Aspects of structures and depositional environment of sand bodies within tomboy field, offshore western Niger Delta, Nigeria

Značilnosti struktur in okolja odlaganja peščenega materiala v območju Tomboyja, priobalna delta Zahodnega Nigra, Nigerija

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Abstract: Sand bodies deposited across normal growth faults and associated rollover anticlines are critical reservoirs for the accumulation of oil and gas. This paper addresses aspects of structures and depositional environments of some sand bodies within the Tomboy field, offshore western Niger Delta. Structural interpretation was undertaken to identify and assign faults found in the 3-D seismic volume. Time and depth structure maps in combination with well logs were used to produce for five horizons, namely: H1 to H5 and identify the depositional environments respectively.

Two major growth faults (F4 and F7 which are normal, listric concave in nature), three antithetic (F1, F3 and F6) and two synthetic faults (F2 and F5) were identified. Structural closures identified as rollover anticlines, and displayed on the time/depth structure maps; suggest probable hydrocarbon accumulation at the downthrown side of the fault F4. Point bars, distributary channel and mouth bars, barrier island and tidal channels are the depositional environments. This study shows that the Tomboy field is made up of sand bodies deposited in different environments across normal, growth faults and associated rollover anticlinal structures.

Izvleček: Peščen material, odložen ob sinsedimentnih normalnih prelomih in z njimi povezanimi naleglimi antiklinalami, so pomembna nahajališča nafte in plina. Članek se ukvarja z značilnostmi struk-

Original scientific paper

tur in okolja odlaganja peščenega materiala v območju Tomboyja v priobalni delti Zahodnega Nigra. S strukturno interpretacijo smo ugotovili prelome iz 3-D seizmičnih podatkov. Na podlagi strukturnih kart v časovni in prostorski domeni ter z elektrokarotažami smo izdvojili pet stratigrafskih horizontov in ugotovili njihova sedimentacijska okolja.

Določili smo dva večja sinsedimentna preloma (F4 in F7, ki sta normalna in listrično konkavna), tri antitetične (F1, F3 in F6) in dva sintetična preloma (F2 in F5). Strukturne pasti v naleglih antiklinalah, ki smo jih identificirali na strukturnih kartah, nakazujejo možnost akumulacije ogljikovodikov v spuščenem krilu preloma F4. Sedimentacijska okolja so meandrske sipine, razvodni kanali ter sipine v ustju, pregradni otoki in plimski kanali. Študija je pokazala, da polje Tomboy sestavljajo peščenjaki, ki so se odložili v različnih sedimentacijskih okoljih ob sinsedimentnih normalnih prelomih in z njimi povezanimi strukturami naleglih antiklinal.

Key words: structures, depositional environment, Niger Delta
Ključne besede: strukture, sedimentacijska okolja, delta reke Niger

INTRODUCTION

The Niger Delta Basin to date is the most prolific and economic sedimentary Basin in Nigeria. It is an excellent petroleum province, ranked by the U. S. Geological Survey World Energy Assessment as the twelfth richest in petroleum resources, with 2.2 % of the world's discovered oil and 1.4 % of the world's discovered gas (Klett et al., 1997; Petroconsultants, Inc. 1996). By virtue of the size and volume of petroleum accumulation discovered in this basin, various exploration strategies have been devised to recover the enormous oil and gas deposits. These comprise onshore exploration of oil and gas as well as on continental shelf, and in deep offshore.

Sand bodies were deposited across normal, growth faults and associated rollover anticlines and represent important reservoirs for the accumulation of oil and gas, especially in the Niger Delta. It has been documented in the Niger Delta that growth faults and rollover anticline structures serve as traps for petroleum accumulation (Merki, 1972; Orife & Avbovbo, 1982).

In this study, GeoGraphix software combined with well logs and 3-D seismic volume were used to show how structural deformation and depositional

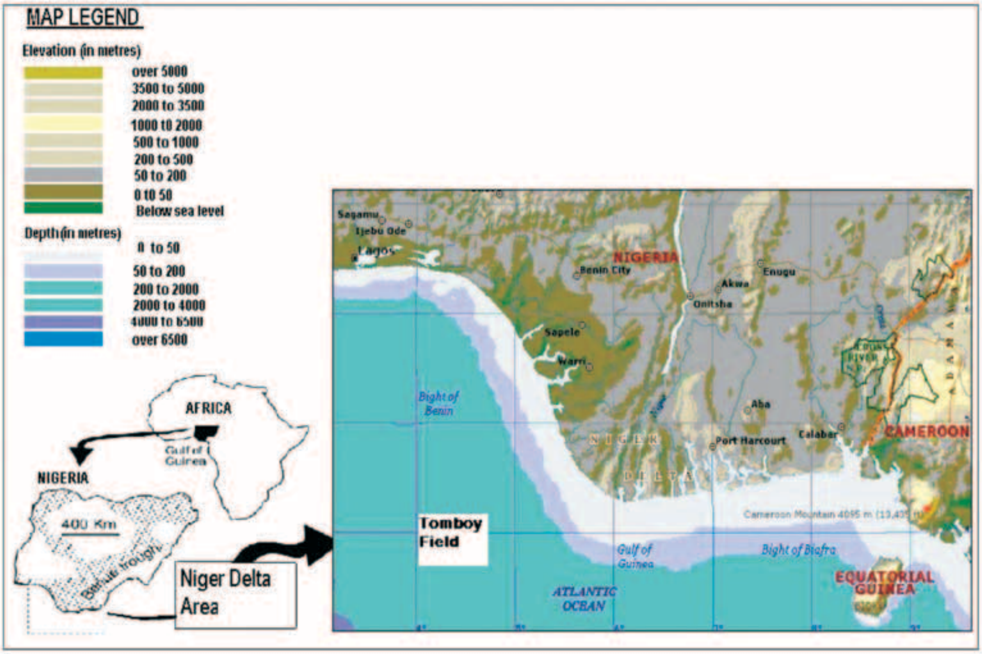

Figure 1. Location map of the study area (Modified from Owoyemi, 2004 and Microsoft Encarta, 2006)

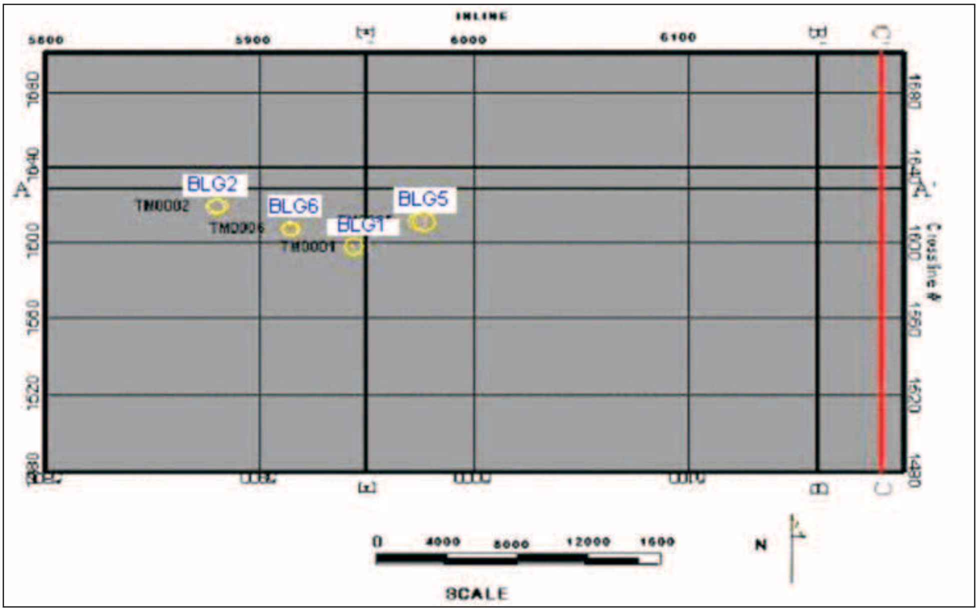

Figure 2. Seismic Survey Base Map of the Tomboy Field showing the location of the four studied wells and seismic section

environment can influence the accumulation of oil and gas. These can assist in well placements and narrow down areas for detailed exploration and production.

STUDY AREA AND REGIONAL GEOLOGY SETTING

The area of study, Tomboy Field, is located within the western margin of offshore Niger Delta (Figure 1) and belongs to Chevron Texaco Limited concession. The seismic base map of the area originates from latitude 4.0 ^{o}N and longitude 4.5 ^{o}E, covering an area of 55 km^2 (Figure 2). The in-lines and cross-lines are in the ranges of 5800 to 6200 and 1480 to 1700 respectively and with a spacing of 25 m between lines.

The four wells, namely BLG1, BLG2, BLG5 and BLG6, utilized for this study were drilled to the depths of 13,019.00 ft (3,945.15 m), 12,996.0 ft (3,938.18 m), 11,541.50 ft (3,497.42 m) and 11,674.50 ft (3,537.72 m) respectively. These four wells have composite well logs which include gamma ray; resistivity, sonic, and neutron/density logs. The 3-Dimensional seismic volume is in SEG-Y format, whereas the well log data are in LAS format.

The Tomboy field is located within the geological setting of the Niger Delta where clastic wedges are deposited along the failed arm of a triple junction system. Originally, the Delta was formed during the breakup of the South American and African plates during the late Jurassic (Burke, 1972; Whiteman, 1982). The two rift arms that followed the southwestern and southeastern coast of Nigeria and Cameroon developed into the passive continental margin of West Africa, whereas the third failed arm formed the Benue Trough which is located under the Gulf of Guinea, offshore Nigeria. After an early history of rift filling in the late Mesozoic, the clastic wedge steadily prograded into the Gulf of Guinea during the Tertiary as drainage expanded into the African Craton with consequent subsidence of the passive margin.

These upward-coarsening strata, offlapping this continental margin, have been divided into three diachronous lithostratigraphic units, namely the Akata, Agbada, and Benin Formations (Figure 3; Short & Stauble, 1967; Doust & Omatsola, 1990). The Akata Formation is the oldest of the units and composed mainly of marine shales which range in age from Eocene to Recent. The Agbada Formation overlies the Akata Formation and comprises mainly alternating deltaic sandstones with shale. It age ranges form Eocene to Recent. The Benin Formation is the youngest in the lithostratigraphic succession, and comprises sandstone, grits, claystone and streaks of lignite. Its age ranges from Oligocene to Recent.

The Niger Delta is subtly disturbed at the surface but the subsurface is affected by large scale synsedimentary features such as growth faults, rollover anticlines and diapirs (Doust & Omatsola, 1990; Stacher, 1995). The structural style, both on regional and on the field scale, can be explained on the basis of influence of the ratio of sedimentation to subsidence rates. The different types of structures are namely, simple non-faulted anticline rollover structures, faulted rollover anticline with multiple growth faults, or anticline faults and complicated collapse crest structures (Evamy et al., 1978). Others are sub-parallel growth fault (k-block structures) and structural closures along the back of major growth faults (Figure 4).

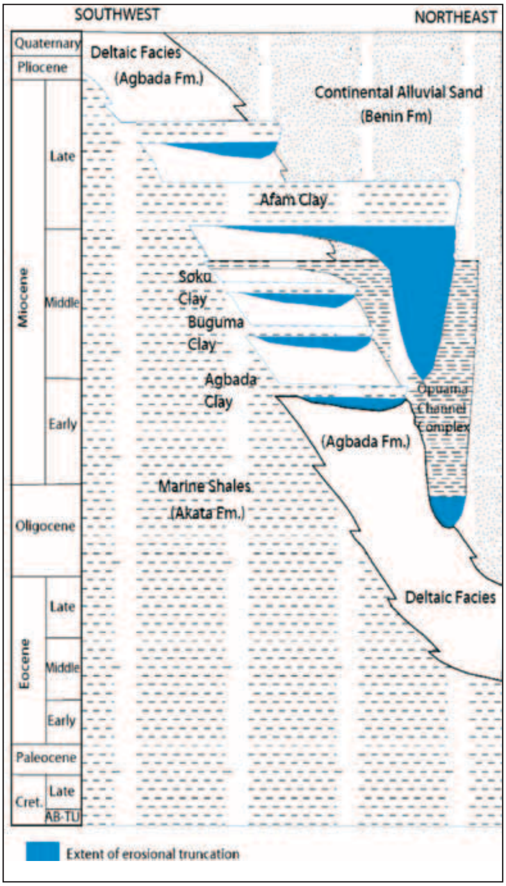

Figure 3. Stratigraphic column showing the three formations of the Niger Delta (After Shannon and Naylor (1989) and Doust and Omatsola 1990)

Continental-margin collapse structures exert control on depositional and stratigraphic patterns within the Niger Delta

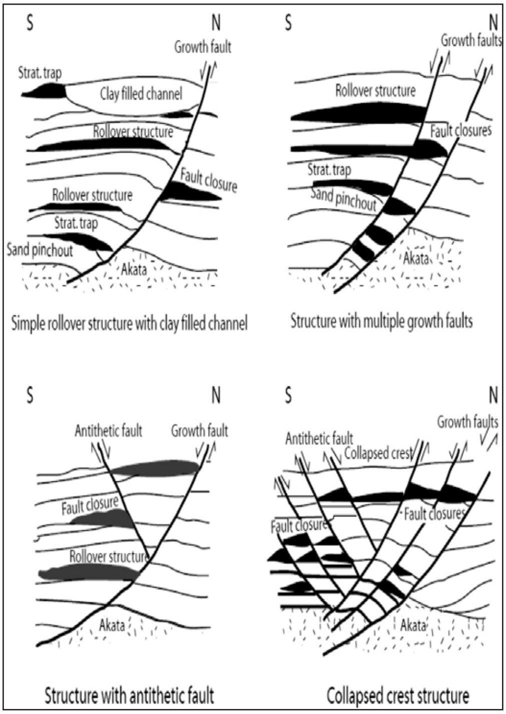

Figure 4. Examples of Niger Delta oil field structures and associated trap types (After Doust and Omatsola, 1990 and Stacher, 1995)

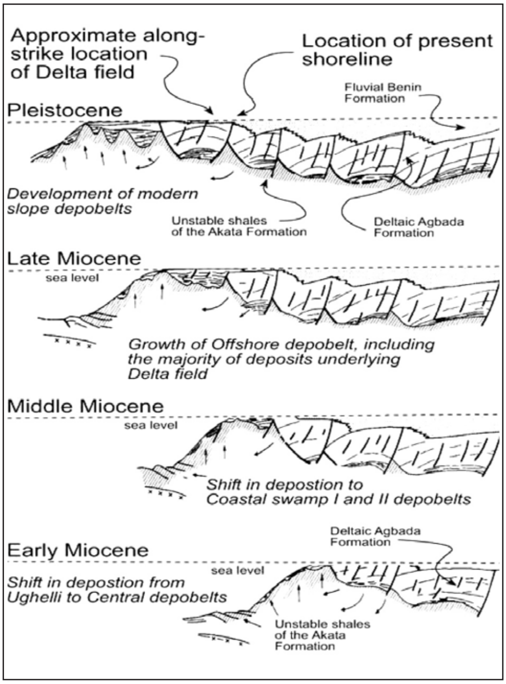

Figure 5. Schematic diagram showing the development of successive growth-fault-bounded depobelts during progradation of the unstable Niger Delta clastic wedge (After Knox and Omatsola, 1989)

clastic wedge (Figure 4). At the largest scale, these structures extend laterally along depositional strike across nearly the entire Niger Delta (hundreds of kilometers), defining "mega structures" of Evamy et al. (1978) and associated "depobelts" that are tens of kilometers wide perpendicular to the shoreline (Knox & Omatsola, 1989; Doust & Omatsola, 1990). Six regional depobelts were deposited during the 25 Ma - from Early Miocene to present (Figures 5 and 6). Depobelts tend to become finer-grained laterally away from areas of most rapid delta progradation and basinward away from areas of most rapid growth fault development (Doust & Omatsola, 1990). Smaller-scale faults and associated structural deformation accommodating collapse of depobelts tend to be more complex near the progradational axis of the delta than at its margins. This pattern of deposition continues still today, with extensional development of the growth faults on the modern shelf and slope, and compressional uplift near the toe of the slope (Armentrout et al., 2000; Hooper et al., 2002).

Materials and methods

GeoGraphix software was combined with well logs and seismic data using laid down procedures as shown in Figure 7. The top and base of the Agbada Formation were determined using the reflection characteristics of the 3-D seismic volume, stratigraphic indicators and the nature of the gamma ray curves that characterize this interval. The lithologies penetrated by the studied wells were determined by setting the cut-off point at 65 API on the gamma ray logs. Major and minor faults were identified, traced and assigned using the GeoGraphix software. The faults which were picked at an interval of 10 on the in-lines section were subsequently reflected on the cross-lines sections.

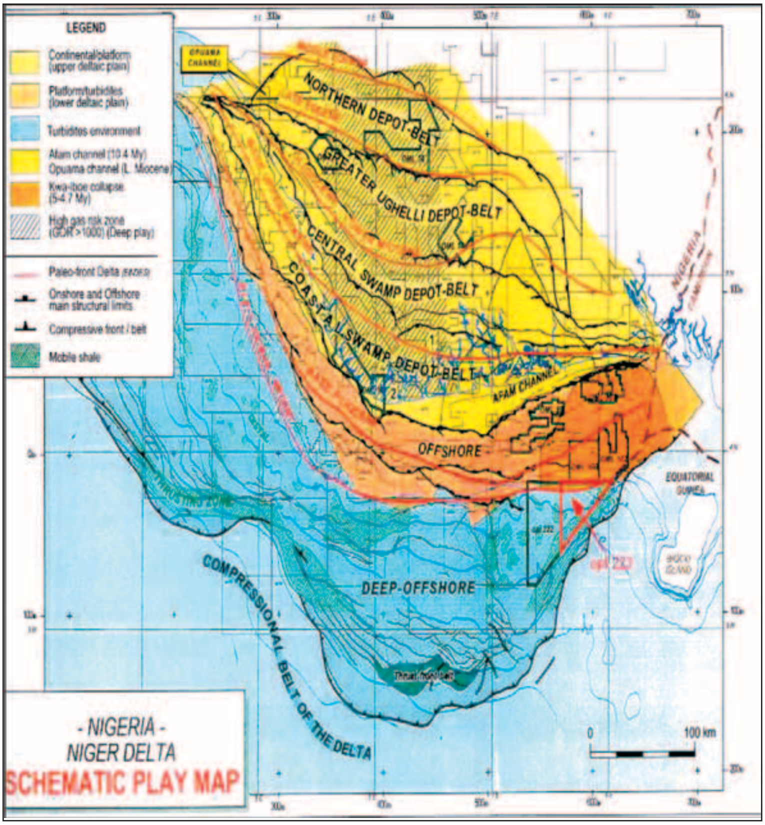

Figure 6. Map of Niger Delta showing the depobelts (After Weber, 1971)

Five horizons were defined on the top of sand bodies from the gamma ray and resistivity log sections (Figure 8). These horizons were later correlated in the 3-D seismic volume in order to produce time and depth structure map of the horizons. After correlation, time and depth structure maps were produced using the GeoAtlas module of the GeoGrapix software. The time-depth relationship was determined by plotting the checkshot data available for the well BLG1 using Microsoft Excel. Interpretation of depositional environments is based on the combination of the gamma ray log with resistivity log signatures which were corroborated by Schlumberger (1985) and Busch (1975) charts (Figures 9 and 10).

Results and discussions

Seismic Record and lithologic identification of the field

Reflection characteristics between 0 s and about 1.35 s two-way travel time observed from the seismic record show

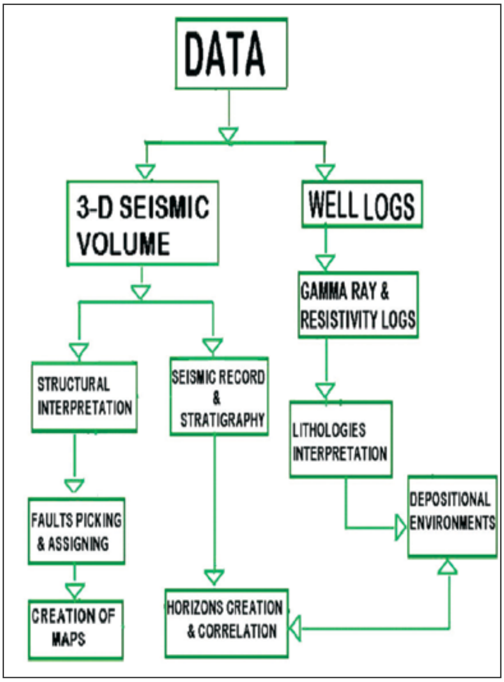

Figure 7. Work flowchart of study

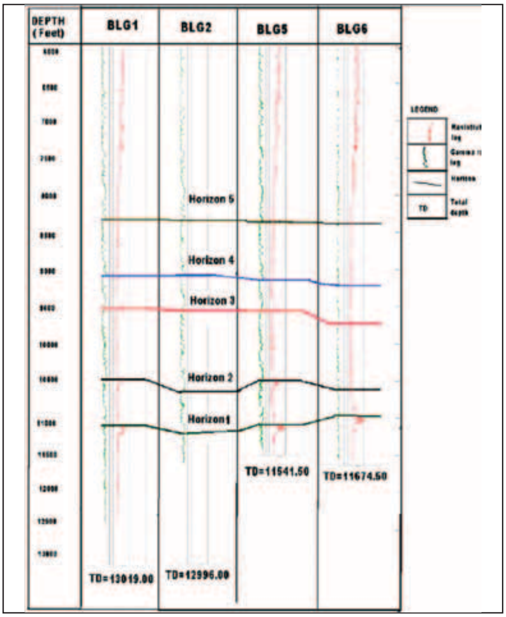

Figure 8. Cross section of the four wells showing horizons delineated on the top of sand bodies

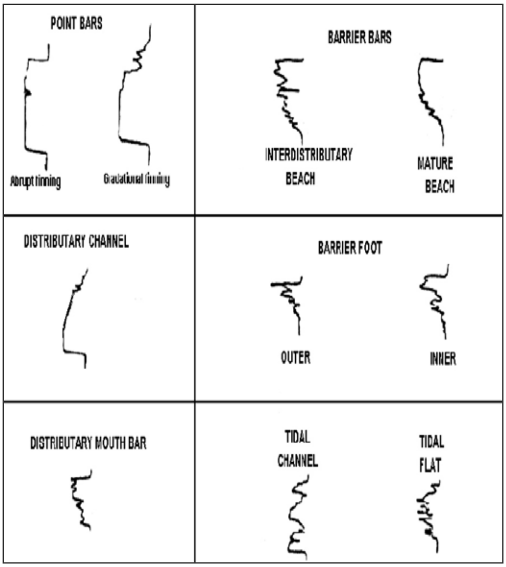

Figure 9. Recognition of depositional environments using gamma ray logs from deltaic reservoirs (After: Schlumberger, 1985)

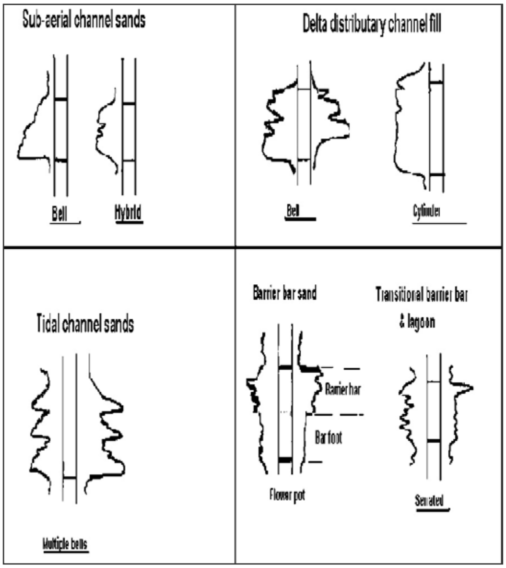

Figure 10. Assortment of gamma ray and resistivity log shapes suggestive of depositional environment (After: Busch, 1975)

a characteristics low amplitude, parallel, and discontinuous reflection patterns of the field (Figure 11). Based on regional studies and the uniformly blocky, low-value gamma-ray patterns observed within this interval, this portion can be inferred as the Benin Formation (Weber, 1971; Orife & Avbovbo, 1982; Doust & Omatsola 1990; Diedjomahor et al., 2002; Larue & Legare, 2004; Obiora, 2006). The reflection interval between 1.35 s to 2.8 s two-way travel time, consist of parallel and high amplitude reflections that is diagnostic of Agbada Formation (Figure 11). Below the 2.8 s two way travel time, are chaotic, low amplitude reflections interpreted as the Akata Formation.

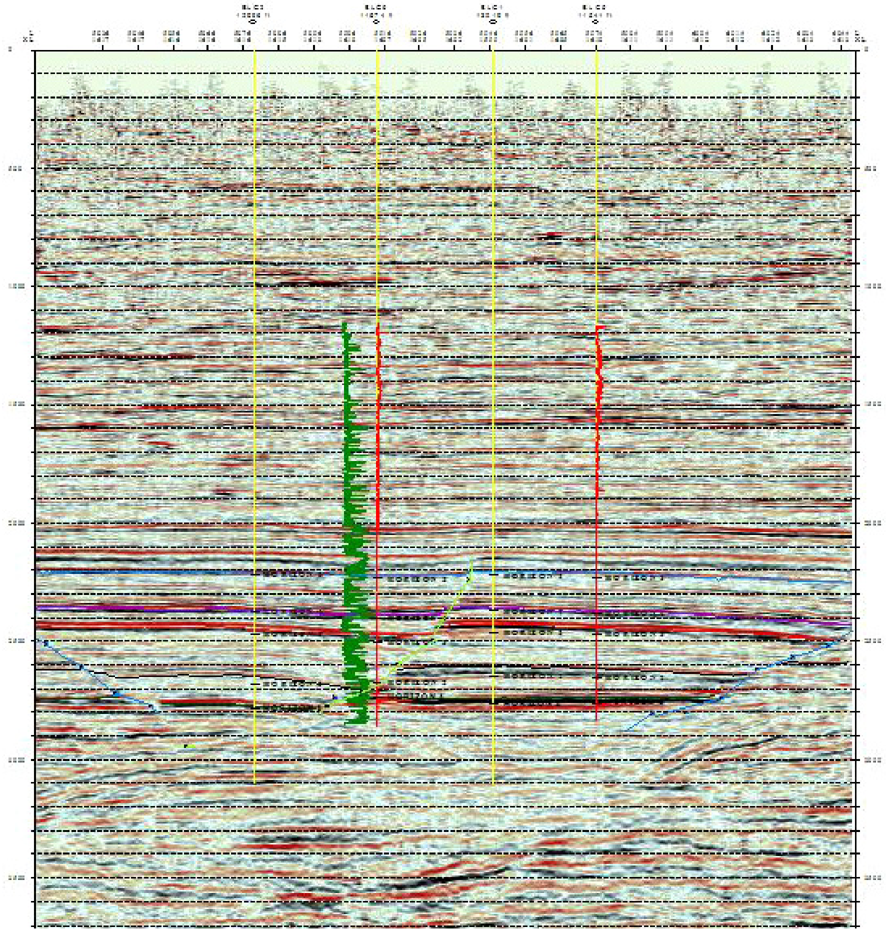

Figure 11. Seismic section showing the four wells and their respective gamma ray and resistivity logs, stratigraphy, faults, horizons and seismic reflection characteristics of the study area.

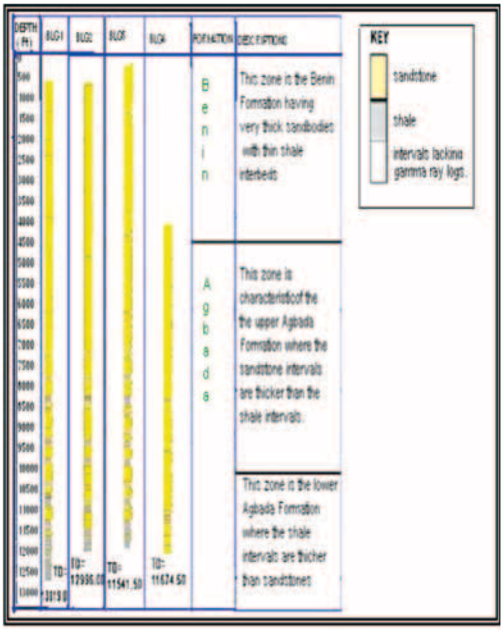

Figure 12. Lithology logs of the Tomboy Field

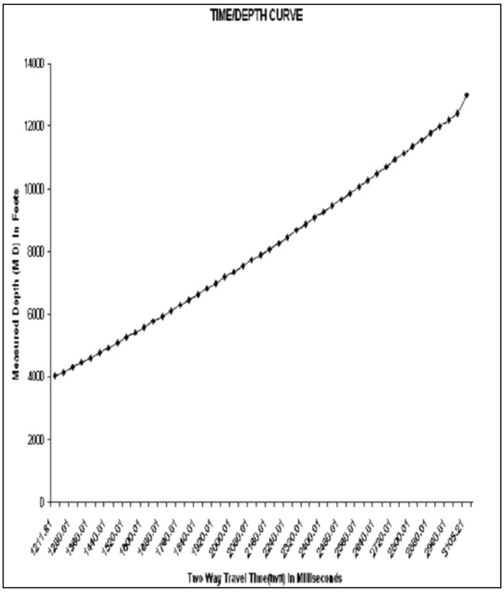

Figure 13. Plot of depth against two ways travel time (TWT) in milliseconds

The four wells located within the field, penetrated two different lithological zones. The first zone lies between the depth intervals 0ft to 5076 ft (1538.18 m), and comprised mainly thick sand bodies with few very thin shale interbeds (Figure 12.). The second zone extends from the depth of 5076 ft (1538.18 m) to about 12900 ft (3909.09 m) and can be regrouped into upper and lower parts. The upper part shows a characteristic where the sandstone intervals are thicker than the shale, whereas in the lower part, a reversed situation is the case. This zone is equivalent to the zone of 1.35 s to 2.80 s two ways travel time, observed from the seismic record and can be assigned to the Agbada Formation (Doust & Omatsola, 1990; Owoyemi, 2004).

Time and depth structural maps

Time and depth structural contour maps were produced for the five horizons defined on top of sand bodies , namely, H1 to H5 (Figure 8). Both types of structural contour maps show similar structural relationship. This linear relationship was also corroborated by the linear curve observed from the plot of depth against time using the check shot data of the well BLG1 (Figure 13).

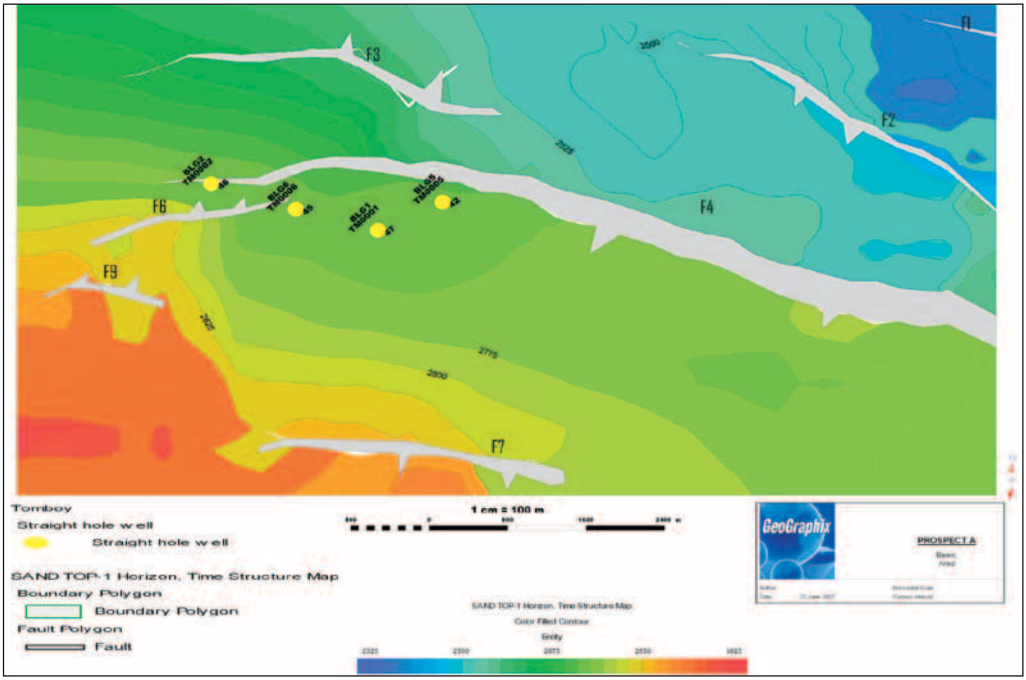

Figure 14. Time Structure Map of Horizon 1

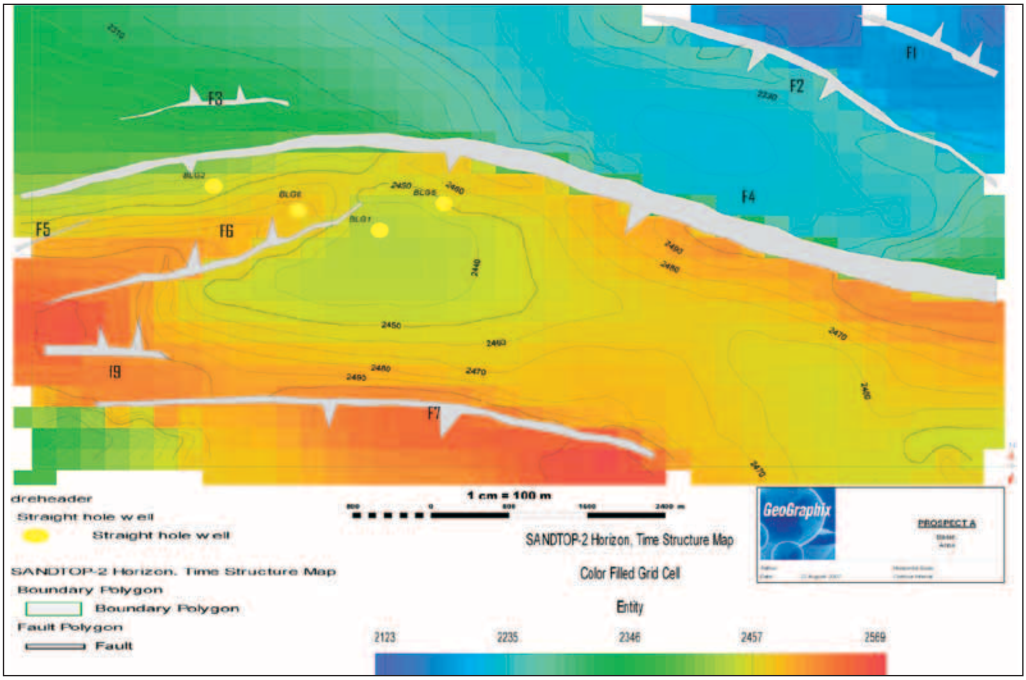

Figure 15. Time Structure Map of Horizon 2

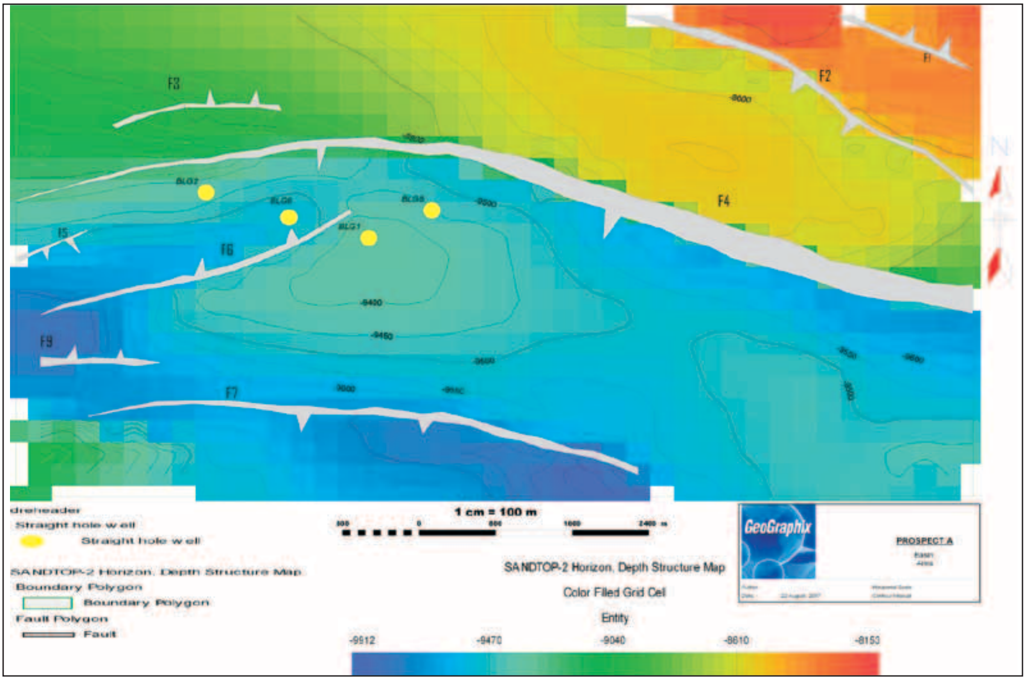

Figure 16. Depth structure map of Horizon 2

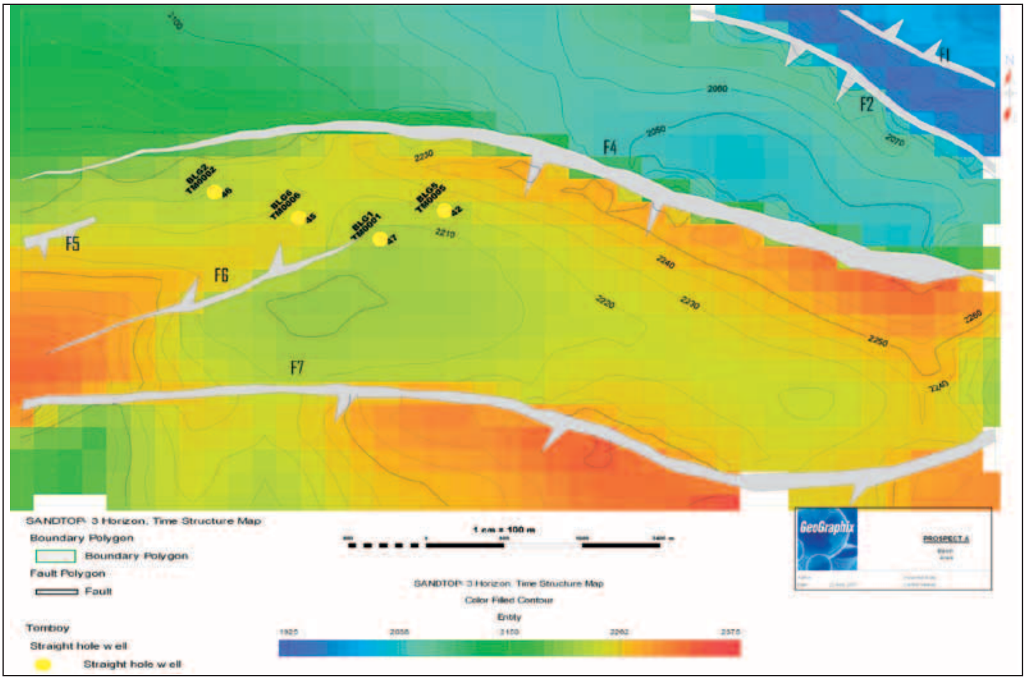

Figure 17. Time Structure Map of Horizon 3

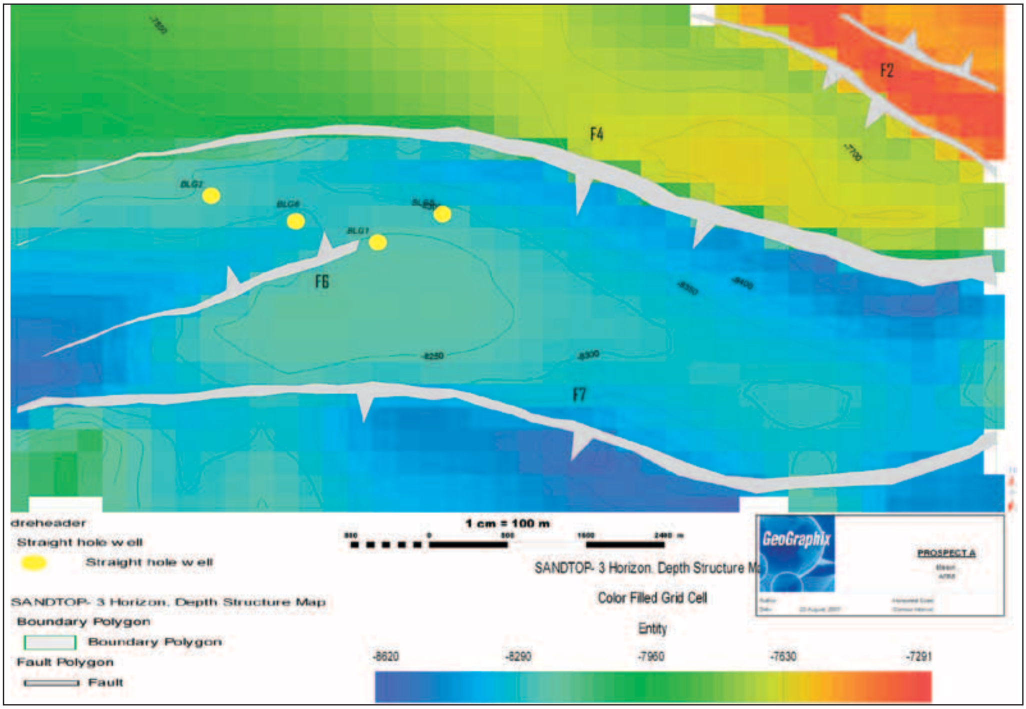

Figure 18. Depth Structure Map of Horizon 3

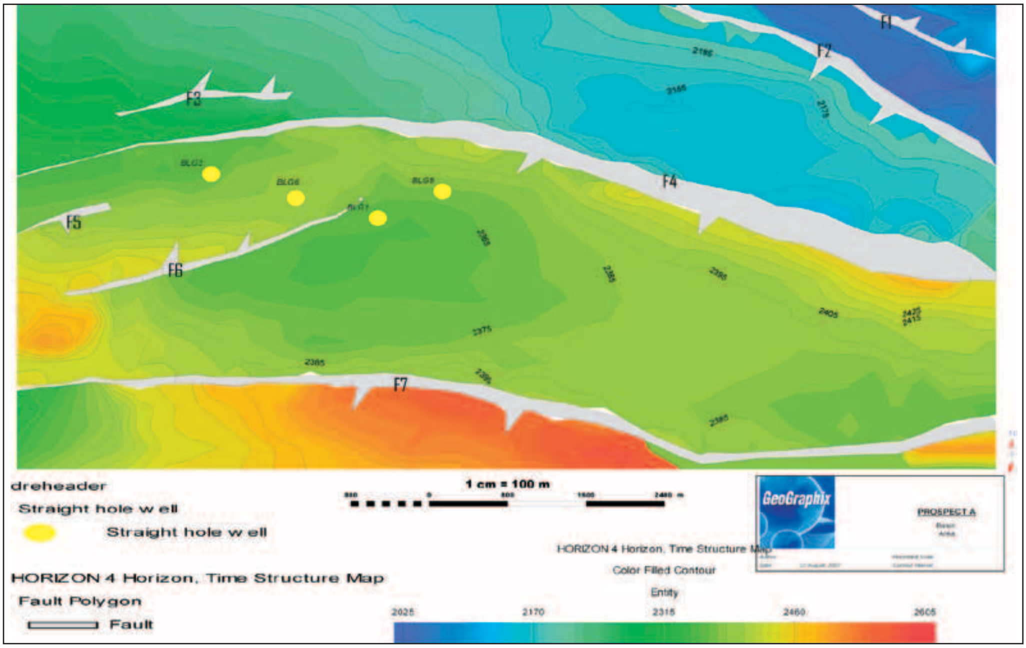

Figure 19. Time Structure Map of Horizon 4

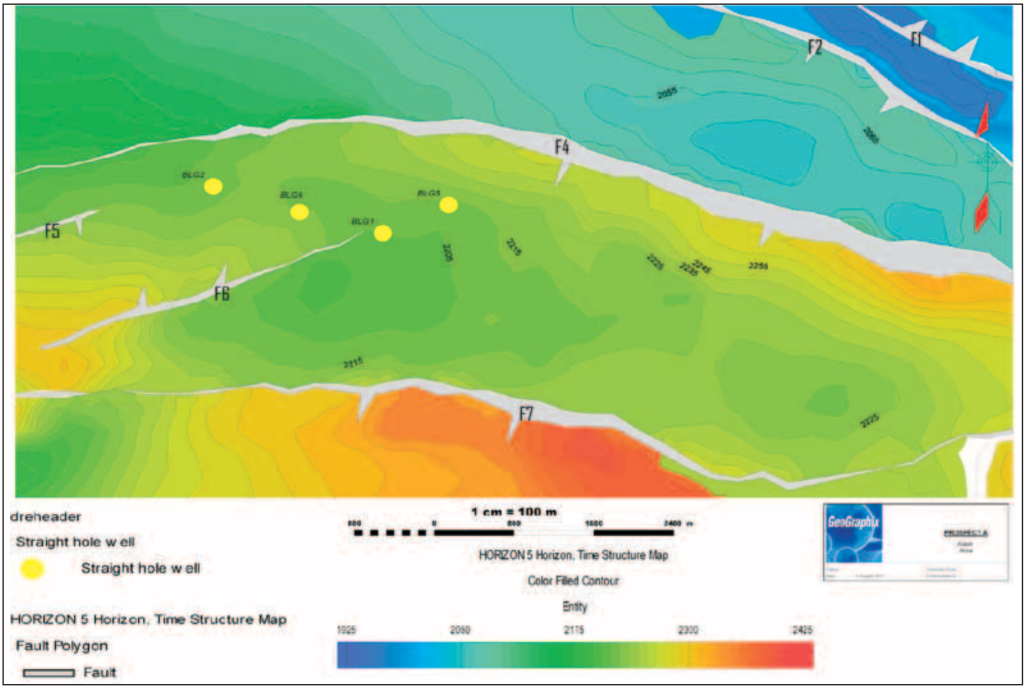

Figure 20. Time Structure Map of Horizon 5

The time and depth structure contour maps show system of differently oriented growth faults F1 to F7 (Figures 14–20). Faults F4 and F7 are the major growth faults, dipping towards southwest and are quite extensive. The fault F4 lies centrally within the mapped area and extends up to 85 % of the entire breadth of the mapped area. A rollover anticline formed as a result of deformation of the sediments deposited on the downthrown block of the fault F4. The fault F7, is also extensive and shows sub-parallel relationship with the fault F4. This sub-parallel relationship is sustained in all the structural contour maps. The fault F4 is observed to be closer to the shoreline and can be interpreted as the active fault, while the F7 is inactive fault, but must have been active in the past and located in offshore direction of the F4. Antithetic faults are F1, F3 and F6, and synthetic faults are F2 and F5, and occur at different positions, at the edge of the mapped area (Figures 14–20).

Sealing Potential and Play Prospect of the Study Area

Evidence of growth faulting and "rollover" anticline associated with the Tomboy Field can be deduced from the time and depth structural contour maps (Figures 14 to 20). The trapping potential of the field can be attributed to faults or anticlines, acting either as fault assisted or anticline closures respectively (Orife & Avbovbo, 1982; Sales, 1997). Anticlinal and fault assisted closures are regarded as good hydrocarbon prospect areas in the Niger Delta (Weber & Daukoru, 1975). Trapping of hydrocarbons in an anticline is simply by means of closure which may be dependent or independent on faults. The rollover anticlines are formed on the downthrown block of the fault F4, which indicate structural closure in these areas (Figures 14–20).

The sealing capability of the faults is dependent on the amount of throws and shale/clay smeared along the fault planes (Busch, 1975; Weber & Daukoru, 1975). According to Weber & Daukoru (1975), faults can be sealing if either the throws are less than 492 ft (150 m), or the amount shale/clay smeared along the fault planes is greater than 25 %. The average throws of the major faults F4 and F7 calculated are 570.8 ft (173 m) and 511.0 ft (154.85 m) respectively (Tables 1 and 2). Judging by the amount of throws, the faults F4 and F7 are not sealing. However, they are probably sealing, considering the amount of shale/clay smeared along the fault plane. Generally, in the Niger Delta, as reported by Weber & Daukoru (1975), the soft and over- pressured Akata Shale, in most cases rises up to fill the fault zone, thus enhancing their sealing capabilities.

Table 1. Table showing throws of fault F4

HORIZONS	Downthrow Depth/feet	Upthrow Depth/feet	Throw of Fault
Horizon 1	1029.7	9787.5	505.8
Horizon 2	9833.9	9251.3	582.6
Horizon 3	9185.9	8650.0	535.9
Horizon 4	9099.1	8423.6	675.5
Horizon 5	8442.1	7887.7	554.4

Average: 570.8

Table 2. Table showing throws of fault F7

HORIZONS	Downthrow Depth/feet	Upthrow Depth/feet	Throw of Fault
Horizon 1	10767.0	11072.9	305.7
Horizon 2	10216.2	10672.9	456.7
Horizon 3	9367.07	100035.07	668.0
Horizon 4	9034.96	9327.47	592.5
Horizon 5	8302.8	8834.93	531.1

Average: 511.0

It can be deduced from this study that the wells were located to target the rollover anticline formed on the downthrown side of the fault F4 (Figures 14–20). The oil and gas reserves recoverable deduced from the time and depth structure maps vary widely (Weber & Daukoru, 1975). The height of oil above the spill- point and the geographic extent of oil pool are directly related to the type of closure in which the hydrocarbons are trapped. Individual prospects of the closures, as illustrated in the Figures 14 to 20, can be ascribed as good prospect (Weber, 1971).

Depositional environment

In the absence of biostratigraphic and other well data, a combination of gamma ray and resistivity curve signatures were used to deduce the depositional environments based on their characteristic patterns from mainly the well BLG 1.

Various depositional environments including point bars, distributary channel, distributary mouth bar, barrier bar, regressive sand, tidal flat, barrier foot and tidal channel fill were identified within the subsurface of the Tomboy Field (Figures 21a–21e). These are based on log characteristics and details as discussed in Adesina (2007).

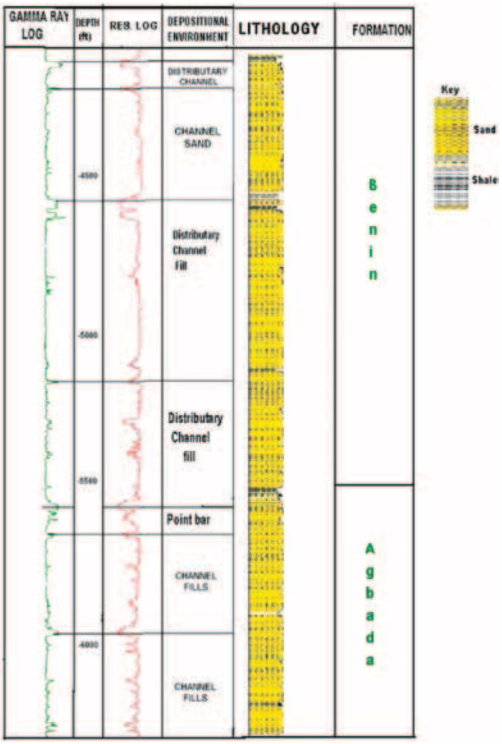

Figure 21a. Gamma ray and Resistivity Logs showing depositional environments from depth interval between 4000 ft (1363.63 m) to 6500 ft (1969.69 m) within well BLG1.

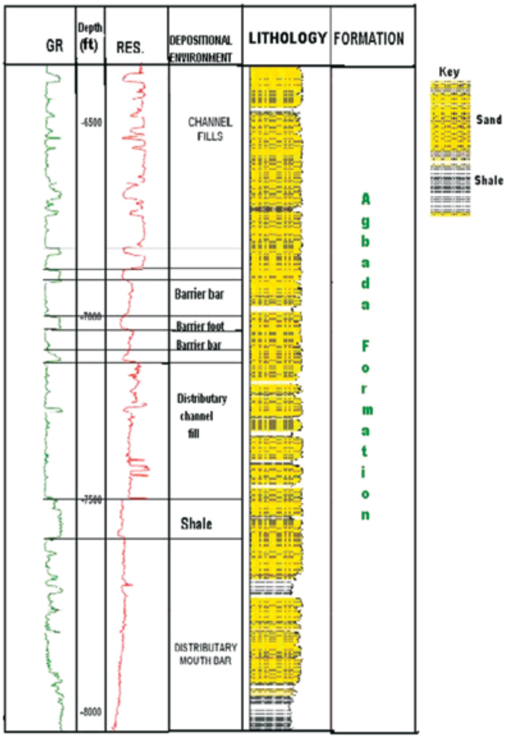

Figure 21b. Gamma ray and Resistivity Logs showing depositional environments from depth interval between 6500 ft (1969.69 m) to 8000 ft (2424.24 m) within well BLG1

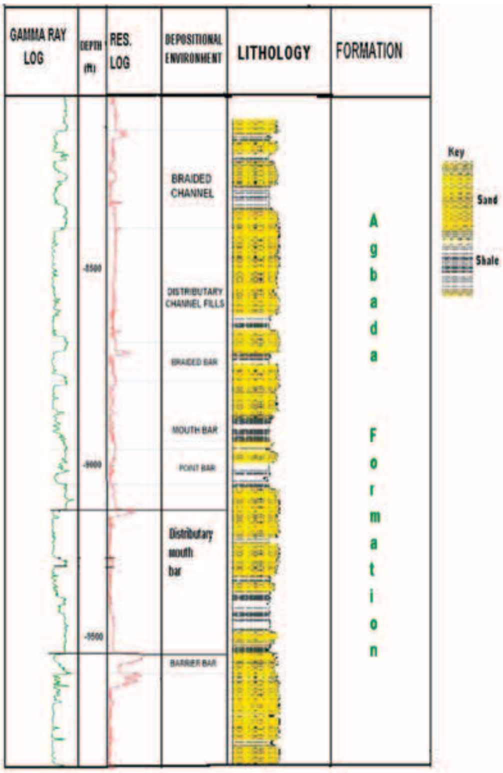

Figure 21c. Gamma ray and Resistivity Logs showing depositional environments from depth interval between 8000 ft (2424.24 m) to 10000 ft (3030.30 m) within well BLG1

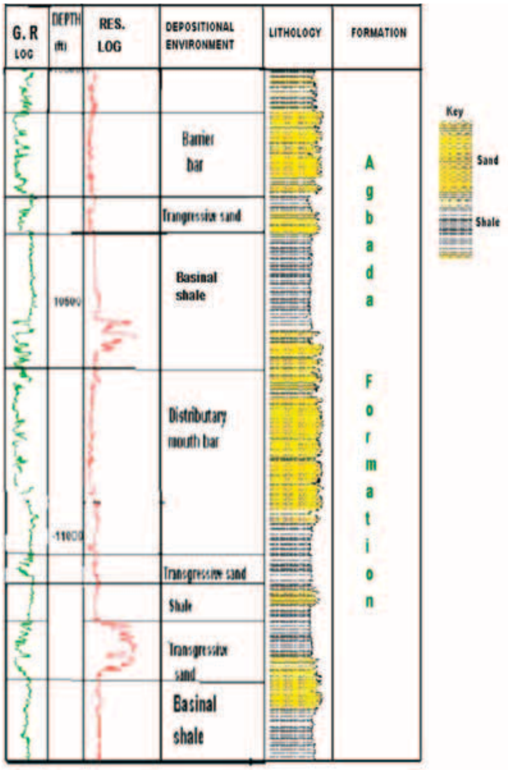

Figure 21d. Gamma ray and Resistivity Logs showing depositional environments from depth interval between 10000 ft (3030.3 m) to 11500 ft (3484.84 m) within well BLG1.

CONCLUSIONS

Seismic and well log data have been used to illustrate structural characteristics of identified sand bodies within the subsurface of the Tomboy field. This was made possible by creating time and depth structural contour maps of five horizons using the GeoGraphix interpretational tool. The time and depth structure maps show subsurface structural geometry and possible hydrocarbon trapping potential. Two major growth faults, namely F4 and F7, were observed to extend throughout the entire mapped area. The F4 is the active growth fault located near the shoreline, while F7 is an older inactive fault located offshore which must have been active in the past. The rollover anticline exists at the down-thrown block of the fault F4, which is suggestive of probable hydrocarbon accumulation potential of the sand bodies. The depositional environments identified were barrier bar, channel fill, tidal flat, tidal channel, point bar, distributary mouth bar and tidal ridge. These can serve as reservoirs for the accumulation of oil and gas.

It can be deduced from this study that the four wells located in the Tomboy field were drilled to target the rollover anticline formed on the downthrown block of the fault F4. This study, however, can provide additional information for precise well placement in further exploration and production of oil and gas.

Within the limits of the available data, it is recommended that further studies should include integration of velocity (check shot) and biostratigraphic data of all the wells. This will provide more reliable data for interpretation of the depositional environments.

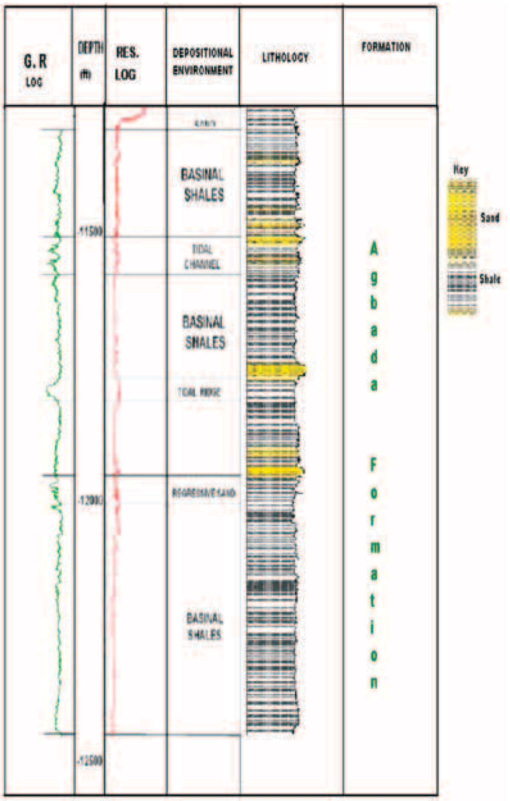

Figure 21e. Gamma ray and Resistivity Logs showing depositional environments from depth interval between 11500 ft (3484.84 m) to 12500 ft (3787.87 m) within well BLG1.

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