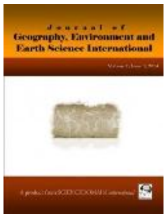

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Facies Analysis and Depositoinal Environment of D-3 Reservoir Sands Vin Field, Eastern Niger Delta

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Facies analysis and depositional environment identification of the Vin field was evaluated through the integration and comparison of results from wireline logs, core analysis, seismic data, ditch cutting samples and petrophysical parameters. Well log suites from 22 wells comprising gamma ray, resistivity, neutron, density, seismic data, and ditch cutting samples were obtained and analyzed. Prediction of depositional environment was made through the usage of wireline log shapes of facies combined with result from cores and ditch cuttings sample description. The aims of this study were to identify the facies and depositional environments of the D-3 reservoir sand in the Vin field. Two sets of correlations were made on the E-W trend to validate the reservoir top and base while the isopach map was used to establish the reservoir continuity. Facies analysis was carried out to identify the various depositional environments. The result showed that the reservoir is an elongate , four way dip closed roll over anticline associated with an E-W trending growth fault and contains two structural high separated by a saddle. The offshore bar unit is an elongate sand body with length: width ratio of >3:1 and is aligned parallel to the coast-line. Analysis of the gamma ray logs indicated that four log facies were recognized in all the wells used for the study. These include: Funnel-

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shaped (coarsening upward sequences), bell-shaped or fining upward sequences, the bow shape and irregular shape. Based on these categories of facies, the depositional environments were interpreted as deltaic distributaries, regressive barrier bars, reworked offshore bars and shallow marine. Analysis of the wireline logs and their core/ditch cuttings description has led to the conclusion that the reservoir sandstones of the Agbada Formation in the Vin field of the eastern Niger Delta is predominantly marine deltaic sequence, strongly influenced by clastic output from the Niger Delta. Deposition occurred in a variety of littoral and neritic environment ranging from barrier sand complex to fully marine outer shelf mudstones.

Keywords: Facies; environment; littoral; ditch cuttings.

1. INTRODUCTION

A sub-surface study of the Agbada Formation in the Vin oilfield of the eastern Niger Delta was undertaken in order to determine the facies and depositional environment of the reservoir sand- bodies. Facies analysis provides useful information on paleoenvironmental reconstruction. Depositional environment and their component facies form the primary building block of reservoirs and exert a fundamental control on the Vin field reservoir quality, behaviour and recovery efficiency. In this study, prediction of the depositional environment was made by the usage of wireline log shapes of facies combined with the result from cores and ditch cuttings sample description. The Vin field sequence comprises cyclically alternating successions of sandstones and shale. More than 10 discrete sand-bodies, varying in thickness from 16m to 230 m, some of which constitute oil and gas reservoirs, were developed in places in the formation. Among these sand bodies, only the D-3 reservoir sand produces petroleum from 14 wells in Vin field. The D-2 reservoir sand also contains hydrocarbon that is not of economic significance, although it was useful in interpreting the environment of deposition.

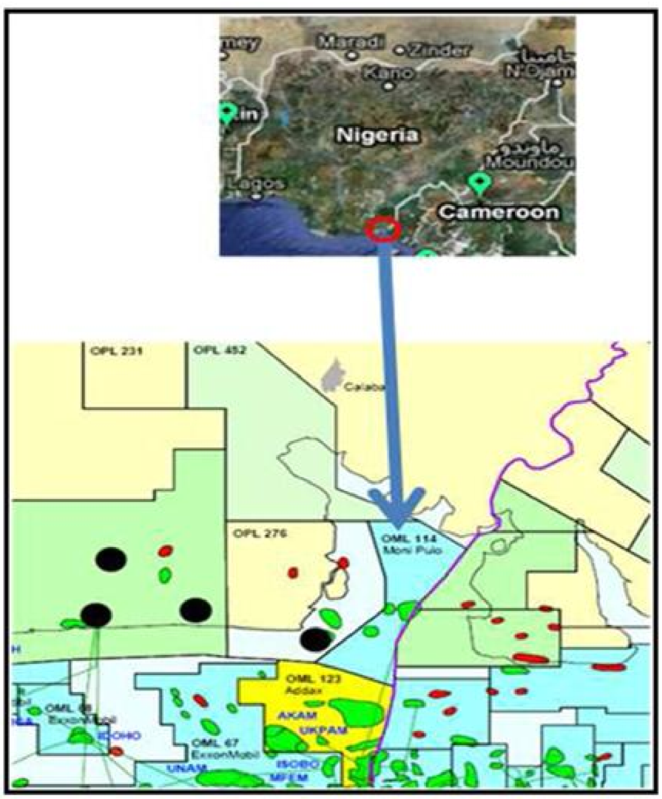


Fig. 1. Location of Vin field

Extensive descriptions of depositional facies and environments in Niger Delta Basin are presented in many publications. Some of these include Amajor and Agbaire [1], Nton and Adesina [2], Onyekuru et al. [3], Reijers [4] among others. This study, therefore, utilizes these previous research as well as that of Selly [5] and Amajor and Agbaire [1] who defined the depositional history of the reservoir sandstones of the Agbada formation in the Akpor and Apara oilfields, eastern Niger Delta using integration of well logs with ditch cutting samples.

Using the proposed integrated methodology will lead to a significantly more accurate reservoir description and 3-D reservoir model, which can be used to forecast reservoir behaviour and enhance recovery. The Vin field is located 30km offshore in the shallow waters of the Eastern Niger Delta with an average water depth of 76ft (Fig. 1). A total of 49 wells have been drilled in the field, out of these, 21 have been pilot holes, 2 have been water injectors and 18 have been horizontal production wells. Two of the wells drilled (A2 and A9) penetrates the Akata Formation in the Niger Delta at 8930ft and 8500ft respectively.

2. GEOLOGY OF STUDY AREA

The geology of the Niger delta has been extensively discussed by several authors. The present study builds on work of Short & Stauble [6], Weber [7], Weber & Daukoru [8], Evamy et al. [9], Ejedawe [10], Doust & Omatsola [11], and [4]. The evolution of the delta is controlled by pre- and synsedimentary tectonics as desc ribed by Evamy et al. [9], Knox & Omatsola [12] ,Reijers et al. [13] and Reijers [4]. 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 fills in both the Cretaceous and Tertiary.

The stratigraphy of the study area falls within the extensional Miocene to Pleistocene age (Fig. 2). The structural pattern is characterised by South

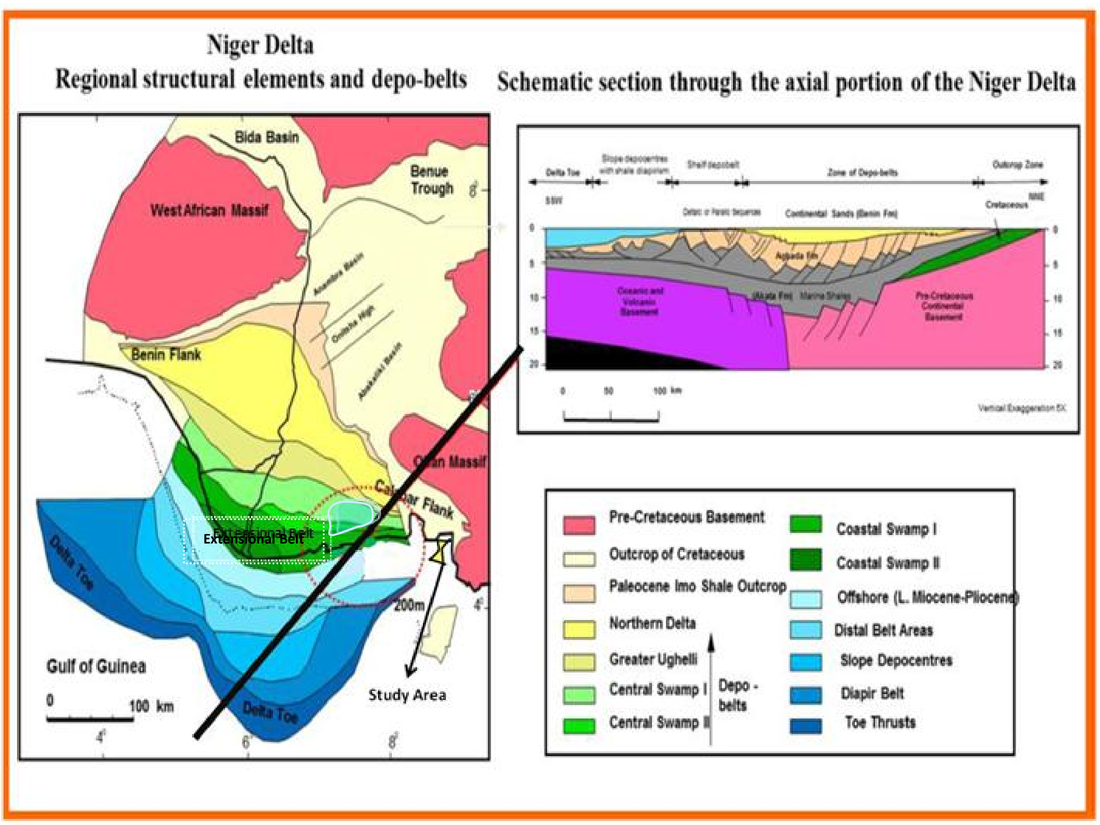


Fig. 2. Regional structural element and schematic section through eastern Niger Delta (Modified from Corredor et al. [14])

dipping NE-SW trending growth faults and counter regional faults, which defined and controlled sedimentation especially the prospective Biafra Member and the Agbada Formation.

The stratigraphic sequence in the south-eastern flank of the Niger delta shows a marked facies change in comparison with the sequence in the central part of the delta. The Agbada formation in SE Niger delta is divided into four local members: D-1, Qua Iboe, Rubble and Biafra member Orife and Avbovbo [15].

From bottom to top, the eastern offshore stratigraphy (Fig. 3) is divided into:

AKATA SHALE of Middle Miocene age is Pro-deltaic and under-compacted dark shale deposited in deep marine environment.

AGBADA FORMATION: Consist of alternating Upper Miocene to Pliocene marine shales and fluvio-marine sands ranging from lower coastal plain to delta front environment which can be sub-divided into:

- **BIAFRA Member:** A pro-grading old Miocene sandy deltaic system.
- **RUBBLE BEDS Member:** Deposited during the transition Miocene- Pliocene.
- **KWA IBOE SHALE Member:** Thick Pro-deltaic shales of early Plio-cene age.
- **D1 Member** which represents the upper sand bearing series of the prograding young Pliocene deltaic system.

SANDY BENIN FORMATION of Pleistocene to present age. The Benin Formation is the unconsolidated fresh water sand proceeding Agbada Formation. Oil and gas accumulations have only been encountered in the Kwa Iboe, Rubble Beds, and mainly in the Biafra Member which contains the best reservoirs (Fig. 4).

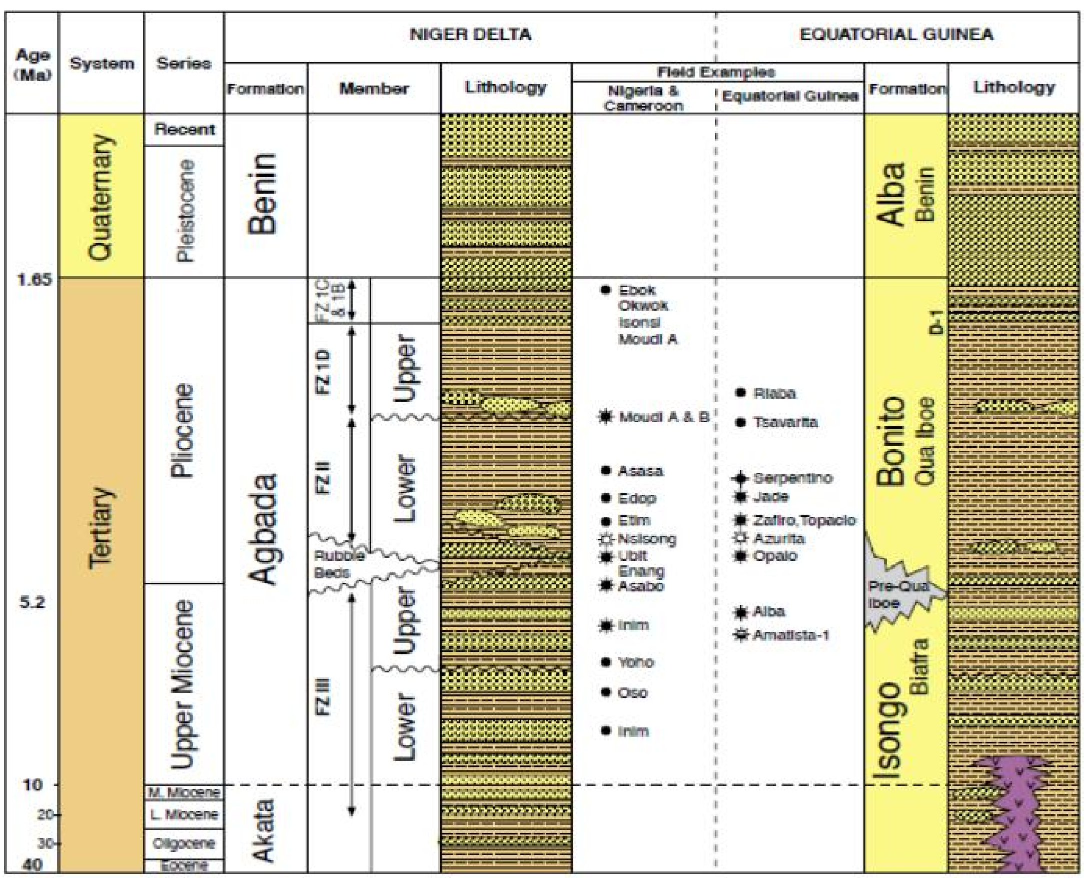


Fig. 3. Lithostratigraphy of the southeastern Niger Delta (Joseph et al. [17])

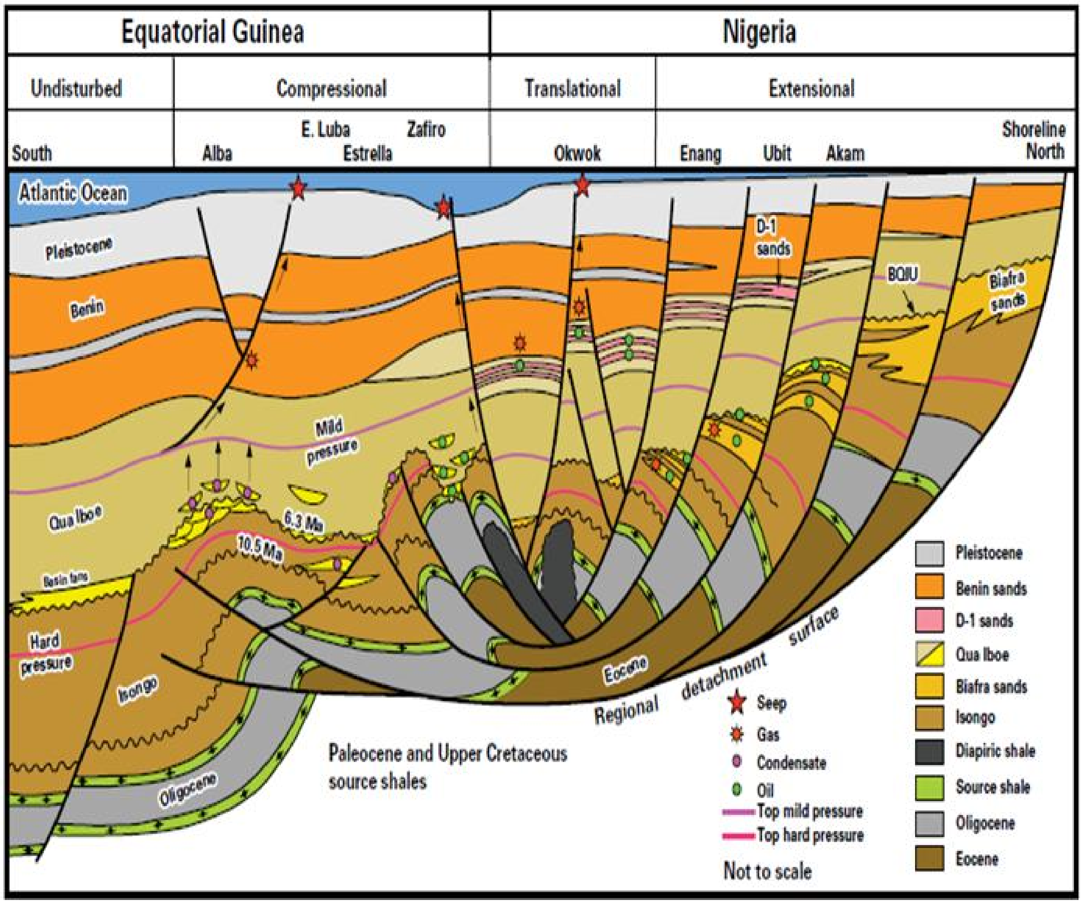


Fig. 4. Stratigraphic model of S-E Niger Delta (Joseph et al. [17])

3. MATERIALS AND METHODS

The data used for this research was collected from Moni Pulo Limited under the auspices of Lulu Briggs chair, Institute of Petroleum Studies University of Port Harcourt. The data set include the following: Well data for 22 wells (exploratory, pilot, horizontal and injection wells), Surface location map of the wells, LWD logs (22 wells), Survey data (22 wells), 3D Seismic data, Core data for A2P2 (1 well) and wireline data.

The seismic dataset include 3D-Pre-stack data in SEG-Y format and well data (logs) in various digital formats. The seismic and well data was loaded into Petrel database. Well log correlation and formation evaluation analysis were carried out with Gamma ray, resistivity, sonic, neutron and density logs. A combination of log suits (GR, neutron, density and resistivity), and petro-physical evaluation results (volume of shale, porosity and water saturation) were used in validating the top and base of the reservoir. The sands in both the eastern and western flank of Vin field were correlated. The fluid contact and fluid in the reservoir were characterized using Neutron – density, bulk density and resistivity logs. The Gamma ray index was used to determine the percentage of shale and the dominant lithology. The prediction and construction of the depositional environment was based on the use of wireline logs and ditch cuttings Weber [7], Amajor and Agbaire [1] and Selly [5], (Fig. 5). This was due to the lack of core samples and core photos for this study.

Gamma ray log was used to measure the shaliness of a formation. Such gradual changes are indicative of the litho-facies and the depositional environment of the rock, and are associated with changes in grain size and sorting (Fig. 6).

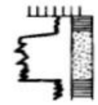
Log motif			
Glauconite and shell debris (high-energy marine)	Tidal channel	Tidal sand wave	Regressive barrier bar
Glauconite, shell debris, carbonaceous detritus, and mica (dumped marine)	Submarine channel		Prograding submarine fan
	Turbidite fill	Grain flow fill	
Carbonaceous detritus and mica (dumped)	Fluvial or deltaic channel	Delta distributary channel	Prograding delta or crevasse splay

Fig. 5. Paleoenvironmental interpretation of SP/gamma ray log motifs and borehole ditch cuttings data (After Selley [5])

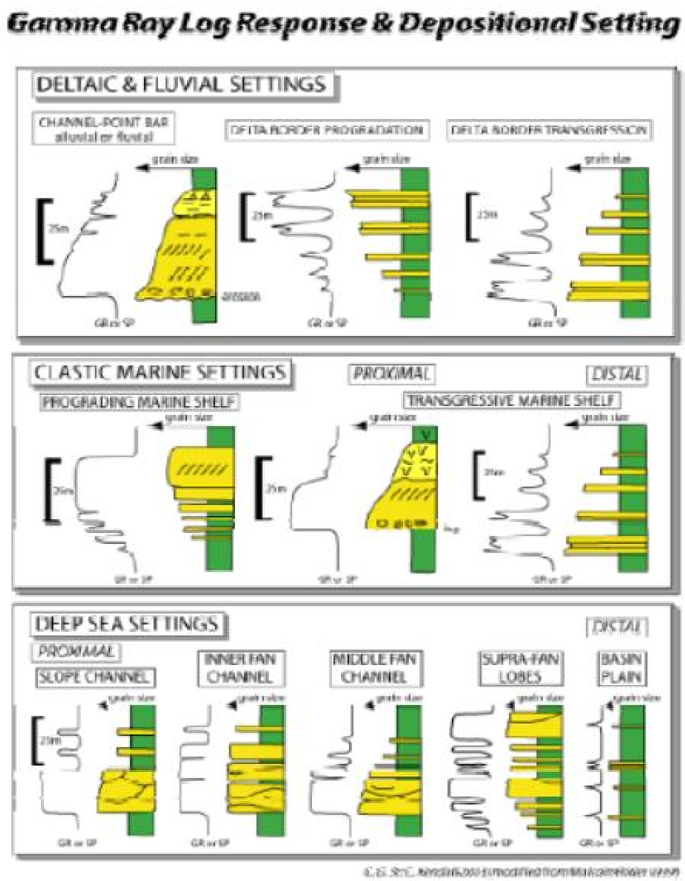


Fig. 6. Sedimentologic facies indications from gamma ray log. (Modified from Serra)

4. RESULTS AND DISCUSSIONS

4.1 Structure

The 3D seismic data quality is good, showing good events continuity and reflection termination against faults (Fig. 7). The structural style of the field is entirely composed of normal growth fault separating the region of interest from the north (Fig. 8)

The study shows that the Vin field is characterized by rollover anticline associated with an E-W trending growth fault to the North (Fig. 9A). It exhibits 4-way dip closure (Fig. 9B) and two structural highs, Vin West and Vin East, separated by a saddle (Fig. 10). The structure is most apparent within the Agbada formation, suggesting synsedimentary development. The synsedimentary growth faults activated at the delta front retards the advancement of the sandy Benin Formation. The down thrown part becomes the new focus of Agbada paralic facies deposition until subsidence stabilizes; by then a maximum thickness of Agbada Formation has been deposited [16].

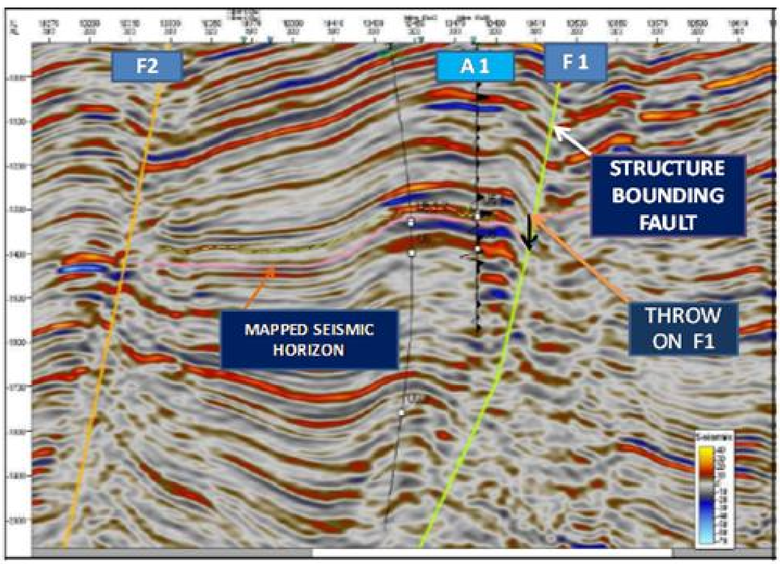


Fig. 7. Fault interpretation on an Inline 10488

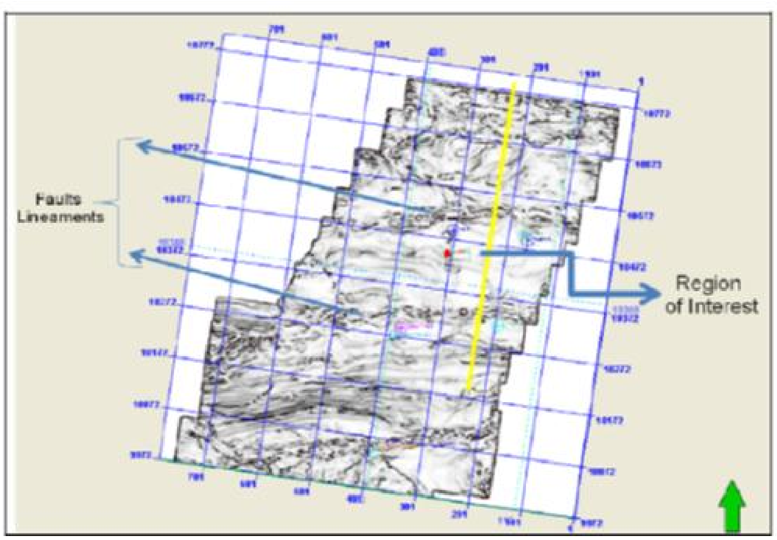


Fig. 8. Variance cube Time slice at 1300ms, showing fault lineaments and the ROI

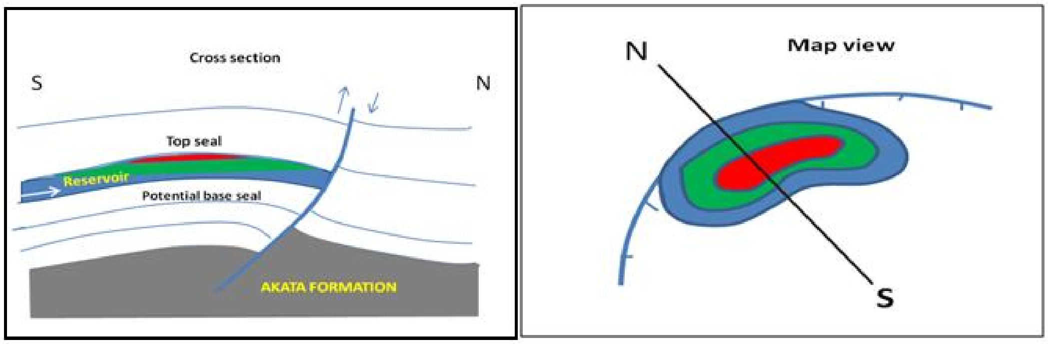


Fig. 9 (A and B) Schematic diagram showing the roll over anticline and four way dip closure

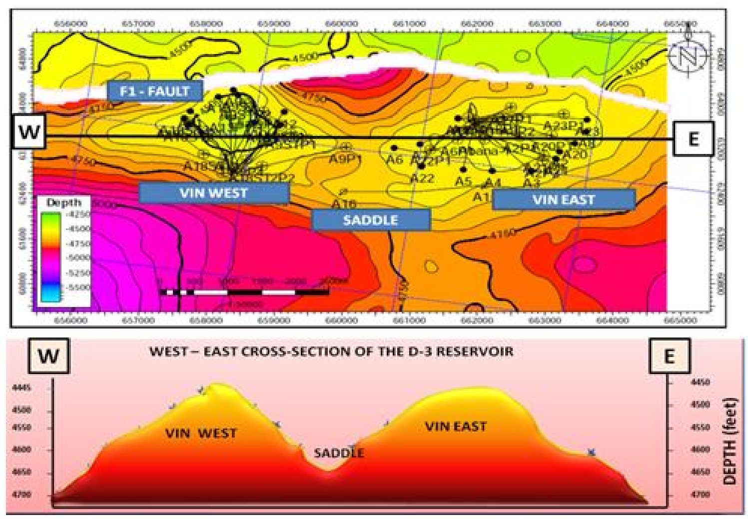


Fig. 10. Structure of the D-3 reservoir showing the E – W trending growth fault and two structural highs

4.2 Stratigraphic Correlation

Stratigraphic correlation was carried out to establish the stratigraphic framework of the D-3 reservoir. The stratigraphic correlation of the Western part of the field consisting of wells (A13P1 – E1 – A9P3) as shown in (Fig. 11), while that of the Eastern part of the field consisting of wells (AP61 - AI – A2P1) as shown in (Fig. 12). Petrophysical attributes suggest that open hole gamma ray, deep resistivity well- log data and porosity logs, can be used to predict facies distribution in wells that lack core control [17]. A combination of log suites (GR, density, neutron, and resistivity) and petrophysical evaluation results (volume of clay, porosity and water saturation) were used in validating the tops and bases of the reservoir. Three facies were defined based on log signatures and cut-off. The D-3 reservoir consists of sand, silt and shale sequences. It is characterized by clean sands with some silt and shale intercalations. It is bounded at the top and base by distinctive shale units.

Field-wide correlation from the Western to the Eastern part of the field was also carried out. As shown in (Fig.13), a transect passes through the selected wells. The transect line W – E connects wells (A9P2 – A16 – A15 – A2PA – A8). All depths for the stratigraphical correlations are true vertical depth subsea (SSTVD). An appropriate datum of 2000ft was chosen. This was the base of the Qua Iboe shale which is the first major regional shale marker typical of the base of Benin sands. The D-3 reservoir has fairly constant thickness from one well to another, laterally extensive and cuts across all the wells in the field.

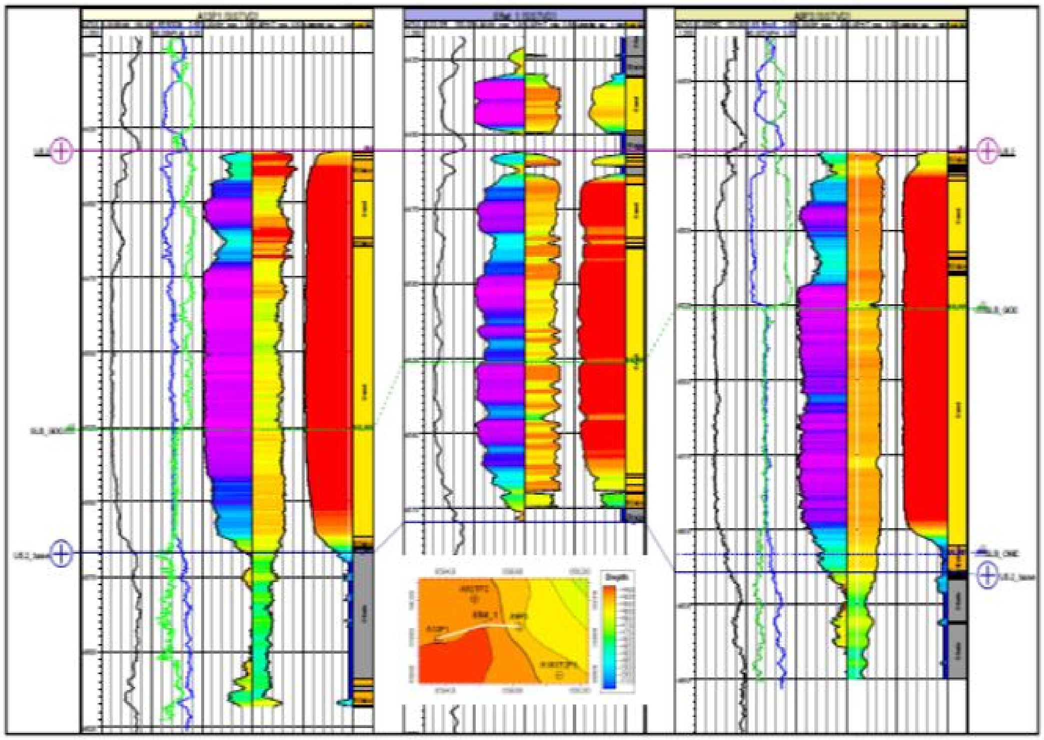


Fig. 11. Stratigraphic framework of D-5 reservoir in Vin West

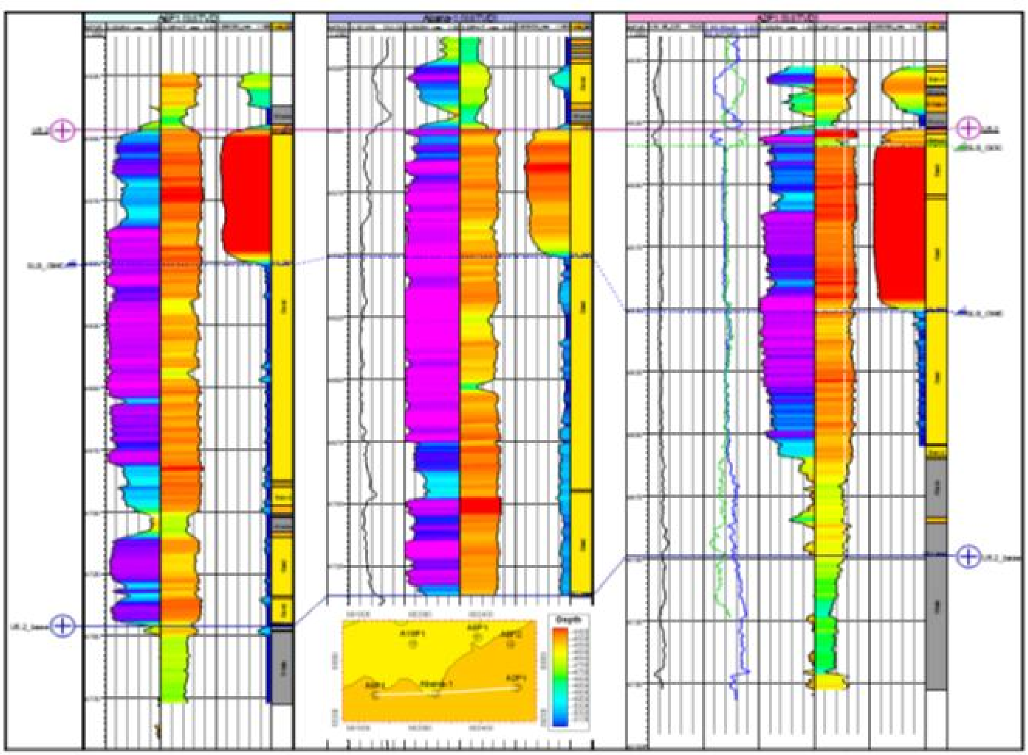


Fig. 12. Stratigraphic framework of D-5 reservoir in Vin East

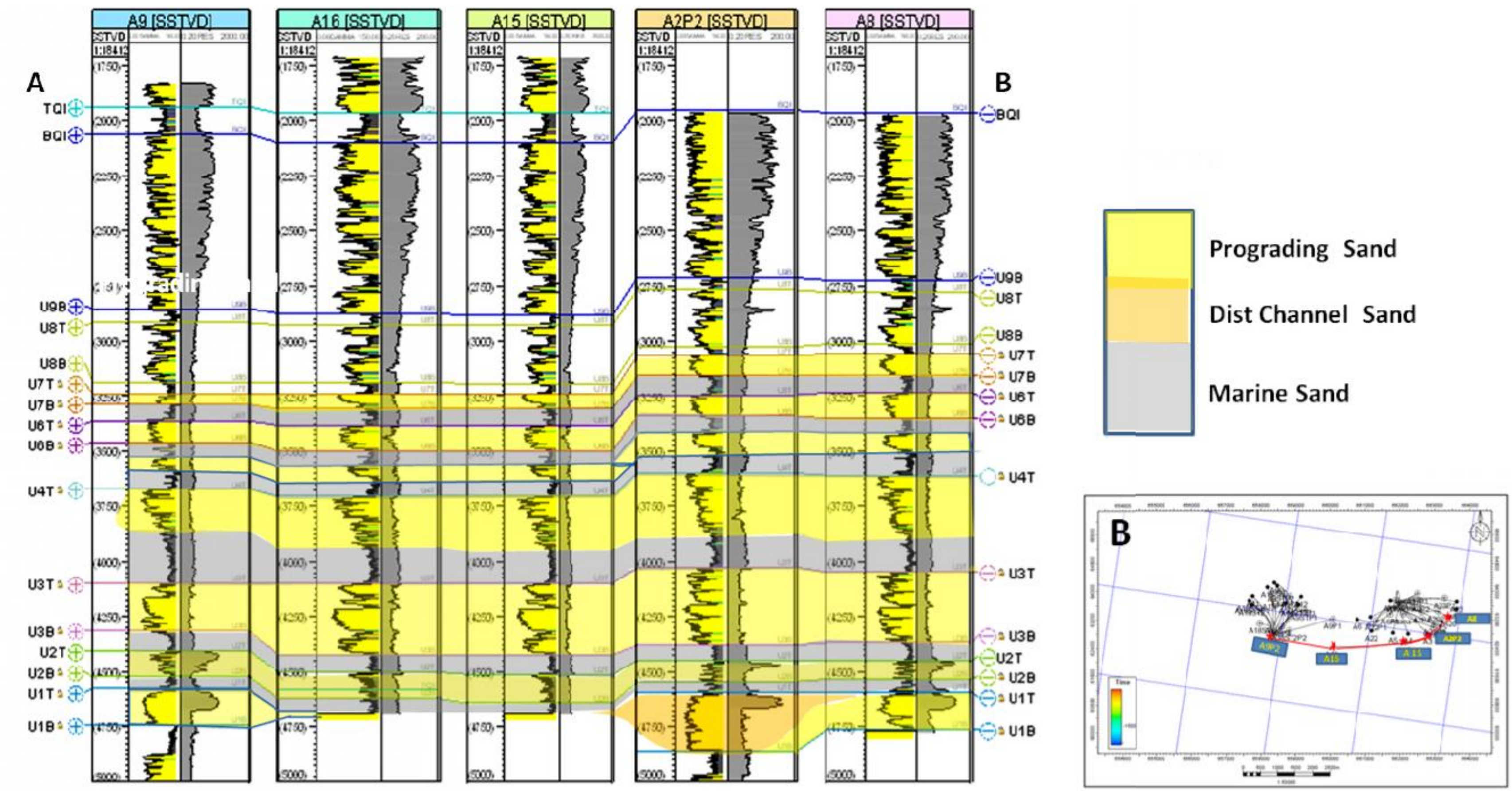


Fig. 13. A. stratigraphic correlation of Vin field from west to east. B. the transect line W–E connectimg wells (A9P2 – A16 – A15 – A2PA – A8)

4.3 ISOPACH Map

In this study, isopach map is useful in determining the shape of the field, position of the shoreline, areas of uplift, sand studies and growth history analysis of the sands.

Sand accumulation is better developed in the western than eastern part of the field. The D-3 reservoir has fairly constant thickness from one well to another. The gross thickness of the reservoir ranges from 111ft to 305ft, as shown by the isopach map (Fig. 15). The overall trend in thickness reflects general thinning towards the flank of Vin East and Vin West of the field. The map also confirms two structural highs Vin west and Vin east with a saddle in between. It can be inferred that the sand was supplied by a distributary channel which was latter reworked by wave action to form long bars almost parallel to the coast line. The difference in thickness of the two structural highs can be due to difference in the rate of sediment supply to each structural high or due to higher rate of erosion and sediment reworking in the eastern high than the western high. In addition, we can infer that the shoreline could have been very close at the time of formation of the reservoir sand. The elongate nature of the sand body also suggests a sand bar.

4.4 Reservoir Continuity and Geometry

Knowledge of reservoir continuity is a prerequisite to establish the reserve and identifying the method for recovering it. Potter [18], proposed a scheme to classify and quantify the lateral continuity of sands. Two major groups of sand (sheet and elongate bodies) were recognized. Sheet bodies are continuous with length: width ratios of 1:1 and occur in environment ranging from turbidite fans and crevasse- splays [5]. The elongate bodies have a length: width ratio of 3:1, are generally deposited in barrier bar environments (Fig. 16).

Vin field is an elongate sand body with length: Width ratio of >3:1. According to Selly [5], the best known of the elongate sand are the ribbon or shoestrings which are generally deposited in barrier environment (Fig. 17).

4.5 Facies Analysis and Depositional Environment

Facies analysis provides useful information in paleoenvironmental reconstruction.

Selley [5] considered the shapes of well-log curves as basic tool to interpret depositional facies because shape of log is directly related to the grain size of rock successions. Cant [19] defined five different log curve shapes used to interpret the depositional environment and also considered the study of core with relation to logs as important tool of facies interpretation in the subsurface.

Analysis of the gamma ray logs indicated that four log facies were recognized in all the wells used for the study. They include: Funnel-shaped

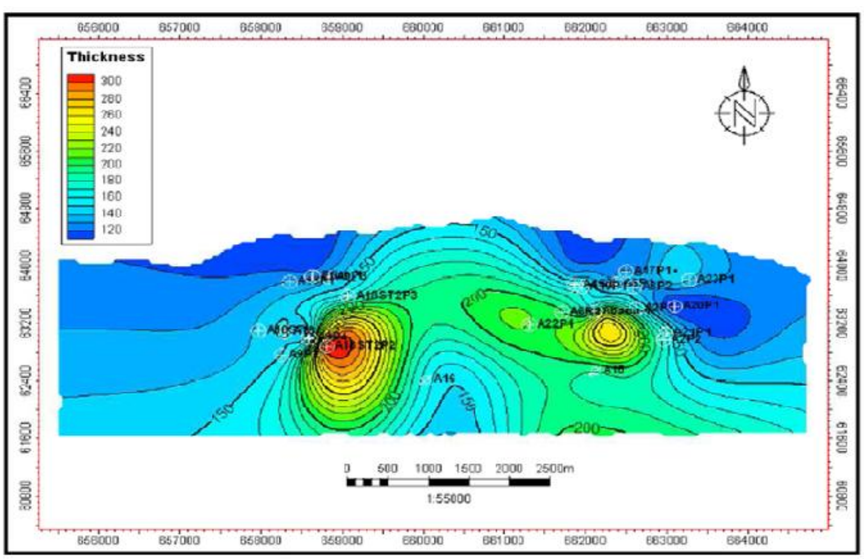


Fig. 15. Model of D-3 Reservoir Isopach map

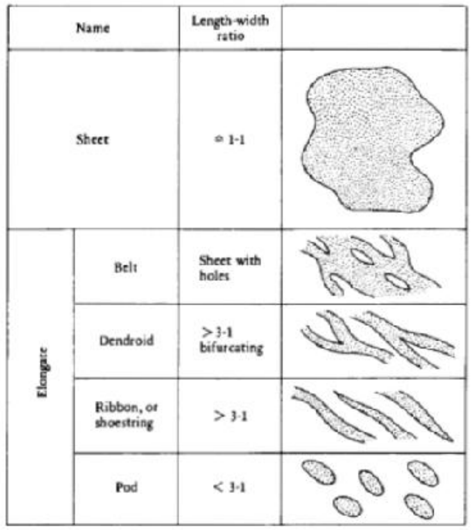


Fig. 16. Nomenclature of sand body geometry (After Potter, 1962 [18])

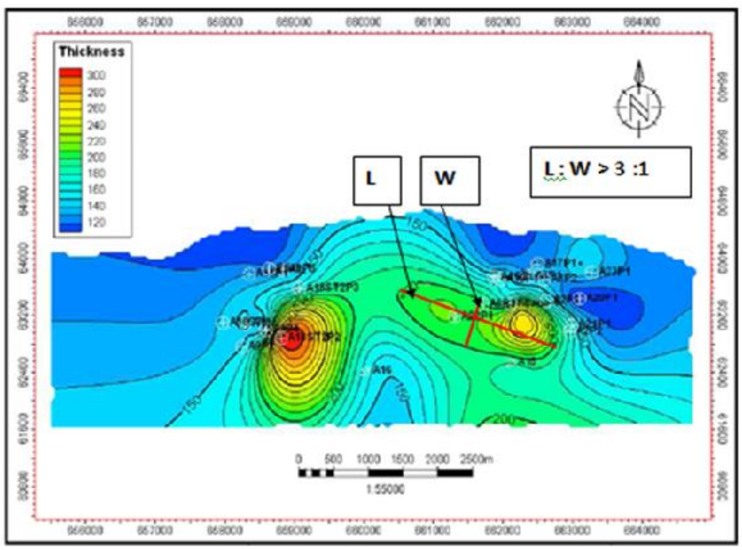


Fig. 17. D-3 Reservoir Thickness map showing length to width ratio

(coarsening upward sequences), bell-shaped or fining upward sequences, the bow shape and irregular shape. Based on these categories of facies, the depositional environments were interpreted.

4.5.1 Facies A (Bell Shaped succession)

The gamma ray log trend of the bell shaped succession is characterized by consistent upward decreases from maximum value of log reading in trend. The bell shape succession is seen in well A2P1, A2P2.

4.5.1.1 Description

The bell shaped gamma ray log trend in the D-3 reservoir sand, occurs between depths of 4600ft and 4950ft SSTVD in well A2P1.It is serrated, with sharp basal contact and with a thickness of about 350ft (Fig 18). At sand A2P2, (Fig 19) it occurred between depths 4520ft to 4720ft SSTVD. Ditch cutting and core sample description indicates that the unit comprises a fining upward textural gradient (fine to medium grained sand at the base and shale to silt at the top).The sand is well sorted subangular to subrounded, Carbonaceous detritus and mica are common. Vertically the percentage, thickness and grain size of the sandstone strata decreases and the upper part of the unit is dominated by thin bedded heterolithics. The mudstone strata are commonly dark grey, organic rich with carbonaceous plant material.

4.5.1.2 Interpretation

These attributes favours deposition of the top of the sand in a marine environment, possibly in shallow marine due to the fining upward log signature. This represents a decrease in depositional energy. This presence of glauconite indicates deposition in a shallow marine environment [5]. Bell shaped successions with carbonaceous detritus are deposited in environments of deltaic distributary channel [5, 1]. The overall fining upward log trend and grain size, reflects decrease in flow velocities related to either lateral accretion of channel point bars or channel abandonment. These intervals are interpreted as the product of deltaic distributary channel (point bar).

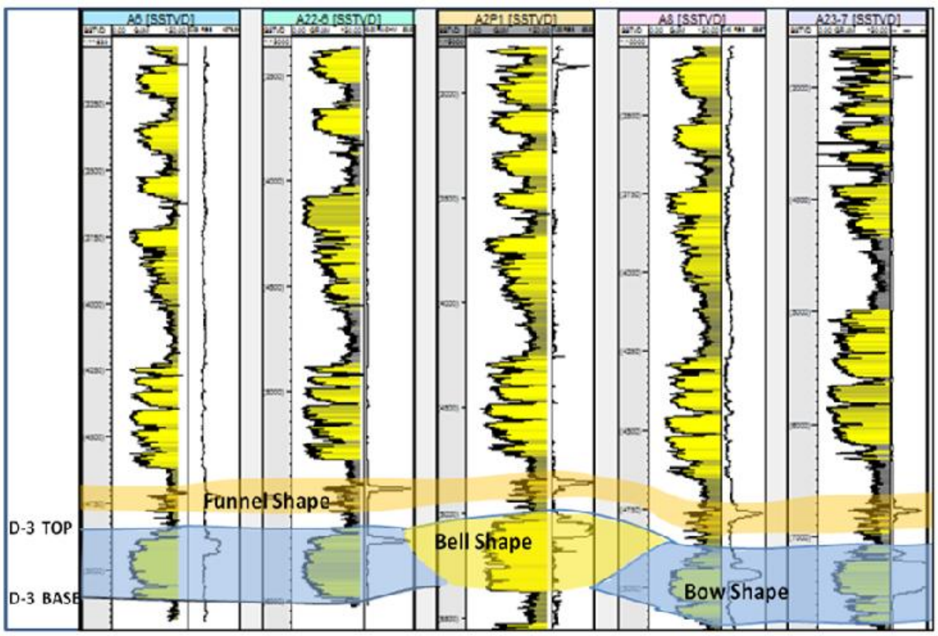


Fig. 18. East – West stratigraphic correlation of the D3 sand showing the Bell shape log signature of well A2P1

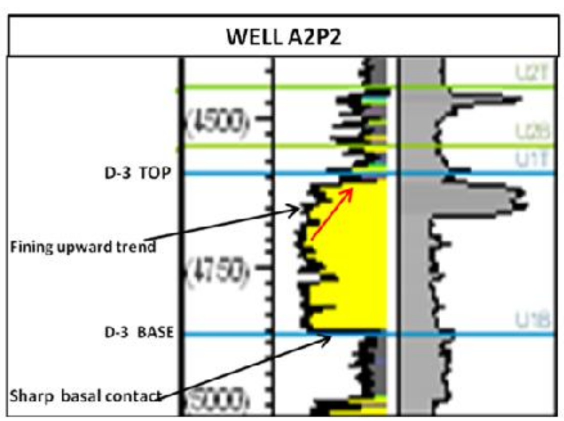


Fig. 19. Bell shaped log trend showing sharp base and fining upward trend

4.5.2 Facies B (Funnel Shaped succession)

The gamma ray log trend of the funnel shaped succession is characterized by consistent upward increases of log reading in trend. The funnel shape succession is seen in almost all the wells that penetrate the D3 sand in the field (Fig 20). It consists of stacked series of successions varying up to 20 to 25m in total thickness (Fig 21).

4.5.2.1 Description

Ditch cutting description indicates that the unit comprises a coarsening upward textural gradient (shale to silt at the base, and fine to very fine grained sand at the top). The sand is very fine to fine grained, well sorted with interbed of shale and carbonaceous detritus. There is presence of fossil (shell fragment) and it is micaceous, glauconite is absent.

4.5.2.2 Interpretation

According to Selley [5], the environments of shallowing-upward and coarsening successions are divided into three categories namely; Regressive barrier bars, prograding marine shelf fans and prograding delta or crevasse splays. Facies B is not likely to be a crevasse splay because one of the main differences between a crevasse splay and a prograding delta is the depositional scale. The funnel shaped log motifs in the entire D-2 reservoir across the wells in this study are not less than 59 ft. Both regressive barrier bars and prograding submarine fan are usually deposited with glauconite and shell debris [5,20]. The characteristics suggest that the environment of deposition is a prograding delta since no glauconite is recorded in this succession. It is overlain by marine shale.

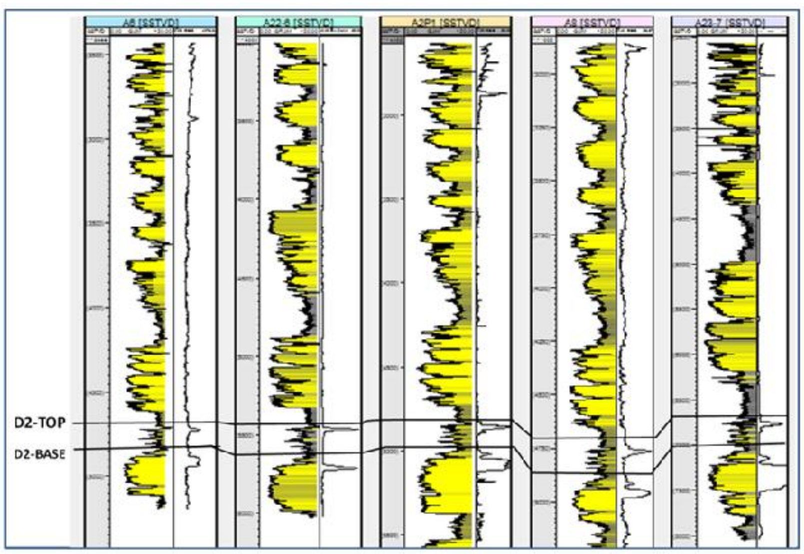


Fig. 20. Section of the D3 sand showing the top and base of the reservoir

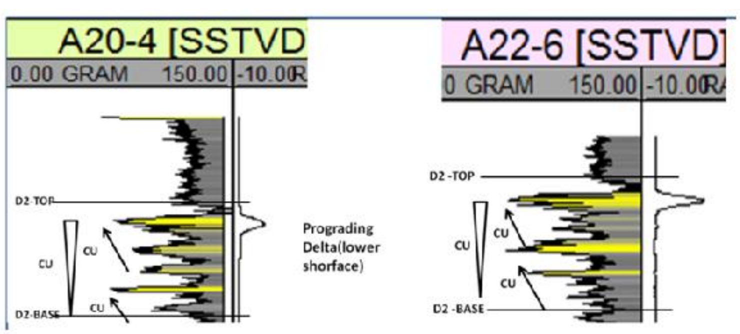


Fig. 21. Section of the D3 sand showing the top and base of the reservoir

4.5.3 Facies C (Bow Shaped succession)

The bow trend (also known as the barrel trends) consists of a cleaning upward trend, overlain by a dirtying-up trend of similar thickness and no sharp break between the two. It is identified in almost all the wells in the D3-sand Vin field. This is the hydrocarbon producing reservoir in the field (Fig. 22)

4.5.3.1 Description

The bow shaped gamma ray log trend in the D-3 sand ranges in thickness from 111ft to 310ft. It is characterized by a gradational contact above and below the gamma ray trend (Fig. 23). Ditch cutting description indicates that the sand is fined to very fine grained, well sorted, subangular to subrounded, carbonaceous detritus and mica is common. Glauconite is present.

4.5.3.2 Interpretation

It is the result of a waxing and waning of clastic sedimentation rate in a basinal setting, where the sediment is constrained by base level. Shallow marine bow motif occur where growth faulting may have constrained regression and allowed a thick transgressive body to develop [21].Marine transgression and coastal subsidence by growth fault forces facies belt to migrate landward.

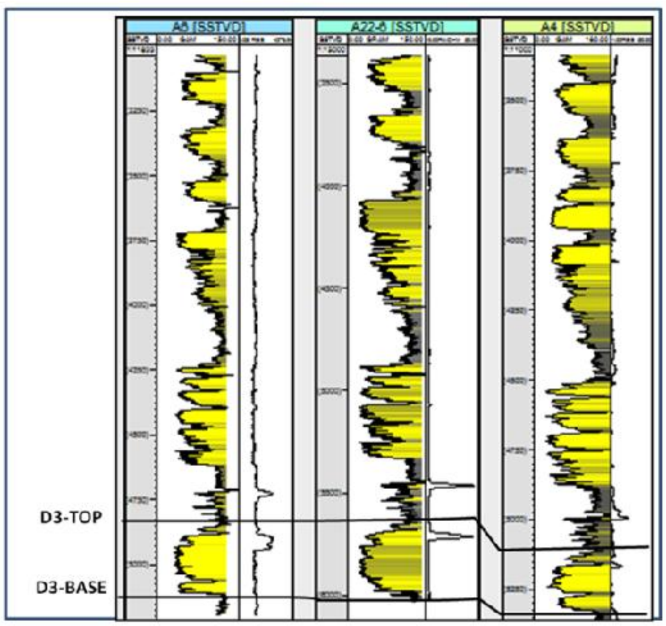


Fig. 22. Section of the D3 sand showing the top and base of the reservoir

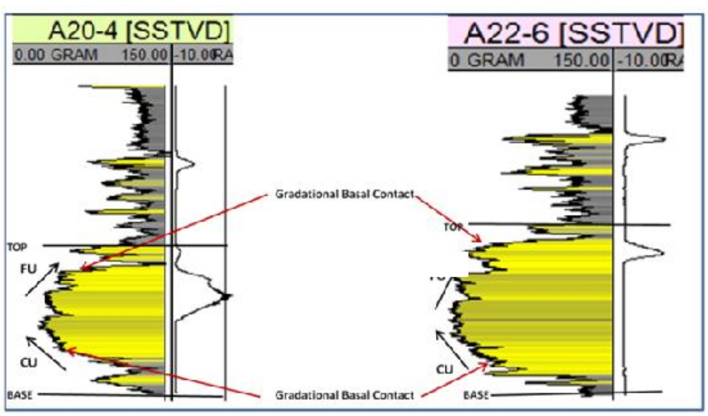


Fig. 23. Gamma ray trend of the bow shape in the D3 reservoir showing coarsening upward (CU) and a fining upward shape, gradational top and base, and top and base of the reservoir

According to Cant, 1992 [19], the environment of deposition is reworked offshore bar or a regressive to transgressive shore face delta. The barrier shoreface unit is an elongate sand body with length: width ratio of >3:1. According to Selly [5], the best known of the elongate sand are the ribbon or shoestrings which are generally deposited in barrier environment.

4.5.4 Facies D (Irregular log trend)

The irregular trend abounds in the analysis of all the wells in Vin field (Figs. 24). According to Emery and Myers [21], Irregular trends have no systematic change in either base line, or lack the clean character of the boxcar trend. They represent aggradations of a shaley or silty lithology.

4.5.4.1 Description

The ditch cuttings samples descriptions show grey to dark grey, firm to hard, sub blocky to blocky, carbonaceous. Non-calcareous claystones and siltstones were recovered from this unit. Similar log signature have been identified in well A9P2 with ditch cutting sample description showing grey/green and greybrown, carbonaceous, micro micaceous and non calcareous claystone and siltstone. The occasional abundance of plant remains indicate that the clays were deposited in the inner to middle neritic zones in the shelfal setting.

4.5.4.2 Interpretation

The environment is characteristically, a blanket of clays and fine silts deposited from suspension, with high lateral continuity and low lithologic variation.

On regional evidence, this unit is thought to have been deposited during the marine transgression associated with depositional subsidence which led to marine transgression. The occurrence of carbonaceous and micaceous materials suggests deposition in shallow marine setting in the inner to middle neritic zone. These units form laterally extensive reservoir seals.

4.6 Conceptual Depositional Model

Analysis of the wireline logs and their core/ditch cuttings description has led to the conclusion that the reservoir sandstones of the Agbada Formation in the Vin field of the eastern Niger Delta is predominantly marine deltaic sequence, strongly influenced by clastic output from the Niger Delta. Deposition occurred in a variety of littoral and neritic environment ranging from barrier sand complex to fully marine outer shelf mudstones. The conceptual depositional model is shown in (Fig. 25)

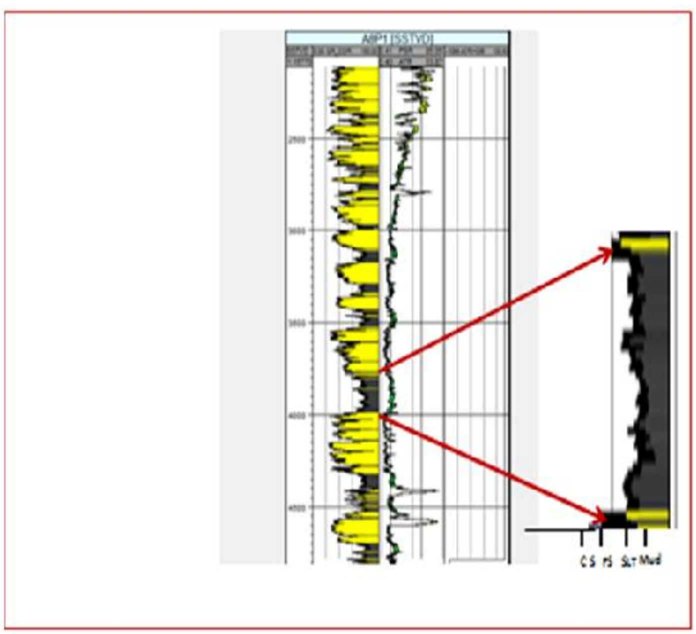


Fig. 24. Irregular log trend of well 8, Vin field

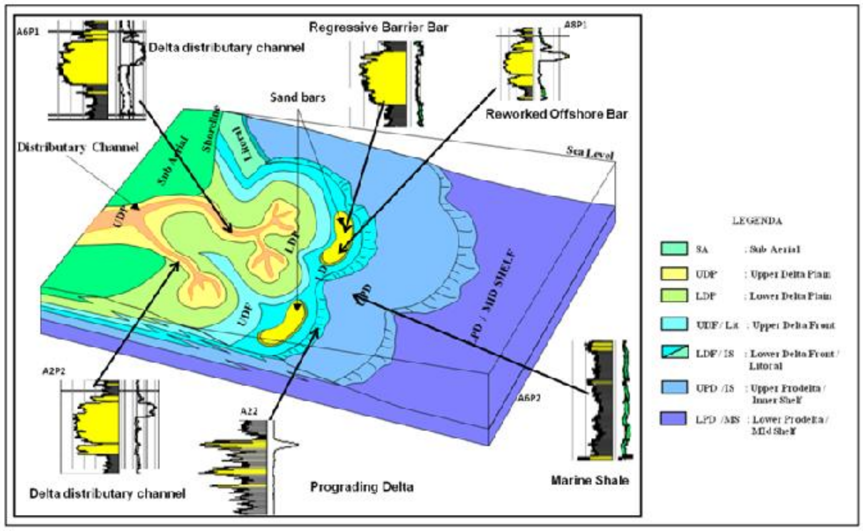


Fig. 25. Conceptual model of the depositional environment of the D3 sands, Vin field

4.7 Depositional History of the D-3 Reservoir Sand

In the absence of core sample, it is possible to use a combination of litho logical information gleaned from cuttings and geophysical log information to produce palaeo environmental interpretations of rock sequences.

The sequential development of the deltaic and barrier bar was discussed based on the isopach map, stratigraphic cross-sections and structural growth fault. The offshore bar unit is an elongate sand body with length: Width ratio of >3:1 and is aligned parallel to the coast-line. The maximum thickness of 305ft and 250ft, developed in the western and eastern part of the field representing two structural high which is separated by a saddle (Fig. 26). The difference in thickness of the two structural highs was due to difference in the rate of sediment supply to each structural high or due to higher rate of erosion and sediment reworking in the western high than the eastern high. The sand was supplied by distributary channels, which were further reworked by wave action to form long bars parallel to the coastline (Fig. 27). During period of relative sea level fall, the sediment progrades

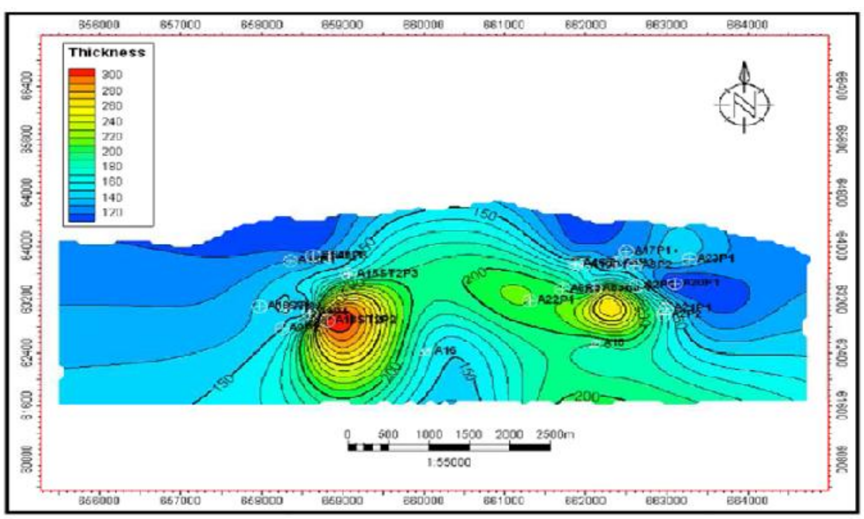


Fig. 26. Isopach map of the reservoir sand body at Vin field

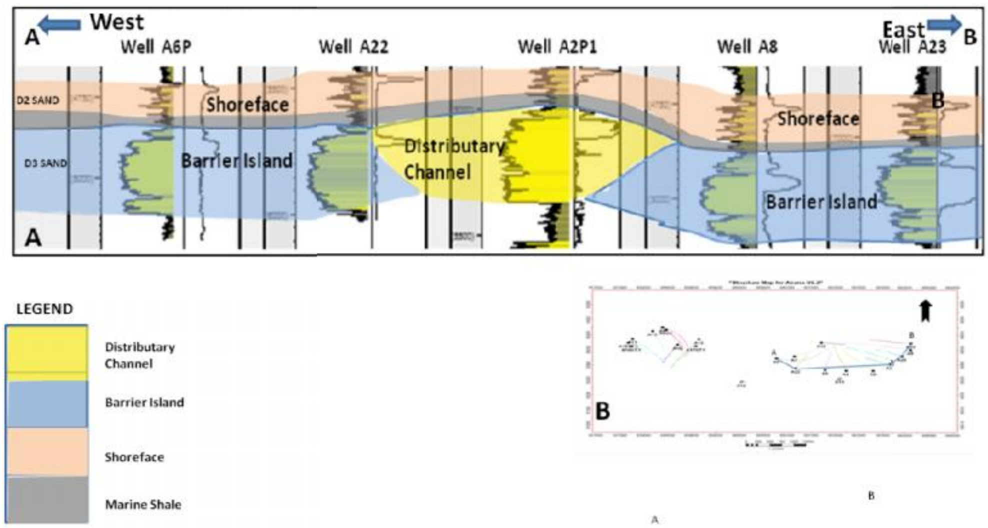


Fig. 27. E-W Stratigraphic cross section of the reservoir sand body showing the Barrier island, distributary channel and the shoreface environment

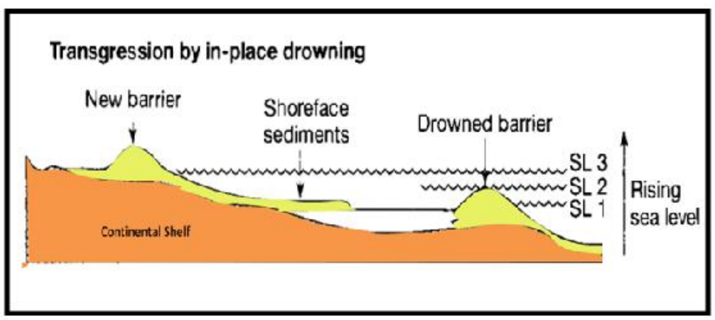


Fig. 28. Effect of rapid sea level rise producing in place drowning

under condition of large sediment supply relative to sea level change and the distributary channels cut into the elongate barrier sand. Due to the effect of growth faulting and subsequent coastal subsidence, marine transgression occurs upon delta-lobe switching leading to intense wave reworking and transformation of mouth bar/beach ridges to barrier islands [5]. (Boggs 2006) explained that with more rapid subsidence, in-place drowning due to the flooding during sea level rise possible caused the barrier to be covered by water, resulting in the wave zone moving landward until a new sand barrier forms on the inner side of the lagoon (Fig. 28). Drowning of barrier islands led to offshore bars.

5. CONCLUSION

Seismic, well log, core and ditch cutting data integration to study the Vin field in offshore eastern Niger Delta revealed that the D-3 reservoir is an elongate , four way dip closed roll over anticline associated with an E-W trending growth fault and contains two structural high separated by a saddle. The gamma ray log and ditch cutting samples indicated that four log facies were recognized in all the wells used for the study. These include: Funnel-shaped (coarsening upward sequences), bell-shaped or fining upward sequences, the bow shape and irregular shape. The depositional environments were interpreted as deltaic distributary channels, regressive barrier bars, reworked offshore bars and shallow marine. Analysis of the wireline logs and their core/ditch cuttings description has led to the conclusion that the reservoir sandstones of the Agbada Formation in the Vin field of the eastern Niger Delta is predominantly marine deltaic sequence, strongly influenced by clastic output from the Niger Delta. Deposition occurred in a variety of littoral and neritic environment ranging from barrier sand complex to fully marine outer shelf mudstones.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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