.2.9 Seismic Facies Analysis: Seismic facies analysis was carried out based on continuity, amplitude, configuration and frequency of seismic reflections within each of the sequences delineated in the study area.

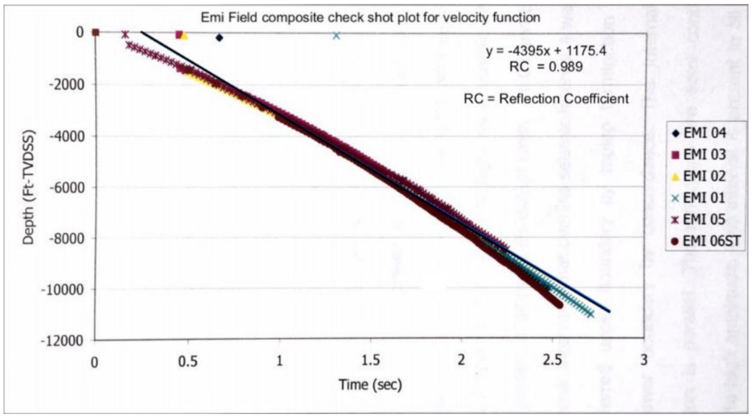

Figure 5. Composite Plot of checkshots data from all wells in the Study Area

Depths of the sequence boundaries from well logs in wells Emi 04 and Emi 03 where seismic-to-well tie was very good, were transferred to seismic line X35 (figure 3 and figure 6), to establish the equivalents of the sequences as identified on well-logs with those on seismic data. From the seismic-to-well tie, the different depositional sequences as identified and delineated on well-logs, were then established on the seismic reflection profiles. Thereafter, the patterns/configuration, continuity, amplitude and where possible, the frequency of the seismic reflections within each identified seismic interval were analyzed for the seismic facies.

2.2.10 Integrated Sequence Stratigraphic Analysis/Interpretation of Well and Seismic Data: An integrated sequence stratigraphic analysis of well and seismic data is a multidisciplinary approach to sequence stratigraphic interpretation. The method combines high-resolution biostratigraphic data, paleobathymetric data, well-logs and seismic data, to provide a comprehensive interpretation of sequence elements within a stratigraphic unit. In the study area, the method was procedural and involved: interpretation of major unconformities and significant faults; interpretation of higher order depositional sequences; interpretation of sequence sets; production of sequential-stratigraphic correlation section in depth, in which all the candidates for sequence boundary, maximum flooding surface, transgressive surface, and systems tract, were correlated from well to well based on well and seismic data where possible and, identification of possible prospects.

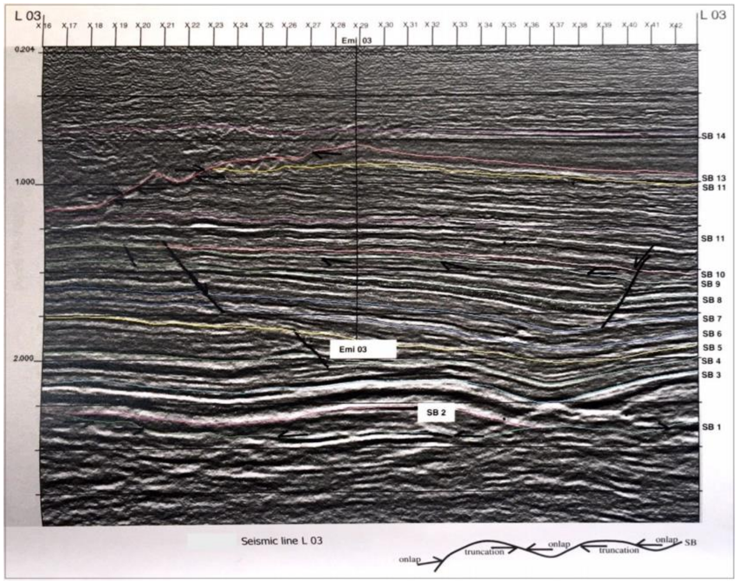

Figure 6. Seismic line L03 showing interpretation of sequence boundaries and seismic facies

2.2.11 Integrated Sequence Stratigraphic Analysis/Interpretation of Well and Seismic Data: An integrated sequence stratigraphic analysis of well and seismic data is a multidisciplinary approach to sequence stratigraphic interpretation. The method combines high-resolution biostratigraphic data, paleobathymetric data, well-logs and seismic data, to provide a comprehensive interpretation of sequence elements within a stratigraphic unit. In the study area, the method was procedural and involved: interpretation of major unconformities and significant faults; interpretation of higher order depositional sequences; interpretation of sequence sets; production of sequential-stratigraphic correlation section in depth, in which all the candidates for sequence boundary, maximum flooding surface, transgressive surface, and systems tract, were correlated from well to well based on well and seismic data where possible and, identification of possible prospects.

2.2.12 Faults and Unconformities: Faults were interpreted on seismic data at places of discontinuity of seismic reflection with observable vertical separation between the reflectors above and below. On well-logs, faults were interpreted where there were missing marker(s) when correlating marker log signatures from one well to another. Unconformities are surfaces of erosion or non-deposition of sediments. These surfaces show on seismic reflection profile as onlaps and truncations of reflections above and below the surfaces respectively, and almost always, infer sequence boundaries Vail, (1987). On well-logs, it was a bit more difficult to differentiate between faults and unconformities. However, where a missing section was observed in two or more wells at the same or nearly same correlative depth in the study area, an unconformity was suspected.

2.2.13 Biostratigraphic Analysis: Results of biostratigraphic analysis of ditch cuttings from well Emi 06 ST, composited at 90 feet and 60 feet interval for palynostratigraphic and micropaleontological interpretations respectively, were provided for the study. Various palynological zones, sub-zones and palynocycles were interpreted for the different intervals in well Emi 06 ST. The various zones, sub-zones and palynocycles established for Emi 06ST, were referenced against the zonal schemes of Evamy *et. al.,* (1978). The zonal boundaries and their associated log signatures and lithologic data allowed correlation with wells without biostratigraphic data although with great uncertainty.

2.2.14 Higher Order Sequence Boundaries and Sequences: The method used in the interpretation of higher order sequence boundaries hence, higher order depositional sequences in the study area, was similar to the method used in the delineation of regional (3rd order) sequence boundaries, hence, regional depositional sequences. The main difference however, was in their identification criteria which were higher order frequency (localized) events. This is because higher order sequences are thinner analogues of the regional sequences, hence, their depositional processes and architecture remain same (Zeng and Hentz, 2004). Another difference was that seismic criteria were not involved as these higher order sequence boundaries are below the resolution of seismic event. For example, within each delineated candidate for regional depositional sequence, localized points at which there were coarsening upwards patterns between maximum flooding surfaces, upward coarsening pattern changed to upward fining pattern, aggradational log pattern was overlain on an interbedded log pattern and, there was abrupt increase in silt and sand content over hemipelagic shales, were used to delineate candidates for higher order sequence boundary (figure 7). Localized minor shift in biofacies assemblage in the way that minor/localized shift occurs in the stacking patterns of well-log profiles, was also used to constrain the candidates for higher order sequence boundary. These were observed at points of localized or less significant abundance of and diversity minima from the biostratigraphic checklist, with the possible higher order sequence boundaries most often positioned somewhat above the next downhole minor increase in fossil abundance and diversity (minor flooding surfaces). After delineating the candidates for higher order sequence boundaries, the units within two successive higher order sequence boundaries were interpreted as the candidates for higher order depositional sequences.

2.2.15 Sequence Sets: Interpretation of sequence sets in the study area was based on the scale of interpretation. For example, all the higher order frequency sequences and systems tracts within the regional lowstand systems tract of any of the identified regional sequence candidates in the study area, became sequence elements of the regional lowstand systems tract. The regional lowstand systems tract therefore became a lowstand sequence set (LSS) (figure 8). Similarly, all the higher order sequences and systems tracts within the identified regional transgressive and highstand systems tracts, became sequence elements of the respective regional systems tracts. The individual regional systems tracts then became sequence sets hence, we have transgressive sequence set (TSS) and highstand sequence set (HSS).

2.2.16 Sequence Stratigraphic Correlation: In the sequential stratigraphic correlation, the shale marker at all identified maximum flooding surfaces in well Emi 06ST that had complete well data, was used as the correlation datum in all the sequences in the well based on the method of Neal *et. al.,* (1994) and Neal *et. al.,* (1995).

These surfaces were then used to further guide the delineation of correlation datums like sequence boundary, transgressive surface and the sequence elements. The sequence elements and their corresponding bounding surfaces as delineated in well Emi 06 ST, were correlated in depth, in all the other wells in the study area. The correlation was basically lithostratigraphic-based and achieved primarily by well-logs with controls from seismic and key markers validated by biostratigraphic data.

2.2.17 Prospects Identification: Three key surfaces were interpreted seismically using the conventional method of Cox (1996). Time and hence, depth structure maps were produced. A representative map of one of the mapped surfaces is shown in figure 9. Fault-dependent and four-way closures as well as stratigraphic closures from the maps were considered as possible prospect candidates. Thickness map of one of the regional lowstand systems tracts was also generated by additive seismic interpretation process (figure 10) to assess sand distribution within the systems tract in the study area. The thickness map was used to assess and understand sand distribution in the lowstand depositional systems in the study area. This is a key element in prospect generation.

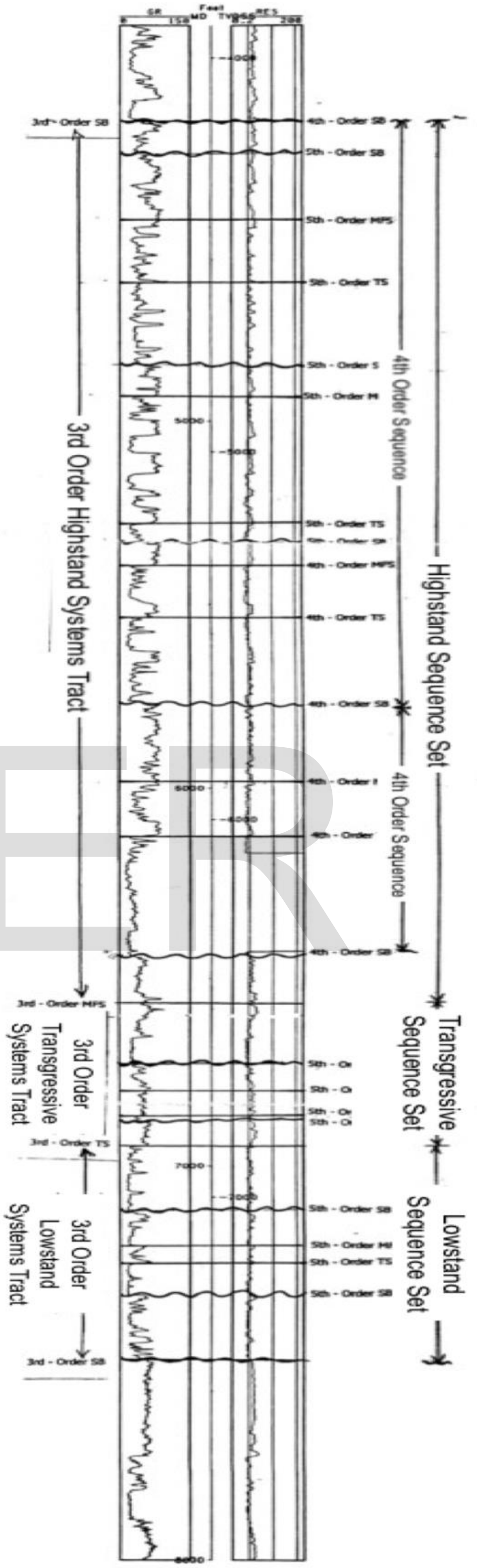

Figure 7. Illustration Higher Order Sequences

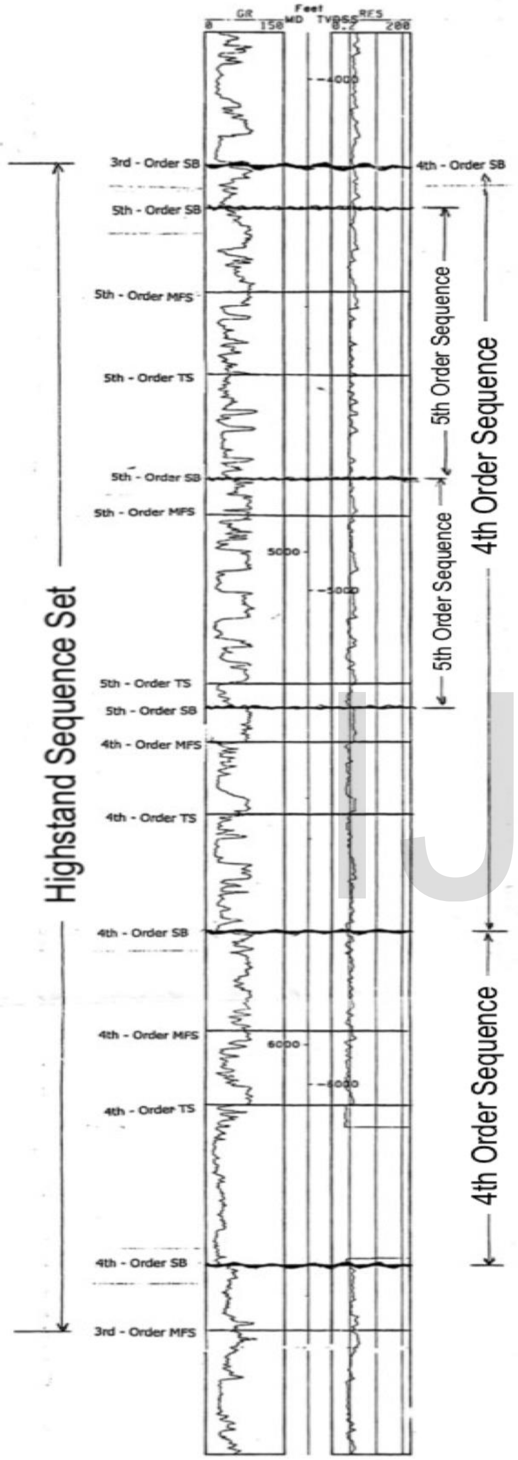

Figure 8. Illustration of Sequence Set

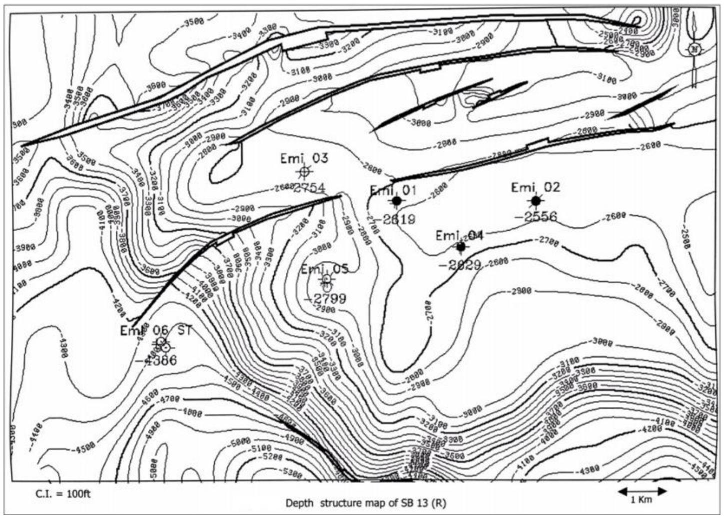

Figure 9. Depth structure map of SB 13 (R), one of the key regional surfaces

3.0 Results and discussion

Fourteen (14) candidates for depositional sequence boundary and thirteen (13) candidates for depositional sequence have been identified and correlated across the entire well in the study area (figure 11). Three of the sequence boundary candidates have been interpreted as regional (3rd order) sequence boundary candidates. They are: SB 1 (R), SB 9 (R) and SB 13 (R-TSSB/FSSB). SB 13 (R-TSSB/FSSB) is a Transgressive

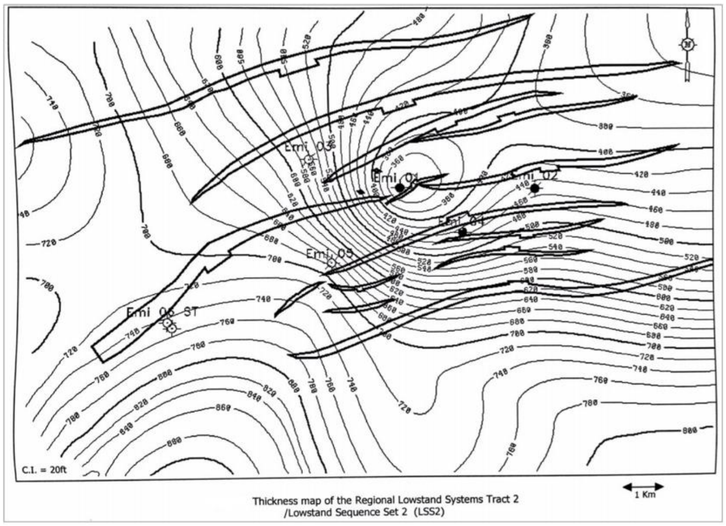

Figure 10. Thickness map of the Regional Lowstand Systems Tract 2/Lowstand Sequence Set 2

Surface Sequence Boundary (TSSB)/Flooding Surface Sequence Boundary (FSSB). Most of the sequence boundary candidates in the study area occurred at intervals where abrupt increase in silt and sand occurred over shale and also, where aggradational stacking pattern of log motifs was overlain on an interbedded log pattern. Only a few of the sequence boundary candidates occurred at intervals where upward coarsening pattern changed to upward fining pattern. No sequence boundary candidate was picked at intervals of coarsening pattern between candidates for maximum flooding surface. This is however because the depositional model of vail *et. al.,* (1977) and Van Wagoner, (1990) was used in this study. As a first approximation, candidates for sequence boundary are placed at the base of the first important sand occurrence indicated by gamma ray (GR) or self spontaneous (SP) log above a maximum flooding surface. The bases of sand bodies with a blocky or flat-bottomed GR or SP profile are often good candidates for sequence boundary. In applying biostratigraphic data, candidates for sequence boundary are commonly associated with a shift in biofacies assemblage.

On seismic reflection profiles, only one of the regional sequence boundary candidates (SB 13 [R-TSSB/FSSB]) showed clearly as an unconformity surface. The other two regional sequence boundary candidates (SB 1 and SB 9) were not clearly shown as unconformity surface. This might have been since the erosional or non-depositional process that resulted in the unconformity, did not last for a long time or, did not remove large thickness of strata (Armentrout, 2000).

Thirteen (13) transgressive surface candidates have been interpreted in the study area. Three of these are regional (3rd order) transgressive surface candidates. They are: TS 5 (R), TS 10 (R) and SB 13 (R-TSSB/FSSB). The other ones are higher order transgressive surface candidates (figure 11). Similarly, thirteen (13) maximum flooding surface candidates have been interpreted in the study area. Three (3) of them are regional maximum flooding surface candidates and, are: MFS 6 (MX), MFS 10 (MX) and MFS 13 (MX). The other ones are higher order maximum flooding surface candidates (figure 11) and are technically referred to as minor flooding surface candidates.

Interpretation of candidates for transgressive surface from seismic data was unreliable as the first significant marine-flooding surface across the shelf within the sequence could not have been observed with certainty. This might have been caused by limited resolution of seismic event. From biostratigraphic data, it was also difficult to interpret candidates for transgressive surface. This was probably due to the coarseness of sampling intervals for biostratigraphic data apart from the generally thin transgressive units in the study area.

Maximum and minor flooding surface candidates in the study area were identified with ease from well data. The minor flooding surface within sequence candidate 12 was completely eroded in the study area at the Base Qua Iboe unconformity surface.

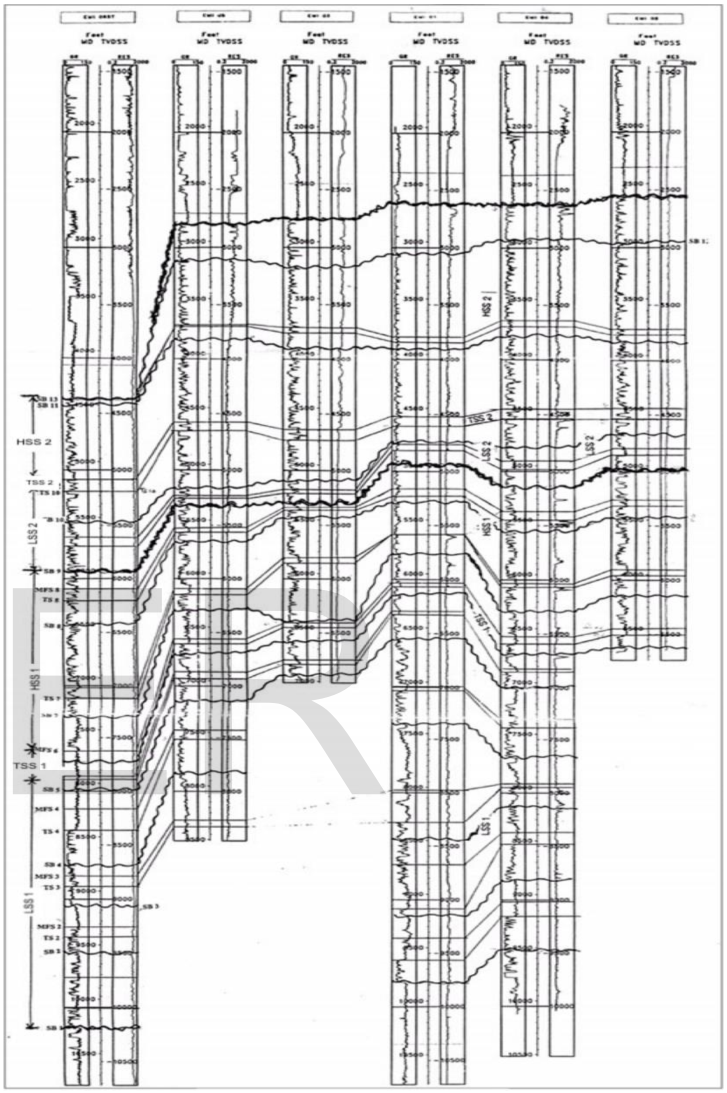

Figure 11. Sequential correlation of all sequence elements in the Study Area

The average gross thickness of highstand systems tracts (HSTs) varies from 105 feet to 315 feet with average net-to-gross thickness percentage ranging between 38% to 67% (table 1). Average gross thickness of lowstand systems tracts (LSTs) varies from 159 feet to 204 feet with average net-to-gross thickness percentage ranging between 62% to 80% (table 1). The average gross thickness of transgressive systems tracts (TSTs) varies from 56 feet to 139 feet with average net-to-gross thickness percentage ranging between 6% to 19% (table 1). The lateral distribution of the thickness of these systems tracts on well-logs correlation across the entire study area is shown in figure 11.

The individual systems tract candidate in the study area is generally continuous with variation in thickness in the down-dip direction. These variations reflect changes in the accommodation space histories of the area with changing sea level. For example, the expansion of the thickness of the highstand systems tracts is probably due to the large accommodation space created for sedimentation during relative sea level rise which precedes highstand depositional systems. This results in a series of coastal onlaps of sediments. Also, the highstand systems tract is a stable systems tract thus, enhancing sedimentation. The lowstand systems tract forms during relative sea level fall. At this time, limited accommodation space is created with sediments prograding faster into the basin. This systems tract is unstable with a lot of down-cutting and by-passing of sediments. The generally thin TSTs in the study area is however not unconnected with the high sedimentation rate in the Niger Delta (Reijers, 1996) which probably did not allow for enough accommodation space to be created for sedimentation especially at the transgressive times. Moreover, the transgressive systems tracts form during the flooding phase with little deposition of marine-rich sediments. Within some sequences in the area, erosion has visibly altered their lateral continuity. The effect of erosion is more prominent in sequence 12 where the entire transgressive and highstand systems are completely eroded.
The sandstone count analysis in the study area shows that the area consists of appreciable sandstone thickness. Stacher (1994) stated that the 3rd order sequences in the Niger Delta could be as thick as 4000 feet. Krassay and Totterdell (2003) reported a thickness of about 5000m for the combined Benin and Agbada Formations. Except for the transgressive systems tracts, the gross thickness, net thickness and net-to-gross thickness percentages for the other systems tracts are significant. The average net-to-gross thickness percentages are greater for lowstand systems tracts than for the highstand systems tracts in the area. This is probably because within the lowstand systems, the sediments are reworked and, the silty and shaly components winnowed/flushed out leaving a very clean sandstone unit within the lowstand systems. Sediments of the transgressive systems tracts are generally marine-rich with very low net sandstone percentages (Armentrout, 2000).

Table 1. Average thickness of Lowstand Systems Tracts (LSTs) in the Study Area

Average Thickness of Lowstand Systems Tracts (LSTs) in the Study Area

LSTs	Wells					
	Emi 1	Emi 2	Emi 3	Emi 4	Emi 5	Emi 06ST
Gross	167	159	231	195	204	190
Net	134	116	167	143	152	118
Net-to-Gross (%)	80	73	73	73	75	62

Table 2. Average thickness of Transgressive Systems Tracts (TSTs) in the Study Area

Average Thickness of Transgressive Systems Tracts (TSTs) in the Study Area

TSTs	Wells					
	Emi 1	Emi 2	Emi 3	Emi 4	Emi 5	Emi 06ST
Gross	103	90	78	106	56	139
Net	18	7	6	6	5	27
Net-to-Gross (%)	17	8	7	6	9	19

Table 3. Average thickness of Highstand Systems Tracts (HSTs) in the Study Area

Average Thickness of Highstand Systems Tracts (HSTs) in the Study Area

HSTs	Wells					
	Emi 1	Emi 2	Emi 3	Emi 4	Emi 5	Emi 06ST
Gross	369	415	309	317	347	319
Net	215	256	207	160	181	120
Net-to-Gross (%)	58	62	67	50	52	38

The analysis of seismic facies within the thirteen sequences in the study area is summarized in table 2. Toplap relationship exists between the reflections and the upper boundary in sequences 1, 2, 3, 5, 7 and 8. Concordance relationship exists between the reflections and the upper boundary in sequences 4, 6, 9, 10, 11 and 13 while truncation relationship exists between the reflections and the upper boundary in sequence 12.

Between the reflections and the lower boundaries, downlap relationship exists in sequences 1, 2, 3, 6, 8 and 9 while concordance relationship exists in sequences 4, 5, 7,10,11 and 12. Onlap relationship exists in sequence 13. The internal configuration of the reflections is parallel in most of the sequences. In the other ones, it is either variable to sub-parallel, parallel and slightly divergent or parallel and even. Amplitude strength of the reflections is moderate to high in most of the sequences while reflection continuity is generally continuous in almost all the

International Journal of Scientific & Engineering Research, Volume 10, Issue 12, December-2019
ISSN 2229-551

sequences. Seismic reflection configurations have been proven to be an invaluable tool in the interpretation of depositional energy within seismic sequence (Mitchum Jr. et. al., 1977). The internal configurations of all the seismic sequences interpreted in the study area are mostly parallel. Since parallel internal configuration suggests uniform rates of deposition on a uniform subsiding shelf or stable basin plain setting, it suggests directly that the depositional patterns in the study area were of uniform rates of deposition. Reflection continuity of seismic facies is closely associated with continuity of strata. Continuous reflections suggest widespread, uniformly stratified deposits. This characteristic of seismic facies in the study area was greatly expressed in the good lateral continuity of the systems tracts. The high and moderate amplitudes observed in the study area indicate the unique characteristic feature of the paralic sequence of Agbada Formation.

Although, there is a general consistency in the trend of both the regional and higher order lowstand systems tracts distribution in the study area, there is a relative growth in the higher order lowstand systems tract of sequence 10 (LST 10) around wells Emi 03 and Emi 05. Within the area around these wells, there is a general thinning in the regional lowstand systems tract 2 (LST 2) that accommodates LST 10. Similarly, well Emi 01 showed a relative growth in the lowstand systems tract of sequence 9 (LST 9) compared to the general thinning in the regional lowstand systems tract 2 (LST 2) in the area around well Emi 01 (figure 12). These localized thick lowstand systems are potentially good stratigraphic plays. The up-dip portions of truncations and toplapping reflections at the upper boundaries of some of the sequences, and even those of the onlapping reflections at the lower boundaries of some of the sequences too, are potential exploration targets. These termination points have been proven to provide excellent trapping mechanisms for hydrocarbon accumulation (Vail *et. al.,* 1977).

Seismic Facies Analysis					
Sequences	Relationship with Upper Boundary	Relationship with Lower Boundary	Internal Configuration	Amplitude Strength	Reflection Continuity
1	Toplap	Downlap	Variable to Sub-Parallel	Moderate to High	Continuous
2	Toplap	Downlap	Parallel to Sub-Parallel	Moderate	Continuous
3	Toplap	Downlap	Parallel and Even	Moderate to Low	Continuous
4	Concordance	Concordance	Parallel and slightly divergent	Moderate to High	Semi-continuous
5	Toplap	Concordance	Parallel	Moderate to High	Continuous
6	Concordance	Downlap	Parallel	Moderate	Continuous
7	Concordance	Concordance	Parallel and slightly divergent	Moderate to High	Moderate to Continuous
8	Toplap	Downlap	Parallel	Moderate to High	Continuous
9	Concordance	Downlap	Parallel	Moderate	Continuous
10	Concordance	Concordance	Parallel	High	Continuous
11	Concordance	Concordance	Parallel	Low	Continuous
12	Truncation	Concordance	Parallel to Even	Moderate to Low at lower/middle portion, Very High at upper portion	Continuous
13	Concordance	Onlap	Reflection-free	Very low	Continuous

Table 4. Seismic facies analysis of the sequences in the Study Area

The trap style for the lowstand unit below the unconformity surface at SB 13, is combination (stratigraphic and structural). Based on the depth structure map on SB 13 and the seismic reflection profile at well Emi 04, there are good closures within the study area. The closures are predictably good prospects. The unconformity provides a good stratigraphic barrier for the upward migration of hydrocarbon from the lowstand unit below it. The shale above SB 13 (figure 11) is a possible excellent seal for the underlying reservoir. Highstand systems form excellent reservoirs in the late-highstand fluvial sediments (Wornardt, 1991). The thickness map of the regional lowstand systems tract showed a general thickening to the southern part of the study area on the downthrown side of the faults. Along strike in the study area, thickness distribution of the lowstand systems is near-even. The excellent blocky sands of the lowstand systems are clearly very attractive potential reservoirs. Lowstand systems also form good reservoirs as the sands have excellent porosity and permeability except maybe where the sand grains are feldspathic or lithic (Wornardt, 1991). The shale of the transgressive systems above the TS 10 (R) is predictably, a potential source of an excellent seal for the underlying lowstand systems reservoir. According to Wornardt, (1991), the transgressive surfaces form good hydrocarbon sealing surfaces. Some of the systems tracts associated with the higher order sequences in the study area have excellent reservoir properties and are predictably, good flow units. During well completions operations, these flow units are potentially good perforation intervals.

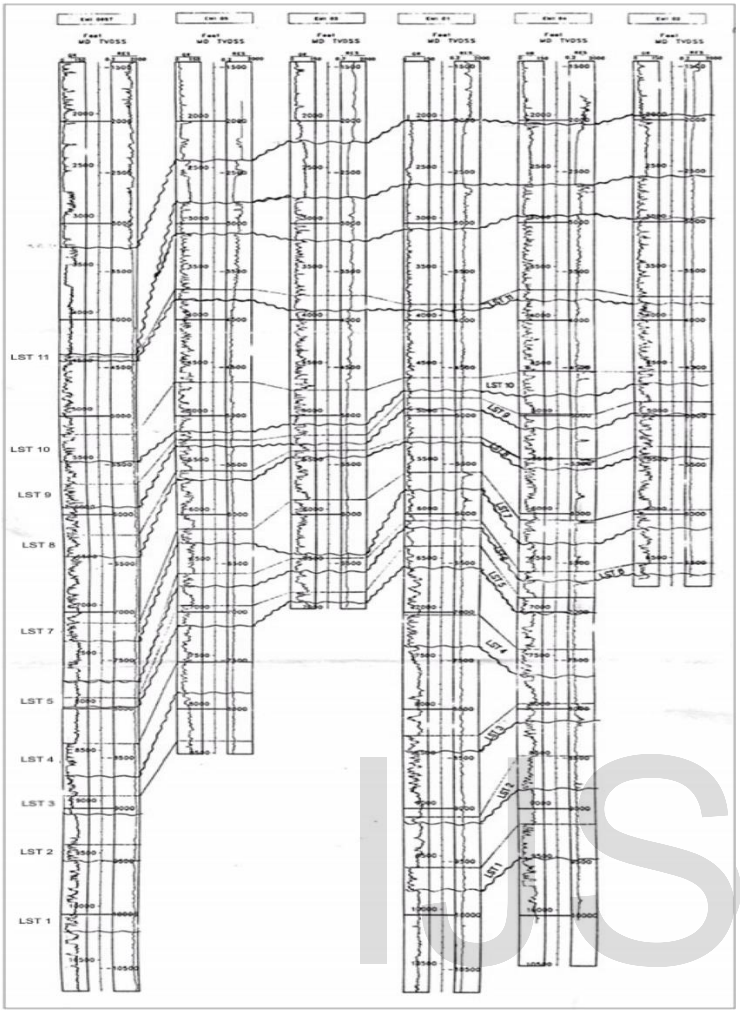

Figure 12. Well-log correlation/thickness distribution of Lowstand Systems Tract (LST) in the study Area

Conclusion

The detailed integrated sequence stratigraphic analysis of well and seismic data in the study area divided the area into two (2) regional depositional sequence candidates and thirteen higher-order depositional sequence candidates. The depositional sequence candidates and their associated systems tracts were delineated and interpreted based on vertical and lateral lithofacies variations, relationship of the seismic reflection pattern with the bounding surfaces and, stacking patterns of parasequences and parasequence sets.

Toplap and concordance relationships existed between the stratigraphic units and the upper boundary of most of the sequences candidates. Downlap and concordance relationships existed between the stratigraphic units and lower boundary of almost all the sequence candidates.

Up-dip portions of the truncations and toplapping stratigraphic units, and even top of onlapping stratigraphic units interpreted in the study area, are predictably good exploration targets. The thick lowstand systems units with high net-to-gross percentages, are predictably excellent reservoirs. The shales of the transgressive systems tracts overlying the lowstand systems in the study area, are potential sources of excellent cap rock/seal for the underlying lowstand prospects.

A greater part of the stratigraphic sequence analysis carried out in this study was based on well-logs primarily. The other tools (biostratigraphic data and seismic data) were used to validate one aspect or the other of the interpretations and deductions made from well-logs. In almost all cases especially in the delineation of candidates for sequence boundary, maximum flooding and transgressive surfaces, there was virtually no difference between interpretations from well-logs and those from available biostratigraphic data. Aspects that seismic reflection profiles could resolve, did not also show any significant variance with interpretations from well-logs. Biostratigraphic data are very expensive to acquire. It is time intensive too. Well-logs are cheaper and easier to acquire. They also provide better correlation for unitization of field. Therefore, complete well-logs suites have been found to be a close substitute to biostratigraphic data to a very great extent for sequences stratigraphic analysis. The sequential stratigraphic correlation all sequence elements and the higher order sequential stratigraphic interpretation in the study area enhance delineation and correlation of thin reservoirs (flow units) and hence, discovery of possible by-pass hydrocarbon zones in the study area.

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