

3-D Seismic Interpretation and Structural Analysis of Ossu Oil Field, Northern Depobelt, Onshore Niger Delta, Nigeria.

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ABSTRACT

Seismic interpretation in an area seriously affected by complex structural deformation is typically difficult and strongly model-driven because of problems associated with imaging. Within the Ossu field, the Agbada Formation consists of multiple vertically-stacked reservoir sequences. The objectives of this work are to illustrate the processes of iterative seismic interpretation and structural modeling and to show how 3-D seismic data acquired in the study area was used in imaging sub-surface structures.

A multi-disciplinary approach which included petrophysics, seismic, and volumetric methods were undertaken to achieve these objectives. A combination of structural based geometric models with seismic and well data was used to constrain the interpretation. Results of this study revealed a complex pattern of subsurface structures with the northern area having predominantly widely spread simple rollover structures bounded by growth faults. Faulted rollover anticlines prevail in the middle zone while the southern area is characterized by collapsed crest structures. The -7480ft sand contains non-associated oil trapped in annealment phase trap while the -4540ft sand contains associated oil. The oil in reservoir A is not in commercial quantity; whereas only about 1.7 million barrels is recoverable from the estimated 8.6 million barrels for reservoir I. Key exploration risk is that growth-faulted anticlinal traps are segmented by normal faults.

(Keywords: structural interpretation, Ossu field, Niger Delta, seismic, growth faults)

INTRODUCTION

The Ossu oil field is located onshore Niger Delta, some 55 km south of Onitsha in the southwestern sector and straddles at deeper levels to the west

into the concession border with Shell. The Ossu field is located approximately 4 km to the west of the Izombe field at an elevation of 25m above mean sea level in a drowned river valley affected by seasonal flooding which limits the access to the field during the rainy season (Figure 1).

The Ossu field rollover structure is situated in the distal part of the northern depositional belt of the Niger Delta. The producing sequence (4500 – 8500ft tvd ss) consists of fourteen stacked hydrocarbon reservoirs characterized by large gas caps with underlying thin oil rims (10ft – 70ft). A system of antithetic and synthetic normal faults compartmentalizes the reservoirs below 5700ft tvdss (true vertical depth subsea) into several blocks of variable sizes.

Adedokun (1981) studied the petrology, provenance and depositional environments of the reservoir sandstones of Ossu–Izombe Oil field. Esedo and Ozumba (2005) delineated the structural styles in the nearby Oguta North Prospect. They noted that the main risks associated with this prospect include lack of amplitude support in the main reservoirs, possible fault seal failure and the lateral extent of some of the reservoirs. An integrated seismic interpretation, petrophysical evaluation, and volumetric approach were therefore used to delineate the structures and estimate the possible reserves contained in the Ossu field.

Geological Framework

The geology, stratigraphy and structure of the Niger delta basin have been extensively discussed in several key publications (Short and Stauble, 1967; Merki, 1971; Weberand and Daukoru, 1975; Avbovbo, 1978; Evamyetal, 1978; Whiteman, 1976; Owoyemi and Brain, 2006; Bilotti and Shaw, 2005).

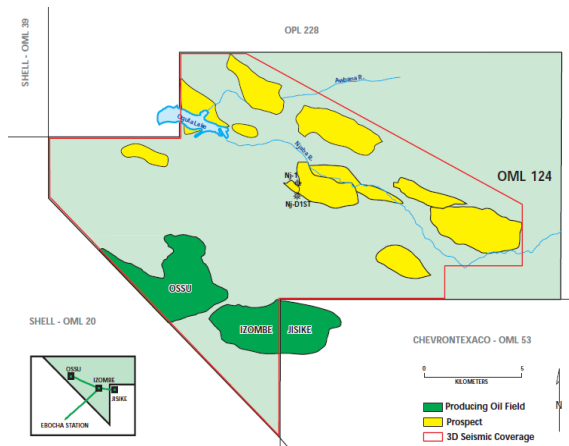


Figure 1: Production and Prospectivity Map showing the location of the Ossu Field of OML124 Oil Block, and the 3-D Seismic Survey Coverage.

The Niger delta basin is situated on the continental margin of the Gulf of Guinea between latitude 3° and 6°N and longitude 5° and 8°E. Figure 2 is the geology map of Niger delta basin, showing regional structural elements and depobelts of the Niger delta basin.

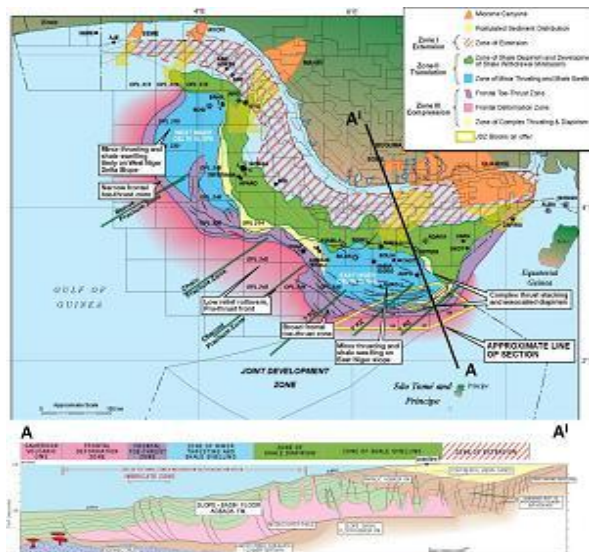


Figure 2: Regional Structural Elements and Depobelts of the Niger Delta Basin (from van den Beukel & Larroque, 1993).

The areal extent of the Niger delta is about 75000km² with a clastic fill of about 12000m. It ranks amongst the world's most prolific petroleum producing tertiary deltas that together account for about 5% of the world's oil and gas reserves.

Sedimentation in the depobelts is a function of sediment supply and of accommodation space created by basement subsidence and growth faulting. Growth faults, triggered by a pene-contemporaneous deformation of deltaic sediments are the dominant structural features in the Niger delta. They are generated by rapid sedimentation load and gravitational instability of the Agbada sediment pile accumulating on the mobile undercompacted Akata shales. Toe thrusting at the delta front, lateral flow and extrusion of the Akata pro-delta shales during growth faulting and related extension also account for the diapiric structures on the continental slope of the Niger delta in front of the prograding depocenter with paralic sediments (Doust and Omatsola, 1990; Reijers, 1996).

Three major depositional cycles have been identified within Tertiary Niger Delta deposits (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in late Paleocene to Eocene time, reflects the progradation of a "true" delta, with an arcuate, wave and tide dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990) also called depocentres or megasequences, separated by major syn-sedimentary fault zones (Figure 2).

The Niger Delta evolved in a protracted style where subsidence and sedimentation within a depobelt may have been facilitated by large scale withdrawal and seaward movement of undercompacted and geopressed marine shales under the weight of advancing paralic clastic wedge (Doust and Omatsola, 1990). At a certain stage however, further subsidence and sedimentation could no longer be accommodated and the focus of deposition shifted basin ward to form a new depobelt. Similarly, syn-sedimentary and most post sedimentary faulting ceased with the abandoned depobelt. A depobelt therefore, forms the structurally and depositionally most active portion of the delta at each stage of its development.

These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basin-ward (Doust and Omatsola, 1990).

MATERIALS AND METHODS

Data Base

In this study, seismic interpretation and structural analysis of the OML 124 oil block was confined to the Ossu Field. The main data used in this study includes a 3-D seismic grid augmented by a few wells and outcrop data from the basin margins. In the Ossu field, twenty-two (22) seismic lines (average spacing of 2km) with a total length of over 350km were shot. In addition, six wells were available: A-1, A-2, A-3, A-4, A-5 and A-6, together with checkshot data. Published surface geological maps and reports used in the structural analysis include the 1:50,000 geologic map of Niger Delta basin which provided the regional outcrop data and structural units of Niger Delta basin. In addition, the 1:50,000 geologic map of Niger Delta province provided outcrop patterns and bed orientations.

A synthetic seismogram was generated using sonic and density logs from Ossu_A₁ with checkshot from the same well. Generally, the seismic-to-well tie is good and has been achieved with a -4 ms time shift. This tie formed the first step in picking events, which corresponded to the tops of the sands for interpretation. Mapping of the seismic reflections, picking of faults, loop tying were carried out manually. A total of three events corresponding to the tops of reservoir sands in Ossu field were mapped. Time to depth conversion of the mapped time events was carried out using a velocity model based on the Ossu 3-D migration velocities calibrated using the velocity model (T-Z) from Ossu A-2.

RESULTS AND INTERPRETATION

Seismic Interpretation

Seismic interpretation of Ossu field revealed that the structural style that characterize the field were mainly back-to-back structures, growth faults, synthetic and antithetic faults, shale diapirs and collapsed crested structures; see interpretations on lines 345, 395, 425 and 450, and the developed structural model (Figures 3 and 4). All these structures are consistent with the structural styles existing in the Niger Delta oil province as discussed by Evamy, et al., 1978; Doust and Omatsola, 1990, among others.

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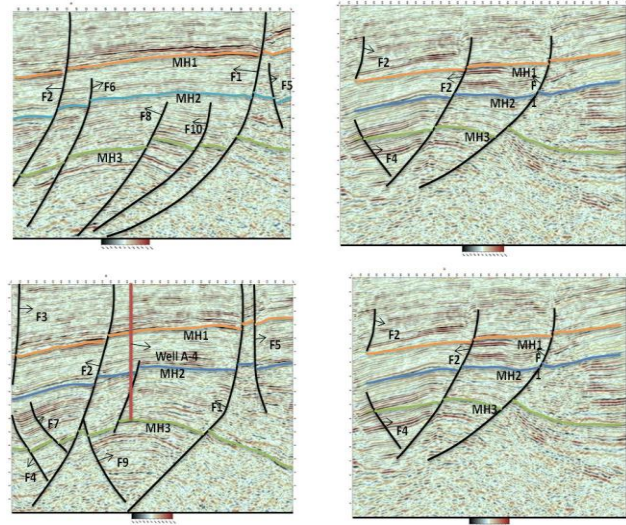


Figure 3: Interpretation of Inlines (a) 345, (b) 425, (c) 395 and (d) 450, Showing Intense Faulting. (Note high-angle thick-skinned normal (synthetic growth) faults with rollover geometries and evidence of faulted rollover anticline, major growth faults with associated antithetic faults, and an evidence of back-to-back faulting as a result of the mobile Akata shale).

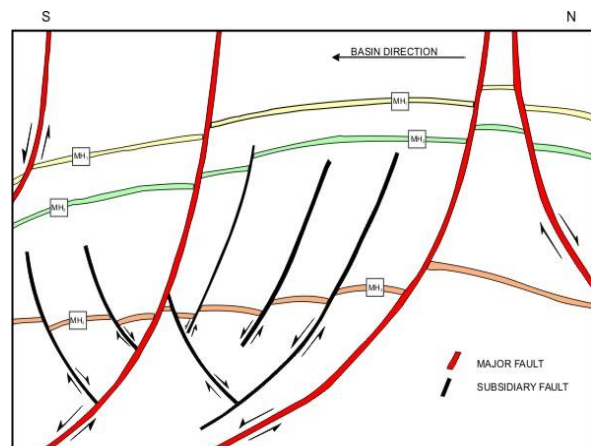


Figure 4: Structural Model based on Seismic and Geologic Observation, showing the Effects of the Major and Subsidiary Growth Faults on the Agbada Formation in the Ossu Field of OML 124. (Deformation is more pronounced in the hanging-wall sides of the major growth faults).

The presence of shale diapirs and collapsed crested structures exemplified by the top of -7480ft sand characterizes the Recent Niger Delta continental shelf. The existence of these structures in the Northern depobelt, points to the fact that this field was once a continental shelf during the Cenozoic Niger Delta Complex development as a regressive offlap sequence. Similarly, the funnel shaped motif of the reservoir H also emphasizes this fact (Esedo and Ozumba, 2004).

Structural deformation of top of -7480ft sand can be attributed to high energy deposition of fluvial sand by River Nun and gravitational slumping caused by piercing upward of shale from the base of the depobelt, giving rise to syn-depositional faulting and complex structures, respectively. However, from the time and depth maps of the -7480 sand (Figure 7), it can be deduced that the prospect is an anticlinal dip closure (annealment phase trap) flanked to the east and to the west by structurally high areas. These two high areas are good structural leads and require more work to define them; which may include acquiring more seismic data to the east and to the west of the field and detailed structural interpretation done on them to ascertain if a closure exist. Similarly, AVO analysis of the leads will help determine if the reservoir is saturated with brine or hydrocarbon. The structural interpretation and AVO analysis should be done before any well is drilled, to avoid the chances of losing the reservoir drive.

Petrophysical Interpretation

The petrophysical results (Table 1) revealed that though the -4540ft sand of well A-4 has a good porosity, it cannot be of commercial use as it has little hydrocarbon saturation (in percentage). Time and depth maps of the MH₁ horizon were produced in order to have an understanding of the shallow subsurface structures before proceeding with that of the target reservoir sand (-7480); see Figure 7.

These maps show that the main structures housing the hydrocarbon are growth faults and rollover anticlines. This is buttressed by the clear rollover anticlinal evidence on the correlation of the -4540ft sand (Figure 8). The maps also revealed that the top of the Agbada Formation is not densely faulted. The -7480ft sand of well A-4, located in Ossu field, has a porosity of 19% which was later corrected to 16.5% by the Density-

Neutron Crossplot (Figure 5). A porosity of 16.5% is good for a sandstone reservoir rock as discussed by Levorsen, 1967. This porosity value can be justified when compared with the volume of shale present in the reservoir, estimated at 35.8% from the Density-Neutron crossplot. The question of "if the well will be producible or not" was answered by the resistivity-porosity crossplot which showed a cluster of points below the 60% water saturation line (6). Therefore, the reservoir is producible.

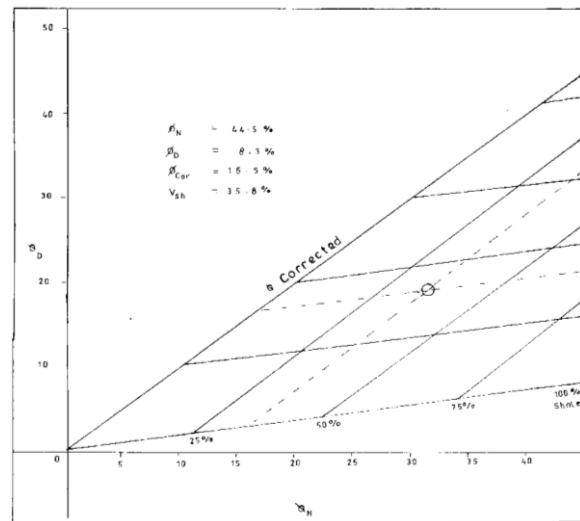


Figure 5: Density-Neutron crossplot of the payzone of Ossu field.

Similarly, the well log of reservoir H revealed a funnel-shape motif which is an indication of a coarsening up succession. This can be interpreted as a deltaic progradation or a shallow marine progradation (Van Wagoner et al., 1990), in a high energy depositional environment. This environment do not favor the existence of marine organisms which when they die, are incorporated into the sedimentary rock to form sedimentary organic matter which is a good source rock for hydrocarbon production. Marine organisms exist in a slack energy depositional environment. Therefore, one can infer that the oil was not formed in the reservoir but rather was migrated from the source rock to the reservoir where it was trapped.

Hydrocarbon Potential of the Payzone

Using a volumetric approach, the original oil in place, for the target reservoir, was estimated at

Table 1: Summary of the Petrophysical Evaluations. (The highlighted reservoirs (A, F, and I) represent horizon MH1, MH2, and MH3 that were mapped on the seismic section).

Reservoirs	Top	Base	NTG	Porosity	S _w (%)	S _h (%)	Contact	Fluid type
A	4540	4650	0.800	15	62.50	37.50	OWC@4588	Oil&Gas
B	4790	4820	1.000	48	35.50	64.50	GDT	Gas
C	4910	5010	0.700	29	60.00	40.00	OWT@4950	Oil
D	5210	5250	0.625	24	73.63	26.37	OWC@5230	Oil
E	5380	5410	0.667	24	97.45	2.55	ODT	Oil
F	5685	5730	0.625	23	52.53	47.47	GOC@5705	Oil&gas
G	5815	6000	0.630	24	91.07	8.93	OWC@5890	Oil
H	6580	6830	0.542	22	82.70	17.30	GOC@6590	Oil&gas
I	7480	7565	0.642	19	39.00	61.00	OWC@7530	Oil

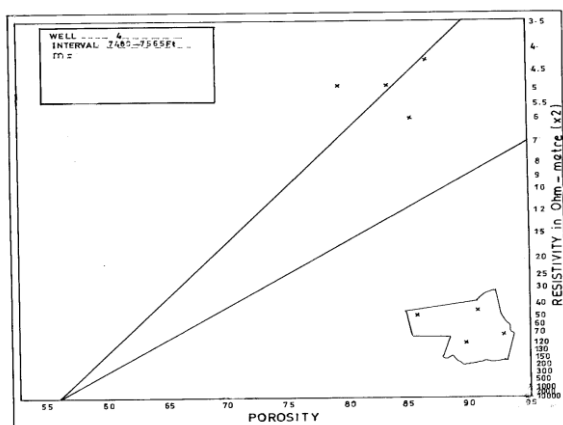


Figure 6: Resistivity-Porosity Cross Plot of the Pay Zone with the Cluster of the Points Below the 60% Water Saturation Line Encircled.

12.07 million barrels. This amount has a surface equivalence of about 8.62 million barrels.

This amount has a surface equivalent of about 8.62 million barrels. With an estimated recovery factor of 20%, only 1.7 million barrels can be produced from the surface equivalence of the reserve (Table 2). The low recovery factor can be attributed to lack of gas drive and appreciable water drive since the recovery factor is dependent on the drive mechanisms. Nevertheless, the primary production can be increased if improved oil recovery method (engineering technique that include water flood and enhance oil recovery) is used to recover the oil. A water flood can recover 5 to 50% of the remaining stock tank oil in place. The water must be compatible with the producing formation and not cause reactions that will decrease the permeability of the formation being

flooded. Also, the suspended solids that can plug the pores should be removed by filtration. Organic matter and bacteria that produce slimes should be neutralized by biocides. Similarly, oxygen should be removed from the water to prevent corrosion.

Table 2: Showing Volumetric Reservoir Data and Reserves for Reservoir I.

SAND (Reservoir I)	-7480Ft.
Gross, Rock Volume (GRV)	24087.9 acrefoot
Net-to-gross	64.2%
Water Saturation (S_w)	39%
Formation Volume Factor	1.4
Estimated Recovery factor	20%
Oil saturation	61%
Original Oil In Place	12,075,304 barrels
Stock Tank Oil in Place	8,625,217 barrels
Recoverable Reserve	1,725,043 barrels

DISCUSSION

Information extracted from the 3-D seismic data volume resulted in more understanding of the structural styles and architecture, and accurate delineation of reservoir blocks in the study area. The results suggest more development opportunities in the Ossu oil field of OML 124 (Oil Mining Lease). The proposed structural model shows that the F₁ and F₂ major growth faults and the numerous subsidiary synthetic and antithetic faults are syn-depositional. These faults affect the architecture of the sandstone bodies stacked in these intervals (i.e., the Agbada paralic sequence). Normal faults triggered by the

movement of deep-seated, overpressured, ductile, marine shale have deformed much of the Niger Delta clastic wedge (Doust and Omatsola, 1989). Many of these faults formed during delta progradation and were syn-depositional, affecting sediment dispersal. Fault growth was also accompanied by slope instability along the

continental margin. Faults flatten with depth onto a master detachment plane near the top of the over-pressured marine shales at the base of the Niger Delta succession. Structural complexity in local areas reflects the density and style of faulting. Simple structures, such as flank and crestal folds, occur along individual faults.

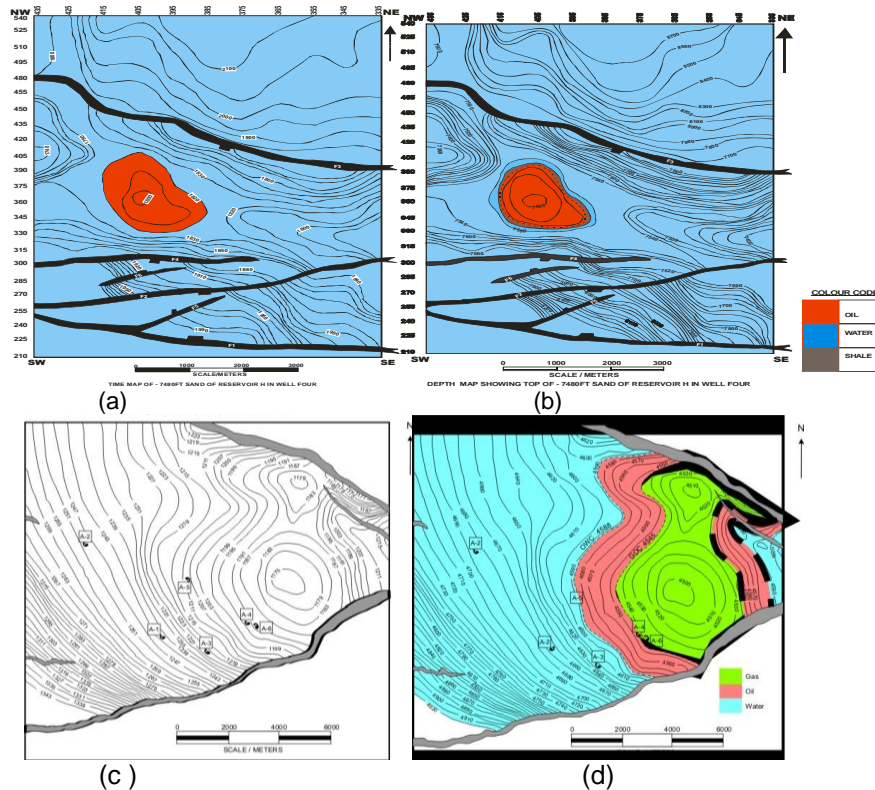


Figure 7: Structural Maps of the Study Area Showing (a) Time Map of -7480 sand, (b) Depth Map of -7480 sand, (c) Time Map of -4540ft sand, and (d) Depth map of -4540ft sand, showing the, F2 and F3 Major Faults and Three Subsidiary Faults.

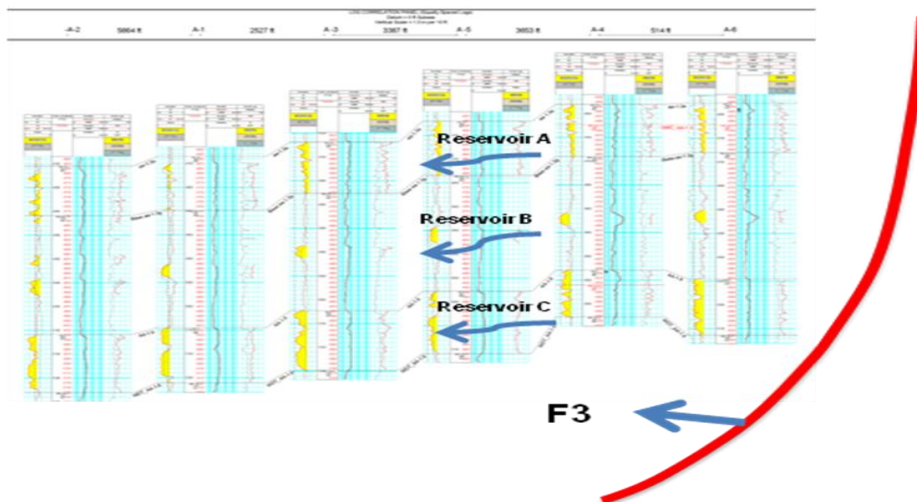


Figure 8: Well Log Regional Correlation in the Study area showing the Correlation of Reservoirs A, B, and C, which Revealed Evidence of Rollover Anticlinal Structures Bounded by the F3 Growth Fault (position inferred).

Hanging-wall rollover anticlines developed because of listric-fault geometry and differential loading of deltaic sediments above ductile shales. More complex structures, cut by swarms of faults with varying amounts of throw include collapsed-crest features with domal shape and strongly opposing fault dips at depth. For any given depobelt, gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapirs, rollover anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy and others, 1978; Xiao and Suppe, 1992). These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes.

In many parts of the older Northern half of the Delta the counter-regional fault is weakly developed or not developed at all apparently due to the small volume of the underlying mobile shale. Consequently the dominant structural style is the rollover structure. The intervening flank area is replaced by well developed macrostructures that provide for lateral translation of the extension. Where well and seismic control are limited, a process of iterative seismic interpretation, cross-section balancing, and structural map analysis may help guide the interpreter towards a reasonable 3-D structural geometry.

Pitfalls in interpretation include horizon misidentification and velocity effects. Pitfalls in cross-section balancing include 3-D movement patterns and seismic line orientation at an oblique angle to tectonic movement direction. With complex deformation, it may be especially difficult to find cross-sections aligned with the directions of both extensional and contractional movements. Despite these potential pitfalls, seismic interpretation and mapping can be used in structurally complex basins to outline structural trap geometries.

CONCLUSION

The seismic data volume resulted in better understanding of the structural styles, architecture, and in accurate delineation of reservoir blocks in the study area from the Niger Delta basin. The proposed structural model shows that the F3 and F2 major growth faults and the numerous subsidiary synthetic and antithetic

faults are syn-depositional. These faults affect the architecture of the sandstone bodies stacked in these intervals (i.e., the Agbada paralic sequence) with depth. We suggest more development opportunities in the northeast and southwest flanks of Ossu oil field as they show evidence of possible anticlinal closures. With the increasing demand for energy leading to the fluctuation of oil price, an average oil price of about 60 US dollars per barrel will generate about \$103,502,580 million US, from a primary production of 1.725 million barrels in the field.

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REFERENCES

1. Adedokun, O.A. 1981. "Petrology, Provenance and Depositional Environments of the Reservoir Sandstones of Ossu-Izombe Oilfield, Imo State, Nigeria". *Journal of Petroleum Geology*. 4(1):35-36.
2. Asquith, G. and Gibson, C. 1983. *Basic Well Log Analysis for Geologists*. The American Association of Geologists Petroleum Geologists: Tulsa, OK. 96-200.
3. Avbovbo, A.A. 1978. "Tertiary Lithostratigraphy of Niger Delta". *American Association of Petroleum Bulletin*. 62:295-300.
4. Bilotti, F. and J.H. Shaw. 2005. "Deepwater Niger Delta Fold and Thrust Belt modeled as a Critical – Taper Wedge: The Influence of Elevated Basal Fluid Pressure on Structural Styles". *AAPG Bulletin*. 89(11):1475-1491.
5. Doust, H. 1989. "The Niger Delta Hydrocarbon Potential: A Major Tertiary Niger Delta Province". *Proceedings of KNGMG Symposium, Coastal Lowstands, Geology and Geotechnology*. The Hague, Kluwer Acad. Publ.: Dordrecht. 22-25.
6. Doust, H. and Omatsola, E. 1990. "Niger Delta". In: Edwards, J. D., and Santogrossi, P.A. (editors). *Divergent/Passive Margin Basins, AAPG Memoir*. American Association of Petroleum Geologists: Tulsa, OK. 48:239-248.

7. Esedo, R. and Ozumba, B. 2004. "New Opportunity Identification in a Mature Basin: The Oguta North OML Prospect in 20, Niger Delta". *Proceedings of the 28th Annual SPE International Technical Conference and Exhibition*. Abuja, Nigeria. August 2-4, 2004; SPE 98812. *Journal of Petroleum Science and Engineering*. 1:91-104.
8. Evamy, B.D., Harembourne, J., Kamerling, P., Knaap, W.A., Molley, F.A., and Rowlands, P.H. 1978. "Hydrocarbon Habitat of the Tertiary Niger Delta". *AAPG Bulletin*. 62:1 –39.
9. Levorsen, A.I. 1967. *Geology of Production*. W.H Freeman and Company: New York, NY. 724.
10. Merki, P.I. 1972. "Structural Geology of Cenozoic Niger Delta". *First African Regional Geological Conference 1970; Proceedings*. Ibadan University Press, Ibadan, Nigeria. 251 –266.
11. Owoyemi, A.O. and Willis. 2006. "Depositional Patterns Across Syndepositional Normal Faults, Niger Delta, Nigeria". *Journal of Sedimentary Research*. 76:346-363.
12. Reijers, T.J.A., Petters, S.W., and Nwajide, C.S. 1997. "The Niger Delta Basin". In: Selley, R.C. (editor). *African Basins -Sedimentary Basin of the World 3*. Elsevier Science: Amsterdam, The Netherlands.151-172.
13. Tuttle, M.L.W., Charpentier, R.R., and Brownfield, M.E.1999. "The Niger Delta Basin Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa". Open-File Report 99-50-H. United States Geological Survey: Washington, D.C. 44.
14. Van Wagoner, J.C., Mitchum, R.M., Coampion, K.M., and Rahmanian, V.D. 1990. "Siliciclastic Sequence Geophysicists Stratigraphy in Well Logs, Cores, and Outcrops". *American Association of Petroleum Geologists Methods in Exploration Series*. 7:55.
15. Weber, K.J. and Daukoru, E.M. 1975. *Petroleum Geology of the Niger Delta: Proceedings of the 9th World Petroleum Congress*. Geology. Applied Science Publishers, Ltd.: London, UK. 2:210-221.
16. Weber, K.J, G. Mandl, W.F. Pilaar, F. Lechner, and R.G. Precious.1978. "The Role of Faults in Hydrocarbon Migration and Trapping in Nigerian Growth Fault Structures". *Offshore Technology Conference of Society of Petroleum Engineers of AME 10th Offshore Technology Conference Proceedings*. 1978. 4:2643 –2653 (OTC 3356).
17. Weber, K.J. 1987. "Hydrocarbon Distribution Patterns in Nigerian Growth Fault Structures Controlled by Structural Style and Stratigraphy". *Journal of Petroleum Science and Engineering*. 1:91-104.
18. Whiteman, A.J.1982. *Nigeria: Its Petroleum Geology: Resources and Potential*.1&2. Graham and Trotter: London, UK. 394.
19. Wiener, R.W., Helwig, J.A., and Rongpei, J. 1997. "Seismic Interpretation and Structural Analysis of the Rifted Thrust Belt, Jiangnan Basin, China". *The Leading Edge*. 60(8):1177 – 1183. Volume 1 and 2.
20. Xiao, H. and Suppe, J. 1992. "Origin of Rollover". *American Association of Petroleum Geologists Bulletin*. 76:509-229.

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