Sequence Stratigraphic Analysis of Parts of the Niger Delta

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Abstract A sequence stratigraphic analysis was carried out on the sedimentary packages of parts of the Niger Delta hydrocarbon province. This paper focuses on the identification and classification of depositional sequences as well as their systems tracts. Well log data using log signatures and parasequence stacking patterns, reflection terminations and continuity of events in seismic sections from ten wells and biofacies data from two wells were employed. Two complete and one incomplete depositional sequences and their associated facies were identified from middle – late Miocene. Sequences reveal the presence of two major system tracts, namely Transgressive system tract and the Highest and system tract. Six key stratigraphic surfaces: SB 8.5Ma, MFS 9.5Ma, SB10.35Ma, MFS 10.4Ma, SB 10.6Ma and MFS 11.5Ma were identified. Well log patterns indicate a regime of low to high energy environment and subenvironments ranging from proximal marine through lower shoreface and upper shoreface to fluvitile. Biostratigraphic analysis reveals that the sediments were deposited in the coastal deltaic to middle neritic environment. Sand distribution in the highst and system tracts have good reservoir characteristics with net-gross of 70-80%, high porosity values of 25-35% and and good permeability values of 3000 to 4000mD. The transgressive shale forms excellent seals for potential stratigraphic traps in the area. The study indicates that the integration of well log data, biostratigraphy and seismic data provides a powerful tool for petroleum system analysis, improved stratigraphic correlation, source rock prediction and most importantly reduces risk in prospect generation..

Keywords maximum flooding surface, sequence, parasequence, systems tracts, reservoir quality, prospect generation

Introduction

As conventional petroleum resources continue to diminish around the globe, exploration and production companies have little option but to produce and develop smaller and more complex reserves of which it is believed that there are good prospects in the Niger Delta. Sequence stratigraphy, which is applied in this study is a highly successful exploration In the exploration and production of petroleum and mineral resources.

The concept of sequence stratigraphy was initiated and developed through seismic stratigraphy as a methodology for stratigaphic interpretation [1]. It was first applied in the Niger delta where it has since re-enforced the potential for prediction of hydrocarbon habitats [2]. The aim of this study is to carry out a sequence stratigraphic analysis of an anonymous field within parts of the Coastal Swamp depo-belt of the Niger Delta with a view to identifying and classifying the depositional sequences and their associated facies.

The objectives of this research are to: determine the major chronostratigraphic surfaces and units in the study area, using the available well logs, seismic data and biofacies data. Identify system tracts associated with potential hydrocarbon emplaced in order to reduce the overall exploration risk; furthermore, to carry out Sedimentological characterization of reservoir sands within the system tracts. Finally, undertake a paleoenvironmental reconstruction of the study area.

Geology of Niger Delta Basin

The Niger Delta is the most prolific sedimentary basin within the Western African sub-continent. It is known to be one of the world's top twelve accumulations of recoverable petroleum; having reserves over thirty four billion barrels of crude oil and ninety three trillion cubic feet of gas [3].The tectonic setting of this basin has been attributed to the divergence of the African and South American Plates and creation of Southern Atlantic it

has also being proposed that a triple junction developed [4]. Grant (1971) suggested RRF (ridge-ridge fault) mechanism for the initiation of this separation [5]. Wright, (1976) on the other hand proposed an RRR (ridge-ridge-ridge) mechanism [6]. The inactive rift of this triple structure is the Anambra/Benue rift valley where the Oceanic crust was inactive. The rivers' depositional centers moved seawards and in consequence, the coastal plain deposits became progressively younger in that direction. The Niger Delta complex has undergone little deformation at the upper level but the subsurface had experienced major deformation by large scale syn sedimentary features such as growth fault, rollover anticlines and diapers

Location of Study Area
The study area is located in OML 18 and 24 about 40km South West of Port Harcourt, which is part of the Coastal Swamp Depobelt of the Eastern Cenozoic Niger Delta (Fig.1). Its co-ordinates are longitudes $6^0 46^{'}$- $6^0 53^{'} E$ and latitudes $4^0 28^{'} – 4^0 32^{'} N$ and covers a total area of about 154Km^2 with a perimeter of about 50km. Ten wells were used for the research. Sediment deposition in this area started in early Miocene times.

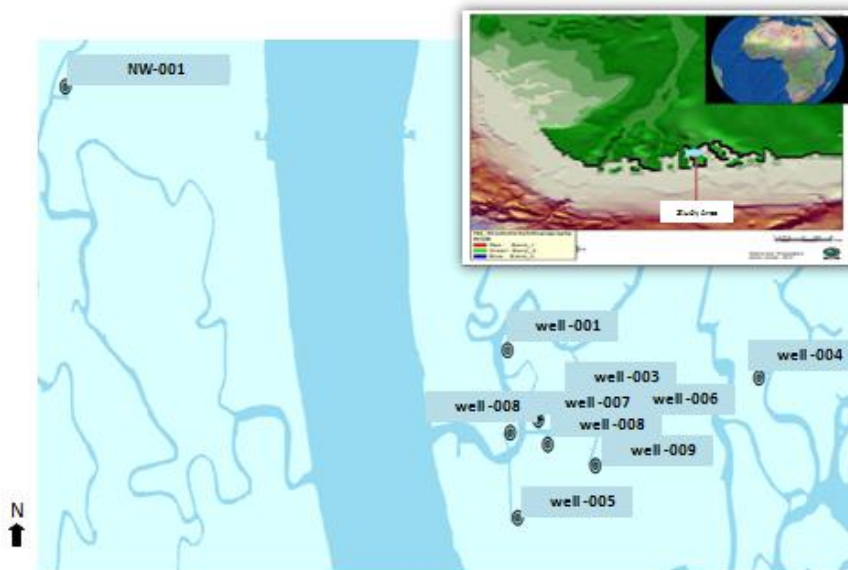*Figure 1: Map of study area (inset) and location of wells across the field*

Materials and Method
The materials used for this study include the following: Base map of the study area showing well locations, Log suites which include Gamma ray logs, resistivity logs; neutron density logs, and porosity logs, Biofacies data, Paleobathymetric environment of deposition, 3D seismic section of the field, and Niger Delta Cenozoic chronostratigraphic chart.

Methodology
A sequence stratigraphic approach modified,after Posamentier et al. (1988), Van Wagoner et al. (1990), Vail and Womardt (1990), Mitchum and Van Wagoner (1991), and Stacher (1994) was applied in this work [1-2, 7-8]. This approach involves well data analysis seismic analysis and the integration of data.

Well Data Analysis
This entailed the following: This entailed the following: establishing foraminifera and palynomorph zones in wireline logs, Interpretation of depositional environments, subdivision of time stratigraphy, establishment of chronostratigraphic surfaces and mapping of net to gross of reservoir sands.

Seismic Analysis
Seismic analysis involved the interpretation of faults and chronostratigraphic surfaces.

Data Integration

The data integration entailed the following: Well to seismic tie, mapping of chronostratigraphic surfaces and identification of reservoirs and trap.

Wireline Logs

The log motives were observed for stacking patterns, parasequences and parasequences sets of depositional Systems in order to identify the stacking patterns, gamma ray log trends were utilized. A continuous decrease on gamma ray represents falling sea level which thus represents a regression of sea and a progradation of the delta. This therefore gives a progradational stacking pattern. An increase in the value of gamma-ray log reading represents rising sea-level which in turn represents a transgression of the sea and a retrogradation of the deltaic sediments, thus a backstepping stacking pattern.

Stratigraphic surfaces are established at the beginning and terminating points of a stacking pattern. Candidate maximum flooding surfaces are expected at the peak point of a retrogradational stacking pattern while sequence boundary is expected at the end point of a progradational stacking pattern and beginning point of the next retrogradational stacking pattern. The effects and importance of wire line logs as measuring tools with respect to grain sizes and distribution is proportional to the energy of depositional currents and to the environment of deposition [10]. Gamma ray logs are also useful for correlating wells, calculating the reservoir thickness, evaluating shale volume and determining depositional environments or reservoir sands.

Well to Seismic Tie

A well to Seismic tie was also generated to match the surfaces interpreted on the well logs to the seismic in the study area (Fig.4).

Biofacies Data

From the total planktonic and faunal diversity and abundance, a generalized sea level curve was generated. Increasing total abundance and diversity of the curve indicates rise in sea level while decrease in total faunal abundance indicates falling sea level. The high peaks in the curve were interpreted as candidate maximum flooding surface while minimal zone in the fauna abundance are interpreted as candidate sequence boundaries [11].

The Chronostratigraphic Chart

Fig. 2 shows the Niger Delta Cenozoic chart (Shell Petroleum Development Company). The ages of the chronostratigraphic surfaces delineated in this study were obtained from this chart using SPDC's P and F zones established from the biostratigraphic data.
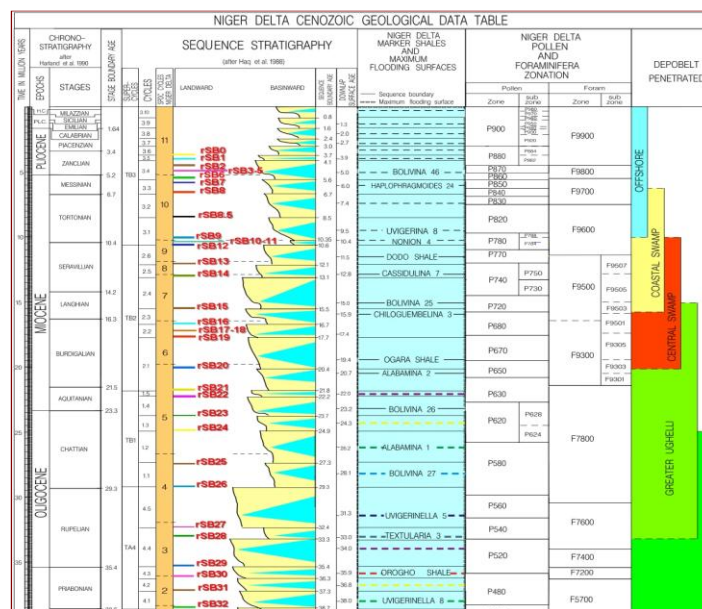

Figure: 2 The Niger Delta chronostratigraphic chart (Haq et al, 1988, Harland et al, 1998)

Results and Discussions

The combination of the biofacies data, well log and seismic data resulted in the delineation and identification of maximum flooding surfaces and sequence boundaries

In general, three maximum flooding surfaces (9.5Ma, 10.4Ma and 11.5Ma) and sequence boundaries (8.5Ma, 10.35Ma and 10.6Ma) were identified from the ten wells.

Maximum flooding surfaces

Maximum flooding surfaces are distinguished by an abrupt increase in water depth and contain the highest fauna/planktonic diversity peaks. On logs, it corresponds to the lowest resistivity values and the highest gamma ray values. On seismic it is downlap surface. The transgressive system tracts is crown by the maximum flooding and indicates the convergent point of the retrogradational stacking pattern of the TST to the progradational stacking pattern of the HST. The MFS denotes the end of major flooding surface found in the TST (Dominic and Keith, 1996).

Maximum Flooding Surface (9.5 Ma)

The maximum flooding surface (MFS 9.5Ma) occurred at a depth of 5746ft (1751m) at well_001, 5617ft (1712m) at well_002 (figs 3). The bathymetric setting is generally in the inner neritic. The faunal abundance of the MFS displays high peaks. On the seismic section, MFS (9.5Ma) was at 1909.50ms (fig 5).

Maximum Flooding Surface (10.4Ma)

This occurred at a depth of 10660ft (3249m) at well _001, 10522ft (3207m) at well_002, 10612ft (3235m) at well_005, 10663ft (3250m) at well_004 and 7505ft (2288m) at well_NW 001(fig 3).On the seismic, it occurred at 3129.89ms. (Fig 5)

Maximum Flooding Surface (11.5Ma)

This occurred at a depth of 9861ft (3006m) at well_Nw 00l, 13289ft (4050m) at well_002 and 13379ft (4078) at well _005 (figs. 3 and 5). On seismic it occurred at 3300ms. (Fig.6)

Sequence boundaries

Sequence boundaries are unc$_0$nformities up dip and a relative conformity down dip. As an unconformity, its surface is exposed and eroded; the downdip is noted by a seaward change in facies. This shift is transgressional in which the shoreline moves seawards due to sedimentati$_0$n. Sequence boundary is produced by a relative sea level fill, produced by change on the rate of tect$_0$nic subsidence. In this research, sequence boundaries are obtained from stacking patterns in the log signatures and biofacie analysis. Sequence boundaries are found in sand units, indicating the beginning or end of a new depositional sequence. Three sequence boundaries 8.5Ma, 10.35Ma and 10.6Ma were delineated from the ten wells on the study area.

Sequence Boundary (8.5Ma)

This occurred at a depth of 5949ft (1813m) at well_004, 5587ft (1703m) at well_001 and 5617ft (1712m) at well_002 (fig 3 and 5).. The bathymetric setting is at proximal fluvial marine for well_001. The faunal abundance is low –absent. On seismic section, SB 8.5Ma occurs at 1658.50ms (Fig 6).

Sequence Boundary (10.35Ma)

The SB occurred at a depth of 8882ft (2738m) at well_002, 9011ft (2747m) at well _004, 8886ft (2708m) at well_005 and 8785ft (2678m) at well_004 (figs. 3 and 5). The bathymetric setting is generally barren to middle neritic to shoreline. On the seismic section, it occurs at 2400 milliseconds (Fig.6).

Sequence Boundary (10.6Ma)

This SB occurred at a depth of 10254ft (3125m) at well_NW001, 11294ft (3442m) at well_001, 11158ft (3401m) at well_002,11313ft (3448m) at well 004 and finally 11254ft (3430m) at well_005 (figs 3 and 5). On the seismic section it occurs at 3556.74ms (Fig 6).
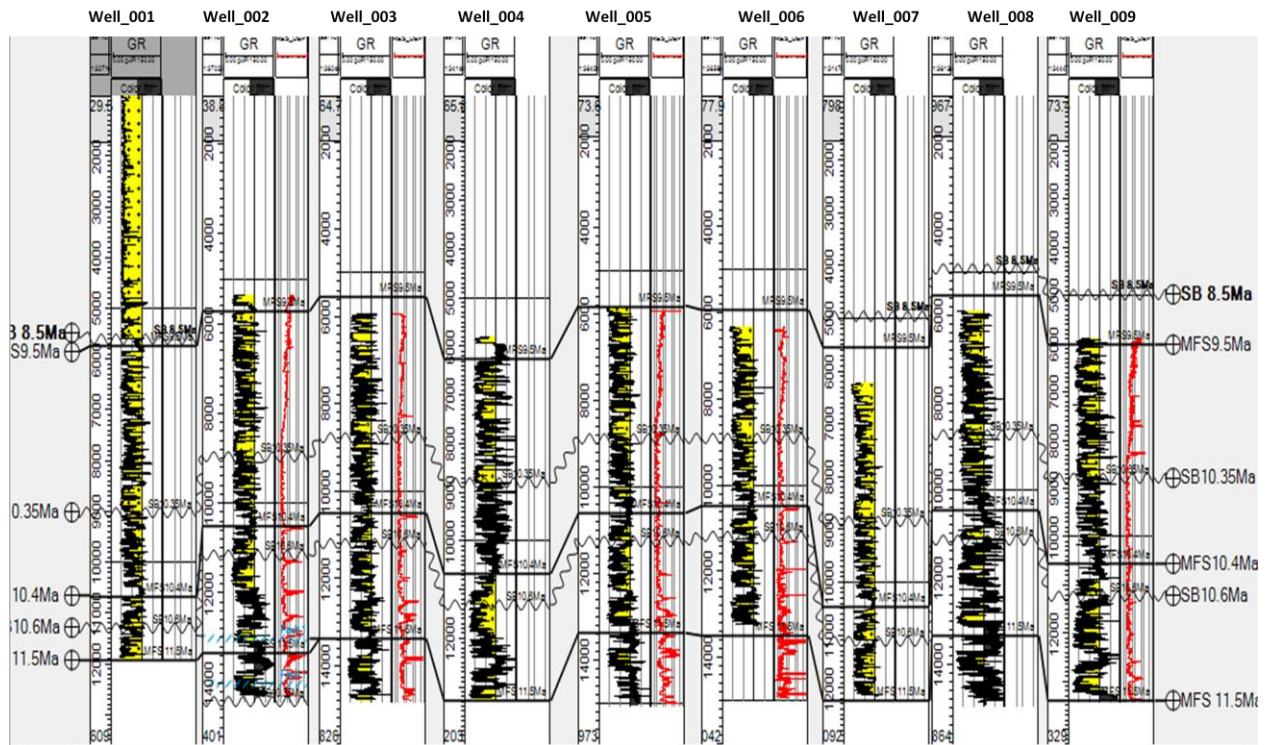
Figure: 3 Stratigraphic correlations showing the interpreted chronostratigraphic surfaces as well as the chronostratigraphic unit in wells 005,002 and 001 respectively.

Figure: 4 Well to seismic tie of well 005, showing the best match at MFS 11.5Ma

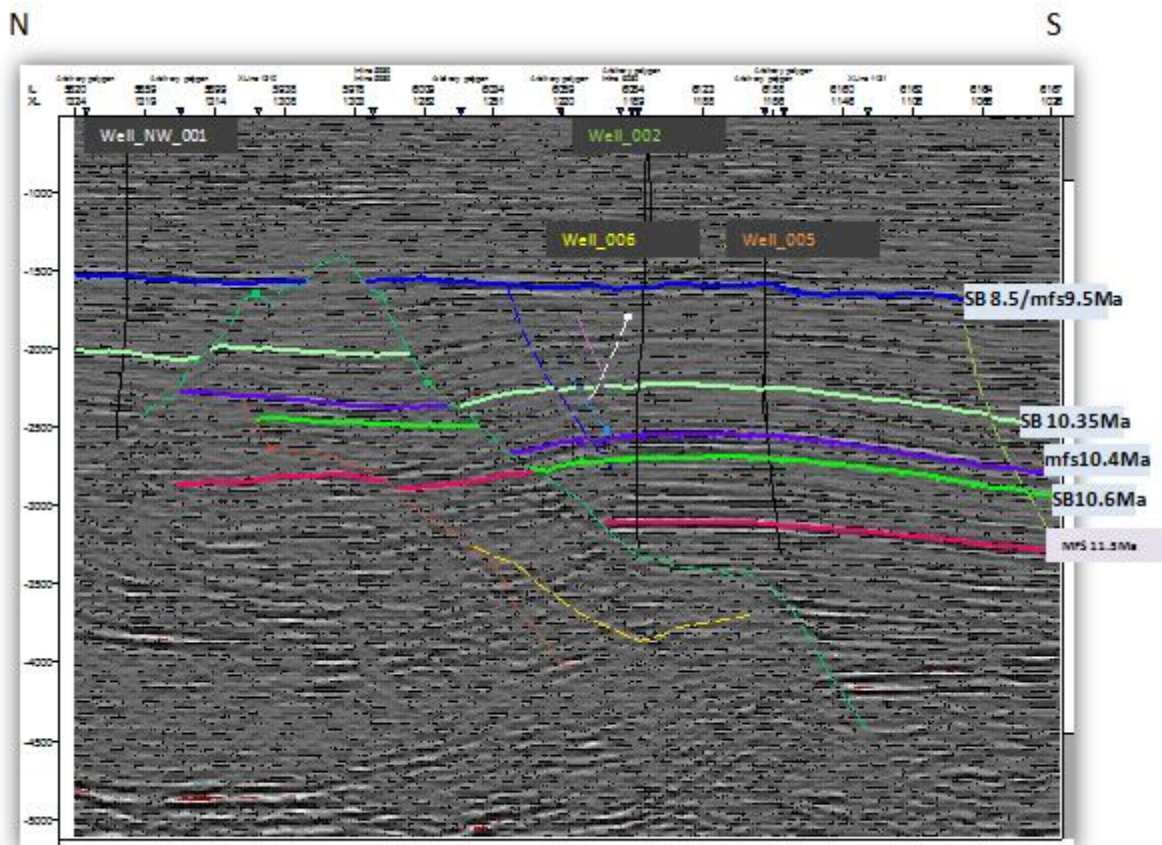*Figure 5: Stratigraphic correlation across the field.*

Figure: 6   Interpreted chronostratigraphic surfaces on the seismic section of the study area

Conclusion

From the results obtained, it is concluded that the application of sequence stratigraphy to the study area has enhanced the interpretation of the stratigraphic build-ups, recognition of isochronous surfaces and identification of prospects and leads. The correlation of isochronous, laterally persistent transgressive marker shales across fault blocks permits the recognition of the thickening or expansion of sedimentary sequences on the down-thrown blocks.

Acknowledgment

References

[1]. Vail, P.R., and W.W. Wornardt, 1991, An integrated approach to exploration and development in the 90's: well log- seismic sequence stratigraphy analysis, Gulf Coast: Association of Geological Society transaction, 41, p 430-650

[2]. Stacher, P.,1995, Present understanding of the Niger Delta hydrocarbon habitat, in M.N. Oti, and G. Postma, eds., Geology of Deltas: Rotterdam, A.A. Balkema, p. 257-267.

[3]. Tuttle, M.L.W., M.E. Brownfield, and R.R. Charpentier, 1990, "Tertiary Niger Delta (Akata-Agbada) petroleum System (No. 701901), Niger Delta province". Cameroon, and Equatorial Guinea, Africa: U.S. Geological Survey Open File report 99-50H, p.1-13.

[4]. Burke, K.C.B., T.F.J. Dessauvagie, and A.J. Whiteman, 1971 , The Opening of the Gulf of Guinea and the Geological History of Benue Depression and Niger Delta: Nature phs sci., 233 (38) P51 – 55.

[5]. Grant, N. K., 1971, South Atlantic, Benue trough and Gulf of Guinea Cretaceous triple junction: *Bull. geol. Soc. Am.* 82,2295-2298.

[6]. Wright, J. B.,1976, Fracture systems in Nigeria and initiation of fracture zones in the South Atlantic: *Tectonophysics* 34, 43-47.

[7]. Posamentier, H.W. and P.R. Vail, 1988, Eustatic Controls on clastic deposition II-sequence and systems tracts models, in C.K., Wilgus, B.S. Hastings, C.G. St. C. Kendall, H.

[8]. Van Wagoner, J.C., R.M. Mitchum, K.M. Campion, and V.D. Rahmanian, 1990, Siliciclastic sequence stratigraphy in well logs, cores and outcrops: American Association of Petroleum Geologists Methods in Exploration Series, v. 7. pp. 1-55

[9]. Mitchum, R.M. Jr., and J.C. Van Wagoner, 1991, High-Frequency sequences and their stacking patterns: Sequence stratigraphic evidence of high-frequency eustatic cycles: Sedimentary Geology, vol. 70, p.131-160.

[10]. Visher, G.S. 1969, Grain size distributions and depositional processes: Journal of Sedimentary Petrology 39: 1074-1106.

[11]. Armentrout, J.M. and J.E. Clement, 1991, Biostratigraphic Calibration of Depositional cycle: a case study in High Island – Galveston-East Break area, Offshore Texas. In sequence stratigraphy as an Exploration Tool. Concepts and practices (ed. By J.M. Armentrout and B.F. Perkins). Eleventh Annual Conference, June 2-5, Texas Gulf Coast Section: Society of Economic Paleontologist and Mineralogist, P.21-51.