Sequence Stratigraphic Framework of the "Paradise-Field" Niger Delta, Nigeria.

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ABSTRACT

The "Paradise-Field" is located within the Coastal Swamp II and the shallow western offshore of the Niger Delta. The high resolution biostratigraphic report for the representative well P-1 in the "Paradise Field" was used in the sequence stratigraphic analysis. The eustatic cycles recorded in the penetrated stratigraphic intervals have been correlated to the regional chronostratigraphy of the Niger Delta for the prediction and dating of sequences recognized from the well logs. In the study area, one candidate maximum flooding surface (MFS) dated 11.5Ma was recognized based on the maximum shale peak, the separation of high neutron and low density values with corresponding high gamma readings. Also, one sequence boundary (SB) dated 10.6Ma is identified based on the inflection from overall progradation to overall retrogradation of parasequences in the shallowing sand units.

The relative thickness of the systems tracts reveals changes in sediment accumulation rates as a result of varying local conditions which may include the effect of gravity, tectonics, availability of accommodation space, and eustatic sea level changes. In the five wells studied, the three systems tracts (the highstand systems tract, the low stand systems tract, and the transgressive systems tract) are all represented except in Well P-1 with only LST and TST.

(Keywords: geological exploration, biostratigraphic, petroleum, Niger River, depocenters)

INTRODUCTION

The prolific demand for hydrocarbon products since the 20th century prompted intensified exploration for oil and gas accumulation in reservoir rocks. This led to an extensive study of the Niger Delta depocenters after a long while of non-productive search in the Cretaceous sediments of the Benue Trough (Doust, 1989; Doust and Omatsola, 1990).

Petroleum in the Niger Delta is produced from sandstones and unconsolidated sands predominantly in the Agbada Formation. Recognized known reservoir rocks are of Eocene to Pliocene age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness. (Evamy et al., 1978).

Based on reservoir geometry and quality, the lateral variation in reservoir thickness is strongly controlled by growth faults; with the reservoirs thickening towards the fault within the down-thrown block (Weber and Daukoru, 1975).

The objectives of the present work are to correlate the regional chronostratigraphy of the Niger Delta (Figure 1) to the eustatic cycles recorded in the penetrated wells, interpret the biostratigraphic data to identify the maximum flooding surfaces and inferring distinct candidates for systems tracts and key sequence boundaries using the wireline logs. Reservoir geometry distribution, reservoir quality trends and possible hydrocarbon trapping sites can also be inferred using the sequence stratigraphic framework.

METHODOLOGY

- Correlation of the regional chronostratigraphy of the Niger Delta to the eustatic cycles recorded in the penetrated wells.
- Interpretation of the biostratigraphic data to identify the maximum flooding surfaces.

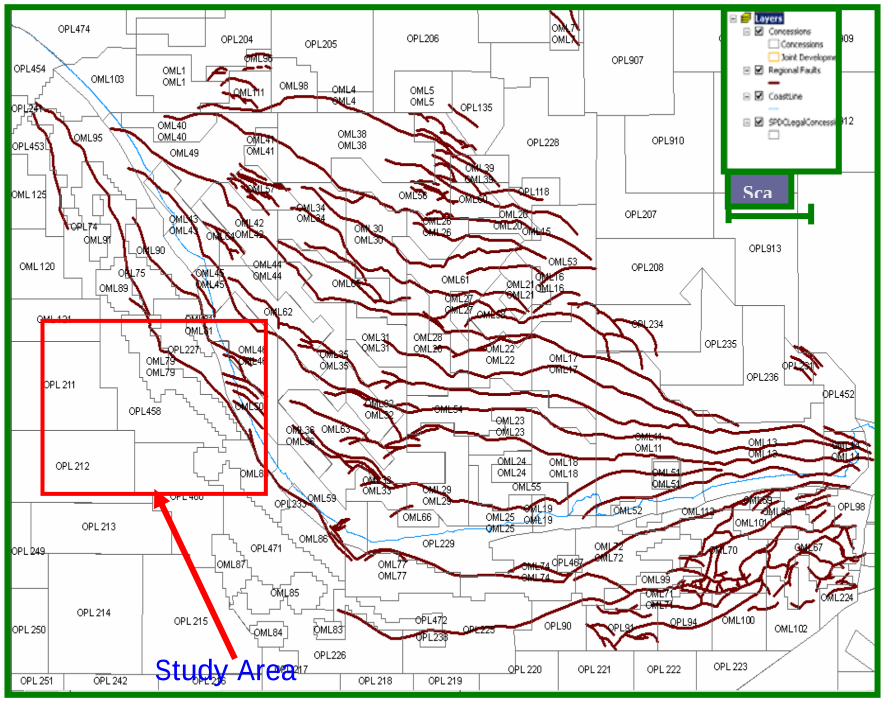

Figure 1: Simple Concession Map of Niger Delta Showing Structurel Building Faults, Exploration Blocks, and Study Area.

- Marking distinct candidates for systems tracts and key sequence boundaries using the wireline logs (Emery and Myers, eds., 1996).

- Interpretation of various systems tracts.

Stratigraphic Setting

The study area (Figures 1&2) is located within the transition between the Coastal Swamp II and the western Offshore Niger Delta. The Tertiary Niger Delta covers an area of about 75,000 km^2 and is composed of an overall regressive clastic sequence which reaches a maximum thickness of 30,000 to 40,000 ft (9,000 to 12,000 m) (Evamy et al., 1978). Sedimentation in the basin started in the late Paleocene/Eocene, when sediments began to build out beyond the troughs between the basement horst blocks at the northern flank of the present delta area.

The structural configuration and the stratigraphy of the Niger Delta have been controlled by the interplay between rates of sediment supply and subsidence (Evamy et al., 1978; Doust and Omatsola, 1990).

Eustatic sea level changes and climatic variations influence the sedimentation rates while the flexure (tectonics) of the basement and differential loading and settlement on unstable shale may have controlled the subsidence. The growth of the Tertiary Niger Delta is schematically shown by a series of maps with the principal depocenters for selected microfloral units between the Paleocene and the Pliocene (Figure 3).

Hydrocarbons are concentrated along the updip or proximal edge of the successive depocenters. The Niger delta can be subdivided lithologically into an upper series of massive sands and gravels (Benin Formation), deposited under continental conditions (Evamy et al., 1978).This grades downward through a transitional series composed mainly of sand but with some shale, into an alternation of sandstone and shale (Agbada Formation), deposited under paralic conditions. Also, in the section below, marine shale predominates and the associated sandstone units are very likely to be turbidities (Figure 4). The study area falls within the transition between the Coastal Swamp II and the Offshore, and the age is upper Miocene.

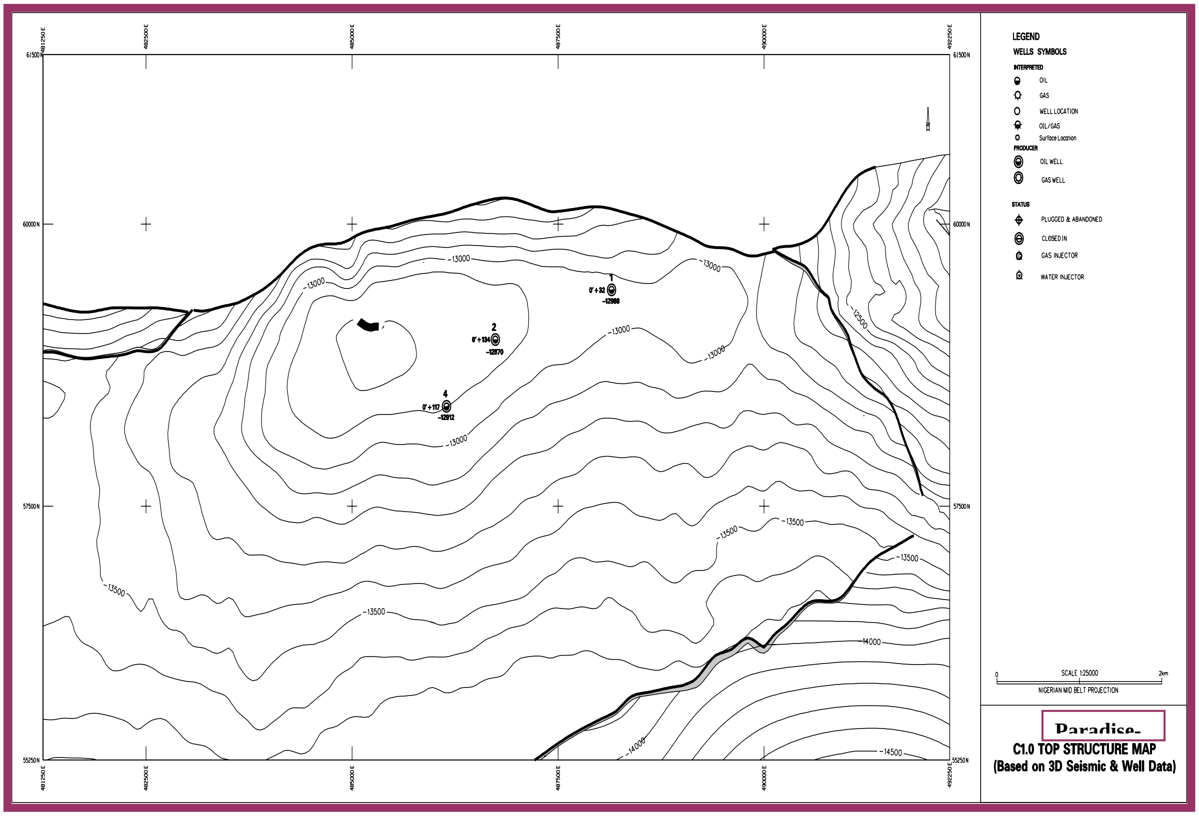

Figure 2: Location and Top Structural Map of the Paradise Field, Niger-Delta.

Sequence Stratigraphic Framework and Depositional Environment

From the five wells studied, the three systems tracts (highstand systems tract, HST; lowstand systems tract, LST; and transgressive systems tract, TST) are represented except in Well P-1 with only LST and TST. The summary of the identified systems tracts for all the wells are shown in Tables 1 to 5.

Lowstand Systems Tract (LST)

The type of sediments associated with LST in the studied wells occurs as lowstand prograding wedges. These sediments were deposited when relative sea-level was at or near the shelf margin and rising slowly but were slow enough for sedimentation to keep pace with shelf-edge deltaic process (Posamentier and Vail, 1988).
The lowstand prograding wedge interval in the studied wells is characterized by thick intervals of blocky deltaic sand bodies being laterally prograded into by the proximal lagoon shales.

The prograding lowstand wedge complexes are identified in all the wells as follows; P-1 (12998 – 13280+…ft); P-2 (12869 – 13050ft), P-3 (12818 – 13090ft), P-4 (12914 – 13105ft) and P-5 (12870 – 13034ft). These intervals correspond to channel fill environment with aggradational parasequence set.

Transgressive Systems Tract (TST)

This system tract develops as a result of an increase in the rate of sea-level rise which has an overall deepening upward bathymetric signature. The shelf is no longer in tune with the rising sea-level. Deltaic progradation ceases and much of the sand is trapped updip in the estuaries (Posamentier and Vail, 1988). The TST is observed in Well P-5 (13269 – 13500ft) and Well P-3 with a maximum flooding surface at the upper boundary (MFS 11.5Ma) (Figure 5).

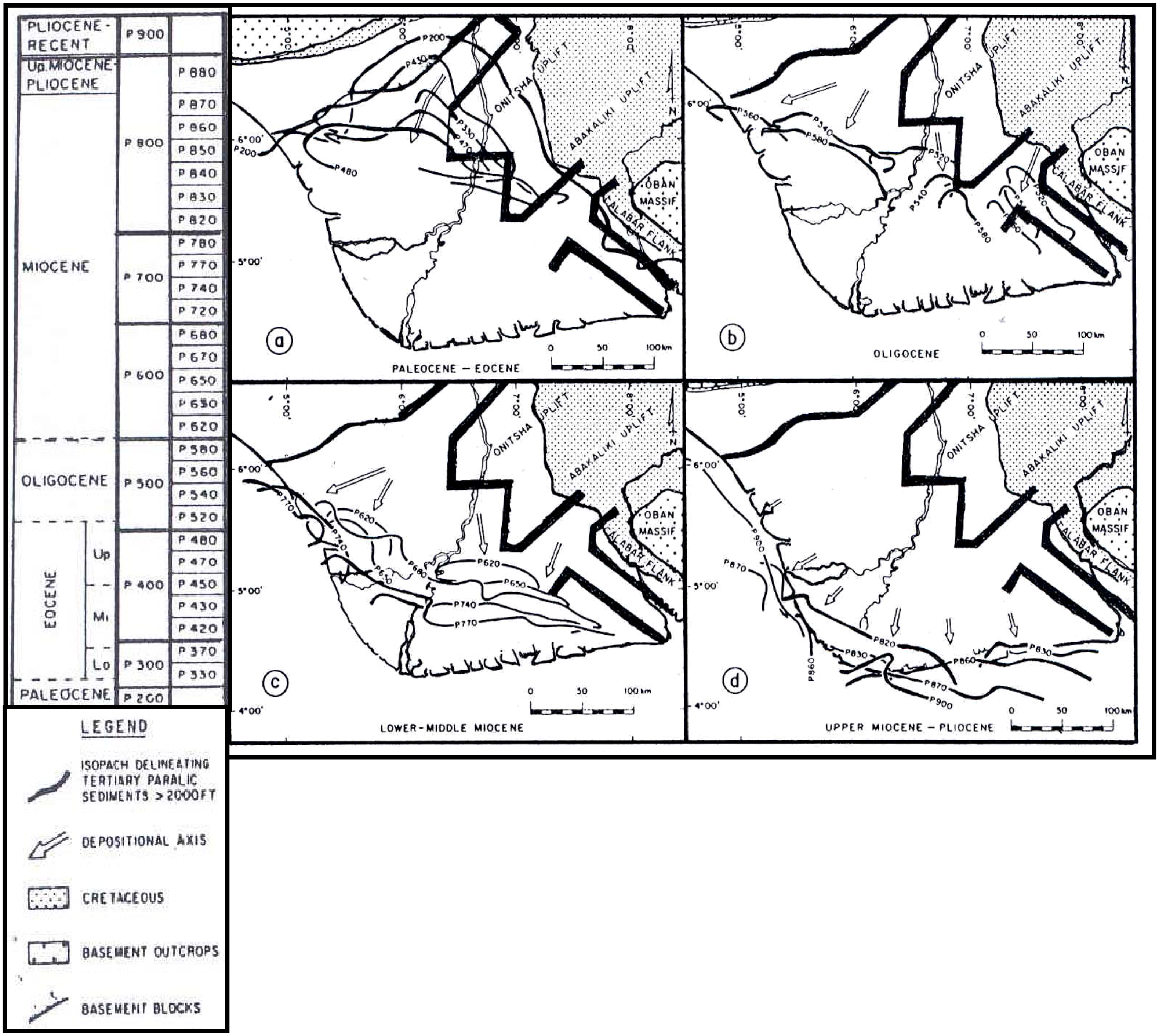

Figure 3: Stratigraphic Evolution of Tertiary Niger Delta (Modified from Evamy et al., 1978).

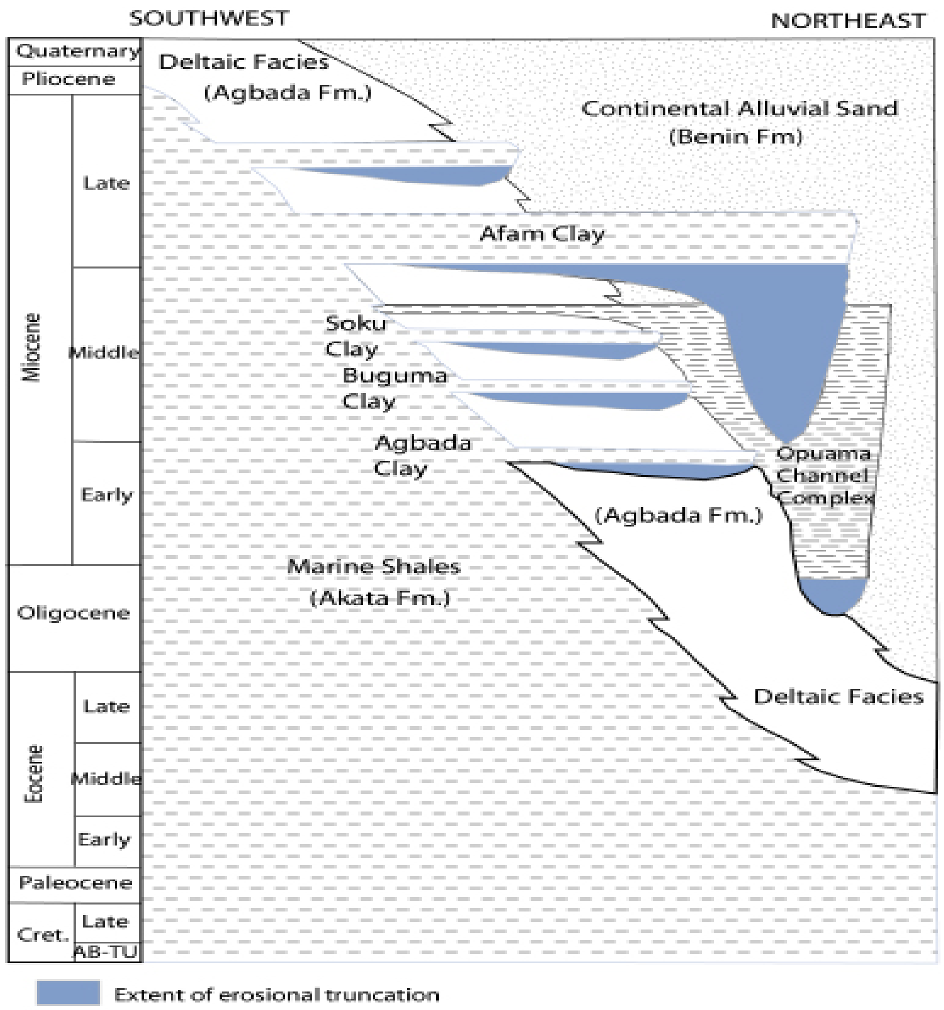

Figure 4: Stratigraphic Column Showing the Three Formations of the Niger Delta (After Shannon and Naylor (1989), and Doust and Omatsola (1990)).

Table 1: Summary of Identified Systems Tract for Well P-1.

Surfaces	Systems Tract	
	Depth (ft)	Remarks
	TST	An initial deepening of a typical proximal lagoon that grades into a sub-tidal environment with an overall prograding gamma ray signature
TSE	12998	
	LST	An initial prograding and aggrading (blocky) parasequence sets depicting a channel fill environment

Table 2: Summary of Identified Systems Tract for Well P-2.

Surfaces	Systems Tract		
		Depth (ft)	Remarks
	TST		An initial deepening of a typical proximal lagoon that grades into a sub-tidal environment with an overall prograding gamma ray signature
TSE		12869	
SB (10.6Ma)	LST		A blocky or cylindrical trending and aggradational parasequence set depicting a channel fill environment
		13050	A prograding parasequence set with upward coarsening signature of a typical shore face environment
	HST		

Table 3: Summary of Identified Systems Tract for Well P-3.

Surfaces	Systems Tract		
		Depth (ft)	Remarks
	TST		An initial deepening of a typical proximal lagoon that grades into a sub-tidal environment with an overall prograding gamma ray signature
TSE		12818	
	LST		A prograding to blocky stacking pattern with intermittent deepening, depicting a channel fill environment
SB (10.6Ma)		13090	
	HST		An aggrading to prograding parasequence set and contains condensed section; indicated by the maximum separation of Neutron-Density log signature and lowest resistivity values. The prograding parasequence sets indicate shore face environment.
MFS (11.5Ma)		13288	An overall deepening upward sequence shown by the consistent high gamma ray values.
	TST		

Table 4: Summary of Identified Systems Tract for Well P-4.

Surfaces	Systems Tract	Depth (ft)	Remarks
TSE	TST		An initial deepening of a typical proximal lagoon that grades into a sub-tidal environment with an overall prograding gamma ray signature
		12914	
SB (10.6Ma)	LST		A blocky and massive (or cylindrical trend) aggrading parasequence set depicting a channel fill environment
		13105	
	HST		A prograding parasequence set with upward coarsening signature of a typical shore face environment

Table 5: Summary of Identified Systems Tract for Well P-5.

Surfaces	Systems Tract	Depth (ft)	Remarks
TSE	TST		An initial deepening of a typical proximal lagoon that grades into a sub-tidal environment with an overall prograding gamma ray signature
		12870	
SB (10.6Ma)	LST		The stacking pattern showing blocky progradational to aggradational parasequence depicting a channel fill environment
		13034	
	HST		An aggrading to prograding parasequence and contains condensed section; indicated by the maximum separation of Neutron-Density log signature and lowest resistivity values. The prograding parasequence sets indicate shore face environment
MFS (11.5Ma)			
		13269	
	TST		An overall deepening upward sequence shown by the consistent high gamma ray values

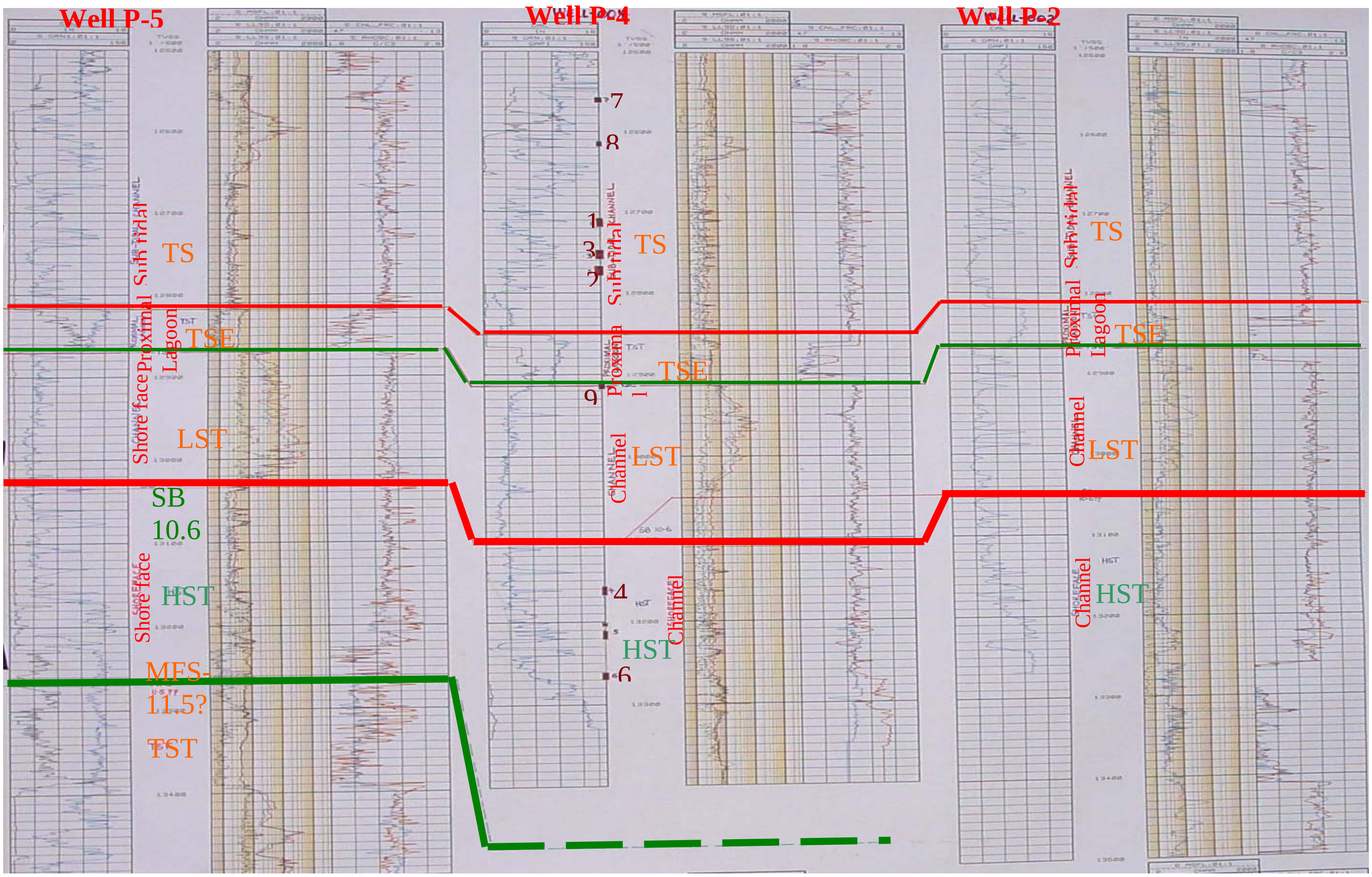

Figure 5: The Dip Section Sequence Stratigraphy of the Paradise-Field, Niger Delta, Nigera.

At the upper boundary of the LST is transgressive surface of erosion which marks the first marine incursion landward in the transgressive systems tracts (TST). This is identified in all the wells, which started with an initial deepening signature of a typical sub-tidal channel environment. The constant deepening interval above the LST depicts a proximal lagoon setting which drowns the blocky lowstand wedge complexes (Figures 5 and 6). In all the wells studied, the proximal lagoon shales act as seal rocks to the underlying channel fill reservoirs which contain the greatest hydrocarbon saturation with great sand thickness.

Highstand Systems Tract (HST)

During this stage, the sea-level rise decreases and they are characterized by initially aggradational deep sea shales that grade into intervals of shallowing upwards. Both fluvial and deltaic sands near the top of the unit prograde laterally into neritic shales. The highstand systems tract is identified in four (4) wells as follows; P-2 (13059 – 13260ft), P-3 (13090 – 13288ft), P-4 (13105 – 13292ft), and P-5 (13034 – 13269ft).

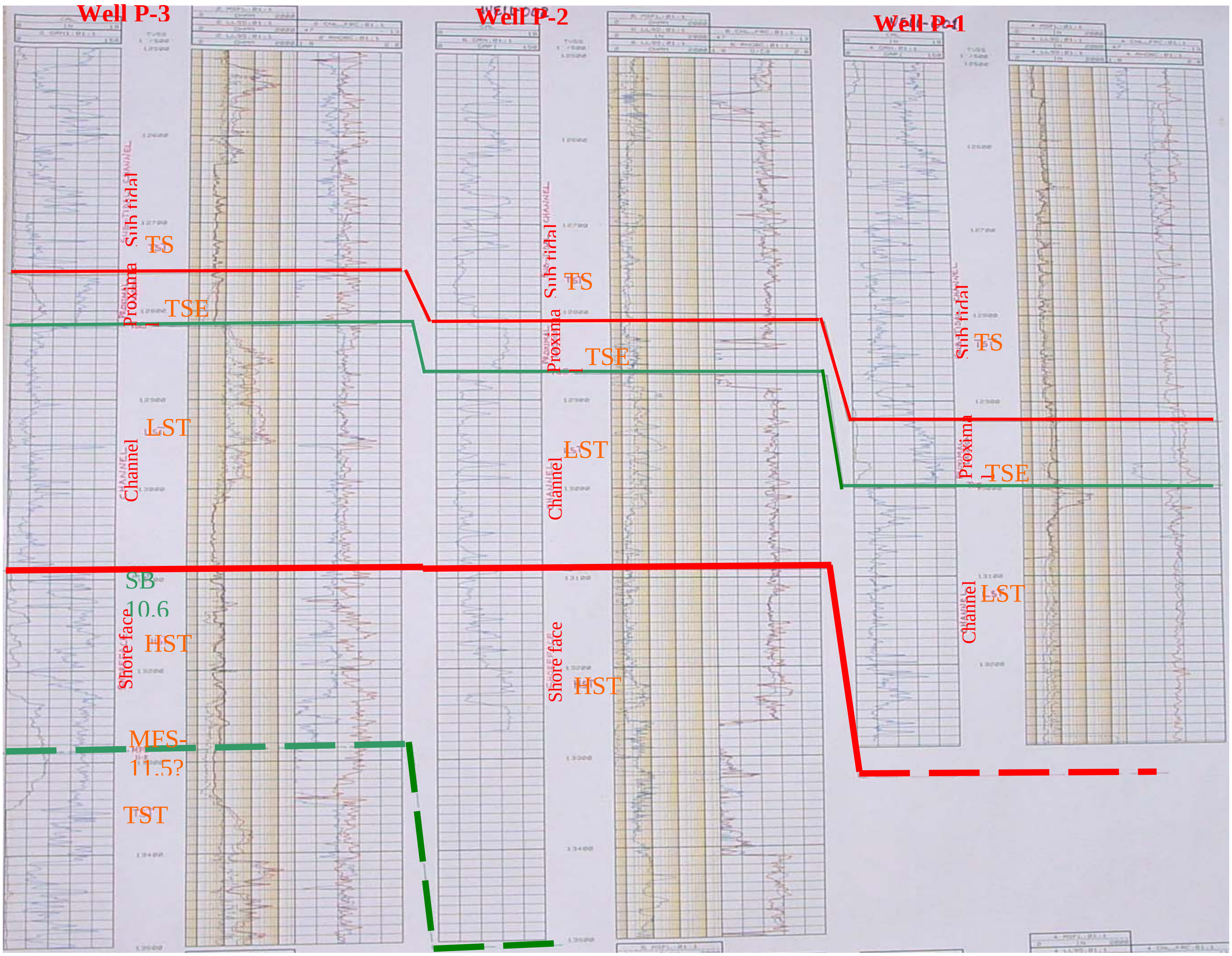

Figure 6: The Strike Section Sequence Stratigraphy of the Paradise-Field, Niger Delta, Nigera.

This prograding highstand complex corresponds to the shoreface depositional environment. The coarsening upward sequence with occasional deepening signature gives rise to a moderate to good porosity value with intercalation of shales that tend to reduce porosity and permeability(figs.7&8). Nevertheless, the shoreface sands of the highstand systems tract generally have good reservoir quality (porosity and permeability).

DISCUSSION AND CONCLUSION

In the "Paradise Field", one candidate maximum flooding surface (MFS) dated 11.5Ma was recognized based on the maximum shale peak, the separation of high neutron and low density values with constituent high gamma readings (Figure 5).

Also one sequence boundary (SB) dated 10.6Ma is identified basically on the inflection from overall progradation to overall retrogradation of parasequences in the shallowing sand units. The relative thickness of the systems tracts reveal changes in sediment accumulation rate as a result of varying local conditions which may include the effect of gravity, tectonics, availability of accommodation space, and eustatic sea level changes.

Since the primary seal rocks in the Niger Delta are the inter-bedded shale within the Agbada Formation, the juxtaposition of reservoir sands against shale beds due to faulting creates good seal integrity. The shale provides seals in the form of clay smears along these synsedimentary faults and vertical fault seals in a compressive stress setting.

On the flanks of the delta, major transgressive erosional events of early to middle Miocene age form canyons that are clay filled (Figure 4); like the proximal lagoon setting overlying all the channel reservoirs in the study area. In all the wells studied, these proximal lagoon shales act as seal rocks to the underlying channel fill reservoirs which contain the greatest hydrocarbon saturation with great sand thicknesses which increase on the distal part of the field (i.e. dip section; Figure 5).

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SUGGESTED CITATION

Anyiam, A.O. and A.W. Mode. 2008. "Sequence Stratigraphic Framework of the "Paradise-Field" Niger Delta, Nigeria". Pacific Journal of Science and Technology. 9(1):227-237.

Pacific Journal of Science and Technology