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Research Article

SEQUENCE STRATIGRAPHIC STUDIES OF X-FIELD, CENTRAL/COASTAL SWAMP DEPOBELTS, NIGER DELTA NIGERIA

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ABSTRACT

Sequence stratigraphic frame work of the Middle – Late Miocene deposits within the Central/Coastal Swamp Depobelts of the Niger Delta was carried out using wireline logs, biofacies data and seismic section. Five bounding stratigraphic surfaces comprising three candidate maximum flooding surfaces and two candidate sequence boundaries were delineated using progradational and retrogradational stacking pattern. Four maximum flooding surfaces; MFS 17.4Ma, 15.9Ma, 15.0Ma, and 12.8Ma, and four sequence boundaries; SB16.7Ma, 15.5Ma, 13.1Ma and 12.1Ma which subdivided the field under study into four major third-order genetic sequences were delineated. The associated systems tract, highstand and transgressive systems tracts, show variable reservoir development across the field. The highstand systems tracts act as reservoir rocks while the transgressive systems tracts act both as seal and source rocks. The structural patterns across the study area are simple synthetic, antithetic and associated roll over anticlines. Depositional environments determined from the wireline log motif include fluvial channels, distributary channels, distributary mouth bar, tidal channels, tidal flats and barrier island.

INTRODUCTION

Exploration activities had been concentrated in the past in the Eocene-Pliocene sequence, but as the delta becomes better understood, exploration efforts are gradually being shifted to both the offshore (Pliocene-Pleistocene sections) and the flanks of the delta where cretaceous prospects are expected.

Since the early seventies, stratigraphic analysis of the Pliocene-Eocene series of the Niger Delta has focused mainly on the regional scale depositional history (Murat, 1992).

Sequence stratigraphy is a technique used in dividing, analyzing and mapping sedimentary rocks. It is based on the recognition of hierarchy of stratal units including beds, bed-sets, parasequence, parasequence sets, and sequences bounded by chronostratigraphically significant surfaces of erosion, non-deposition, or their correlative surfaces. This study presents a local sequence stratigraphic framework of an X-field in the Onshore Niger Delta and summarizes its implications for petroleum geology

Aim and objectives of the study: The aim of this study is to establish the sequence stratigraphy of the area understudy and apply the results to the evaluation of its hydrocarbon potential

The study will be restricted to the third order depositional cycle (0.5-3 million years) as categorized by Vail *et al.* (1991), and will also cover the following;

- Interpretation and identification of lithology using Gamma ray and Resistivity logs.
- Defining the sequence stratigraphic framework in the study area by identifying the major strata surfaces using gamma ray and resistivity logs and confirming those surfaces with the available biostratigraphic data.
- Using the biostratigraphic data and well logs to correlate wells across the study area to see how laterally extensive the various genetic units are.
- Identification and correlation of systems tract of the wells penetrated
- Identification of environments of deposition of the reservoir sand bodies using well log signatures.

(a) Location of Study Area: The X-Field is situated within the Central/Coastal Swamp Depobelts of the Eastern Niger Delta. The distance between Wells 1 and 3 is approximately 5.76km while that between Wells 3 and 2 is approximately 7.3km.

(b) Previous Studies: The sedimentation pattern of the modern Niger Delta was described by Allen (1963), while the paleo-environmental reconstructions of the Niger Delta were highlighted by Porrenga (1965 and 1967) using diagnostic facies of specific environment. Weber (1971) described the depositional cycles and types of reservoir rock in the Niger Delta. He also studied the influence of depositional environments on the petrophysical properties of the reservoir rock continuity and inhomogeneities.

Mahargue et al, (1993) found that the most useful criteria for the recognition of sequence boundaries in the Niger Delta include truncation of underlying reflectors, dip discordance, contrasts in seismic attributes across the sequence boundary, drape and termination of faults at the sequence boundary. The application of sequence stratigraphy concept to the Niger Delta offshore exploration was done by Pacht and Hall (1993), while Stacher (1994) revised the earlier SPDC Bio-and Time stratigraphic scheme and put the scheme in a sequence stratigraphic framework allowing correlation with Hag et al, (1988) sea level using the group Harland et al; (1992) global time scheme.

(c) Lithostratigraphy: Since inception in the early Cretaceous time, the southern basin of Nigeria has been the scene of at least three major depositional cycles (Short and Stauble, 1967). The first, possibly a double cycle, commenced in the Albian time to Coniacian times and involved mainly marine deposition within the whole basin; between Albian to Lower Cenomanian and Turonian to Coniacian time. It was terminated by a brief phase of folding in Santonian formation, which consists of continental and fluvial sands, gravel, and back swamp deposits (2500m thick).

Outcrop sediments in the northern reaches of the Niger Delta Basin, range in age from Eocene to Recent. The Eocene outcrops occur in south of the Benin Flank and the basin areas in the northern fringe of the delta. The recent outcrops are the present coastlines. Surface evidences of Oligocene and Miocene deposits are limited and much of the age determination is uncertain. The approximate surface boundaries of the Eocene-Recent sediments have been indicated. The three major lithostratigraphic units defined in the subsurface of the Niger Delta (Akaka, Agbada and Benin Formations decrease in age basin ward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalent units to these three formations are exposed in Southern Nigeria (Short and Stauble, 1967). The formations reflect a gross coarsening-upward progradational clastic wedge (Short and Stauble, 1967) deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber 1986).

(d) Structures: The Niger Delta Basin has steadily prograded over geologic time and this progradation has been accompanied and helped by the development of growth faults **Figure 1**, associated with rollover anticlines and mud diapirism (Busting, 1988). This has resulted to a series of strike-parallel, fault-bound depositional belts (deposited) which show successive younging from north to south . Four oil field structural features have been recognized by Weber and Daukoru (1975), namely (1) the simple rollover structures (2) structure with multiple growth faults (3) structure with antithetic faults (4) collapsed crest structures. The growth faults have strongly influenced the sedimentation pattern and thickness distribution of sands and shales resulting into hydrocarbon accumulation in the Niger Delta being associated with rollover structures, (Weber, 1986). Individual fault blocks can be grouped into macro and eventually mega structural units called depobelts which constitutes separate provinces with regard to time-stratigraphy,

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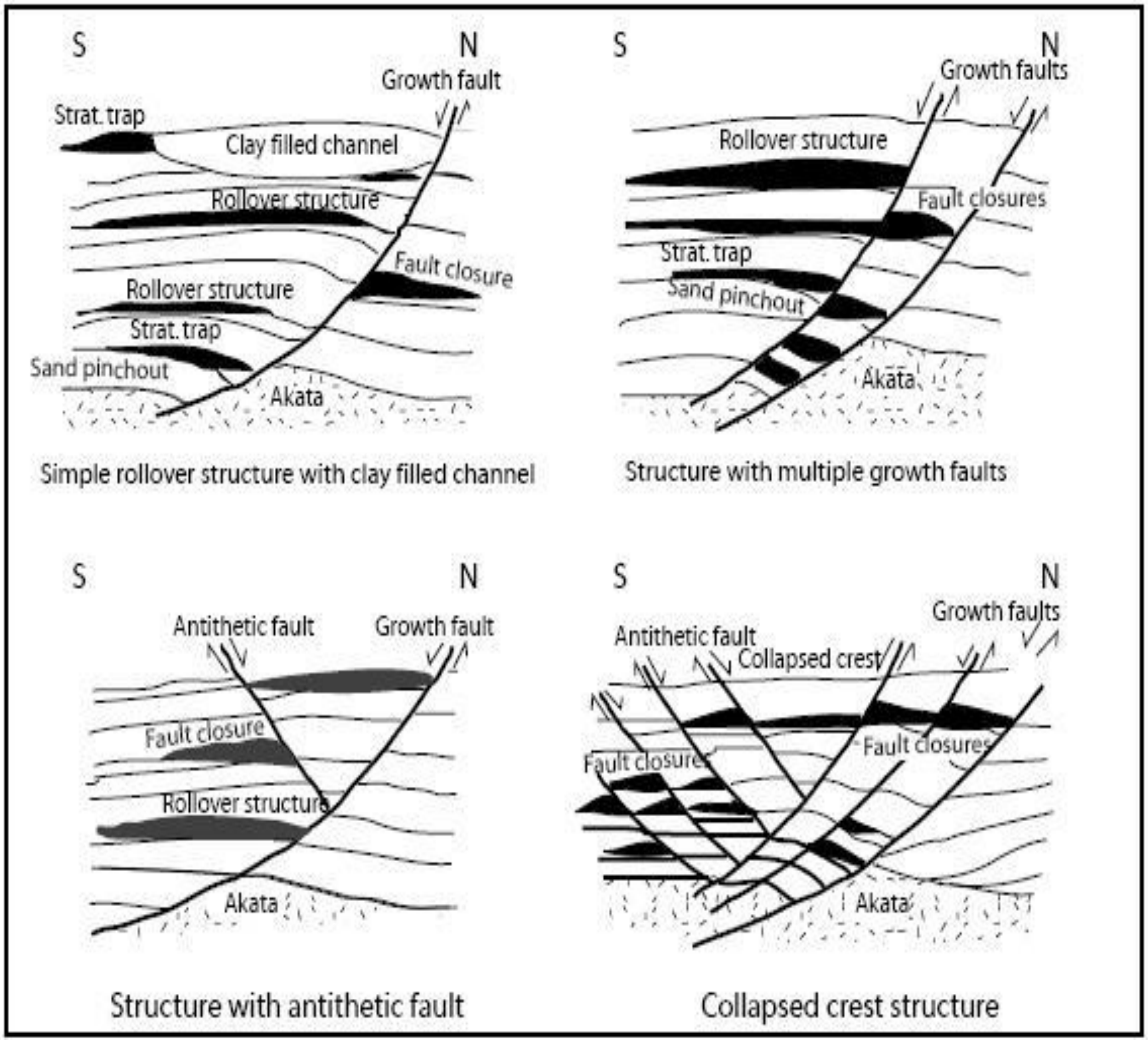

Figure 1: Examples of Niger Delta oil field structures and associated trap types. Modified from Doust and Omatsola (1990) and Stacher (1995

METHODOLOGY

(i) Depositional sequences and systems tracts: The depositional systems are subdivided into stratal units deposited during each phase of a relative sea-level cycle: lowstand, transgressive and highstand. The stratigraphic units of these cycles are called the lowstand system tract, transgressive systems tract, and highstand systems tract respectively (Vail, 1987; Posamentier and Allen, 1999; Plint and Nummedal, 2000).

Relative falls of sea-level occur when eustacy falls at a greater rate than subsidence or when uplift exceeds the rate of eustatic rise (Posamentier et al., 1988). Systems tract is a linkage of contemporaneous depositional systems (Brown and Fisher, 1979), and each systems tract is interpreted to have been deposited during specific phase of one complete cycle of relative fall and rise of sea level, and each depositional system are linked by changes in sedimentary facies (Vail and Wormadt, 1990). When the rate of sea level fall exceeds the rate of subsidence at the depositional-shoreline break, sediment accommodation on the shelf decreases significantly, sediment bypasses the shelf and a lowstand fan may be formed. As the rate of relative sea level decreases to a minimum and then begins to rise, sediment accommodation on the uppermost slope increases and onlapping unit, the lowstand is formed. The lowstand fan and the lowstand wedge are included within the lowstand systems tract.

(ii) Recognition of Condense Section: Condensed sections are thin marine stratigraphic units consisting of a pelagic to hemipelagic sediment characterized by very low sedimentation rate. Statistical data on abundance or diversity of fossil taxa provide insight into rates of sediment accumulation (Armentrout *et al.,* 1990). Regionally, extensive fossil abundance events provide excellent correlation datum if coeval (Armentrout and clement 1990). These abundance events may be a condensed section associated with sediment starvation within the basin depocenter during a maximum rate of sea level rise (Loutit *et al*., 1988; Schaffer, 1990; Mudge and Copestake, 1992; Wyne and Read 2006). Condensed section candidates identified the fossil abundance in well cuttings, and high value on gamma ray logs should correlate the seismically defined regional down lap surface of the prograding highstand systems tract Loutit *et al.,* 1988).

(iii) Fossil abundance events: Total fossil abundance patterns reflect changes in sediment accumulation rates, especially where the changes in these rates are large in comparison to changes in rates of biologic productivity and preservation (Armentrout *et al*., 1990). If biologic productivity remains relatively content during the slowed rate of sediment accumulation during transgression, the middle shelf and deeper transgressive phase deposits will be characterized by increased foraminifera abundance due to relative terrigenous sediment starvation. If the same condition holds during the increased rate of sediment accumulation associated with a prograding system, the accumulated sediment will be characterized by a decrease in fossil abundance due to dilution. Systematic changes in fossil abundance, therefore, may reflect significant, long term dynamic changes in sediment accumulation rates characteristic of different settings within a depositional cycle.

(iv) Seismic stratigraphy: The basic principle of seismic stratigraphy is that within the resolution of the seismic method, seismic reflection follows gross bedding and as such they approximate time lines (Emery et al., 1996).

Vail et al., (1977) stated that the principle parameters used in seismic data interpretation include configuration, continuity, amplitude, frequency, and interval velocity of reflections and that bedding patterns controlling the reflection configurations are related to depositional processes and topography/bathymetry. Continuous density/velocity contrasts produces continuity of reflection which is directly related to depositional processes but, however, the degree of impedance contrasts along the stratal surface controls the amplitude of reflection (Mitcjum *et al*., 1977). This picture is however complicated by the presence of interstitial fluids. Domenica (1974) showed that small amounts of gas in pore spaces can result to a significant decrease in velocity, hence large reflectivity. Bed thickness variations both laterally and vertically also modify the frequency of reflection as a result of velocity changes due to fluid content (Mitchum et al., 1977).

RESULT AND DISCUSSION

(A) DEPOSITIONAL SEQUENCE ON SEISMIC SECTIONS: To define and correlate a depositional sequence accurately; its boundaries must be defined and traced, seismic sequences recognize the fundamental depositional (stratigraphic) units as the depositional sequences. The terms, toplap, onlap, and downlap have been used for describing reflection terminations produced at unconformity surfaces by depositional processes, while baselap is used in defining basal termination (Vail, et al., 1977; Brown and Fisher, 1979).

Toplap is evidence of a non depositional hiatus. It results from a depositional base level (such as sea level) being low to permit the strata to extend farther up dip (Mitchum et al., 1977), and it is commonly associated with the shallow marine deposits, such as deltaic complexes. Onlap is baselap in which an initially horizontal stratum laps out against an initially inclined surface. Distal marine onlap occur basin-ward as distal to prograding clinoform, while proximal onlap occurs shelf-ward as distal to prograding clinoform. Landward onlap shallow marine coastal deposits are called coastal onlap.

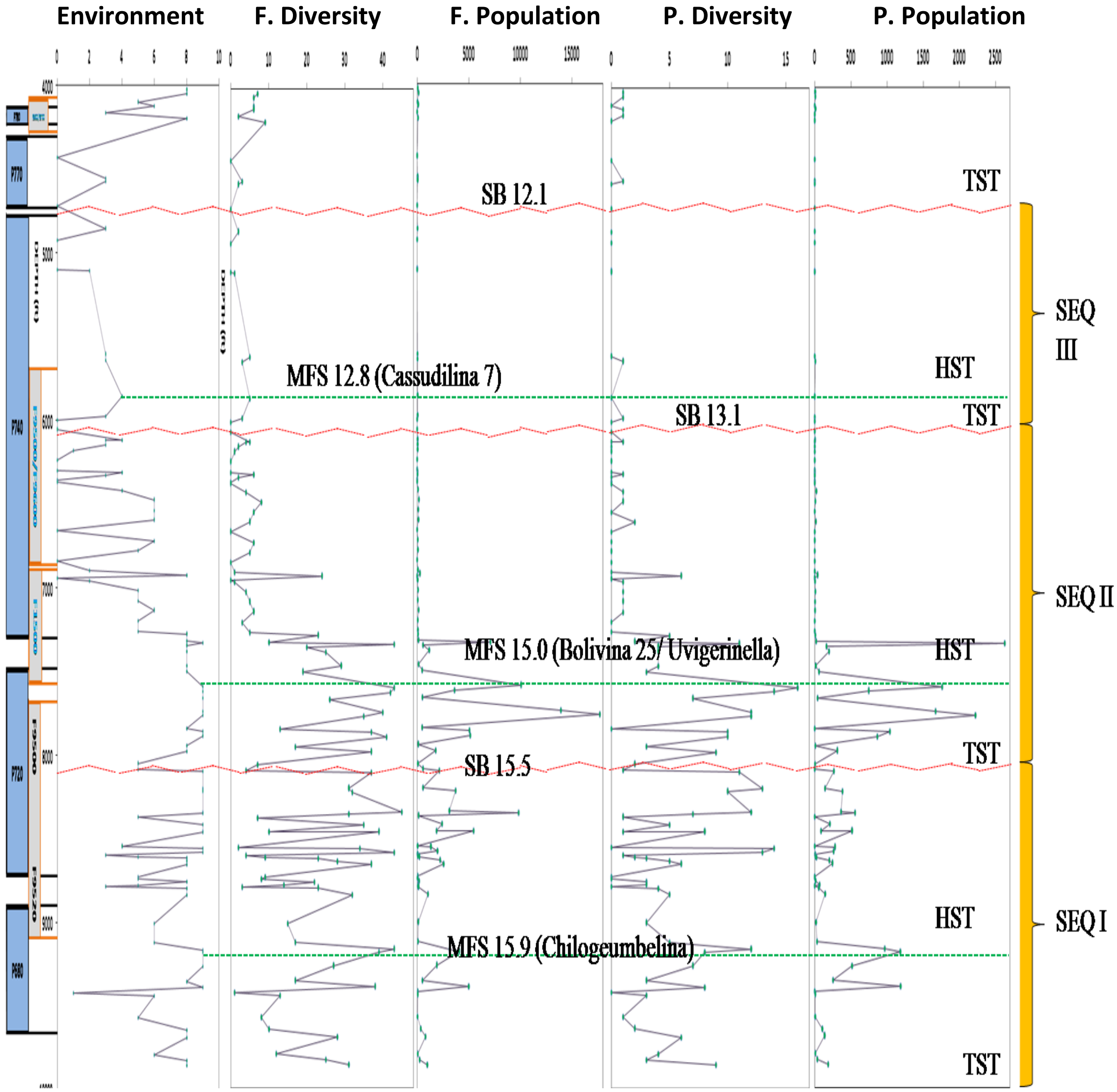

Figure 2: Generalized Biofacies plots of Well 001 showing all the sequences with their associated systems tracts and their ages

While four maximum flooding surfaces (MFS 12.8Ma, 15.0Ma, 15.9Ma and 17.4Ma) and three sequence boundaries (SB 12.1Ma, 13.1Ma, 15.5Ma and 16.7Ma) were also delineated and plotted for well 002

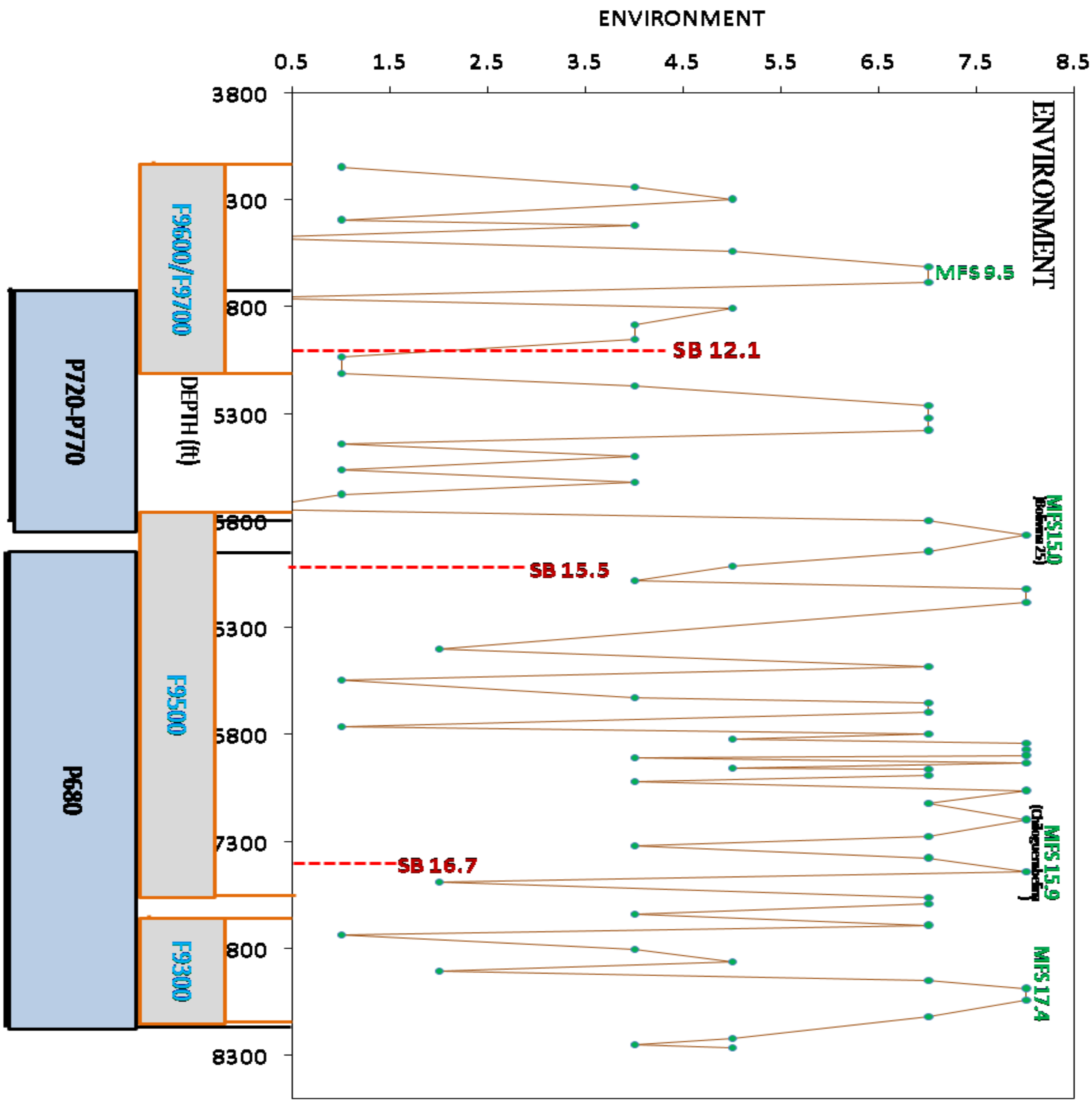

Figure 3: Environment vs depth of biofacies data

Using approximation method, the delineated bounding surfaces for both the stacking pattern and the biofacies plots for both wells (001 and 002) are correlatable. However, the biofacies plots are preferable to the stacking pattern and were used as a validation tool because of its higher resolution ability (age dating of the surfaces).

The chrono-surfaces were subsequently posted on the two wells to confirm their candidate surfaces.

(MA)	WELL 001 (ft)	WELL 003 (ft)	WELL 002 (ft)
MFS 9.5	3950	-	4600
SB 12.1	4800	-	5100
MFS 12.8	5700	-	5380
SB 13.1	6240	-	5746
MFS 15.0	7730	8180	6180
SB 15.5	8325	8400	6400
MFS 15.9	9200	850	6764
SB 16.7	-	8950	7320
MFS 17.4	-	9500	7590

Table 1: Depths and ages of the maximum flooding surface (MFS) and sequence boundaries (SB) penetrated in the studied wells.

All the wells were basically alternating cycles of sea level fall, sea level rise and still stand shown as aggradational stacking pattern. The only difference is the frequency of each cycle which changes from well to well.

(B) DESCRIPTION OF SEQUENCES IN THE STUDIED WELLS:

Sequence I: This sequence occurred only in wells 002 and 003. In well 002, it has a thickness of 1070ft and occurred within 8150ft and 7075ft depth intervals. The sequence starts with a short lived progradational sand unit (HST) at 800ft-8150ft depth interval and changed to retrogradational unit towards the middle of the sequence. The retrogradational unit terminated with the maximum flooding surface (17.4Ma) at 7590ft depth that essentially corresponded with the peak of the underlying marine transgressive event.

Progradation resumed almost immediately at 7600ft depth with high sand input but was disrupted at intervals by thin beds of shale intercalation. The progradation was marked by 16.7Ma sequence boundary at 7320ft depth, which invariably terminated the sequence. The high stand systems tract (HST) has a thickness of 520ft, occurred at 7600-7080ft depth intervals, and marked the transition point in the stacking pattern from a-net-coarsening upward to a-net-fining upward cycle.

In well 003, the sequence 1 at the beginning also started with progradation at 10000-9650ft depth intervals and retrograded between 9650ft -9500ft depth intervals and finally capped by 17.4Ma marine flooding surface. Progradation resumed between 9650ft-8950ft depth intervals before being truncated by 16.7Ma sequence boundary that eventually marked the end of sequence 1 in well 003.

In well 003, the sand units are not as thick and well developed as their equivalents in well 002;

however this sequence is missing in well 001. This could probably be as a result of minimum depth of penetration by the well. The sequence displays electrofacies log motif characteristic of shoreface and stacked distributary mouth bar deposits.

Sequence 4: This is the youngest sequence in the study area. In well 001, it seats directly on top of 13.1ma sequence boundary that terminated the last sequence. It has a total thickness of about 1450ft and occurred within depth intervals of 6250ft and 4800ft. The transgressive systems tract started with a silty shale at the base overlain by a shale unit of about 100ft thick that marked the highest floral/fauna abundance and corresponded with a maximum flooding surface. The MFS terminated the marine transgressive event at 5700ft depth. Progradation followed immediately and changed to aggradational system with some shale intercalation at 5700ft-5100ft depth intervals. The aggradational event then prograded further up to 4800ft depth at which 12.1ma sequence boundary truncated it.

In well 002, the transgressive systems tract (TST) within 5850ft-5640ft depth intervals began with a silty sand unit capped by a shaly unit at 5640ft depth. This marked 12.8Ma maximum flooding surface. The highstand systems tract (HST) between 5600ft-5100ft depth intervals that followed the TST displays well developed sand unit that was truncated by 12.1Ma sequence boundary. This marked the end of the sequence. The sequence was not penetrated by well 003.

In well 001 the sequence has a thicker and better developed sand unit that could act as a better reservoir rock relative to its equivalent in well 002.

In well 001, the sequence displays electrofacies with characteristic of fluvial channel deposits such as stacked fluvial channel sands, flood plain, and multistory fluvial channel in the upper part of the depositional sequence. In well 002, the sequence shows stacked distributary mouth bars and channel sands.

(C) ENVIRONMENT OF DEPOSITION: The environments of deposition in the study area ranges from fluvial channels, distributary channels, distributary mouth bar, tidal channels, tidal flats and barrier bar. Absence of core photos, side wall samples or ditch cuttings however limited further confirmation of the existence of these depositional environments.

Sequence stratigraphic interpretation of the Middle – Late Miocene Central /Coastal Swamp Depobelts in the Niger Delta Region has been carried out using suites of wire line logs, 3-D seismic data and biostratigraphic data.

Five bounding stratigraphic surfaces comprising three candidate maximum flooding surfaces and two candidate sequence boundaries were delineated using progradational and retrogradational stacking pattern. Four maximum flooding surfaces (MFS 17.4Ma, 15.9Ma, 15.0Ma and 12.8Ma) and four sequence boundaries (SB 16.7Ma, 15.5Ma, 13.1Ma and 12.1Ma) defined four genetic sequences (Vail, 1988). These genetic sequences were subdivided into systems tract in the field-wide correlation of the area.

The two systems tracts mapped, namely the highstand systems tract and the transgressive systems tract, are all represented across the filed although at varying thicknesses. The relative thickness of each systems tract probably revealed changes in sediment accumulation rate as a result of varying local conditions including accommodation space, slope setting, sediment supply and changes in sea level.

The northern (proximal end of the basin) part of the field has better reservoir development when compared with that of the basin-ward part (distal end of the basin). The structural patterns across the study area are simple synthetic, antithetic and associated roll over anticlines.

The depositional environments of the clastic wedge interpreted, using standard log signatures of Schlumberger (1985); Emery (1996); Malcolm Rider (1999) and Escolona (2005) range from fluvial channels, distributary channels, distributary mouth bar, tidal channels, tidal flats and barrier island.

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