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Sequence Stratigraphy of Some Middle to Late Miocene Sediments, Coastal Swamp Depobelts, Western Offshore Niger Delta

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ABSTRACT

An integrated interpretation of well logs and biostratigraphic data of three selected oil wells (Exxit 73, 75 and 78) of OML 99 within the western offshore Niger Delta was carried out for the sequence stratigraphic analysis of sediments penetrated by the wells. This enabled the subdivision of the stratigraphic column within the wells into depositional sequences and sedimentary cycles.

Three depositional sequences were identified and they are characterized as highstand systems tract, transgressive systems tract and lowstand systems tract. Three maximum flooding surfaces and three sequence boundaries were also recognized. The depositional environment of the study area is inferred to be of deltaic shelfal-transitional type. These depositional sequences have potential to serve as excellent source rock and seals. Sand percentage calculation showed that the maximum flooding surfaces correspond to the major shale break i.e. high shale content. Further studies also identified the major fault planes and a hydrocarbon potential, speculated probably at 11800ft. Utilizing the Palynological Zonation of Exxit 73, 75 and 78, the ages of the sediments penetrated in the wells were inferred to range from Middle - Late Miocene.

Keywords: *Niger Delta, Sequence stratigraphy, Depositional sequence, Systems tract, Sedimentary cycle, Source rock.*

1. INTRODUCTION

The history of petroleum exploration has shown that there will always be enough possibility of finding more oil and gas, if more accurate exploration technique is employed in the right place. Sequence stratigraphy has turned out to be one of such extraordinary helpful techniques in generating exploration prospects and predicting reservoir and seal quality in both stratigraphic and structural prospects. This concept involves the integration of seismic data, well logs and high resolution biostratigraphic data for provision of chronostratigraphic framework for the analysis, correlation and mapping of sedimentary packages. It encompasses the identification of the key bounding surfaces, systems tracts, depositional sequences and sedimentary cycle deposition; assigning ages to the identified key bounding surfaces as well as correlating genetically related chronostratigraphic surfaces [1, 2, 3]. The three wells used for this study are Exxit 73, 75 and 78. These wells were studied based on the concept of sequence stratigraphy, which facilitated the prediction of the environment of deposition, identification of succession of lithologies and isolation of hydrocarbon traps. The area under investigation is located in the western part of coastal swamp depobelt of Niger Delta. It lies between longitude 40 521 E and 40 561 E and Latitude 50 431 N and 50 481 N (Fig.1).

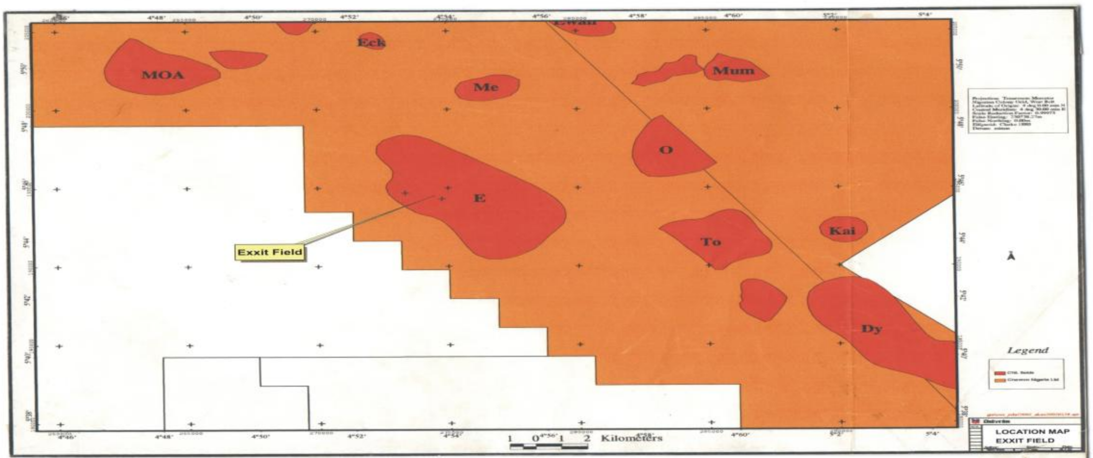

FIG 1: LOCATION MAP OF THE STUDY AREA (EXXIT FIELD)

2. REGIONAL GEOLOGIC SETTING

The Niger Delta basin is situated on the continental margin of the Gulf of Guinea in equatorial West Africa. It is a clastic fill of about 12,000metres with sub-aerial portion covering 75,000 sq. km. and extending more than 300km from apex to mouth [**4**]. The Niger Delta complex developed at the point where the three arms of a triple junction met. This triple junction was formed during the split of the African and South American plates in the Albian times [**4, 5**]. Two of the arms, which followed the southwestern and southeastern coast of Nigeria developed into collapsed continental margins of the South Atlantic, whereas the third failed arm developed into the Benue Trough.

However, true delta development commenced only in the Paleocene times when sediments began to accumulate in the troughs between basement horst blocks of the northern flank of the present delta area. The progradation of the Niger Delta first occurred during the Eocene, probably in response to epeiorogenic movements along the Benin and Calabar flanks, [**6**] and this continued to the present time. Strata were deposited along an unstable progradation margin. This was later seen to result from paralic deposition into a series of depobelts which succeeded each other in time and space, leading to a regular step-like southward progression of the delta referred to as "escalator regression".

The development of the proto-delta was terminated in the Paleocene by a major sea transgression [**7**]. This was followed by a regressive phase in the Eocene as the sea progressively moved southwards. The regressive phase has continued until the present, but is frequently interrupted by generally minor transgressions, resulting in the formation of the modern Niger Delta, which is Eocene to Recent in age. The Niger Delta basin consists of massive and monotonous marine shale at its base. This grades upward into interbedded shallow marine fluvial sands, silts and clays, which form the typical paralic portion of the delta. The uppermost part of the sequence is a massive, non-marine sand unit. These are referred to as the Akata, Agbada and Benin Formations respectively [**8**]. These three lithostratigraphic units are strongly diachronous. However, the Cenozoic Niger Delta complex is greatly affected by large scale synsedimentary features in the subsurface, such as growth faults, roll-over anticlines and diapirs [**6**].

3. MATERIALS AND METHODS

The data used for this study were obtained from a multi-national Oil Company. They include composite logs (Gamma ray and Resistivity logs in scale of 1:1500ft) of the Exxit 73, 75 and 78 wells and high resolution biostratigraphic data consisting of foraminiferal diversity/population, benthic diversity/population, planktic diversity/population, paleobathymetric data as well as microfaunal and microfloral zonation table (F & P zones). The Niger Delta Chronostratigraphic chart and a base map showing the location of Exxit fields in the Niger Delta were also provided. However, there is no seismic data available from the oilfields. All attempts to secure such data were futile. These data were interpreted and integrated to produce the sequence stratigraphic framework of the Exxit field using the methods proposed by [**9, 10, 11**]. Depositional sequences, systems tracts and the key bounding surfaces were interpreted from the well logs and the biostratigraphic data and refined by the delineation of lithologic breaks from sand percentage plots on graphs from which the primary major shale breaks were identified i.e. ranging from 80 – 100% on the plot and which fully corresponds to one cycle for each of the three (3) studied wells. The lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST) were coloured purple, green and orange respectively on the interpreted section.

High Resolution Biostratigraphy

This provides information on depositional environments and paleobathymetry of the study area which range from inner to outer neritic. The paleobathymetry of sediments in the various systems tracts was determined using the benthic foraminiferal assemblages [**9, 10**]. The biostratigraphic data provided were used to recognize the changes in relative paleobathymetry, leading in turn to the recognition of key stratal surfaces, parasequences and systems tracts. The candidate maximum flooding surfaces (MFS) and sequence boundaries (SB) were initially recognized from the checklists and from the plots of species diversity and population abundance by increase and decrease in fauna and flora respectively [**12, 13, 14**]. Their actual positions were confirmed on the well logs. High resolution biostratigraphy also played a critical role in dating the MFS and the SB, so that locally recognized cycles were correlated with globally recognized cycles of the eustatic cycle chart [**15**].

Fossil Assemblages

Fossil assemblages used to interpret the various water depths (paleobathymetry) of the sediments penetrated by the studied wells include the following:

Coastal Deposit: *Textularia spp.*

Shallow Inner Neritic: *Globigerina spp., Uvigerina spp., Bolivina spp., Alabamina spp..*

Proximal Fluvio-Marine: *Ammobaculites spp., Textularia spp., Verneuilina spp..*

Inner Neritic: *Cibicides spp., Eponides spp., Triloculina spp., Nonion spp..*

Inner Neritic to Middle Neritic: *Triloculina spp., Nonionella spp., Globigerina spp., Alabamina spp., Textularia spp..*

Middle Neritic: *Verneuilina spp., Trochammina spp., Anomalina spp., Trochamminoides spp..*

Outer Neritic: *Globigerinoides spp..*

Outer Neritic to Bathyal: *Discorbis spp.,, Cibicides spp., Reusella spp., Spiroloculina spp., Lagena spp..*

Bathyal: *Valvulineria spp., Quinqueloculina spp., Alabamina spp., Textularia spp.*

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4. RESULTS AND DISCUSSION

Lithofacies interpretation

Lithologic interpretation of the well logs gave predominantly sand and shale intercalation, which constitute the Agbada Formation across the three wells of study. The vertical and lateral facies changes of the area under study are largely the function of the variability in the sand and shale thickness known as sand percentage. Sand percentage is one of the most reliable ways of expressing lithofacies and this can be calculated from well logs (Gamma ray) per hundred feet (100ft) interval (Fig. 2 - 4). Wornardt, 1994 [**16**] suggested the various sand percentages that can indicate the different lithofacies. Lithofacies interpreted from sand percentages and well logs can be used for reservoir characterization, burial history and lithofacies zonation. The various lithofacies patterns were sub-divided into prospective and non-prospective sequences based on hydrocarbon prospectivity. The prospective sequences are made up of marine-paralic, paralic and transitional-paralic facies, while the non-prospective sequences that seldom generate or trap hydrocarbons include the continental, continental-transitional and transitional facies. However, the non-prospective sequences can acts as seal. Continental facies were encountered in all the wells (Exxit 73, 75 and 78). Continental-transitional lithofacies unit occured in Exxit 73 and 75 wells, but was absent in Exxit 78. Transitional, transitional-paralic, paralic, marine-paralic and marine lithofacies units were also encountered in all the wells.

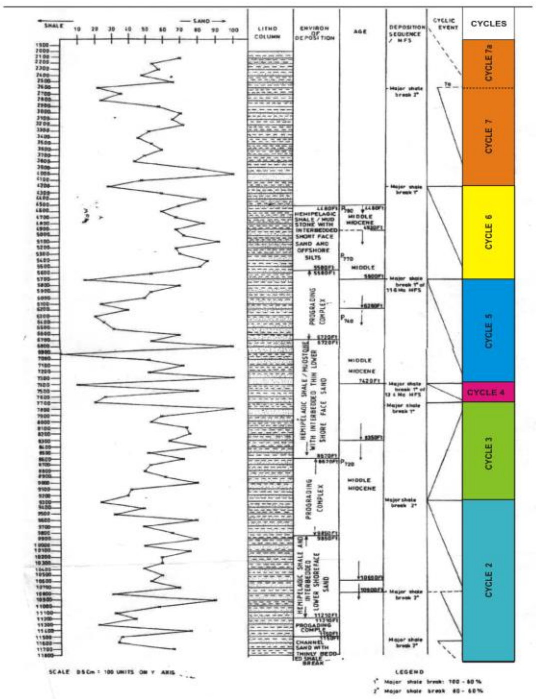

FIG 2: DEPOSITIONAL CYCLE DELINEATION USING SAND PERCENTAGE CALCULATION AND ENVIRONMENT OF DEPOSITION (EXXIT 73)

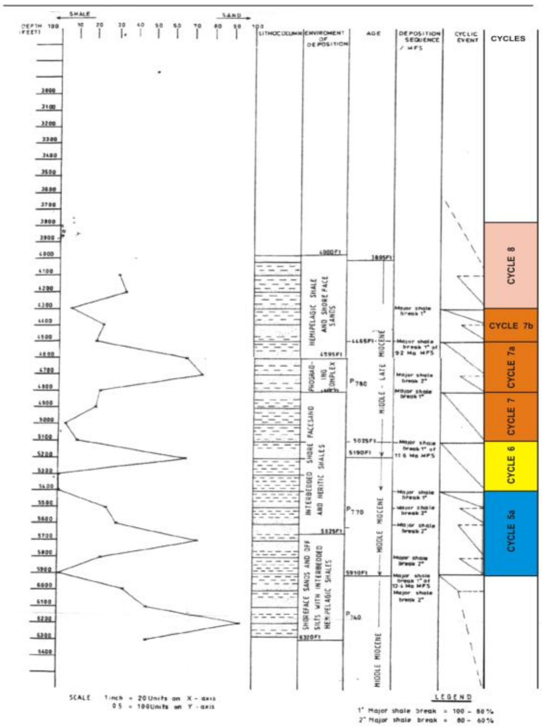

FIG 3: DEPOSITIONAL CYCLE DELINEATION USING SAND PERCENTAGE CALCULATION AND ENVIRONMENT OF DEPOSITION (EXXIT 75)

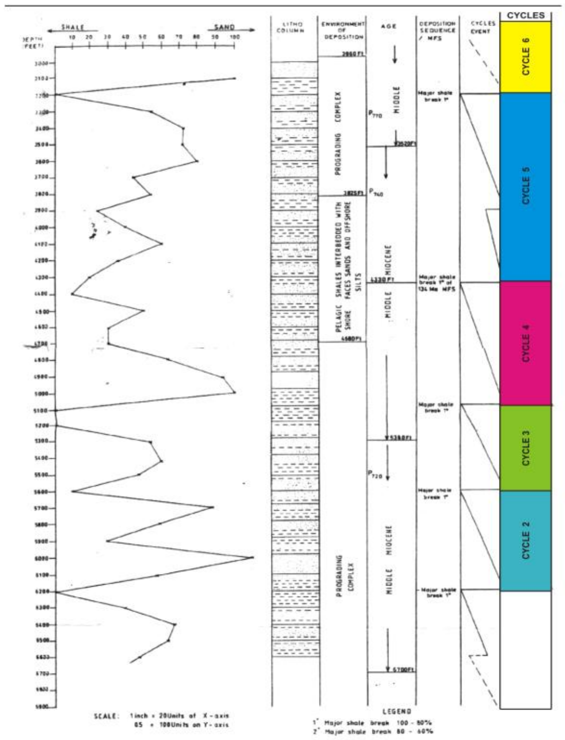

FIG 4: DEPOSITIONAL CYCLE DELINEATION USING SAND PERCENTAGE CALCULATION AND ENVIRONMENT OF DEPOSITION (EXXIT 78)

Biostratigraphic Identification and Age Dating of Key Bounding Surfaces

The key bounding surfaces identified in the study area are the MFS and SB with their corresponding depths. The Niger Delta Chronostratigraphic chart aided in this identification and is also used in dating the key surfaces. 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 transgressive markers identified in the wells are ***Eponides* (13.8Ma and Older), *Globigerinoides subquadratus/Uvigerina sparsicosta* (12.5 - 13.8Ma), *Globorotalia mayeri/Spirosigmoilina oligocaenia* (12.5 – 10.5Ma) *and Uvigerina subperegrina* (10.5 - 8.2Ma).** *Globigerinoides subquadratus/Uvigerina sparsicosta* and *Globoratalia mayeri/Spirosigmoilina oligocaenia* were recognized in all the three wells, while *Uvigerina subperegrina* was identified in Exxit 75 and 78. *Eponides* was only encountered in Exxit 73 (Table 1).

TABLE 1: Summary of Foraminiferal zones showing paleobathymetry interpretation for the wells

Exxit 73

Depth (ft)	Foraminiferal zone	Age (Ma)	Paleobathymetry
11880 – 10000	*Eponides*	13.8 and Older	Inner Neritic
10000 - 6940	*Globigerinoides subquadratus/ Uvigerina sparsicosta*	13.8 – 12.5	Outer Neritic - Shallow Inner Neritic
6940 – 5440	*Globorotalia mayeri/Spirosigmoilina oligocaenia*	12.5 – 10.5	Outer Neritic
5440 – 4780	*Uvigerina subperegrina*	10.5 – 8.2	Shallow Inner Neritic

Exxit 75

Depth (ft)	Foram zone	Age (Ma)	Paleobathymetry
6331 - 5460	*Globigerinoides subquadratus/ Uvigerina sparsicosta*	12.5 and Older	Outer Neritic - Shallow Inner Neritic
5460 - 4770	*Globorotalia mayeri/ Spirosigmoilina oligocaenia*	12.5 – 10.5	Outer Neritic
4770 - 4050	*Uvigerina subperegrina*	10.5 – 8.2	Shallow Inner Neritic

Exxit 78

Depth (ft)	Foram zone	Age (Ma)	Paleobathymetry
6700 - 3825	*Globigerinoides subquadratus/ Uvigerina sparsicosta*	12.5 and Older	Outer Neritic – Shallow Inner Neritic
3825 - 2250	*Globorotalia mayeri/ Spirosigmoilina oligocaenia*	12.5 – 10.5	Outer Neritic

Depositional Environment Interpretation

Several workers have used log motifs that represent sub-environments with main environment in conjunction with other parameters e.g. absence or presence of glauconite and carbonaceous detritus to interpret sand bodies [**17**]. The log pattern is either blocky or cylindrical, funnel or bell shaped. A blocky or cylindrical log pattern indicates relics of fining and coarsening upward small scale, monolithic, high energy, rapid deposit of very coarse sand called channel sands. These sands have an abrupt base representing erosional base of channel fill sequence and are confined to proximal fluvio-marine environment. This was recognized in Exxit

73 at the depth intervals 11800 - 11500ft, 8700 - 8660ft, 6720 - 6670ft, 4480 - 4400ft and 4100 - 4000ft; in Exxit 75, at the depth intervals 6258 – 6066ft and 4536 - 4534ft; and in Exxit 78 at the depth intervals 6384 - 6312ft, 5690 - 5626ft, 4532 - 4426ft and 3825 - 3694ft.

The funnel-shaped log pattern is barrier sand (beach sand) which is coarsening upward with river mouth deposit of distributary channel and the energy of deposition is increasing upward with geologic time as the coastline advances seawards. This is most common in the shoreline environment and the associated lithofacies are shoreface sands and offshore silts with interbedded hemipelagic shales. It is characterized by regressive activities. At Exxit 73, this was recognized at the depth intervals 8760 - 8790ft, 8700 - 8670ft, 6770 - 6720ft, 6660 - 6640ft, 5320 - 5290ft and 3990 - 3930ft; in Exxit 75, at the depth intervals 5630 - 5600ft, 4630 - 4600ft and 4570 - 4540ft; and in Exxit 78, at the depth intervals 4210 - 4180ft, 3830 - 3800ft, 3370 - 3350ft and 3140 - 3100ft.

The bell-shaped log pattern is fining upward with the energy of deposition decreasing upward with geologic time and the coastline moving landward. They are most common to shoreline – shallow marine environments with reworked sand, which are similar to meandering channels sand. It is characterized by transgressive activities. In Exxit 75, this was identified at the depth intervals 6220 - 6170ft, 5980 - 5880ft and 5480 - 5460ft; and in Exxit 78, it was recognized at the depth intervals 6450 - 6430ft, 5252 - 5232ft, 4690 - 4670ft, 4450 - 4400ft, 4012 - 4000ft, 3979 - 3960ft, 3480 - 3450ft, 3420 - 3390ft and 3080 - 3000ft.

Interpretation of Systems Tracts

The three types of systems tracts i.e. lowstand, transgressive and highstand were recognized in the study area. Each systems tract was deposited at a predictable position in an interpreted base level cycle caused by eustacy and has recognizable signature on well logs [**10, 18, 19**].

Lowstand Systems Tract (LST)

Lowstand systems tract (LST) consists of the oldest deposits within a depositional sequence and is bounded at the base by a sequence boundary. It consist of basin floor fan, slope fan and prograding wedge complexes. The basin floor complex which is typically a massive sand body that contains excellent quality sand was recognized at Exxit 75 at the depth intervals 6208 - 6146ft and at Exxit 78 at the depth of 6544 - 6496ft. The prograding complex, which is the upper most unit of the LST, is characterized by an overall coarsening upward pattern, which is interpreted as a gradual overall shallowing upward pattern from marine to non-marine environments. Sand deposition is limited to shoreline areas along the outer shelf, which will include fluvial and shoreface facies that commonly display a coarsening upward well log pattern [**10**]. The prograding complex occurs in Exxit 73 at the depth intervals 11500 - 11210ft, 9850 - 8670ft and 5600 - 5380ft, in Exxit 75 at the depth intervals 6200 - 5976ft, 5300 - 5140ft and 4805 - 4595ft; and in Exxit 78 at the depth interval 6544 - 6100ft.

Transgressive Systems Tract (TST)

This is the middle systems tract in an ideal depositional sequence. The transgressive systems tract (TST) develops as a result of an increase in the rate of sea-level rise [**10**]. It is characterized by retrogradational parasequence sets and it was recognized in all the studied wells. In Exxit 73, it was found at the depth intervals 11370 – 10900ft, 8660 - 7420ft and 5920 – 5800ft; in Exxit 75 at the depth intervals 5976 – 5910ft and 5144 – 5025ft; and in Exxit 78 at the depth interval 4805–4330ft. Reservoir quality sands within the TST units include beach and shoreline facies, and it encompasses environments from littoral to outer shelf neritic.

Highstand Systems Tract (HST)

The highstand systems tract (HST) represents the uppermost unit of a depositional sequence [**10**]. It is characterized by early aggradational to later progradational parasequence sets. In Exxit 73, TST occurs at the depth intervals 10900 – 9850ft, 7420 – 6725ft and 5800 – 5230ft; in Exxit 75, at the depth interval 5910 – 5620ft and in Exxit 78 at the depth interval 4330 – 3825ft.

Depositional Sequence

Generally, a depositional sequence consists of LST, TST and HST. It is a stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities, known as sequence boundaries (Reijers, 1996). On the above premises, Exxit 73, 75 and 78 were interpreted and the following results were obtained. A total of three (3) depositional sequences were recognized, with their depositional environment ranging from inner neritic to outer neritic (Table 2).

TABLE 2: Ages and Depths of Key Surfaces NP – Not Penetrated

Key Surfaces	Dep. Seq.	Exxit 73	Exxit75	Exxit78
10.5Ma SB	3	5230ft	4805ft	NP
11.6Ma MFS		5800ft	5025ft	NP
12.5Ma SB	2	6725ft	5625ft	3825ft
13.4Ma MFS		7420ft	5910ft	4330ft

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13.8Ma SB	1	9850ft	NP	NP
15.0Ma MFS		10900ft	NP	NP

Depositional Sequence 1

This depositional sequence, which was recognized only in Exxit 73 is topped with the 13.8Ma SB. The base of the sequence was not penetrated. The TST is capped by a 15.0Ma MFS.

Depositional Sequence 2

Depositional sequence 2 was identified in all the wells of study, viz: Exxit 73, 75 and 78, starting with the 13.8Ma SB and ends with the 12.5Ma SB. It is made up of LST (prograding complex), TST and HST and they are characterized by the progradational, retrogradational and aggradational parasequence sets respectively. The 13.4Ma MFS capped the TST.

Depositional Sequence 3

This sequence was noticeable in Exxit 73 and 75 and starts with the 12.5Ma SB and ends with the 10.5Ma SB. The systems tracts are characterized by progradational, retrogradational and aggradational parasequence sets with several sand intervals assigned to the coarsening, fining and aggrading patterns of the systems tracts. The TST is capped with 11.6Ma MFS.

Sedimentary Cycle Interpretation

A sedimentary cycle represents a direct link between geological concept, sedimentary process and the formation of stratigraphic sequences. The study of cyclic depositional patterns in the geologic record produced by climatic and tectonic process called Cyclostratigraphy consists of series of stacked coarsening upward or fining upward sequences representing regressive or transgressive events within a basin. The causes of this can be attributed to eustatic sea level, orbital climatic or tectonic effects, time span, volume of supplied sediments and accommodation space, which affect sedimentary sequences and sedimentary cycle. Therefore, a relationship exists between sedimentary cycle concept and sequence stratigraphy (Fig. 5). Eleven (11) discrete cycles represented by figures in ascending order had been erected in Niger Delta and they are defined by shale markers which are assigned definite ages. Three (3) of these cycles have been identified in the study area, namely cycle 7, 8 and 9.

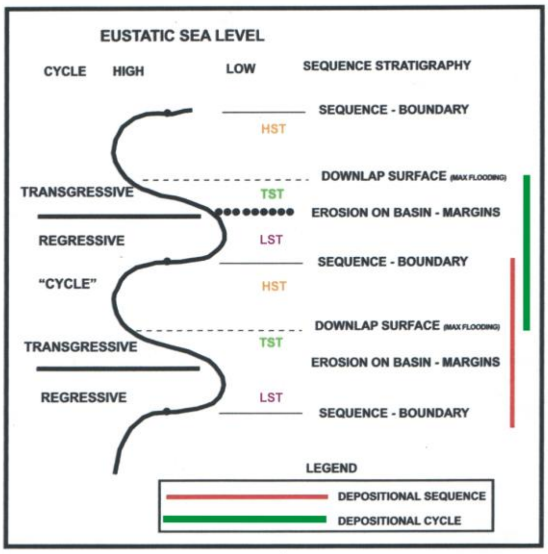

FIG 5: RELATIONSHIP BETWEEN CYCLE CONCEPT AND SEQUENCE STRATIGRAPHY

Cycle 7 (Middle Miocene - P720)

This is marked by 15.0Ma marker shale and is recognized only in Exxit 73 and 78 at 9300ft and 5600ft respectively (Table 5).

Cycle 8 (Upper Miocene - P740)

The Cycle is marked by 12.8 Ma marker shale which was observed in Exxit 73 and 78 at 8350ft and 5380ft respectively. Cycle 8 was also noticed in Exxit 75 at the depth range of between 6381(TD) - 5910ft.

Cycle 9 (Upper Miocene - P770-P780)

The Cycle is marked by 11.5Ma and 10.4Ma marker shales. 11.5Ma marker shale occurs in Exxit 73 at the depth interval 6300 - 4930ft, in Exxit 75 at 5910 - 5190ft and in Exxit 78 at 3520 - 3100ft. The 10.4Ma marker shale was not observed in Exxit 78, probably due to non-deposition of sediments, but in Exxit 75, it was present at 5190 - 4000ft and in Exxit 73 at 4930 - 4480ft (Fig. 6). However, seven (7) locally generated depositional cycles from the sand percentage calculation based on the cyclic events within the three (3) studied wells are penetrated in all the wells. They are referred to as cycle 2, 3, 4, 5, 6, 7 and 8. Cycle 1 was not penetrated at the base. Regionally, these seven (7) locally generated cycles are correlatable with only 3 of the eleven discrete cycles of the Niger Delta. They are Cycle 7 (P720) which corresponds with the generated cycles 2 and 3; Cycles 8 (P740) corresponds with generated cycle 4 and 5, while Cycle 9 (P770 – P780) corresponds with generated Cycles, 6, 7 and 8 (Table 3). Regional Cycles 7 and 8 are prospective and are found in Exxit 73 and 78, but not correlatable with Exxit 75. Though, if drilled deeper, there is possibility of

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coming across a good sand body reservoir, because the base of Cycle 8 was noticed in Exxit 75. Regionally correlatable major prospective Cycle 9 was found in all the wells of study.

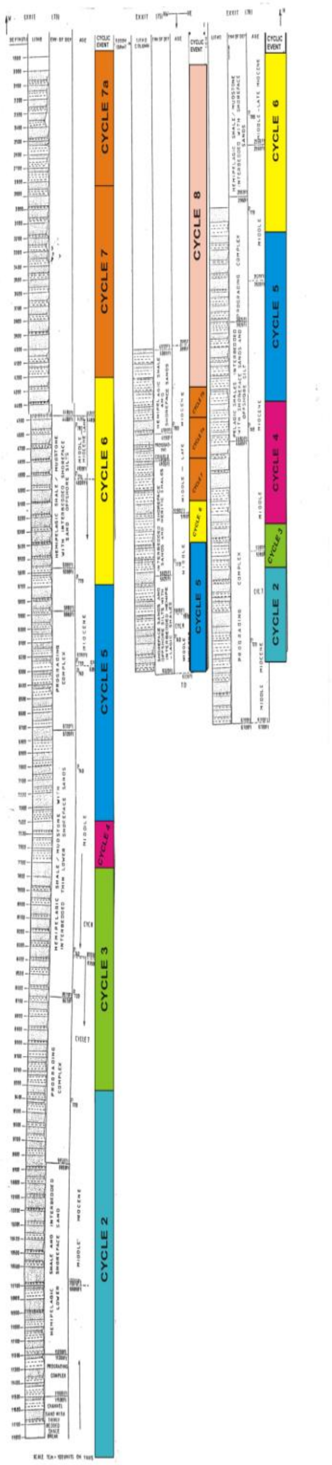

FIG 6: DEPOSITIONAL CYCLES CORRELATION SECTION ACROSS EXXIT 73, 75, 78.

TABLE 3: Cycle Correlation

P ZONES	LOCALLY GENERATED CYCLES	SPDC NIGER DELTA DISCRETE CYCLES
P 720	Cycles 2, 3	Cycle 7
P 740	Cycles 4, 5	Cycle 8
P 770 - P 780	Cycles 6,7,8	Cycle 9

Sequence Stratigraphy of Exxit 73, 75 AND 78

The depositional sequences found in the studied wells are Type-1 sequences [14], containing LST that consist of basin floor fan and prograding complexes; TST and HST. They are also found to be third-order sequences [1], based on their age span (1.0 – 5.0Ma). The stratigraphic column in the Exxit 73, 75 and 78 is then divided from base to top into 3 depositional sequences, namely Depositional sequence 1, Depositional sequence 2 and Depositional sequence 3. The sequence stratigraphic interpretation is as follows:

Exxit 73

The thickness of the sediments penetrated by this well is 11800ft and it was logged from 4100ft through the entire thickness. From the well logs, three (3) MFS at 10900ft, 7420ft and 5800ft were recognized. Consequently, three (3) depositional sequences were identified, viz; Depositional sequence-1, from 11800 to 9850ft, depositional sequence-2 from 9850 to 6725ft, depositional sequence-3 from 6725ft to 5230ft.

Depositional Sequence -1

This sequence consists of basin floor fan complex (11800 - 11379ft), TST (11379 – 10900ft) and HST (10900 – 9850ft). The bottom of the well (i.e. total depth) was taken as the base SB and it is bounded at the top by a SB at 9850ft depth. The MFS is located at 10900ft.

Depositional Sequence - 2

Sequence-2 consists of basin floor fan complex (9850 – 8670ft), TST (8670 – 7420ft) and HST (7420 – 6725ft). It is bounded at the base by a SB at 9850ft and the top by another SB at 6725ft. This sequence has its MFS at 7420ft.

Depositional Sequence - 3

Sequence-3 consists of basin floor fan complex (6725 – 5910ft), TST (5910 – 5800ft) and HST (5800 - 5230ft. It is bounded at the base by a SB at 5625ft and at the top by the SB at 4805ft. Its MFS is located at 5800ft.

Exxit 75

This well was logged from 4100ft to the terminal depth (TD), which is 6200ft. From the well logs, three (3) MFS were recognized at 5625ft, 5025ft and 4465ft, and two (2) SB at 5625ft and 4805ft. Consequently, two (2) depositional sequences were identified, comprising depositional sequence-1, which ranges from TD to 5625ft and depositional sequence-2 which ranges from 5625ft to 4805ft.

Depositional Sequence -1

This sequence consists of slope fan complex (TD to 5976ft), TST (5976 – 5910ft) and HST (5910ft - 5625ft). The bottom of the well (i.e. TD) was taken as the base SB, while the top SB is located at 5625ft. Its MFS is found at 5910ft.

Depositional Sequence - 2

This sequence consists of LST (5625ft - 5130ft); TST (5130ft - 5025ft) and HST (5025ft - 4805ft). Its base SB lies at 5625ft, while the one on top lies at 4805ft. Its MFS is found at 5025ft.

Exxit 78

Exxit 78 is penetrated to a total depth (TD) of 6500ft and it was logged from 3000ft to the total depth. From the well logs, one (1) MFS at 4330ft and one (1) SB at 3825ft were identified. Consequently, one (1) depositional sequence was delineated and it ranges from TD to 3825ft.

Depositional Sequence -1

Depositional sequence-1 consists of the slope fan complex (TD - 4810ft), TST (4810 – 4330ft) and HST (4330 – 3825ft). It is bounded at the base and top by SB at 6500ft and 3825ft respectively. Its MFS is located at 4330ft.

Chronostratigraphic Correlation of the Wells

A chronostratigraphic correlation was carried out across the studied wells (Fig. 7 & 8). Key bounding surfaces (maximum flooding surfaces and sequence boundaries) were used as the correlating surfaces because of their regional extent. It was noticed that the sequence boundaries dated 12.5Ma and 10.5Ma with maximum flooding surface dated 11.6Ma were correlated within Exxit 73 and 75. Sequence boundary dated 13.8Ma was only noticed in Exxit 73 with maximum flooding surface dated 13.4Ma, which is common in all the three (3) wells. The correlation section shows major faults separating the three wells and a hanging wall configuration at 3000ft.

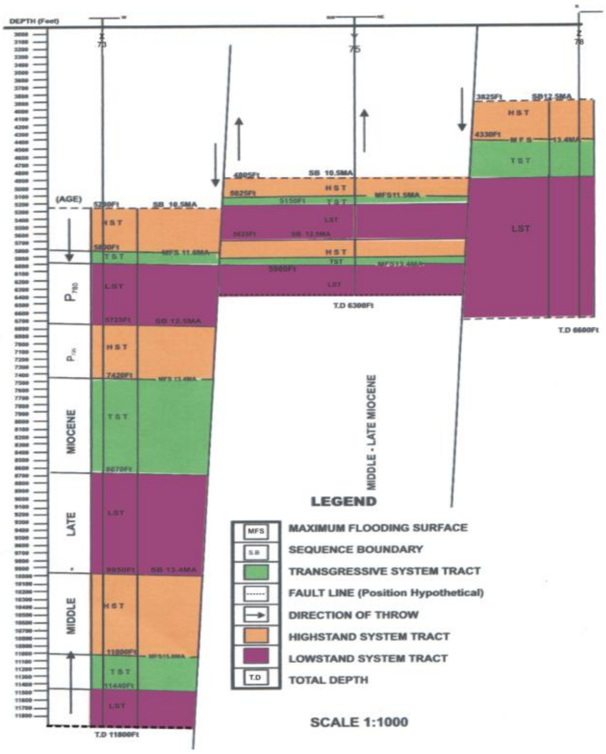

FIG 7: SEQUENCE STRATIGRAPHIC CORRELATION SECTIONS ACROSS EXXIT 73. 75. 78.

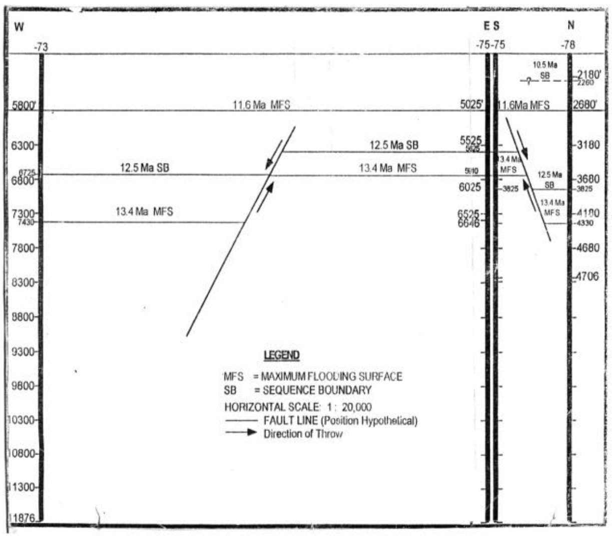

FIG 8: CHRONOSTRATIGRAPHIC CORRELATION OF EXXIT 73, 75, 78.

Exploration and Development Implications

Sequence stratigraphy has enabled Stratigraphers to make valid, potentially economic predictions as to the composition of sedimentary rocks in the geologic record. The mapping of reservoir-quality sands and seals, together with an understanding of the source rocks and migration paths, enable us to select high-quality prospects, such as those associated with the lowstand, transgressive and highstand systems tracts. Reservoir quality sands are found in transgressive systems tracts and they tend to be best developed in shallow inner-neritic water depths [**10**].

The sand is sealed by the overlain hemipelagic-pelagic shale of the same systems tract. Therefore, the transgressive sands of all the sequences in Exxit 73, 75 and 78 wells are good quality stratigraphically trapped reservoirs. The highstand systems tracts are also potential reservoirs because they consist of progressively coarsening upward sand bodies. They are best sealed by shales of the overlying transgressive systems tracts or if overlain by slope fans.

The hemipelagic-pelagic shales of the transgressive systems tracts of the study area are also excellent source rock. Levees of the levee channel of the slope fan complex could be potential source rocks too. It has been reported that shales associated with early progradation in the highstand systems tracts are often lean and gas-prone. Thus, all the sequences in Exxit 73, 75 and 78 of the Exxit field have potential to be excellent source rock. The rapid facies changes between successive systems tracts provide potential stratigraphic traps. Reservoir stratification and continuity vary greatly between systems tracts and this enhanced development of stratigraphic traps in the area [**20, 21, 22**]. Basin floor fans comprise sandstone of good reservoir quality. Prograding complex can also act as a seal if it overlain basin floor fans directly [**18**]. The basin floor fans of Exxit 73 (Sequence-1) and Exxit 75 (Sequence-1) are potential stratigraphically trapped reservoirs. Channel sands could be potential reservoir if sandwiched between two successive levees of the levee channel or overlain by condensed sections of transgressive systems tract. Consequently, channel sand found in Exxit 78 (Sequence-2), Exxit 75 (Sequence-1) and Exxit 73 (Sequence-2 and Sequence-3) are potential stratigraphically trapped reservoirs. There is a displacement of sediment across a fault plane on both the right and left parts of the section in the study area. It is suspected from the result of the correlation section that the major faults identified in the study area can serve as conduits for migration of hydrocarbon, if Exxit 75 and 78 are drilled deeper than their total depth (Fig. 7)

CONCLUSIONS

Sequence stratigraphic analysis was performed on three (3) wells (Exxit 73, 75 and 78) in Exxit Oil field in OML 99 within the coastal swamp depobelt of the Niger Delta, which enabled their subdivision into depositional sequences, systems tracts and depositional cycles. This has shown that the three selected oil wells within the western offshore Niger Delta fall between Middle - Late Miocene age. The integration of the data sets has facilitated the understanding of the process that generated the vertical stratigraphic succession of sediments and lateral facies changes, which are the characteristic feature of the systems tracts. Three (3) major depositional sequences were identified in all the wells studied. Systems tracts, which consists of basin floor fan, slope fan and prograding complexes of the lowstand systems tract, transgressive systems tract and highstand systems tract with three sequence boundaries and three maximum flooding surfaces were also delineated. Using Reijers, 1996 classification of sequence orders, the key bounding surfaces were found to be of third order sequences based on their cyclicities. The structural setting of the field as shown by the correlation panels (Fig. 7 and 8) indicates the hanging wall with fault line depositional model and also the displacement of sediments across the fault planes by the rollover fault systems, which are characteristic of the Niger Delta. This depicts the correlative nature of the isochronous surfaces within and across the field of study.

Lithologic changes as shown by sand percentages are characterized by continental-marine facies of the Agbada Formation. Paleoenvironment interpretations were based on paleobathymetric sedimentary facies derived from biofacies data and well log shapes of the sub-environments which include; channel sands with thinly bedded shale, hemipelagic with interbedded shore face sands and offshore silts. Transgressive sands are associated with transgressive systems tracts while levees of channel sands and shales are associated with early progradation of the highstand systems tract. Cyclical depositional patterns marked by 15.0Ma, 12.8Ma, 11.5Ma and 10.4Ma Marker Shales were identified. These marker shales have high faunal content and correspond to the identified maximum flooding surfaces. Sand percentage calculation with microfaunal data show that the maximum flooding surfaces correspond to the major shale breaks (Fig. 2, 3, and 4). Three cycles namely Cycle 7, 8, and 9 of the eleven (11) discrete Niger Delta Cycles were recognized. Regionally correlatable Cycle 7 and 8 are prospective in Exxit 73 and Exxit 78, but were not correlatable in Exxit 75. Cycle 8 was found in all the wells and the base is marked by the 11.5Ma Marker Shale.

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