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Sequence Stratigraphic Analysis of the Xp Field, Onshore Niger Delta, Nigeria

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ABSTRACT

Sequence stratigraphic analysis carried out on the XP field, Greater Ughelli Depobelt, Niger Delta, revealed three sedimentary sequences within the intervals penetrated by three wells studied in the field. Well logs and biostratigraphic data integrated helped in the identification of three major Maximum Flooding Surfaces (MFS1, MFS2, MFS3) recognized between the intervals of 3840- 3080m (aged 31.3- 26.2Ma) and three sequence boundaries designated SB1, SB2 and SB3, between 4232m and 3140m (aged 32.4 – 27.3Ma). The Maximum Flooding Surfaces were recognized using intervals containing high abundance and diversities of three index fossils (Uvigerinella 8, Bolivina 27 and Alabamina 1) which represent the three regional marker shales identified in the field. The erosional surface coincides with intervals that are barren in faunal activity and also corresponds with the coastal deltaic paleobathymetric depth interpreted as Sequence Boundaries. The sequences depict sediments that were deposited between Early to Late Oligocene period in water depth ranging from coastal deltaic to neritic environments. Three depositional patterns resulting from regression and transgression recognized include progradation, retrogradation and aggradational packages with associated systems tracts. The systems tracts form good reservoirs with prospects in the field.

Introduction

The Niger Delta sedimentary basin situated in the Gulf of Guinea comprises of three stratigraphic sequences of variable geologic characteristics. These can be classified as topset beds, foresets and bottomset as revealed from seismic stratigraphy. The topset portion is a regressive continental unit called the Benin Formation; the foreset units form the prograding Agbada Formation, whereas the marine clay/shale of the Akata Group is the bottomset portion of the delta depositional system. Several works carried out by researchers have revealed the stratigraphy, Sedimentology and structural styles in the basin (Adesida eta al; 1977; Avbovbo, 1978; Weber, 1971; Weber and Daukoru, 1975; Reijers, 2011). Stratigraphically, the oldest formation is the Akata followed by the Agbada and the Benin at the top. The division of depositional packages into genetic units is well understood through the concept of sequence stratigraphy. These genetic stratal units range in scale from laminar to regional scales. The various scales of genetic depositional units co-exist to form the entire fill in a sedimentary basin. Several third order sequences have been established in this study within the Agbada Formation using the sequence stratigraphic concept.

The application of sequence stratigraphic concept in studying the various oil fields in the Niger Delta sedimentary basin is relevance to improved exploration techniques and the discovery of unidentified resources. Sequence stratigraphic application serves as the tool for regional mapping and correlation of stratal units. This study focuses on establishing the sequence stratigraphic framework for the XP field, onshore Niger Delta by integrating both well logs and biostratigraphic data that will aid the understanding and prediction of depositional facies. It is vital to identifying potential source sediments, reservoirs and sealing potentials and the age of the field.

Study Location

The study area, XP – Field, is located in the onshore portion of the Tertiary Niger Delta sedimentary basin (Figure 1, 2), and falls within the Greater Ughelli Depobelt. The three wells (A,B and C) studied in the area are separated at a distance of about 8km between A and B, and B and C, and about 15.2km between A and C covering an area extent of about 18.9 Sq.km (Fig.2). The wells are separated by a set of minor faults and two major faults that appear to be regional as represented on the base map (Fig.2). These faults followed the growth faulting pattern of the Niger Delta as observed on seismic section. The main body of the study area is dissected by several minor to intermediate faults which do not presently appear to impede fluid communication within the major reservoirs.

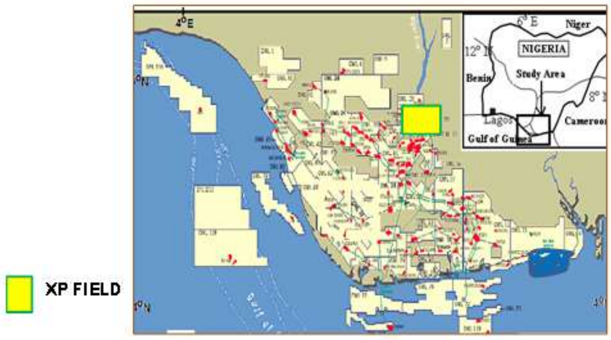

Figure 1: Map of Study Location ((Modified from ENI/ NAOC, 2002 Brochure on Nigeria)

Geologic Setting

The tectonic history and the evolution of the Niger Delta sedimentary basin have been reported by many workers (Weber and Daukoru, 1975; Short and Stauble, 1967; Whiteman, 1982, Doust and Omatsola, 1990).

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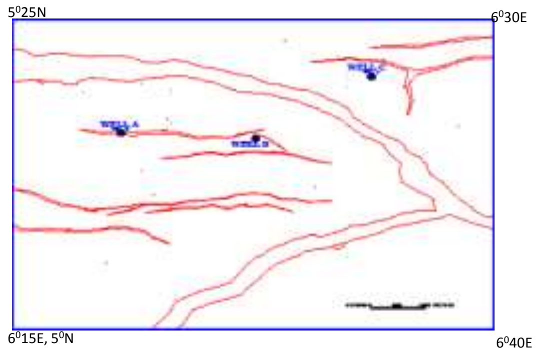

Fig. 2: Well Location Map of XP Field

The basin evolved following the separation of African and South American plates during the Early Cretaceous times. This was followed by the opening of the South Atlantic Ocean and several episodes of transgressions and regressions accounted for the sedimentary units in both the Cretaceous and Tertiary Southern Nigerian sedimentary basins. The sequence of evolution of the delta started with the continent-continent break up, filling and the folding Santonian event of the Benue Trough, the development and filling of the Anambra basin, and the subsequent development of the Niger Delta resulting from the subsidence that occurred down dip of the Anambra Basin. The delta covers an area extent of about 100,000 km^2 and represents the regressive phase of the third cycle of deposition in the southern Nigeria sedimentary basins, which began during the Paleocene and has continued to the present day (Short and Stauble, 1967).

Stratigraphically, the subsurface sedimentary sequences are made up of basically lithofacies of three distinct environments of deposition: continental, transitional and marine. The Benin Formation is the continental unit, comprising of massive continental sands with minor shale streaks and lignite, overlying the Agbada Formation, a sequence of interbedded sand/sandstone and shale occurring in almost equal proportion. The Agbada sandstone forms the reservoir unit, with huge accumulation of hydrocarbon. The basal shale of the Agbada unit forms part of the source rock, whereas the Akata Formation (marine shale) underlying the Agbada is believed to be the major source rock. The delta has prograded through time for a distance of more than 300 km from the apex to the present delta nose (Doust and Omatsola, 1990). It is segmented into several geomorphological units, displaying a concentric arrangement often referred to as depobelts, which started with the oldest Northern Delta depobelt to the offshore depobelt. The depobelts depicts the position of the paleo-coastline at different times from Paleocene to Recent. The study location falls within the Oligocene Greater Ughelli Depobelt.

Materials And Methods

The datasets for this study was provided by the Nigeria Agip Oil Company, Port Harcourt, for three wells labeled A, B and C. The data include a suit of well logs of Gamma Ray, Spontaneous Potential, Resistivity, Sonic, Neutron and Density logs; biostratigraphic data for well B containing information on foraminifera abundance and diversity, F-zonation and paleobathymetric data. Niger Delta chronostratigraphic chart, an adaptation of the global chronostratigraphic chart after Haq et al., (1988) was used with the biostratigraphic data to assign ages to the bounding surfaces (Fig. 3).

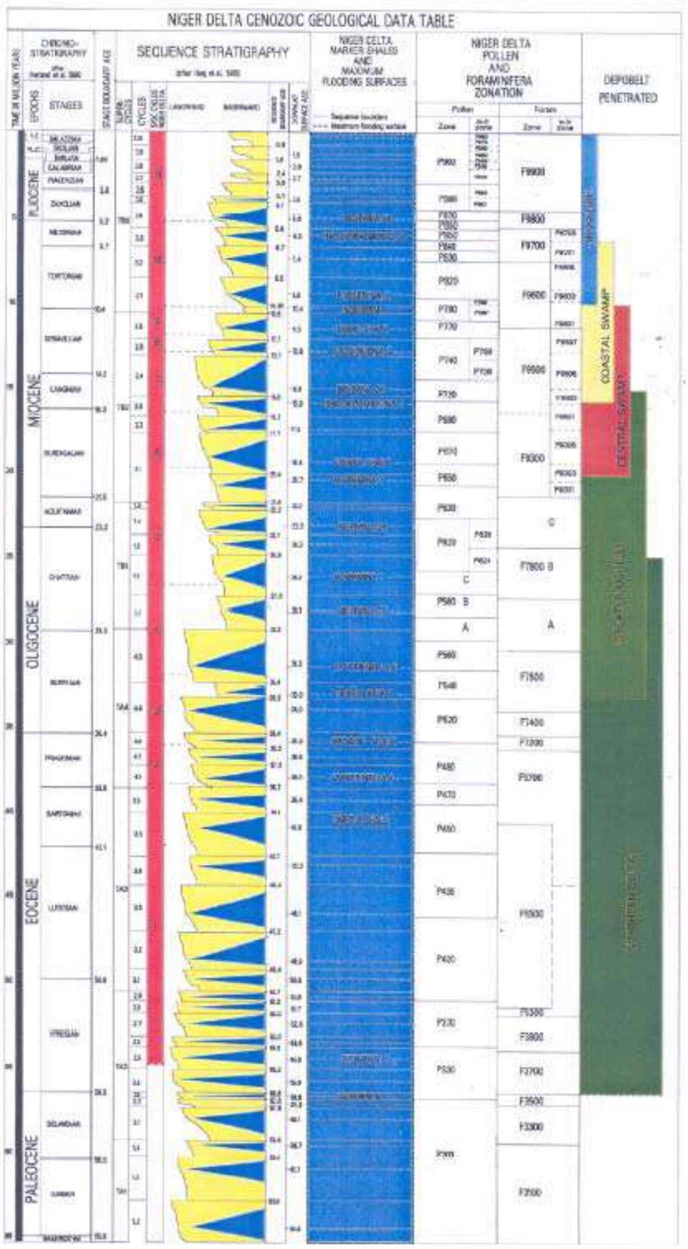

Fig. 3: Niger Delta Cenozoic Chronostratigraphic Chart (Haq et al., 1988).

The method adopted for this study includes digitizing and interpreting well logs to delineate stacking patterns, chronostratigraphic surfaces and depositional sequences. The biofacies data reveal depositional environments, condensed sections and age of the formation. Sequence boundaries were used (based on proposed model by Vail et al, 1977), to subdivide the stratal unit into sequences and mapped as candidates. The biofacies plots involving foraminifera diversity versus depth, foraminifera abundance with depth, and environment versus depth was performed using Microsoft Excel and integrated into the log for detail interpretation.

Results And Discussion

The integration of both well logs and biostratigraphic data has helped in the reconstruction of the sequence stratigraphic framework of XP field. Two major depositional sequences with its internal geometric elements have been reconstructed from three key dated unconformities and flooding surfaces. This trend helps in the determination of stratal continuity, lithologic identification and the prediction of various geologic elements necessary for hydrocarbon prospecting in the field.

Sequence Stratigraphy: Major Chronostratigraphic Surfaces, Systems Tracts and Depositional Environments

Two major chronostratigraphic surfaces used in the identification of depositional sequences in the area are unconformity (sequence boundary) and maximum flooding surfaces (MFS). The sequence boundary concept builds on the ideas of Vail et al., 1977, who based the division of stratigraphic units on unconformity-bound surfaces. Galloway, (1989) described genetic sequences based on marine flooding events that do not rely on widespread development of subaerial erosional surfaces caused by eustatic falls of sea level. Each sequence is recognized using the top and basal chronostratigraphic surface, and the position of the systems tracts that stack to form the sequence.

Sequence Boundaries

The Vail Model was used in the identification of three regional unconformities designated SB1, SB2 and SB3, which subdivides the stratigraphic section into two depositional sequences with the third sequence not dated. Vail, in his sequence stratigraphic nomenclature identified a depositional sequence with respect to the sequence boundary (Vail et al., 1977). Sequence boundaries fall within the sand-bearing intervals (Fig.3a) and correspond with the horizon that is barren in foraminiferal abundance and diversity as represented on the biofacies plots (Fig.5, 6).

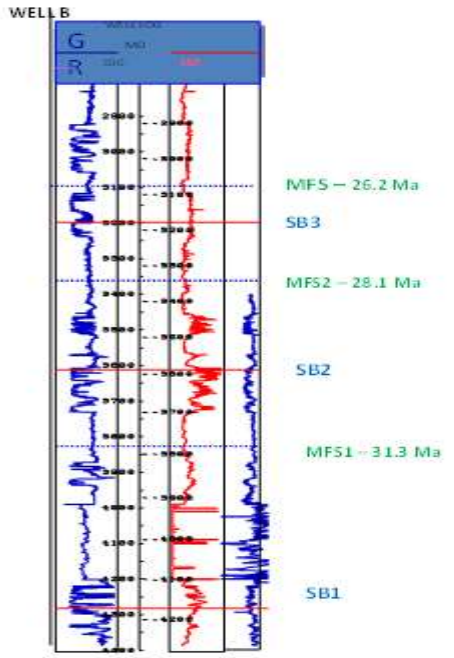

Fig.4a. Log of Well B showing key chronosurfaces

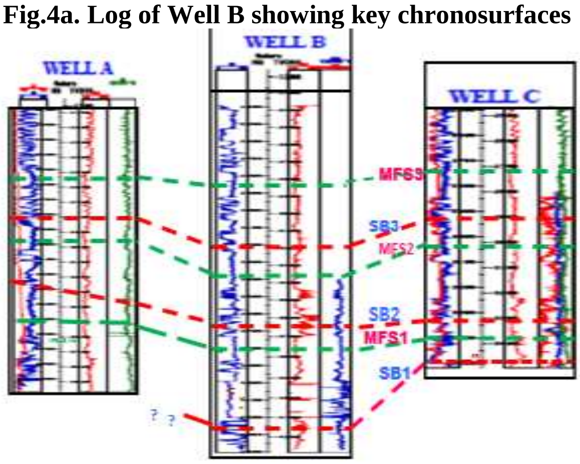

Fig. 4b: Chronostratigraphic correlation of studied wells

These surfaces were also recognized on well logs using log motifs and their consequent stacking patterns, and marked as candidates for sequence boundaries (SB1-4232m, SB2-3638m, and SB3-3140m) (Fig. 4a).

Sequence 1 (4232m – 3640m)

Sequence 1 occurs between sequence boundary 1 (SB1) and sequence boundary 2. SB1 is at 4232m and is dated 32.4Ma. The thickness is about 592m between the intervals of 4232m and 3640m. The sequence starts with an aggradational sandy unit overlying the lower sequence boundary and ends also with a progradational unit at the top, which is the base of sequence 2. The thickness of the sand-body at the base of this sequence is about 70m (4230-4300m) in well B. On top of this unit occurred thick shale that may represent marine deposit. In the entire sequence, only four sand-bodies are delineated which show progradational, retrogradational and aggradational stacking patterns. This sequence is not penetrated by other wells but the top of it forms the base of sequence 2. It is the oldest sequence penetrated by well B in the field.

Sequence 2 (3640 – 3140m)

This sequence begins at the base with a blocky/crescentic shape sand-body between 3640m and 3610m), the base of SB29.3Ma (Fig. 4a). It has a sharp lower and upper contact and represents an aggradational stacking unit typical of Lowstand Systems Tract (LST). The Lowstand Systems Tract forms as the rate of eustatic fall slows. It eventually equals the rate of subsidence and is then exceeded by the rate of subsidence, leading to a slow relative rise in sea-level. The entire sequence is found between the intervals of 3640m-3140m with gross thickness of 500m. A total of three reservoir sand-bodies occurred within this sequence representing majorly progradational sands (regressive sands).

Sequence 3 (3140 – 2400m)

The third sequence boundary (SB3) at 3140m forms the base of sequence 3. The upper sequence boundary is inferred because no paleontological data is available for this boundary to recognize and establish the age of the surface (table 1). The sequence is incomplete as far as this study is concern. It occurs between the intervals of 3140m and 2400m with thickness of about 740m. Four reservoir sand-bodies are encountered in this sequence. Maximum Flooding Surface 26.2Ma occurs within this cycle, and comprises of three thick shale units that are traceable in all the wells with some minor sand-shale intercalations. Likely environments deduced from this sequence based on their stacking patterns include channel sands, point bars, overbanks and deltaic front facies. The sand body here shows gradational a base and sharp upper contact (fig.4a). This contact occurs at depth 3040m in well A, and 2860m in well C. Thick shale overlies this sequence, and above the shale is a massive sand unit with minor shale intercalations that does not seem to be disturbed by the growth fault system. This is the Benin Formation. This sequence is the youngest and may represent the Late Oligocene- Early Miocene deposit.

Maximum Flooding Surfaces (Mfs)

Biostratigraphy uses the chronostratigraphic range of fossil species to correlate stratigraphic sections and their paleo-environmental preference to provide information on depositional settings (Emery and Myers, 1996). It is an important tool in the identification of sequences and systems tracts, dating of sequence boundaries and Maximum Flooding Surfaces (MFS). The biofacies data from Well B reveal abundance and diversity of foraminifera of which three were recognized as index fossils used in identifying and dating the marker shales. Three maximum flooding surfaces designated MFS1, MFS2 and MFS3 are recognized. They show an interval with high peaks of faunal abundance and diversities (Fig. 6, 7), which also correspond to intervals with high gamma ray log values (Fig.4a and 4b).

Maximum Flooding Surfaces represent the period of maximum transgression which separates the transgressive and highstand system tracts. It shows the peak of marine events characterized by abundance and diversities of fauna and flora (fig.6, 7). These three significant surfaces fall within the 3rd order sequence and dated between Early to Late Oligocene. Total benthic foraminifera exceed 70% at each interval compared with the planktics (Table 3). About seven (7) possible MFS were recognized between the depths of about 2400-4400m in well B. These seven flooding surfaces also correspond to high peaks on plot of foraminifera paleobathymetric environments, that fluctuates between inner to outer neritic shelf zone (fig. 5) Three Maximum Flooding Surfaces designated MFS1, MFS2 and MFS3 are confirmed out of seven peaks of candidate flooding surfaces (Fig. 6, Table 2).

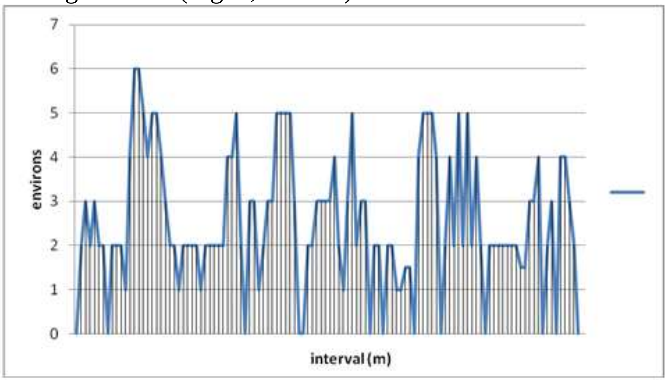

Fig. 5: Biofacies Plot of Foraminifera Environments

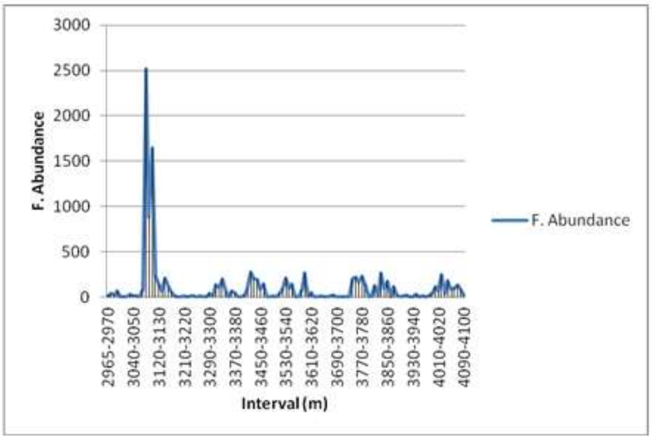

Fig. 6: Biofacies Plot of Foraminifera Abundance

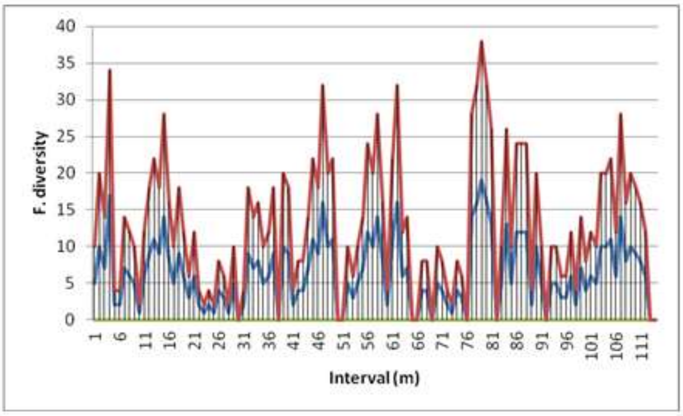

Fig. 7: Biofacies Plot of Foraminifera Diversities

Age Determination

Age determination was based entirely on the results of micropaleontological data, which gives the age of the interval given between Early – Late Oligocene. Three foraminiferal zones were revealed within the stratigraphic range with abundance and diversities of benthic species present in the marine shale (table 1). The foraminifera zones are Alabamina 1, Bolivina 27 and Uvigerinella 5. The Uvigerinella 5 shale falls within Early Oligocene whereas the youngest which is Alabamina 1 falls within Middle to Late Oligocene age.

MFS1- Uvigerinella 5 (31.3Ma)

This is the oldest maximum flooding surface recorded in well B and in the field as well. It occurred at the depth of 3840m, above the first sequence boundary (Table 2, Fig. 4a, 4b). The interval contains over 82% abundance of benthic (table 3) and 18% diversity of plantic foraminifera deposited within the middle to outer neritic paleobathymetric depth.

MFS2 – Bolivina 28.1Ma

The second flooding surface occurred at 3420m and dated 28.1 Ma. Thickness of this shale is about 200m (3250 – 3450m) (Fig. 4a). It forms a regional seal that enhances hydrocarbon entrapment in the field. The reservoir unit capped by this shale shows evidence of petroleum accumulation as seen in the high resistivity value (ILD) (Fig. 4a). About 50% abundance of benthic and 50% planktonic foraminifera occur in this interval within the middle to outer neritic paleobathymetric depth. (Tables 1, 3).

MFS3 – Alabamina 26.2Ma

This is the youngest marine shale dated 26.2 Ma and occurs above the last sequence boundary. The thick shale unit represents sediments that were deposited in the outer neritic paleobathymetric depth with over 90% abundance of benthic foraminifera (table 3). The top sequence boundary in this sequence is absent, and no biozonation data available for it (Table 1).

Systems Tracts

Three systems tracts common in the XP - Field include; Highstand Systems Tract (HST), Transgressive Systems Tract (TST) and Lowstand Systems Tract (LST). Systems tracts are genetically associated stratigraphic units that were deposited during specific phases of the relative sea-level cycle and represented in the rock record as three-dimensional facies assemblages (Posamentier et al., 1988). They are defined on the basis of bounding surfaces, position within a sequence, and parasequence stacking pattern (Van Wagoner et al., 1988).

Highstand Systems Tract (HST)

This sand body displays a coarsening upward trend and it downlaps on the maximum flooding surface. Four of this unit occurs in Well B, and forms the dominant stacking pattern in the field typical of a deltaic progradational depositional setting. There are four HST in well C and three in well A occurring in the two major sequences delineated in the field.

Transgressive Systems Tract (TST)

Transgressive System Tract can be recognized by its position in a sequence and stacking pattern. It occurs between the Maximum Flooding Surface the Transgressive Surface. On well log it shows a fining upward trend of increasing water depth, a retrogradational parasequence stacking.

Lowstand Systems Tract (LST)

The Lowstand Systems Tract is made up of three sub-depositional units; the prograding complex, slope fan and the basin floor fans. The unit forms a prograding to aggradational stacking pattern.

Parasequences are not recognized in the lowstand basin floor and slope fans, possibly because facies in the bathyal to deeper water depths are not sufficiently sensitive to minor changes in sea level which produce parasequences in shallow marine environments (Mitchum et al., 1991). Lowstand System Tracts are recognized in a type 1 sequence. In a type 2 setting, the equivalence of LST is the Shelf Margin System Tract (SMST). The LST lies directly on the lower sequence boundary and is overlain by the Transgressive System Tract. LST occurs in well B between 3040 to 3115m just above SB3, and between 2485 and 2500m in well C. Lowstand systems Tracts contain coarse grained sands/sandstone with good reservoir characteristics.

Depositional Environments

The paleoenvironments of XP Field was reconstructed using standard electrofacies and biostratigraphic data. The environments range from channels, tidal flats, Shoreface to shelf deposits. Channel sands stacked in both aggradational and retrogradational patterns. The range of environments shown in paleobathymetric data (table 3) include inner neritic, middle and outer neritic environments, which fall within the shallow marine shelf depositional setting.

Summary and Conclusion

Sequence stratigraphic concept was applied to the study of XP-field, within the onshore Niger Delta, Nigeria. The datasets applied in the study include well logs and biostratigraphic data. These were integrated to establish the sequences existing in the field. Three dated sequence boundaries marked by surfaces of unconformities were identified in the three wells studied (Fig. 3). Sequence boundary 1 (SB1) is present in well B but wells A and C did not penetrate this sequence (Fig. 4b), whereas SB2 and SB3 cut across the three wells. These surfaces were recognized in well B and used to subdivide the stratigraphic interval into two depositional sequences using Vail et al., 1977 Model. The age of the sediments in the field is dated between 26.2 – 31.3Ma (Early- Late Oligocene) as deduced from the three index fossils (Uvigerinella 5, Bolivina 27 and Alabamina 1) present in the marker shales and correlated with the Niger Delta chronostratigraphic chart. This field falls within the Greater Ughelli depobelt and consists mainly of sands/sandstones and shale within the Agbada Formation. The depositional environments inferred in the study area include channels, Shoreface and shelf environments. The regional shales provide excellent seal and source rock potentials; whereas the systems tracts form good reservoir sands that enhance hydrocarbon accumulation in the field.

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References

Adesida AA, Reijers TJA, Nwajide CS. Sequence Stratigraphic Framework of the Niger Delta Basin. Vienna, Austria, AAPG Int Conf and Exh. 1977; 81: 1359.

Avbovbo AA. Tertiary Lithostratigraphy of Niger Delta: Am Ass Pet Geol Bull 1978; 62: 295–300.

Doust H and Omatsola E. Niger Delta: *in* Edwards JD and Santogrossi PA, eds., Divergent/Passive Margin Basins: AAPG Memoir 1990; 48: 239-248.

Emery D, Myers KJ. Sequence Stratigraphy. Oxford, U. K., Blackwell, 1996: 297.

Galloway WE. Genetic Stratigraphic Sequences in Basin Analysis 1: Architecture and Genesis of Flooding Surfaces by Depositional Units. AAPG Bull 1989; 73(2): 125-142.

Haq BU, Hardenbol J, Vail PR. Mesozoic and Cenozoic Chronostratigraphy and Cycles of Sea-Level Change, In: Wilgus C, Hastings CBS, Kendall CG, Posamentier HW, Ross CA and Van Wagoner JC, Eds., *Sea Level Changes*: *An Integrated Approach*, SEPM Spec Publ, 1988; 42: 72-108.

Mitchum RMJ, Van Wagoner JC. High-frequency Sequences and their Stacking Patterns: Sequence Stratigraphic Evidence of High-frequency Eustatic Cycles. *Sedimentary Geology*, 1991; 70: 131–160.

Posamentier HW, Vail PR. Eustatic Controls on Clastic Deposition II--Sequence and Systems Tract Models. In Wilgus et al 1988: 125-54

Table 1: Microfaunal zonation of XP-Field

Top depth(m)	Bottom Depth (m)	F.Zone	Remarks
2790	2910	F7800	No data
3050	3110	F7800	Alabamina 1
3230	3450	F7800	Bolivina 27
3740	3870	F7600/F7800	Uvigerinella 5

Table 2: Biostratigraphic Data Table

Well name	Chronosurface	Depth (m)	Marker Shale	Age (Ma)	F Zones	P Zone	Epoch	Remark
B	MFS 3	3080	Alabamina 1	26.2	7800	580	Oligocene	Greater Ughelli depobelt
B	MFS 2	3420	Bolivina 27	28.1	7800	550	Oligocene	Greater Ughelli depobelt
B	MFS 1	3840	Uvigerinella 5	31.3	7600 /7800	560	Oligocene	Greater Ughelli depobelt

Table 3: Paleobathymetry and Foraminifera Abundance/Diversity

MFS (m)	Foraminifera Abundance/Diversity	Planktic Foraminifera	Benthic Foraminifera	Biostrat. Unit	Age	Bathymetry
3080	>90%	10%	90%	Alabamina 1	Mid – Late Oligocene	Outer Neritic
3420	>50%	40%	50%	Bolivina 27	Oligocene	Mid-Outer Neritic
3840	82%	18%	82%	Uvigerinella 5	Early Oligocene	Mid-Outer Neritic

Short KC, Stauble AJ. Outline of Geology of Niger delta: Am Ass Pet Geol Bull 1967; 51: 761-779.

Van Wagoner JC, Posamentier HW, Mitchum RM, Vail PR, Sarg JF, Loutit TS, and Hardenbol J. 1988, An overview of the fundamentals of sequence stratigraphy and key definitions, in Wilgus, C.K., and al., e., eds., Sea-Level Changes -- An Integrated Approach, Volume Special Publication 1988; 42: Tulsa, SEPM: 39-46.

Vail PR, Mitchum RM. 1977, Seismic Stratigraphy and Global Changes of Sea Level, Part 1—Overview: AAPG Memoir 1977; 26: 51-52.

Weber KJ. 1971. Sedimentological aspects of Oil Fields in the Niger Delta: Geologie en Mijnbouw, 1971; 50 (3): 559-576.

Weber KJ, EM, Daukoru EM. Petroleum geology of the Niger delta: Proceedings of the 9th World Petroleum Congress, Tokyo, 1975; 2: 202-221.

Whiteman AJ. Nigeria-its Petroleum Geology, Resources and Potential: London, Graham and Trotman 1982: 394.