Application of the Principles of Biostratigraphy and Sequence Stratigraphy at Analysing Petroleum Potential of Field 'Y' in the Niger Delta

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Abstract
The presence of Bolivina 46 was indicative of Pliocene age, however using the diagnostic forams (Amphistegina) present and the Fzone in addition the age could be rightly said to be extending from late pliocene to late miocene in age. The well is said to penetrate Benin formation consisting of continental sandstone with fluvial channels, marsh/swamps in an upper delta plain environment and part of the Agbada formation consisting of transitional sandstone and shale The well penetrated the F9700 to F9900 foraminiferal zone and P800-P900 pollen zone as would also be confirmed on the Niger Delta Chronostratigraphic chart. It can also be inferred that the penetration was restricted to the offshore depobelt. Three maximum flooding surfaces (depths of 2400ft-2500ft @3.4 million years-late pliocene, 3600ft-3650ft @ 3.9 million years-early pliocene and 8500ft-8550ft @6.0 million years -late miocene, respectively) and three sequence boundaries (depths of 3300ft-3400ft @3.7 million years-early pliocene, 4950ft-5000ft @ 4.1 million years-early pliocene and 7550ft @5.6 million years-late miocene, respectively) were identified using foram abundance and diversity plots. Ten sand bodies were identified at different depth intervals and hydrocarbon was identified at the following depths;4480ft to 4570ft (oil),4880ft to 4940ft (oil and gas) and 6560ft to 6640ft (gas). The identified petroleum bearing sands were seen to occur at the highstand system tracts, lying above transgressive system tracts, which are the source rocks. The alternation of highstand systems tract and transgressive systems tract sands and shales respectively seen in the studied well, provides a union of reservoir and seal rocks that is essential for hydrocarbon accumulation and stratigraphic trapping. The interpreted depositional environment of field 'Y' is of deltaic System of non-marine neritic bathyal paleobathymetry.

Introduction

Petroleum potential is basically the probability of discovering an economically viable quantity of petroleum from a geological area or field. This is achievable through analyzing of several factors, primarily the source rock where organic matter has been deposited and transformed into hydrocarbon over a geological time, and others like the reservoir quality, trap formation, seal, migration pathway, etc.

Hydrocarbon is an important source of energy for man and their discovery and exploitation has become a multi-billion dollar industry (Anderson, 1985; Sampson, 1975). According to Fischer, 1974, there is a probability estimate that ~ 80 per cent of total petroleum and coal resources will have been used up within the next 100 years and 300-400 years respectively as in short-term geological time (10 Ma), these resources by definition are non-renewable and thus getting scarcer as man uses them. There is thus a need for proper study to properly discover the present available.

Biostratigraphy encompasses the study of rock strata using fossil organisms, which are used to correlate rock layers across different wells or outcrops, thus analysing the relative ages of sedimentary units. This study of fossil assemblages would be an aid at identifying the different depositional environments convenient for hydrocarbon formation. Biostratigraphy is also an important tool for field-mapping, correlating reservoirs geological control during well drilling, testing stratigraphic and structural interpretations, as exploration has moved toward more structurally complex or/and unexplored areas where seismic information is not usually easy to interpret and thus a need for a reliable zonation.

The application of sequence stratigraphy at observing sea level changes can influence the distribution of facies and a good avenue for analyzing the petroleum reservoir quality and distribution. Sequence stratigraphy acts as a tool in deducing the dispersal of muds, shale and other fine-grained sediments which act as closures and baffles for fluid flow within reservoir sequences and as hydrocarbon source rocks (Posamentier and Allen, 1999).

The approach of studying and interpreting both the biostratigraphy and sequence stratigraphy of a field would enable a detailed understanding of the geological history of the basin and also to identify the petroleum systems and their potentials. This would also aid in predicting the depositional environments associated with petroleum systems as studying of the fossil content, sedimentary facies, and sequence architecture can deduce the paleoenvironmental conditions such as sea level fluctuations, shoreline migration, and basin subsidence, which would act as a vital criteria for recognizing areas of hydrocarbon accumulation.

Significance of Study

In the Niger-Delta petroleum province, there are different encountered cases of dry holes and poorly producing wells, of which is connected to an insufficient architectural study of the field settings and reservoirs. The application of Biostratigraphy and Sequence stratigraphy principles is aimed at reducing the uncertainties of finding prospects and sighting of inter-well drill locations to enable proper planning of production schemes. This also aids in projecting the distribution and geometry of source rock, reservoir, and seal facies within sedimentary basins. This is a key knowledge for identifying good exploration positions and enhancing drilling locations.

Location and Geology of the Study Area

The study area (Fig.1) is located in the Niger delta, between latitudes 4.00N and 4.50N and longitudes 4.50E and 5.00E.

The Niger Delta is a large, arcuate, classical delta of the destructive, wave dominated type (Allen, 1965). It is situated on the continental- margin of the Gulf of Guinea (Fig.2) and extends throughout the province as defined by (Klett et al 1997).

The Niger Delta lies on a passive continental margin with subsidence primarily driven by sediment loading and tectonic activities. Doust and Omatsola (1990) discuss the delta's tectonic framework, emphasizing the influence of rifting and subsidence on sedimentation patterns.

The Niger Delta's geological formation began in the Eocene age to the present day. The delta is a classic example of a passive margin basin, comprising of substantial sediment deposition from the Niger River and its tributaries. The delta's formation was a process of series- transgressive-regressive cycles, which led to the development of extensive deltaic and shallow marine deposits (Evamy et al. (1978).

The Niger Delta comprises of three primary formations: Benin, Agbada and Akata. The Benin formation is composed of continental sands and minor clays, reflecting deposition from braided river systems, and forming the delta's surface geology. The Agbada Formation has an alternating layers of sandstones and shales, representing delta front and delta plain deposits. The sandstones exhibit excellent porosity and permeability and is the principal hydrocarbon reservoir of the Niger Delta. Tuttle et al. (1999) discussed the delta's reservoir properties, emphasizing the heterogeneity and complexity of these reservoirs . The Akata formation are of deep marine shales and clays, rich in organic matter, and with its organic-rich shales, is the primary source rock. Geochemical studies by Ekweozor and Daukoru (1994) confirm the high potential for oil and gas generation within this formation, and thus the main source rock for hydrocarbons.

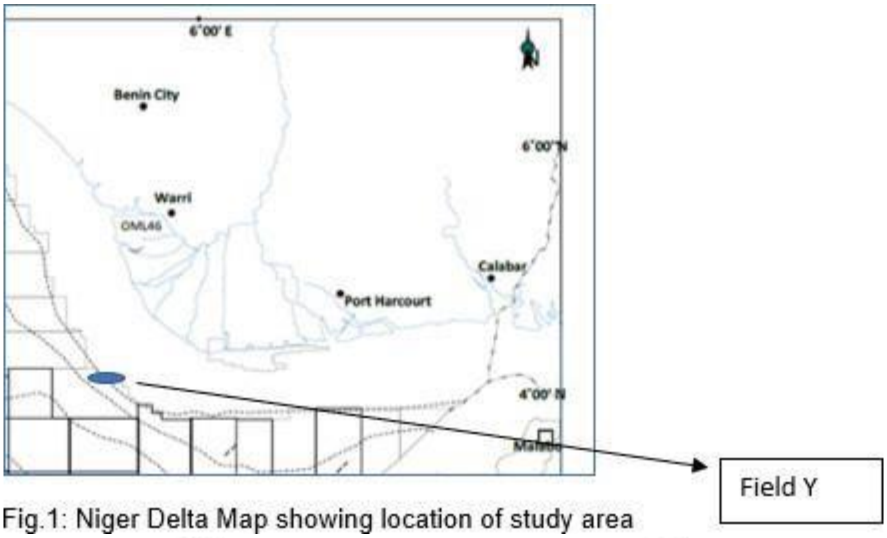

Fig.1: Niger Delta Map showing location of study area

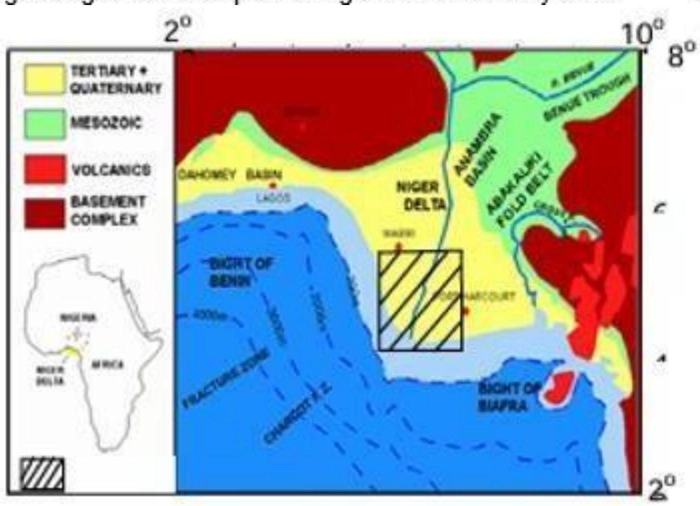

Fig. 2: Index Map of Niger Delta and Offshore Nigeria (after Doust and Omatshola, 1990)

Literature Review

Biostratigraphy and **Sequence stratigraphy** are two crucial disciplines in geology used for the correlation and interpretation of sedimentary rock sequences. Biostratigraphy relies on the distribution of fossils within sedimentary layers to establish relative ages and correlate strata across different regions. Sequence stratigraphy, on the other hand, focuses on the stratigraphic arrangement of sedimentary deposits in relation to changes in sea level and sediment supply, organizing strata into unconformity-bounded sequences (Catuneanu, 2006).

Combining these two methods provides a powerful approach to understanding the temporal and spatial distribution of rock units, which is particularly valuable in hydrocarbon exploration, paleoenvironmental reconstruction, and geological mapping.

Biostratigraphy involves the use of fossil assemblages to establish relative ages of rock layers (Gradstein et al., 2020). Key concepts include:

- **Biozones**: Stratigraphic units defined by the presence or absence of particular fossil species.
- **Index Fossils**: Fossils of organisms that were widespread but only existed for a relatively short geological period, used to define biozones (Ogg et al., 2016).
- **Fossil Correlation**: Correlating rock layers from different locations based on shared fossil assemblages.

Sequence stratigraphy focuses on understanding the cyclic deposition of sediments in relation to changes in sea level and tectonics (Catuneanu, 2006). Core principles include:

- **Sequences**: Stratigraphic units bounded by unconformities.
- **Systems Tracts**: Subdivisions within sequences representing different depositional environments (e.g., lowstand, transgressive, highstand).
- **Sequence Boundaries**: Unconformities or significant shifts in sedimentation patterns used to define the limits of sequences.

Integrating Biostratigraphy and Sequence stratigraphy improves the prediction of reservoir quality and distribution. For example, Posamentier and Vail (1988) demonstrated that sequence stratigraphy could identify potential hydrocarbon reservoirs by correlating depositional sequences with known productive zones, while biostratigraphy can refine these correlations by providing age control.

In the Niger Delta, the application of these methods has enhanced the understanding of sedimentary sequences and their relationship to hydrocarbon accumulation. Short and Stauble (1967) and Doust and Omatsola (1990) have shown how combining biostratigraphic age control with sequence stratigraphic frameworks has helped delineate reservoir units and understand depositional patterns.

Methodology

The sample type used here are side wall cores and ditch cuttings description data of the wells (Y1,Y2,Y3 and Y4), used with the chronostratigraphic chart of the Niger Delta (Fig. 3) to date the surfaces.

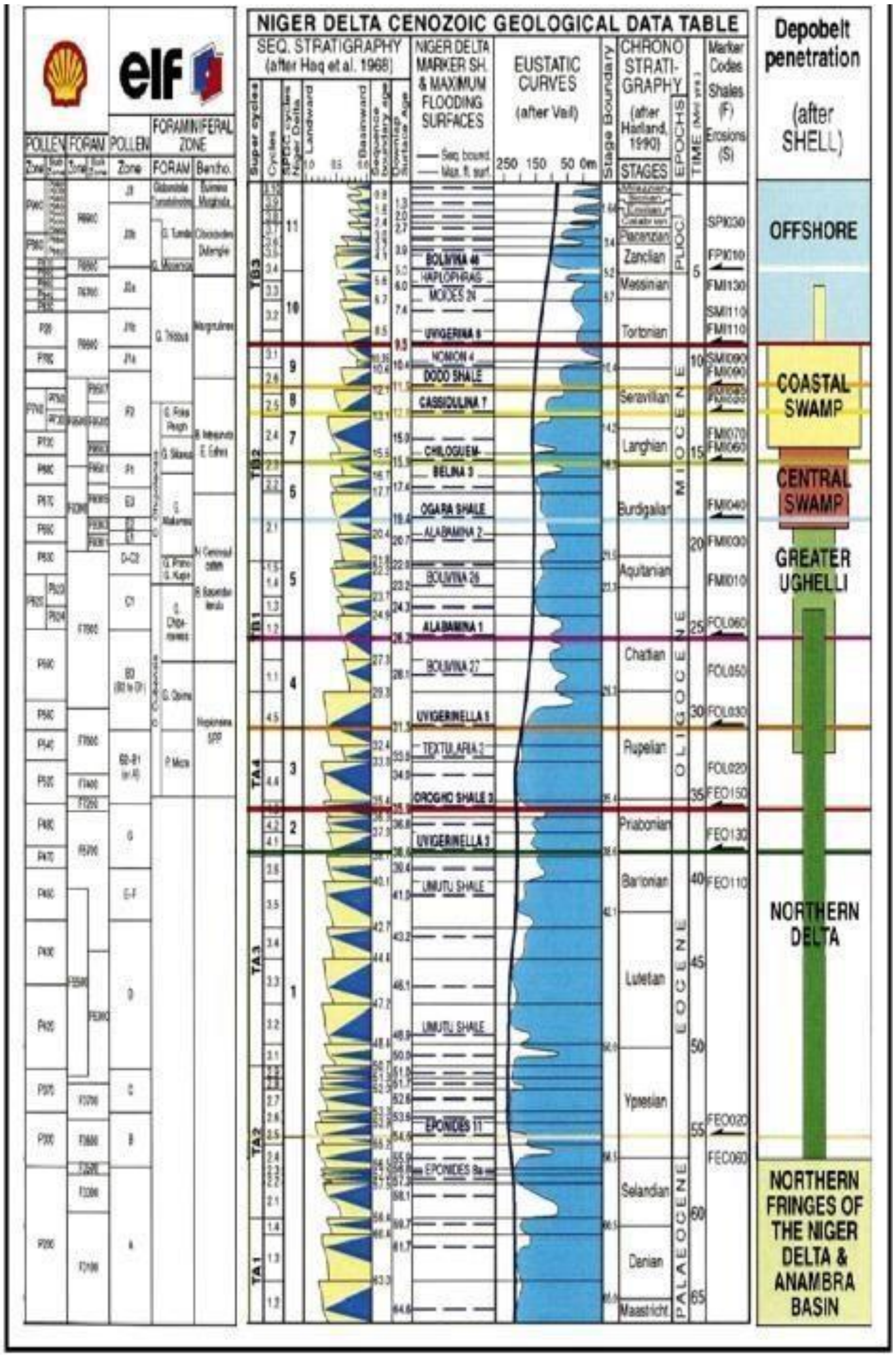

Fig. 3 Niger Delta Cenozoic Chronostratigraphic Chart (Modified from Reijers 2011) The index fossils were identified. Biozonation was done across the wells through correlation to create a stratigraphic framework. The major well logs used were gamma-ray, resistivity, sonic, and

density logs on Petrel software (fig.4 and 5) to interpret lithology which further aided in interpretation of depositional environments based on well log responses, and sidewall core/ditch cuttings data.

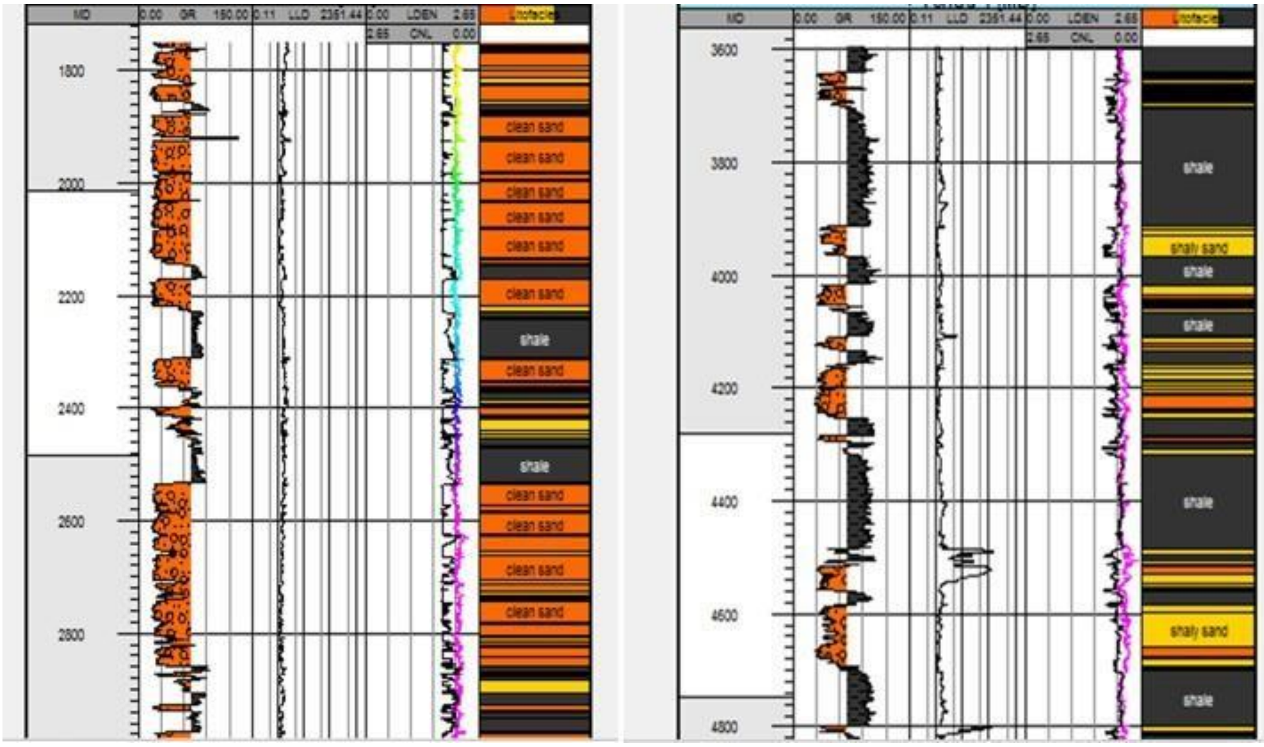

Fig. 4: Well Log section showing identified lithogies.

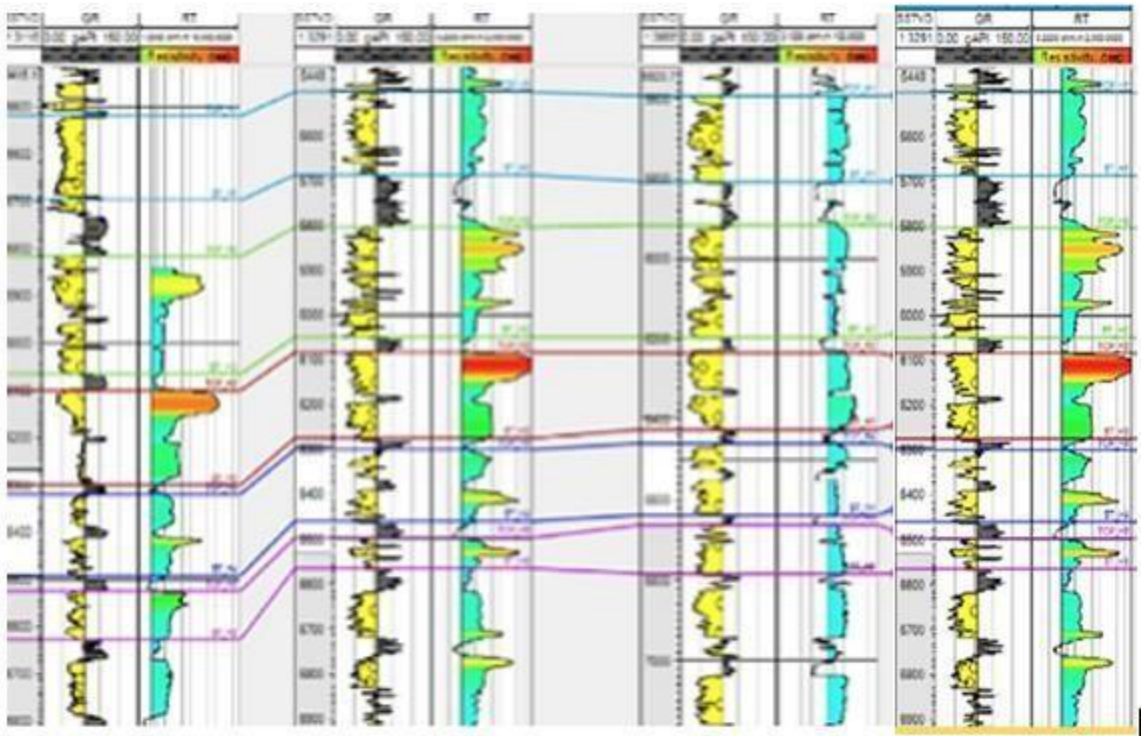

Fig. 5: Correlated Well logs Panel

Stratigraphic boundaries inclusive of system tracts(Fig.6); lowstand, transgressive, and highstand within the stratigraphic record were identified, and also hydrocarbon surfaces as the interpreted facie model enabled prediction of reservoirs, seals, and source rocks distribution across the field as tied on seismic sections (fig.7) to confirm interpretations based on seismic facies. The potential reservoirs were identified within specific Sequence stratigraphic units and also the source rocks and seals distribution was also integrated to Biostratigraphy and Sequence Stratigraphy.

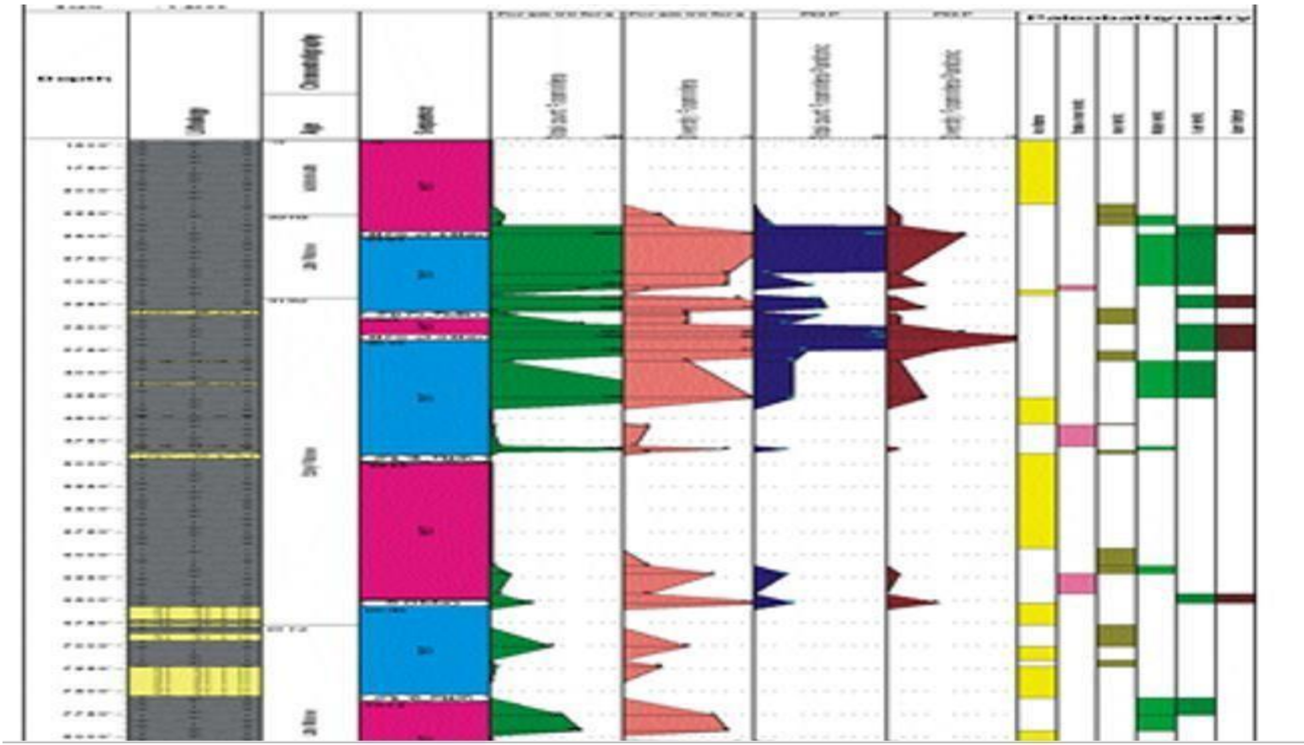

Fig. 6: Strata Bug Plot of Well Y1 showing System tracts

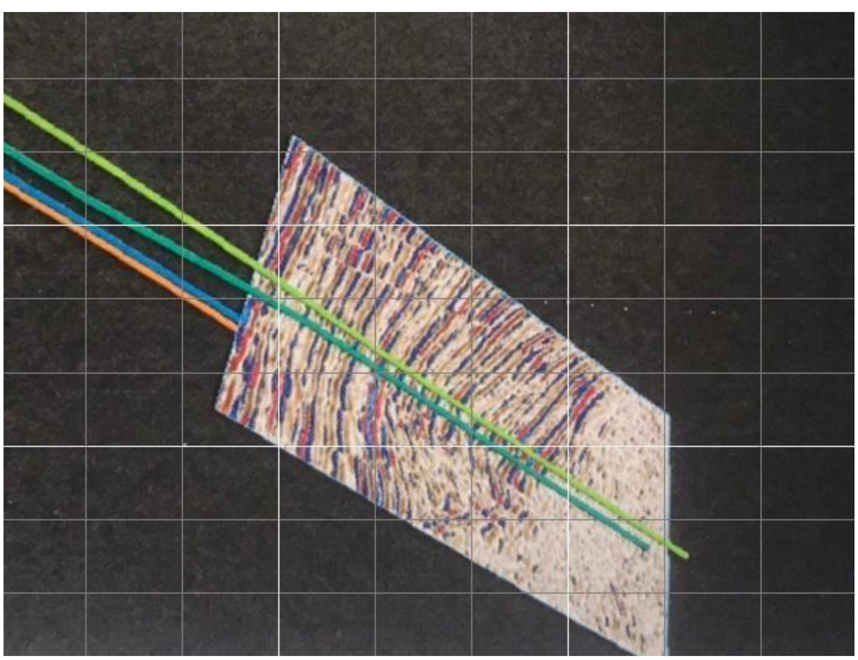

Fig. 7: Seismic to Well Tie of Field Y

Results and Interpretations

- **Regional marker**

The only major regional marker was the Bolivina 46.

- **Age**

The presence of Bolivina 46 was indicative of Pliocene age. But using the diagnostic forams (Amphistegina) present and the Fzone in addition the age could be rightly said to be extending from Late Pliocene to Late Miocene in age. This inference was made using the Niger delta chronostraigraphic chart as a guide.

- **Depobelt**

Based on the chart, it can be seen that the well penetrated Benin formation consisting of continental sandstone with fluvial channels, marsh/swamps in an upper delta plain environment and part of the Agbada formation consisting of transitional sandstone and shale (Fig 3). The well also penetrated the F9700 to F9900 foraminiferal zone as would be seen on the Biostratigraphic charts.

It can also be inferred that the penetration was restricted to the offshore depobelt.

- **Key surfaces**

The maximum flooding surfaces MFS and the sequence boundaries SB were worked out by creating plots based on the foram abundance and diversity and were as follows;

- **Maximum Flooding surfaces**

MFS; 2400ft – 2500ft
MFS; 3600ft – 3650ft
MFS; 8500ft – 8550ft

- **Sequence Boundaries**

SB; 3300ft – 3400ft
SB; 4950ft – 5000ft
SB; 7550ft

- **Age of key surfaces.**

The maximum flooding surfaces MFS and the sequence boundaries SB were worked out by creating plots based on the foram abundance and diversity and were as follows; The Position of the Pzones , Fzones and diagnostic forams were used to work out ages based on the Niger delta chronostratigraphic chart.

•**Maximum Flooding surfaces** MFS 1; Depth; 2400ft – 2500ft
Age; 3.4 million years (Late Pliocene)
MFS 2; Depth; 3600ft – 3650ft
Age; 3.9 million years (Early Pliocene)
MFS 3; Depth; 8500ft – 8550ft
Age; 6.0 million years (Late Miocene)

 Sequence Boundaries
SB 1; Depth; 3300ft – 3400ft
Age; 3.7 million years (Early Pliocene)
SB 2; Depth; 4950ft – 5000ft
Age; 4.1 million years (Early Pliocene)
SB 3; Depth; 7550ft
Age; 5.6 million years (Late Miocene) They
are depicted in the chart below.

 Sequence Interpretation
Interpreting from bottom, it can be seen that from 8750ft, there was a transgression and rise in sea level which culminated in a maximum flooding surface at about 8550 ft. Above 8550ft, there was a drop in sea level and regression which culminated in a sequence boundary at about 7560ft. There was another transgression and sea level rise although it resulted in a flooding surface, it was not a maximum flooding surface. This interpretation is based on the litholog at that depth which was quite close to sandstone and also using the total foram count and diversity. This does not suggest a maximum flooding surface, but possibly a marine flooding surface.
After the flooding episode, there was a continual regression and drop in sea-level up till 4950ft where there was a sequence boundary. At 4950ft, another transgression occurred which culminated in a maximum flooding surface at 3550ft. Then, there was a sea level drop giving rise to a sequence boundary at 3350ft. This episode was followed by another sea level rise and another maximum flooding surface at 2400ft. Then, there was a drop in sea level which continued to the top depth of 1500ft.

The summary of the results of this study is presented below.
Depositional Environment: Deltaic System
Paleobathymetry: Non Marine Neritic- Bathyal
Key surfaces; 3 Maximum flooding surfaces & 3 Sequence Boundaries.
MFS; 2480 ft(3.4ma), 3610ft(3.9ma),8500ft(6ma).
SB; 3850ft(3ma), 4920ft(4.1ma), 7600ft(5.6ma).
Major Regional Marker; Bolivina 46.
P&F Zones; P800-P900, F9700-F9900.

Based on the data and the litholog that was created using the petrel software; Ten sand bodies were deduced as indicated below: Sand body 1; 3320ft – 3359ft

Sand body 2; 3870ft -- 3883ft
Sand body 3; 4106ft –4133ft
Sand body 4; 4484ft -- 4560ft
Sand body 5; 4798ft – 4813ft
Sand body 6; 4884ft –4944ft
Sand body 7; 6570ft – 6720ft
Sand body 8; 6750ft – 6782ft
Sand body 9; 6862ft – 6945ft
Sand body 10; 7228ft –7554ft

Hydrocarbon was identified at the following depths; 4480ft
to 4570ft (Oil).
4880ft to 4940ft (Oil and Gas).
6560ft to 6640ft (Gas).

With the aid of the resistivity log potential hydrocarbon zones were deduced at the following depths; 6490ft to 6550ft and 7140ft to 7170ft. Both proved to be viable because the reservoir sands were found to be juxtaposed between shale which would act as a seal preventing escape of the hydrocarbon.

Conclusion

The identified petroleum bearing sands were seen to occur at the Highstand system tracts, lying above transgressive system tracts, which are the source rocks.

The alternation of highstand systems tract and transgressive systems tract sands and shales respectively seen in the studied well, provides a union of reservoir and seal rocks that is essential for hydrocarbon accumulation and stratigraphic trapping.

Conclusively, the biostratigraphic studies have revealed a rich assemblage of microfossils, including foraminifera and palynological data. The precise dating of stratigraphic layers through biostratigraphy has allowed for the identification of key time intervals associated with significant sedimentation and organic matter deposition, which aided in depositional environment interpretation and also supports identification of various stratigraphic units that are conducive to hydrocarbon generation and accumulation.

Sequence stratigraphic analysis was used to create the sedimentary architecture of the field by viewing the sea-level changes in progradational and retrogradational sequences and its influence on sediment supply and reservoir quality. Mature source rocks were identified as the Maximum Flooding surfaces, and this are significant for hydrocarbon generation. The characterization of reservoir quality through sedimentological studies indicates that the primary reservoirs exhibit favorable porosity and permeability characteristics, essential for hydrocarbon production. The interpreted faults and fractures identified in the field are also recognized as critical conduits for hydrocarbon migration towards the reservoirs.

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