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Facies Description and Sedimentology of FABI Field, Coastal Swamp Depobelt, Niger Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author PSM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author PSM managed the literature searches and analyses of the study performed the analysis. Author NUE managed the experimental process. Both authors read and approved the final manuscript.

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ABSTRACT

Sedimentary facies description and sedimentology of parts of the Coastal Swamp Depobelt have been studied using well logs and core data. Five wells designated FABI 001, 002, 003, 004, and 005 were correlated to establish the lateral continuity of the H7000 sand across the field, and using gamma ray log to corroborate the gross depositional environments of the cored interval. About 51 ft of cored section of well 001 was described to identify lithology and delineate depositional environments based on facies types and sedimentary structures. The results of the analysis showed that the H7000 sand occurred between 12750 and 13500 ft (in well 001) across the five wells at different stratigraphic positions. The sand unit (cored interval) displayed a funnel shape log trend occurring in two prograding parasequences. The upper parasequence is well serrated whereas the lower unit below 13060 ft has little or no serration. Five facies types identified based on sedimentary structures, lithology, and paleontologic content include; cross-bedded sandstone,

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bioturbated cross-bedded sandstone, bioturbated interbedded sandstone and mudstone, bioturbated heterolithic sandstone/siltstone, and silty mudstone facies. Four environments inferred based on facies description include; tidal channel, upper shoreface, lower shoreface, and proximal shelf mudstone. Each facies unit was identified based on lithology and sedimentary structures of the core sample, textural characteristics and gamma ray log trend. The Tidal channel facies displays a fining upward log trend and overlies the upper shoreface facies. Upper shoreface facies is characterized by trough cross bedding, planar cross bedding, alternating parallel cross bedding, and double mud drape. The sandstone is light grey to light brown in colour, fine to medium grained, well sorted, rare hummocky laminations and free of shale successions; whereas lower shoreface is characterized by interbedded sandstone/mudstone facies. The offshore mudstone interval is composed of siltstone and very fine-grained sandstone showing parallel laminations, wavy and current ripple cross-laminations. This examination provided the framework for suggesting that the FABI field sediments were deposited within the shoreface shallow marine systems where both tide and wave activity influence the deposition of sediments.

Keywords: Facies; sedimentation; Agbada formation; shoreface; shallow marine.

1. INTRODUCTION

The paleoenvironments of deposition of sedimentary rocks play significant roles in the identification, location and exploitation of resources contained in the rock. The first step in exploration and development always involve the location of sand bodies, its architecture and quality. These rock attributes dictate porosity and permeability variations and useful in development and production drilling. In seismic studies, facies with good prospects give unique attributes that guide their identification. For instance, high amplitude seismic events are always traced to sand reservoirs that may be hydrocarbon-bearing [1-5]. Geophysical tools help to give good prediction of sedimentary rocks but not without flaws. It is more accurate to describe rock characteristics using cores. Though, it is often difficult to get core data for academic studies for reasons that could be proprietary or absence of acquired cores, it will be rewarding to undertake all sedimentology-related studies using cores. This is because; core samples from either subcrops or outcrops are the only sample that displays in-situ formation characteristics [6,3,7]. Cores are valuable analytical tools for lithology prediction, identification of various depositional elements and environments, characterization of reservoirs, facies analysis, paleontologic studies and all subsurface analysis. Skills in facies analysis and sedimentologic studies can only be enhanced through studies involving core samples (sidewall sample, ditch cuttings, outcrop samples, and conventional cores).

This study utilizes core data and well log to describe facies units and their sedimentology in the Coastal Swamp Depobelt. It is imperative to understand the sedimentology of each depobelt for several reasons:

1. Age differentiation, a factor that affects oil generation, migration and reservoir quality (useful in oil and gas production). The Tortonian sediments are absent in the Northern Delta Depobelt but are present and productive sediments in the Shallow Offshore Depobelt
2. To generate regional facies models that will guide exploration and field development
3. It will provide data bank/resources for data repository centres that will be useful in training young geoscientists
4. Facies analysis is the basis for understanding reservoir quality, geometry and architecture; development strategy, and production mechanism.

1.1 Geology of the Study Area

There are five major depobelts in the Niger Delta sedimentary basin. They include; the Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp and the Offshore Depobelt. These five concentric depositional units are differentiated by growth fault punctuations that terminated each depositional episode during the formation of the depobelts. Each of the events that formed a depobelt occurred within a time line and deferred in age from the adjacent depobelt.

The study area falls within the Coastal Swamp depobelt in the western part of the Niger Delta sedimentary basin (Fig. 1). Three traditional formations of the Niger Delta include: the Akata

Formation, Agbada and the Benin Formation. A proposal for Group status for these formations has been suggested in [8]. The Akata Formation is the basal stratigraphic unit of the Niger Delta. It is composed of predominantly overpressured marine shale with pockets of turbidite sands towards the top. Most of the hydrocarbon accumulated in the paralic Agbada sequence is generated in this shale. The Agbada Formation is an offlap sequence of foreset beds in an alternating sand/sandstone and shale successions. Top of the Agbada occurred at about 5000ft to 6000ft within the swamp and coastal swamp depobelts. It can be encountered as shallower as about 1850ft in the shallow offshore area in the eastern part of the basin [9]. It is the most deformed stratigraphic unit due to upsurging shale diapirism from the Akata Formation and the presence of growth faults. In most of the accumulations, hydrocarbons are trapped in structural closures supported by these major boundary growth faults and their associated rollover anticlines. The shale components of the Agbada Formation form good seals and potential source rocks especially towards the base of the Formation.

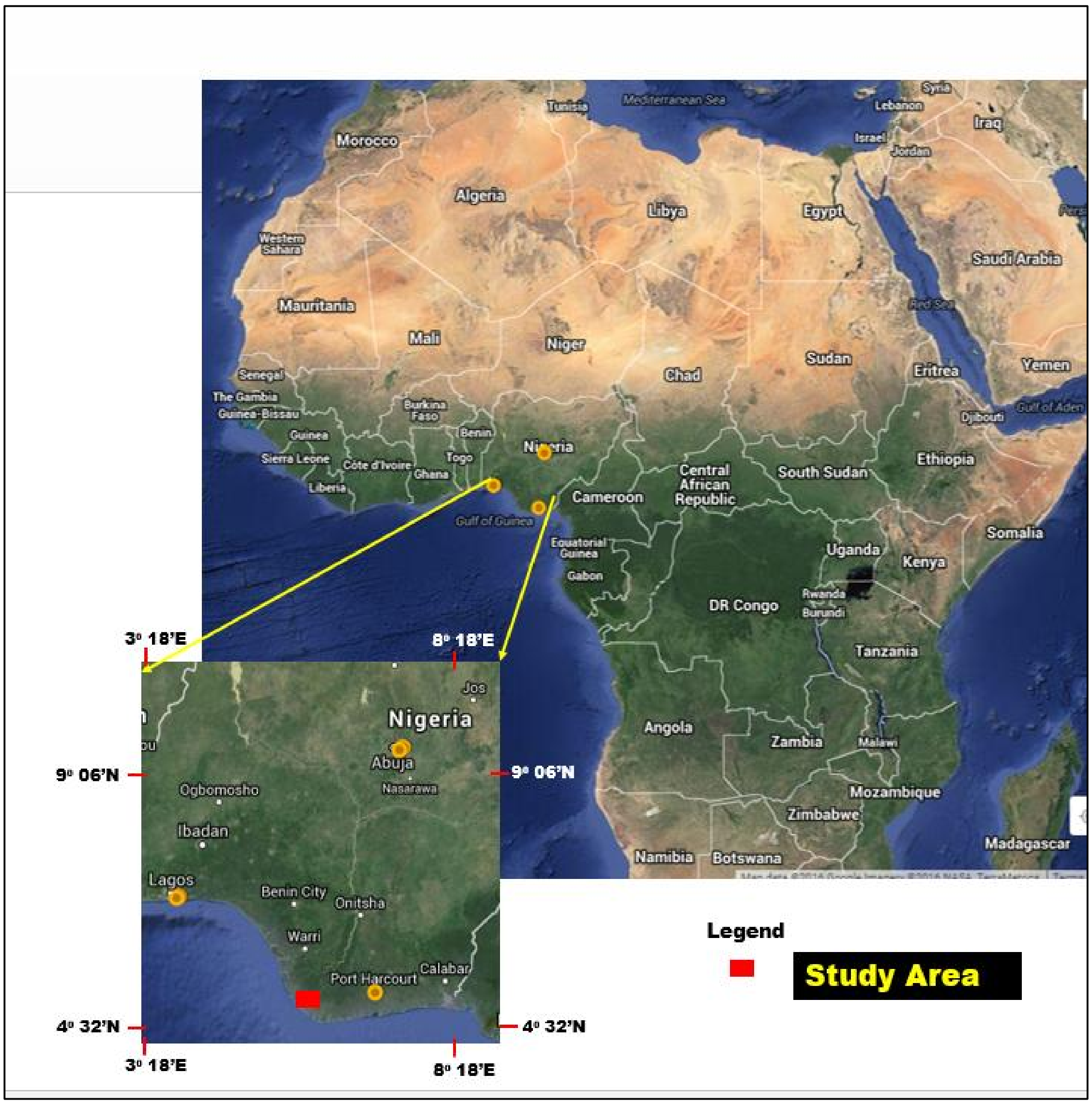

Fig. 1. Location map of the study area

The Benin Formation overlies the Agbada Formation, and is composed of continental sediments deposited within the fluvial systems. It is made up of majorly loose sands, gravels and pebbles (clear, transparent - translucent, medium – coarse grained, occasionally very coarse grained, loose, sub-angular to sub-rounded, sub spherical - sub elongated, poorly sorted) and minor claystone beds. Woody materials, peats and lignite streaks have been recovered from this unit. In onshore oilfields (Northern Delta Depobelt, Greater Ughelli Depobelt), the base of the Benin sand occurred at about 7400 ft; about 1850ft in the shallow offshore area, and totally absent in the deep offshore. In the study area, the base of the Benin Formation is at about 1750 ft. the Benin Formation do not contain oil and gas but may contain some biogenic gases that appear as background gas during drilling operations.

2. MATERIALS AND METHODS

The datasets for this study was provided by the Shell Petroleum Development Company of Nigeria for academic research, based on authorization from the Department of Petroleum Resources. The data include; a suit of well logs comprising of Gamma Ray, Resistivity, Neutron and Density logs; well location map, Core pictures for one well (well 001) and sparse biostratigraphic information. The depth of all the core intervals are in feet.

Well logs from five wells were correlated to establish the lateral continuity of the H7000 sand and its stratigraphic position. The H7000 reservoir stratigraphically is located below Nonion 4 regional shale marker (Table 1), Late Miocene regional marker. Possibly the age of sediments in the field could range from late Middle Miocene to early Late Miocene base on the presence of several unnamed marker shale horizons beneath the H7000 sand (Table 1). Intervals below 13300 ft yield no significant microflora for further age assignment. These regional marker shales are key stratigraphic intervals that aided the establishment of the continuity of key horizons. The almost uniform thickness of the H7000 sand (Table 2) across the five wells is another evidence for a shore-parallel and lateral continuous sandbody (Fig. 2a). The top and base of key sand-bodies were correlated across the five wells (FABI 001, 002, 003, 004 and 005) base on the stacking trends of the reservoirs. The cored interval occurred between 12750 ftMD and 13500 ftMD in well 001. Statistical plots (scattered plots, pie charts and bar charts) for most stratigraphic intervals were generated, and the Vertical Continuity Index (VCI) model of [10], were computed to explain the aspect ratios of sand-bodies. The VCI represents the measured aggregate sand thickness at various locations (well locations) divided by the thickness of the thickest sand. Gamma ray log trends helped to support gross environmental reconstruction. A cored section of about 51ft was described for lithofacies identification and sedimentological interpretation (Figs. 2b; 9a-q). In summary, the workflow for the description of facies and the interpretation of sedimentation in the field include; well correlation, statistical analysis and core description. This study will be useful in the location, development and production of hydrocarbon. It will also give hints on the occurrence of certain sedimentary minerals.

Table 1. Field biostratigraphic report (well 001)

Top depth (ft.)	Base depth (ft.)	Zone type	Zone code	Quality	Remark/Age
0	6000	F	-	No data	
0	6000	P	-	No data	
0	6190	P	-	Undiagnostic	
6250	6490	p	P788/P820	Uvigerina 8	Tortonian [Late miocene]
6550	7090	P	P788	Top nonion 4	
10750	10750	F	F9620	Nonion 4	
6030	11950	F	F9600	Top nonion 4	
7150	11990	P	P784	nonian 4	
12040	13300	P		Undiagnostic. generally poor in microflora	10.4 – 7.4 Ma (age of downlap surfaces)

3. RESULTS

3.1 Lateral Continuity of Facies

Well correlation carried out on the five studied wells (Figs. 2a; and 3) helped to establish the continuity of key stratigraphic zones. Twelve continuous sand horizons occurred between the interval of 6000 and 13500ft across the five wells (Table 2 and Fig. 2a). The H7000 sand interval in well 001 was considered for sedimentological studies because it contains both biostratigraphic and core data. The shore-parallel and continuity of the H7000 reservoir and others depicts a layer-cake architecture. This unit (H7000) concentrated the thickest sediment in the field (Figs. 4, 5 and 6). The vertical and horizontal variability (aspect ratios) of sand bodies has implications on reservoir behaviour during production. Facies architecture, geometry and continuity are important attributes that aids fluid communication, and are fundamental to reservoir characterization, compartmentalization and heterogeneity [7,11,12,13]. The reservoirs show layer-cake architectures and cut-across the entire field. This attribute is typical of shallow marine deltaic front facies. The thickness of the reservoirs as observed from the top towards the base of the well revealed an increase in sand thickness downhole. Vertical Continuity Index (VCI) plot shows a maximum thickness of about 700ft in the H7000 unit (Fig. 8a-l) with almost uniform thickness in all the wells (Figs. 4; 5; 6; 7a-d; 8a-l, Table 3). Lateral continuity and uniformity of thickness is also observed in other reservoirs at the shallower depth, but with varied thicknesses. Variations in thicknesses of sand bodies are related to geologic processes that operated at the time of deposition of the sediments. This could be as a result of rate of sediment supply, accommodation space creation, and the influence of marine and fluvial processes.

Table 2. Top and base of stratigraphic intervals

SAND	ftSS	WELLS				
		FABI-003	FABI-001	FABI-005	FABI-002	FABI-004
D1000	TOP	6042	0	6132	0	6040
D1000	BASE	6262	0	6327	0	6265
D2000	TOP	6294	6303	6451	0	6292
D2000	BASE	6407	6366	6467	0	6441
D3000	TOP	6422	6453	6485	6446	6449
D3000	BASE	6652	6614	6688	6619	6634
D4000	TOP	6680	6658	6713	6648	6647
D4000	BASE	6750	6712	6798	6739	6735
D5000	TOP	6765	6749	6819	6768	6771
D5000	BASE	7021	7042	7072	7019	7032
E1000	TOP	7098	7110	7138	7054	7101
E1000	BASE	7183	7204	7213	7129	7195
E2000	TOP	7195	7223	7228	7138	7204
E2000	BASE	7329	7360	7359	7284	7298
E3000	TOP	7349	7362	7379	7296	7305
E3000	BASE	7657	7701	7672	7586	7604
F5000	TOP	7671	7707	7679	7598	7613
F5000	BASE	7780	7867	7789	7599	7646
F5100	TOP	7789	7882	7797	7758	7721
F5100	BASE	8040	8143	8022	7988	7721
F5200	TOP	8060	8164	8040	8008	7969
F5200	BASE	8302	8404	8271	8233	8196
H7000	TOP	12525	12650	12575	12550	12600
H7000	BASE	13100	13275	13150	13250	13250

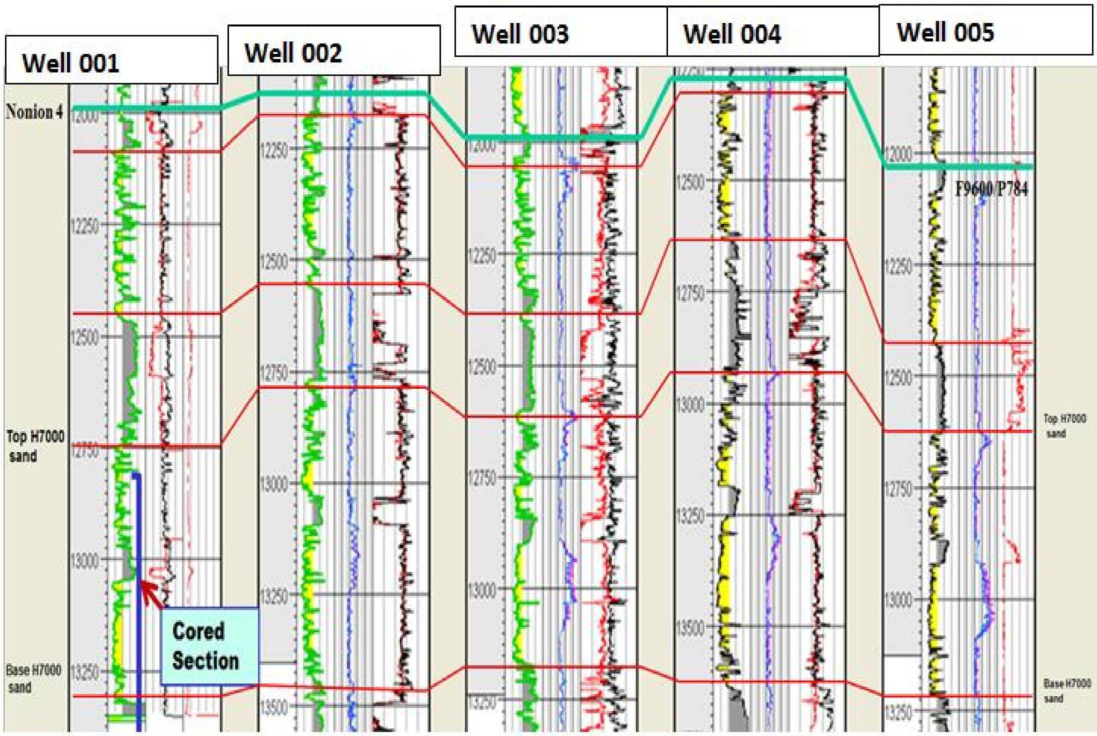

Fig. 2a. Correlation panel showing the continuity of H7000 sand and the cored interval

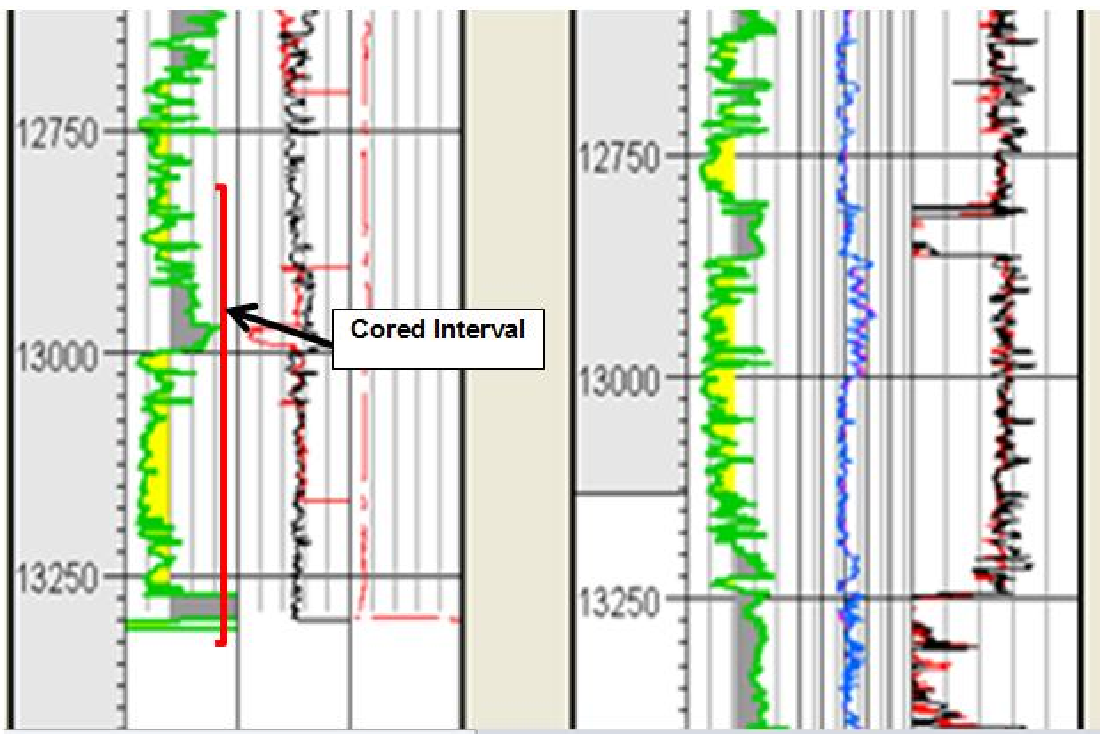

Fig. 2b. Well log showing the cored interval of well 001

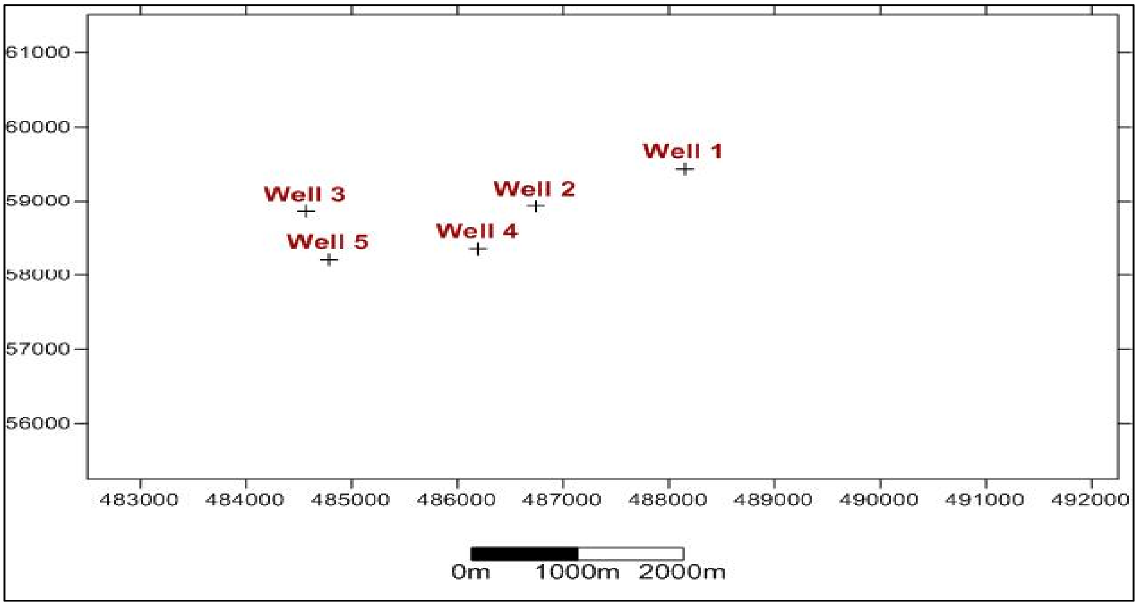

Fig. 3. Well location map of FABI field

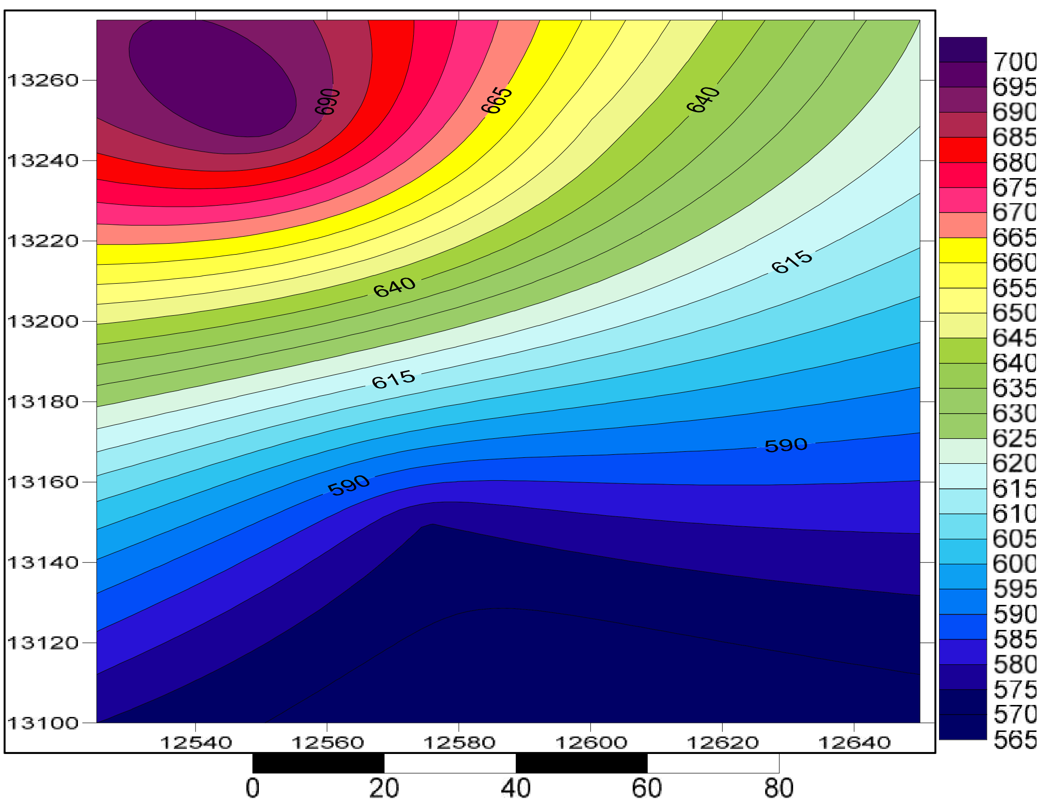

Fig. 4. Thickness contour map for H7000 reservoir across five wells

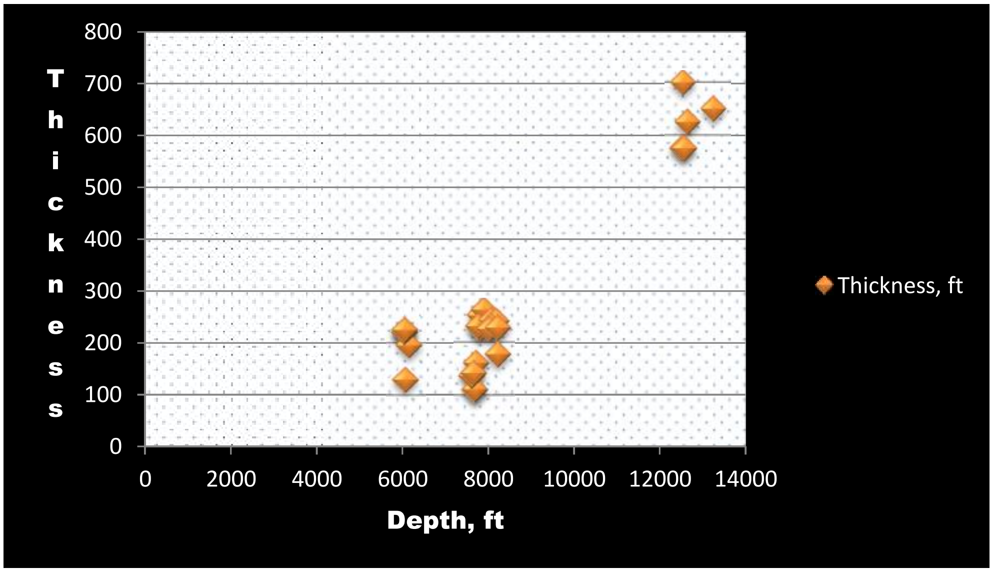

Fig. 5. Plot of thickness versus depth for four reservoirs (F5000, F5100, F5200 and H7000). The H7000 reservoir has the thickest and continuous sediments of between 600 to 700ft. Reservoirs F5000, F5100 and F5200 have range of thicknesses between 150 to 280ft. Gradual increase in thickness is observed with increasing depth

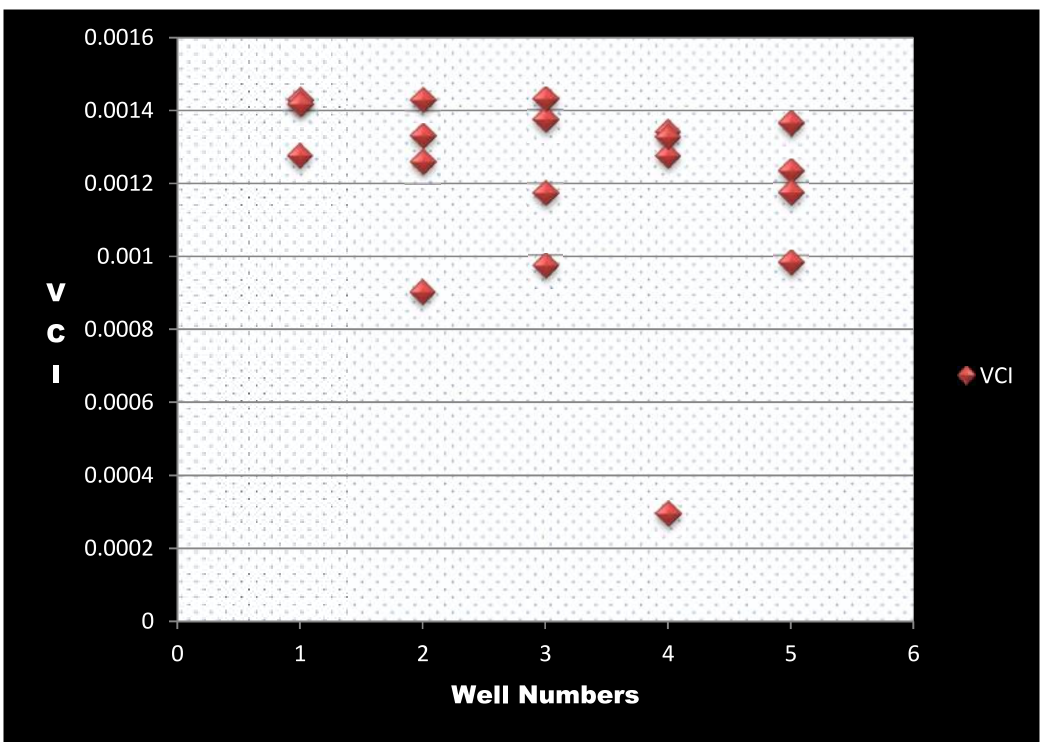

Fig. 6. Plot of Vertical Continuity Index (VCI) versus well points for five reservoirs (D1000, F5000, F5100, F5200 and H7000). Most of the reservoirs displayed laterally continuous architecture across the five wells but with increasing thickness downhole

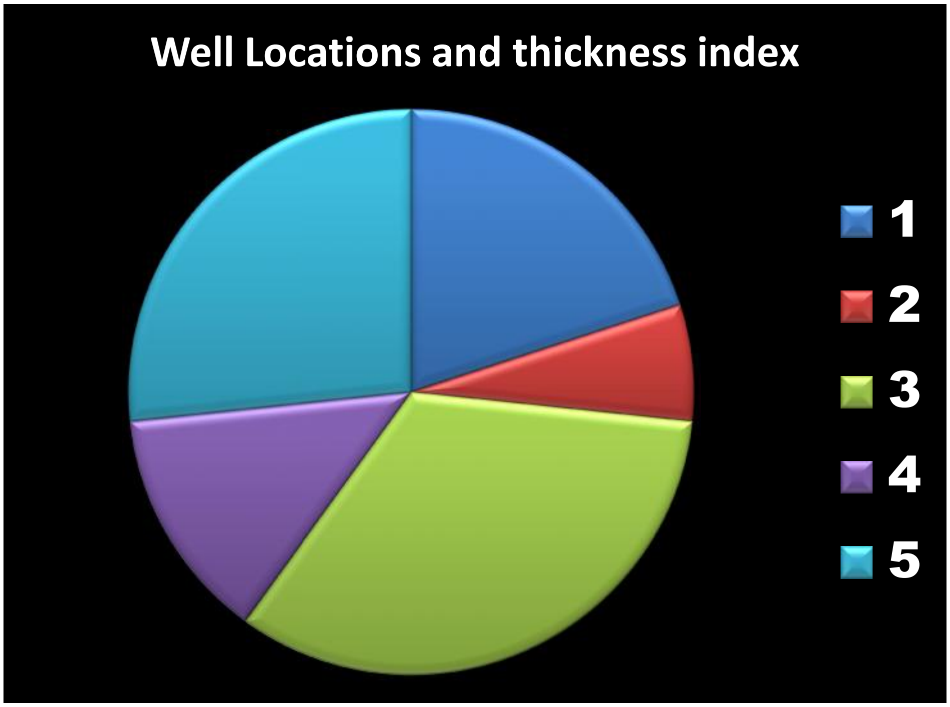

Fig. 7a. Pie Chart for VCI in Reservoir F5000. The numbers from 1 to 5 represent the five wells. Each section of the pie chart represents uniform thickness and continuity of reservoir across the wells. Note the almost equal thickness in wells 1, 3 and 5

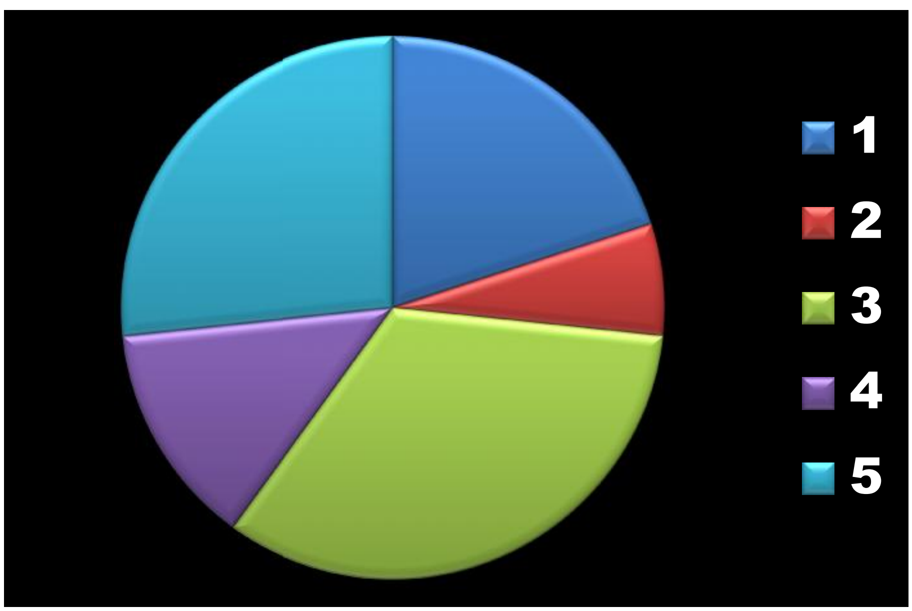

Fig. 7b. Pie Chart for VCI in Reservoir F5100. The numbers from 1 to 5 represent the five wells. Each section of the pie chart represents uniform thickness and continuity of reservoir across the wells. Note the almost equal thickness in wells 1, 3 and 5 as observed in Fig. 7a

Fig. 7c. Pie chart for VCI in reservoir F5200. The numbers from 1 to 5 represent the five wells. Each section of the pie chart represents uniform thickness and continuity of reservoir across the wells. Note the almost equal thickness in wells 1, 3 and 5

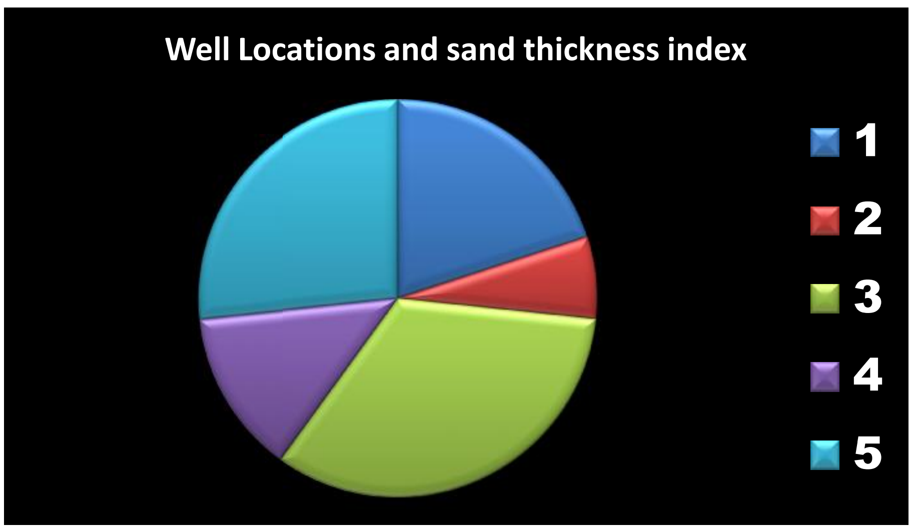

Fig. 7d. Pie chart for VCI in reservoir H7000. The numbers from 1 to 5 represent the five wells. Each section of the pie chart represents uniform thickness and continuity of reservoir across the wells. Note the almost equal thickness in wells 1, 3 and 5

Table 3. Reservoirs and vertical continuity index values

Wells	Reservoir	VCI
3	F5000	0.68125
1	F5000	1
5	F5000	0.6875
2	F5000	0.63125
4	F5000	0.20625
3	F5100	0.961686
1	F5100	1
5	F5100	0.862069
2	F5100	0.881226

Wells	Reservoir	VCI
4	F5100	0.89272
3	F5200	1
1	F5200	0.991736
5	F5200	0.954545
2	F5200	0.929752
4	F5200	0.938017
3	H7000	0.821429
1	H7000	0.892857
5	H7000	0.821429
2	H7000	1
4	H7000	0.928571

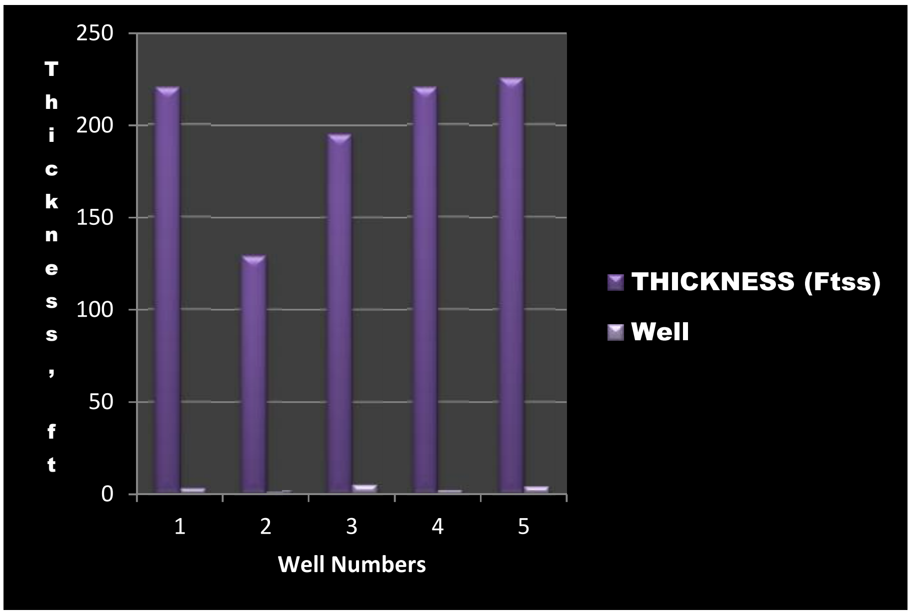

Fig. 8a. Reservoir D1000 (6042-6265ft). Variation in thicknesses is observed in all the wells with thickest sediments in wells 1, 4 and 5, followed by well 3

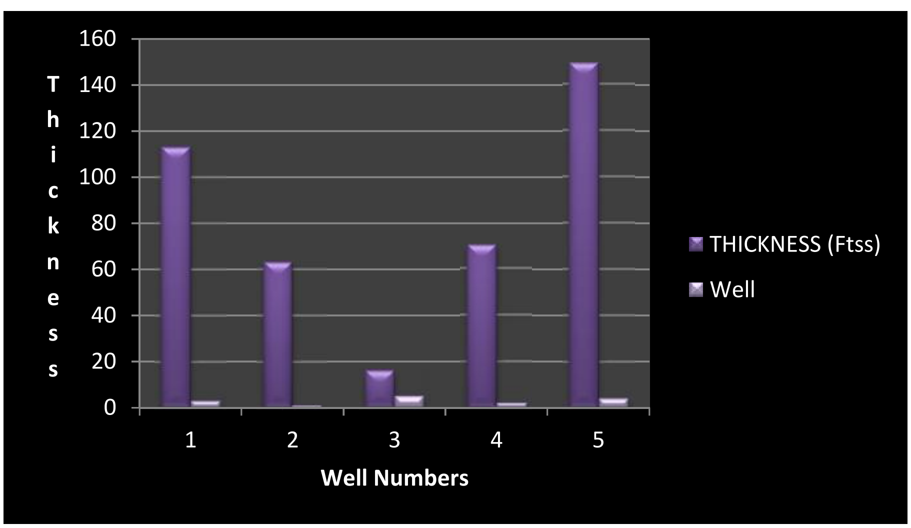

Fig. 8b. Reservoir D2000 (6294-6441ft). Thickest sediment occurred in well 5 followed by 1

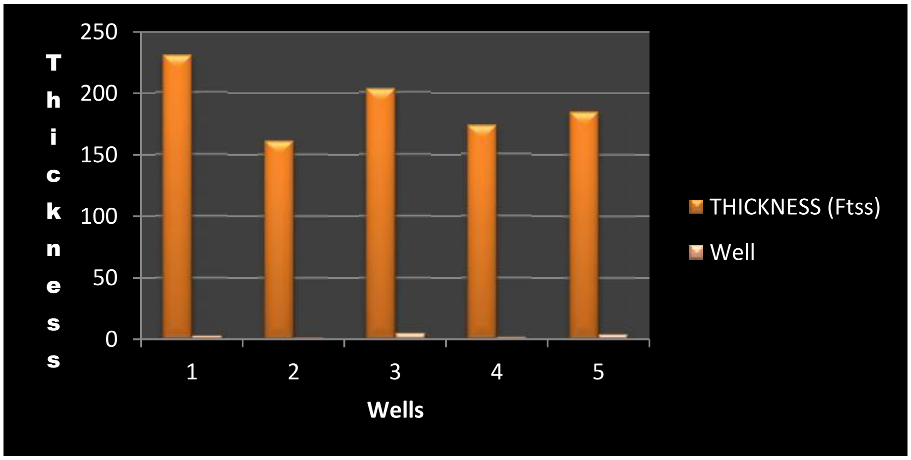

Fig. 8c. Reservoir D3000 (6422- 6634ft). Fairly uniform thickness between 155ft to 230ft observed with increase in depth

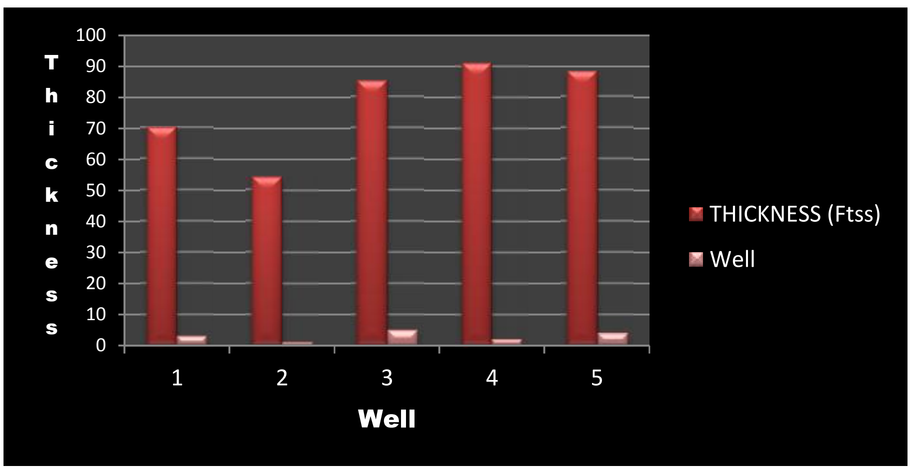

Fig. 8d. Reservoir D4000 (6680-6735 ft)

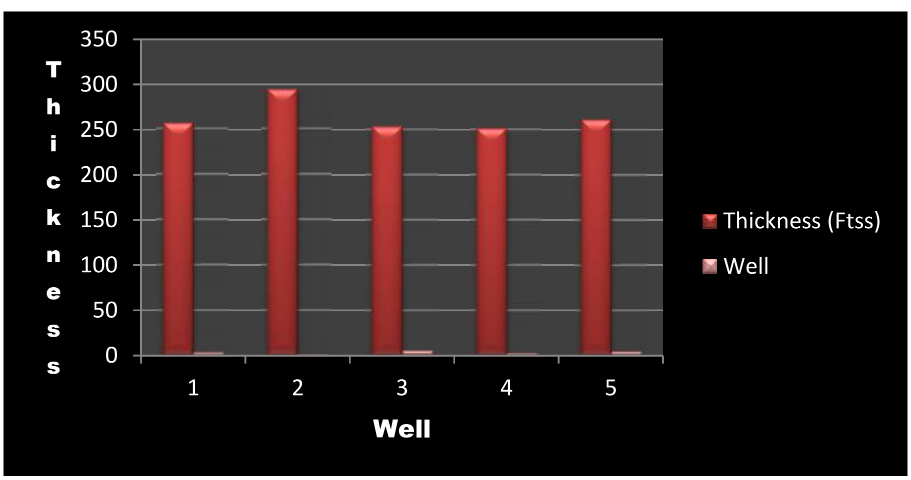

Fig. 8e. Reservoir D5000 (6765-7032 ft)

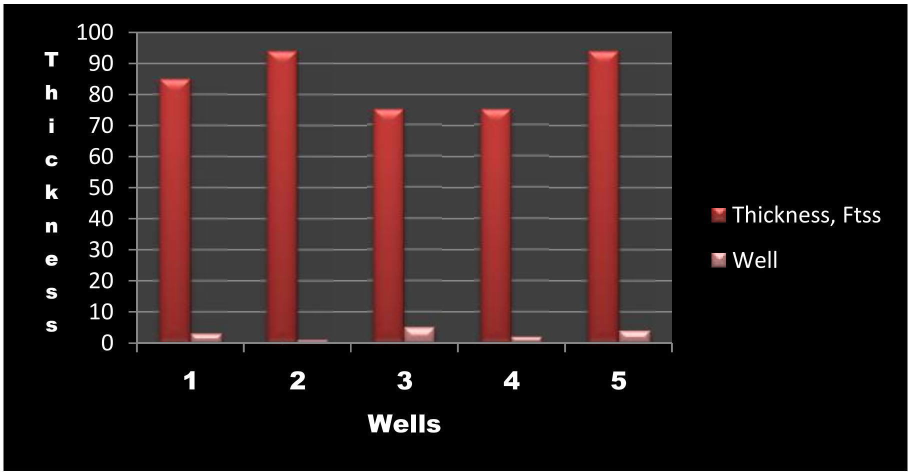

Fig. 8f. Reservoir E1000 (7098-7195 ft)

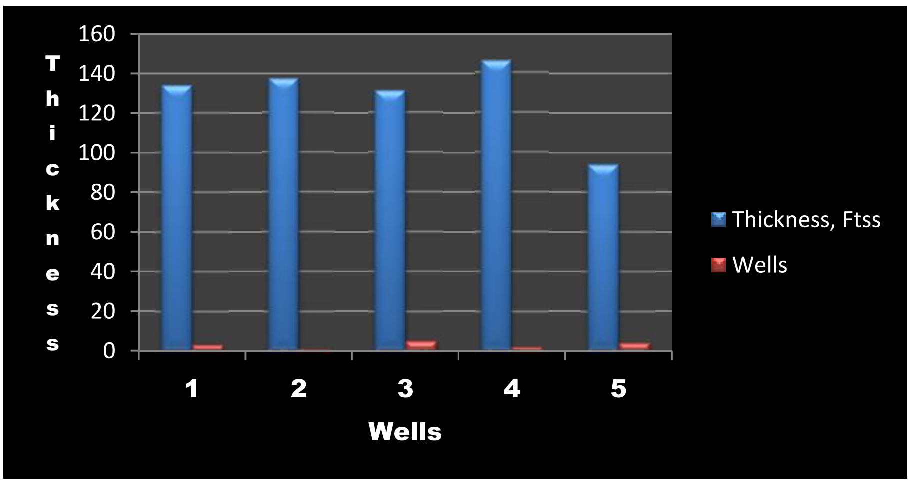

Fig. 8g. Reservoir E2000 (7200-7298 ft)

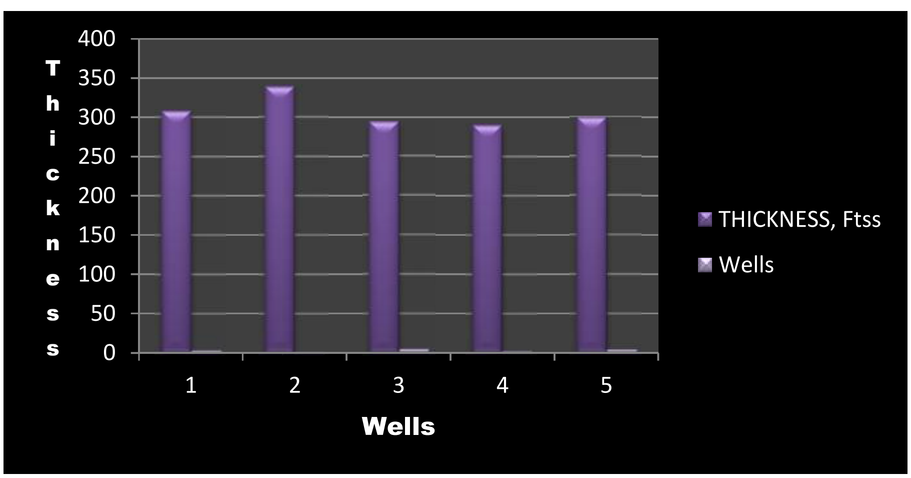

Fig. 8h. Reservoir E3000 (7349-7604ft). Thicknesses between 290 and 340ft observed in this reservoir

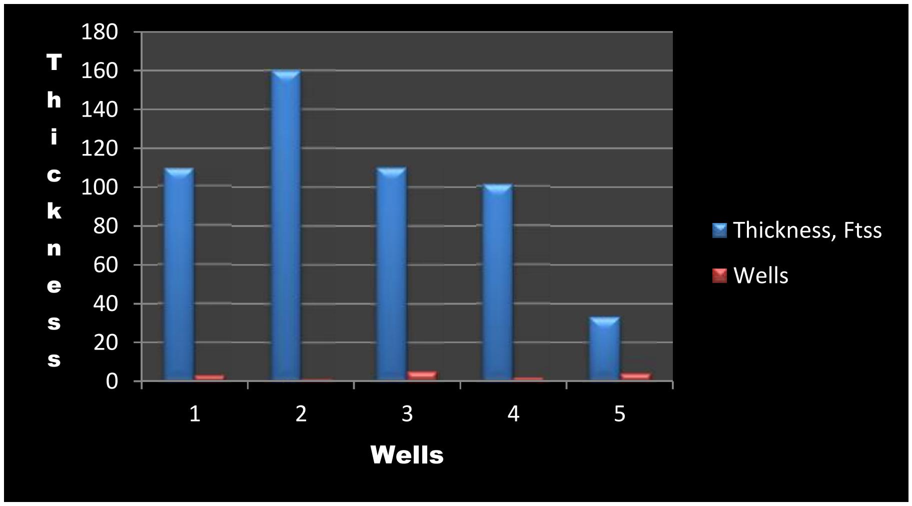

Fig. 8i. Reservoir F5000 (7671-7646 ft)

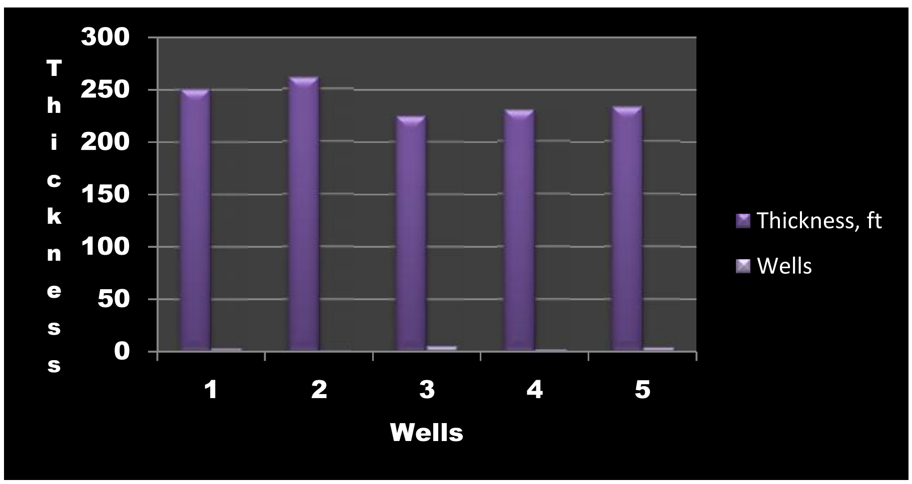

Fig. 8j. Reservoir F5100 (7789-7954 ft)

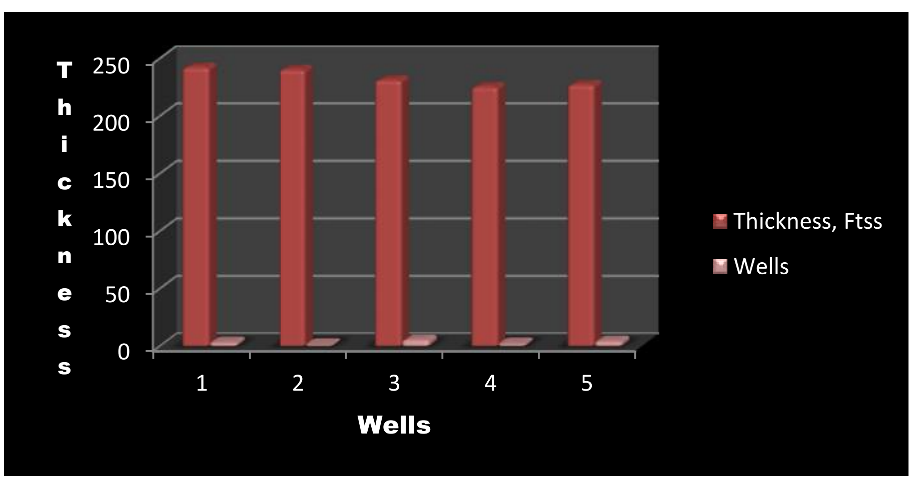

Fig. 8k. Reservoir F5200 (8060-8196 ft)

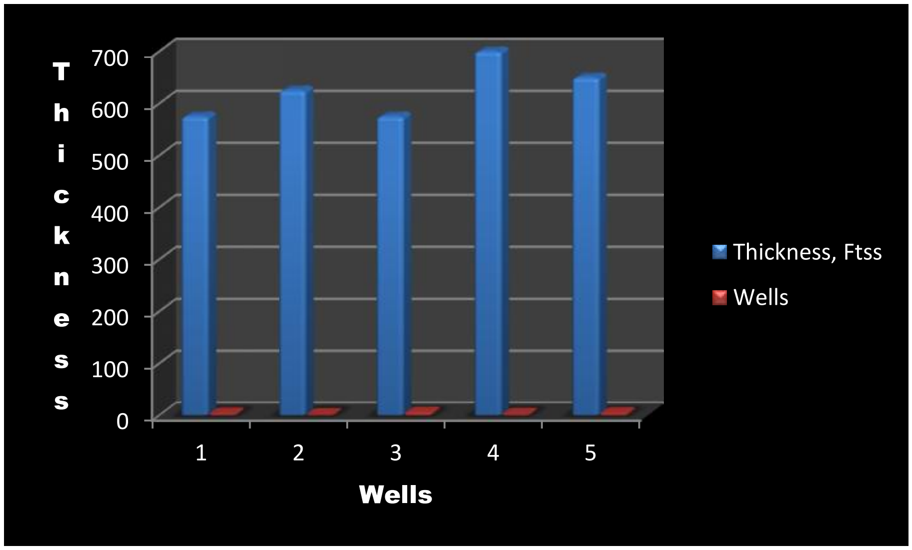

Fig. 8l. Reservoir H7000 (12525-13250 ft)

3.2 Lithofacies Description

Facies A (Cross-bedded sandstone)

Description: This facies is characterized by moderately to well sorted, fine to medium grained sandstones, trough cross bedding, planar cross bedding, alternating parallel cross bedding, and double mud drape. The sandstone is light grey to light brown in colour, rare hummocky laminations and free of shale successions (Fig. 9a-g). Cross-beds typically contain single and paired mudstone drapes along planar laminations towards the base of the facies. This unit contains clean sand with no clay content, minor draped and carbonaceous materials. Bioturbation levels range from slight to moderate commonly caused by *Ophiomorpha* burrows (Figs. 9e-g). The gamma ray log section displays a coarsening upward sequence and it overlies the interbedded sandstone and mudstone or bioturbated sandy mudstone facies. The gamma ray log motif indicates a coarsening upward trend occurring in two parasequences (Fig. 2b) and is laterally continuous based on well correlation (Figs. 2a and 2b). The Upper parasequence (12863 to 13060 ft) of the cored interval is serrated indicating that the section is affected by tidal action. The coarsening upward log motif for the parasequence below this interval is not serrated and signifies more shale free sandstone as seen in the cored intervals at 13313 – 13319 ft and 13435-13438 ft (Figs. 9e-g). It is observed that the intervals with cleaner sand and moderate *Ophiomorpha* burrows (Figs. 9e-g) occurred within the unserrated parasequence, indicating that this environment is exposed to more wave action and higher energy than tidal action as observed in the upper parasequence.

Interpretation: As described above, this facies occurred in two parasequences indicating a stacked progradational depositional system within a shallow marine setting. Each parasequence is capped with a flooding surface (Figs. 2a and 2b). The trough/planar cross-stratification indicates migration of subaqueous dunes in traction current deposition; whereas mud drapes show periods of decrease in flow velocity in which mud settles from suspension. The little or absence of mud and rare hummocky stratification especially in facies at 13313-13319ft, and 13435-13438 ft reflects an unstable high energy condition where marine energy fluxes (waves and currents) occasioned the deposition of planar and cross-beds. In a high energy environment where wave is more active, deposition of very fine grained pelitic sediments such as mud or clay is uncommon. The presence of *Ophiomorpha* burrows within this facies corroborates a high energy condition. The cross-bedded facies has a general trend of coarsening upward succession and is interpreted to be upper shoreface. The upper parasequence is interpreted to be shoreface facies (upper shoreface) influenced by tidal action. The section underlying this facies shows the appearance of mud interbeds indicating a decrease in grain size downward and an overall shallowing upward trend.

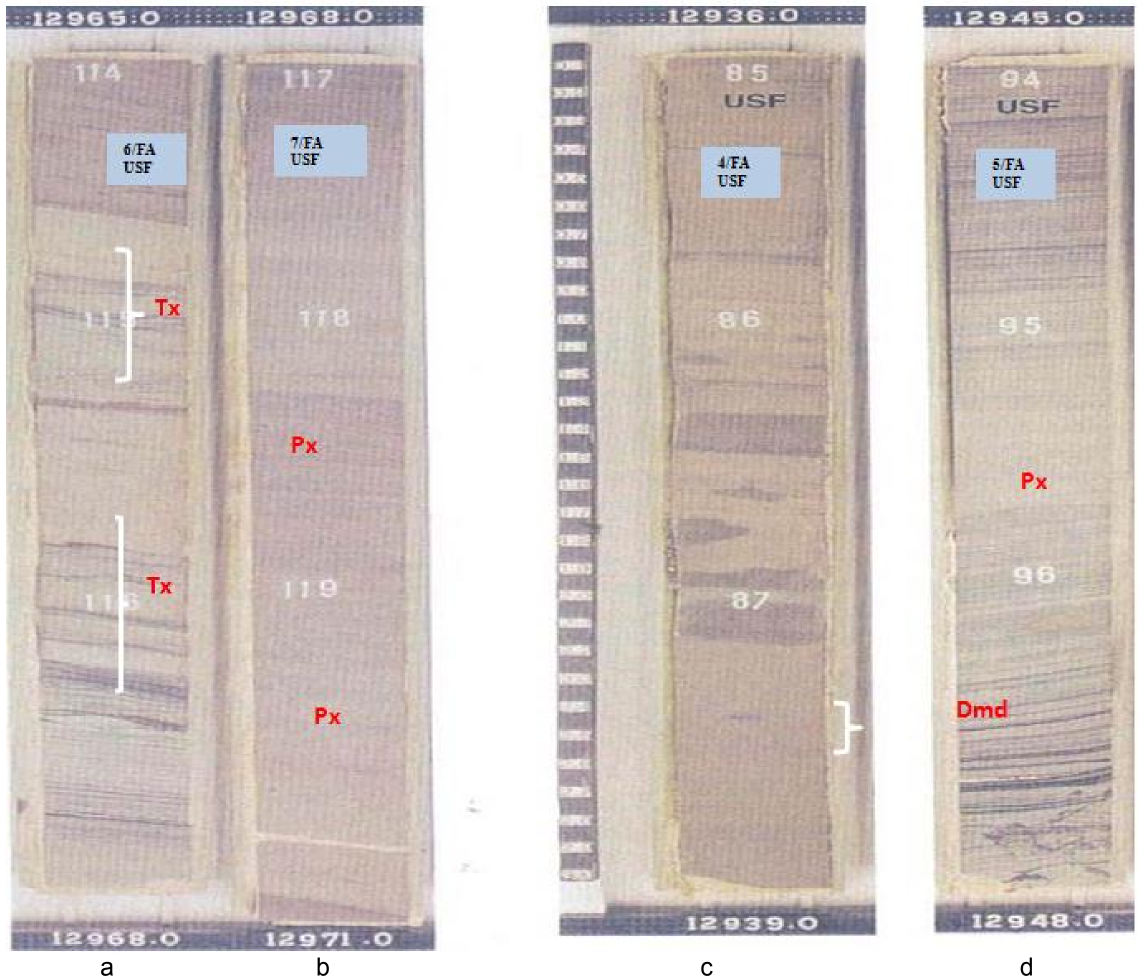

Fig. 9a-d. Cross bedded sandstone facies. Tx: Trough cross bedding; Px: Planar cross bedding; Dmd: Double mud drape

FACIES B: Bioturbated Heterolithic Sandstone (Lower shoreface)

This facies consists of dark-grey, moderate to intensely bioturbated siltstones, mudstones and relics of very fine sands (Fig. 9h-o). The Interbedded very fine grained sandstones and siltstones are heavily bioturbated while some intervals are completely reworked (Fig. 9h-k); the mud beds are essentially slightly bioturbated. Bioturbation types include sparse traces of *Ophiomorpha and Teichichnus* and rare *Conichnus* (Fig. 9h-k). The bioturbated sandy mudstone facies is overlay by interbedded sandy mudstone facies. This facies occurred at 12863.4-12866 ft, 12906-12909 ft, 12948-12951 ft, 13022-13028 ft, and 13054-13060 ft, where it generally forms the basal portion of each coarsening upward unit except in the lowermost sequence where it is underlain by the mudstone lithofacies with the bioturbation extent ranges from slightly bioturbated to completely reworked sediment (Fig. 9h-k and 9l-o).

Interpretation: The intensely bioturbated units indicate reduced sedimentation rates on a low energy, or more slowly prograding shoreface. The hummocky cross stratification reflect sedimentation under conditions of alternating storm and quiet water between storm and fair weather base. The very fine-grained sandstone, siltstone and mudstone interbeds represent fair-weather deposition which may depict the later stage of sediment fallout after the high energy sedimentation. The intense bioturbation leads to partial or complete obliteration of the sedimentary structure (Fig. 9h-k). The heterolithic nature of this facies indicates sedimentation in alternating suspension fallout and bed-loads within a low energy setting below wave base. This facies is interpreted as having been deposited in the lower shoreface environment characterized by poor reservoir quality and low flow potential with porosity range between 4.0-20% [6,14,15,13,6].

FACIES C: Offshore Mudstone (FA1)

This facies is made up of mudstone (Figs. 9p-q) with intervals of siltstone and very fine-grained sandstone showing parallel laminations, wavy laminations, and current ripple cross-laminations. Streaks of very fine silty sandstone laminae occur within the mudstone especially towards the lower part (13238 ft) (Figs. 9p-q) and grade into very fine grained silty sandstone laminations between 13238 ft and 13241 ft (Figs. 9p-q). The laminated silty sandstone below the mudstone facies shows wavy ripple-lamination with very low.

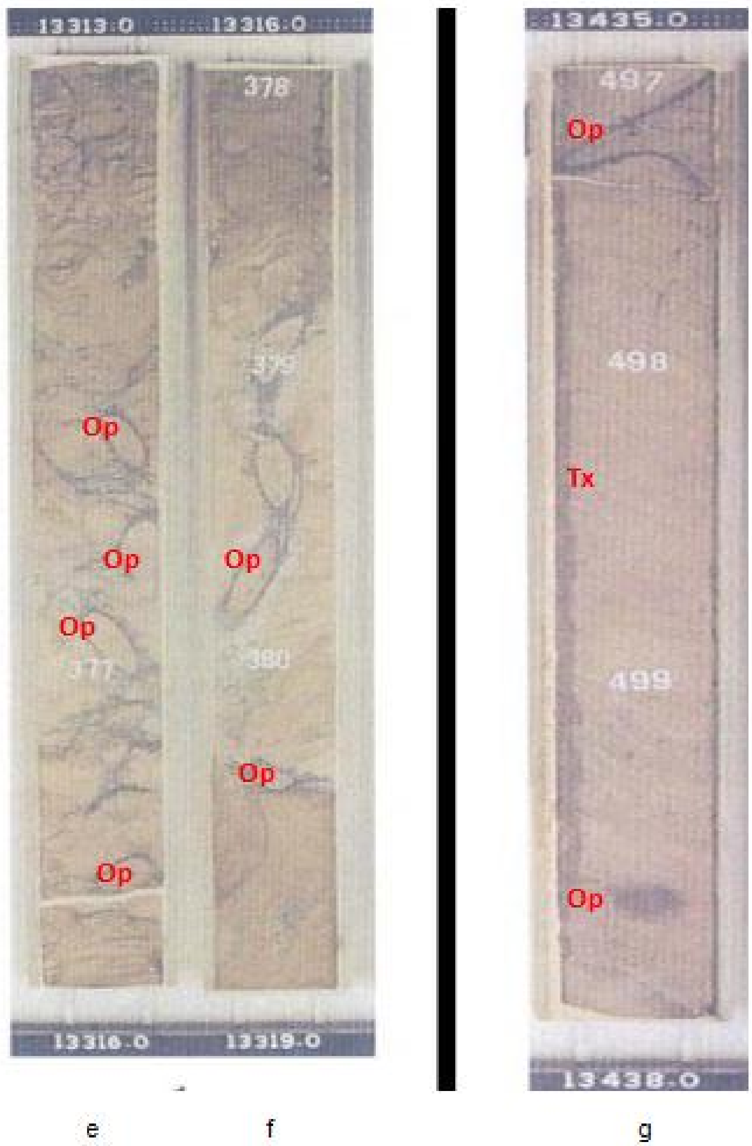

Fig. 9e-g. Cross-bedded sandstone: Op: *Ophiomorpha* ; fine to medium-grained sandstone; trough and tabular cross-beds, minor planar lamination, sparse to moderate *Ophiomorpha* burrows, Tx: Trough cross-bedding

h l j k

Fig. 9h-k. Interbedded sandstone/mudstone facies. Fine- very fined grained silty, laminated and bioturbated heterolithic sandstone. Bioturbated sandy mudstone facies with bioturbation intensity reducing from h-k. Note the contact between the overlying highly bioturbated heterolithic interval and the laminated tidal channel facies towards 12909.0ft (Fig. 9i). M: Mudstone, S: sandstone bed, Ms: Silty Mudstone, H: hummocky cross stratification, Pl: Planolite, XL: Cross laminations with mud drapes

Interpretation: The fine-grained nature of this facies suggests deposition under low energy conditions, where suspension fallout was the dominant depositional process. The rare silty laminae are indicative of the intrusion of more energetic events. Preservation of thin laminations, absence of bioturbation, and dark colours are suggestive of anoxic bottom-water conditions. This facies is interpreted as having been deposited in a shelf environment.

4. DISCUSSION

4.1 Sedimentology of the H7000 Reservoir

The lithologies of the study area are broadly classified into sand and shale as revealed by both well log and core samples. Some siltstones beds also occurred in laminated form interbedded with mudstone or sandstone units.

High gamma ray log signals indicated the shale intervals whereas low gamma ray log values show sand. Increasing gamma ray values to the right of the reference line indicates increasing shale/clay, whereas decreasing gamma ray to the left of the reference line indicates increasing sand percentage. A coarsening upward or fining upward unit within a forestepping or backstepping successions (Fig. 2b) of the log defines stacking patterns of genetic units. This aided well correlation and delineation of sand bodies of interest. The H7000 sand shows a coarsening upward progradational stacking occurring in two parasequences. The reservoir cuts across the five wells with almost uniform thicknesses (Table 4; Fig. 2a; 7a-d; 8a-l). Top of this reservoir occurs at 12525 ft, 12650 ft, 12575 ft, 12550 and 12600 ft in the five wells with average thickness of 625 ftMD.

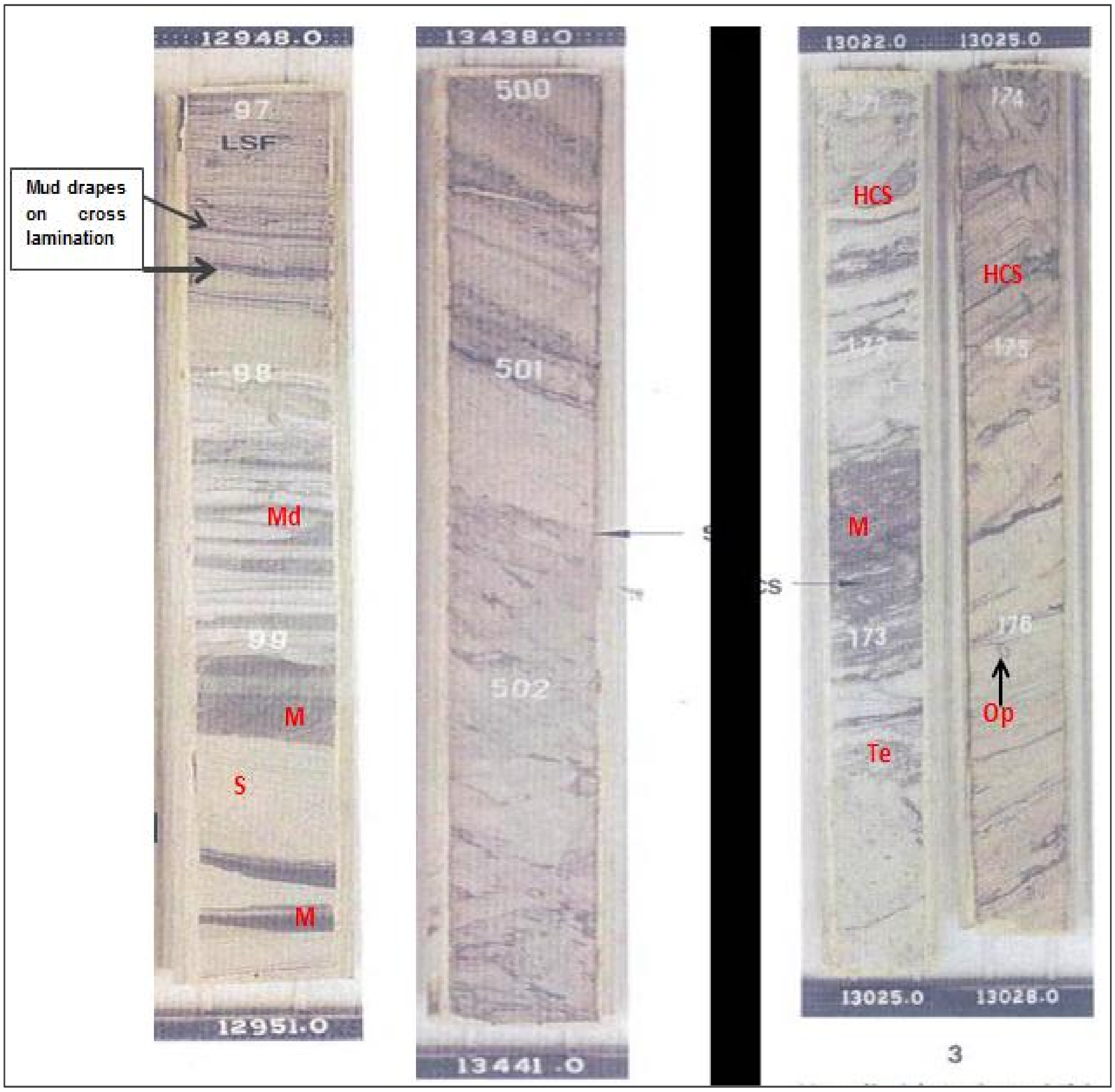

Fig. 9l-o. Bioturbated isnterbedded sandstone/mudstone facies. M: Mudstone, Md: mud drapes, S: Sandstone bed, HCS: Hummocky cross stratification, Te: *Teichnicnus trace, Op: Ophiomorpha trace*. Presence of wavy rippled sandstone. Note the mud drapes along pause plane (black arrows). Amalgamated beds of upper fine-grained sandstone; swaly and hummocky cross-stratification, minor wavy lamination, and wave ripple cross-lamination

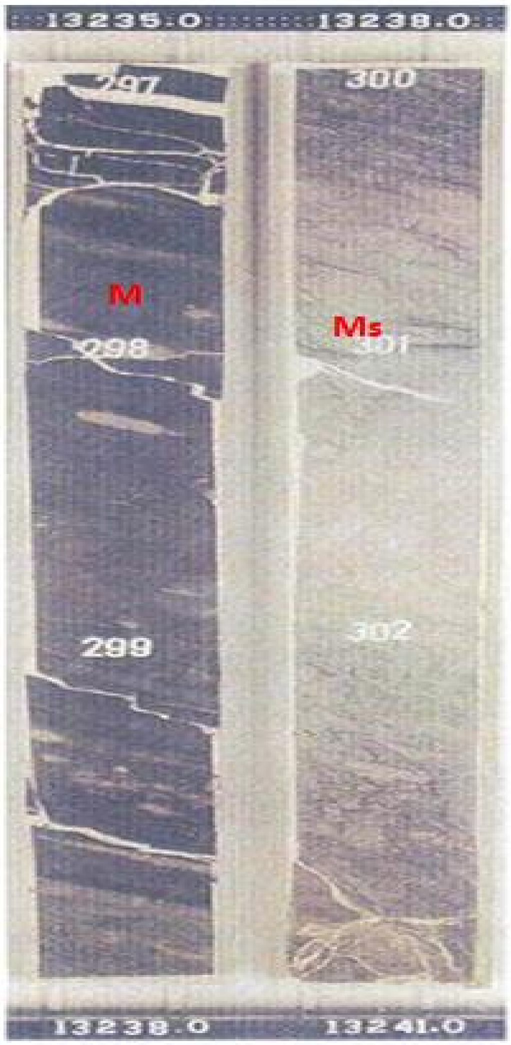

Fig. 9p-q. Mudstone facies: Mudstone facies with silty top. M: Mudstone, Ms: Silty mudstone. Mudstone and siltstone with beds of very fine- to upper fine-grained sandstone; parallel lamination, wave, and current ripple cross-lamination

Table 4. Tops and base/thickness of H7000 sand across five wells

Wells	Top	Base	Thickness (Ft. MD)
FABI 003	12525	13100	575
FABI 001	12650	13275	625
FABI 005	12575	13150	575
FABI 002	12550	13250	700
FABI 004	12600	13250	650
Average thickness			625

Well log and core information showed that the H7000 sand and other similar genetic units in the field were deposited within the shallow marine deltaic front environment. This environment is affected by various marine energy fluxes such as wave action, longshore currents and tidal effects. These processes are responsible for distribution and deposition of sediments within the shoreface (upper and lower shoreface), barrier complexes, tidal flats and channel, Interdistributary bay and mouth bars [6]. The H7000 sand shows typically an environment ranging from offshore mudstone to shoreface subenvironments. Tidal facies separated the upper shoreface and overlies the open marine facies. The coarsening upward trend of gamma ray log confirmed the progradational depositional profile of the sand units. Four facies associations indicating subenvironments of H7000 sand include; shelf mudstone, lower shoreface, upper Shoreface, and tidal channel respectively. The lithofacies types making up the sedimentary unit include; silty mudstone, bioturbated interbedded sandstone and mudstone, cross-bedded sandstone.

Based on log characteristics and the lithofacies description of a portion of the H7000 reservoir, the FABI field environments were deposited within the deltaic front environments influenced by both waves and tidal action. Tide generated structures supporting its influence in the environment include; presence of mud drapes, and sands/shales in heterolithic sequences. The shoreface sequence comprises of the lower and upper shoreface largely dominated by wave activities with minor tidal influence. The section of the shoreface with little or no burrows/bioturbation experienced high energy whereas intermediate to low energy shoreface comprises of stacked laminated to burrowed intervals with repeated erosive storm beds followed by intense burrowing and poor preservation of high energy beds.

4.2 Ichnofacies and Depositional Environments

Most sedimentary structures are attributed to the activities of organisms that lived in such environments during their lifetime. The most visible biogenic structures found in the core samples are majorly ichnofacies. The shapes and morphologies of traces made by these fossils reflect certain environments of deposition and are useful in stratigraphic reconstruction and definition of bounding discontinuities. In the study area, the most visible ichnogenera include; *Ophiomorpha* and *Teichnicnus* traces. In some intervals within the heterolithic facies intense bioturbation disrupted bedding structural trends. Where these traces are abundant in a hydrocarbon bearing sand, they help to enhance fluid flow (permeability) which is relevant to oil and gas production.

The *Teichnicnus* ichnofacies group shows the activities of certain annelids. Their traces reflect the mode of their activity within the environment which could be resting or feeding. They are commonly part of the *Skolithos* and *Cruziana* ichnofacies found within the lower shoreface (Figs. 9l-o), lagoons, bays and brackish water coastal/shallow marine environments. They represent certain worms in their feeding or dwelling position tightly packed in series of concave crescentic laminae formed by horizontal tunneling of organisms moving in the same direction (Figs. 9l-o).

The *Ophiomorpha* ichnogroup records the activities of crustaceans. They represent dwelling burrows of suspension feeding shrimps. The traces range from simple to complex burrows lined with agglutinated peletoidal sediments, nodose exterior and smooth lining of the interior (Figs. 9e-g). They are common elements in the Skolithos ichnofacies and abundant within the shoreface, sandy tidal flats and sandy estuarine settings.

5. CONCLUSIONS

This study has demonstrated that the H7000 reservoir was deposited within the shoreface shallow marine environments, where facies change laterally seaward from coarse grained within the upper shoreface to heterolithics and offshore mudstone towards the shelf. Facies types, architecture and geometry are functions of sedimentology and depositional setting of sediments. Several factors such as sediment supply, sea level change and subsidence would have accounted for deposition of sediments in the field with greater sediment supply during the Tortonian time (Late Miocene) as observed in the H7000 reservoir. Thicker sedimentary units resulted from wave redistribution of sediments supplied within the shoreface high energy environments and presents high potential for hydrocarbon accumulation and production. Facies types and characteristics are functions of environments of deposition regulated by various geologic processes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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