Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/pc
Petroleum & Coal 52 (4) 307-315, 2010

PROSPECTIVITY EVALUATION OF "USSO" FIELD, ONSHORE NIGER DELTA BASIN, USING 3-D SEISMIC AND WELL LOG DATA

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Received August 2, 2010, Accepted October 15, 2010

Abstract

Prospectivity evaluation of the "Usso" field, Onshore Niger Delta was carried out using 3-D seismic and well log data. The target for this study was the -7480ft sand of A-4 well in ""Usso" field which from petrophysical evaluation contained a reasonable percentage of hydrocarbons. The objectives of this study are to show the ability of seismic data to image subsurface structures, explore deeper prospects, to ascertain if the structures and their closures are favourable for hydrocarbon accumulation and to obtain reserve estimates which can help to determine the economics of the field. Within the Northern depobelt, the Agbada Formation consists of vertically stacked reservoir sequences with reservoir thicknesses from the correlating intervals ranging from 25–250 ft. The structural style is dominated by widely spaced simple rollover structures bounded by growth faults .The -7480ft sand was interpreted to contain non-associated oil trapped in an annealment phase trap. Only about 77.6mb can be recovered from the original oil in place which was estimated at 1,207.5mb. This is attributed to insufficient drive mechanism.

Keywords: Prospectivity; Seismic; petrophysics; volumetrics; Niger Delta.

1. Introduction

Several workers have carried out structural analysis in different sedimentary basins worldwide using seismic and well log data [1-2]. Similarly, structural interpretation, petrology, provenance and depositional environments studies of the reservoir sandstones of part of the Northern depobelt was carried out to determine the hydrocarbon potentials of the area by various authors [3-4]. The Northern depobelt is the oldest depobelt in the Niger delta rich hydrocarbon province. The paralic clastic Agbada Formation is the hydrocarbon prospective sequence in the Niger delta. It is characterized by an inter-digitization of sand, silts and clays in various proportion and thicknesses, demonstrating a cyclic sequence of off-lap units. These parallic clastics are the truly deltaic portions of the sequence and were deposited in a number of deltaic-front, delta-topset and fluvio-deltaic environment. The alternation of fine and coarse clastics provides multiple reservoir-seal couplets.

The '"Usso" field is located approximately 4km to the west of Izombe field (Northern depobelt), at an elevation of 25m above mean sea level. It covers an area of approximately 2,300 acres in the south-western part of OML 124 (figure1). Ever since the discovery of the field in 1973, the area of this field is found to contain reasonable accumulation of hydrocarbon. The study presented in this paper is part of the effort to use 3-D seismic method to indicate favorable areas in which exploration can be concentrated especially at deeper levels. Recent 3-D exploration of part of this field has shown that part of this field contains a rollover structure situated in the distal part of the northern depositional belt of the Niger delta. The producing sequences (4500-8500ft tvdss) consist of fourteen stacked hydrocarbon reservoirs characterized by large gas caps with underlying thin oil rims (10ft-70ft).

This work is therefore aimed at showing the ability of seismic data to image sub-surface structures and to ascertain if the structures and their closures are favourable for hydrocarbon accumulation.

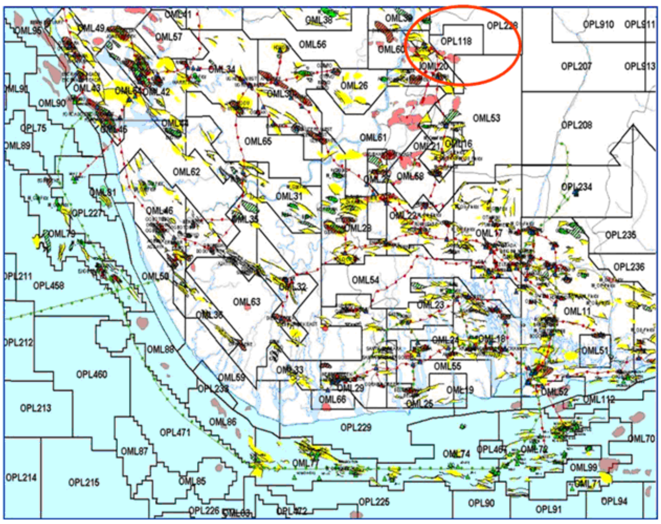

Fig.1 Prospectivity map of the Niger Delta basin, Nigeria showing the area of study

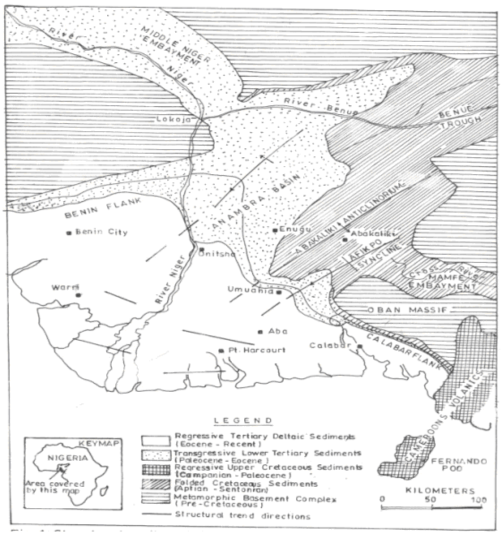

Fig.2 Structural units of Niger Delta basin (Short and Stauble 1967)

2. Background geology

The geology of the Niger delta has been extensively discussed by several authors [5-13]. The Niger Delta is situated on the Gulf of Guinea on the West Coast of Africa. It is located at the southeastern end of Nigeria, bordering the Atlantic Ocean and extends from about latitudes 4^0 to 6^0 N and longitudes 3^0 to 9^0E.The basin is bounded to east by the Calabar Flank, which is a subsurface expression of the Oban Massif [5]. To the west, it is bounded by the Benin Basin, to the South, by the Gulf of Guinea and to the North by Older (Cretaceous) tectonic structures such as the Anambra Basin, Abakiliki Anticlinorium and Afikpo Syncline; see (Figure 2). The tectonic framework of the Niger delta is related to the stresses that accompanied the separation of African and South American plates, which led to the opening of the south Atlantic. The Niger Delta is the largest delta in Africa with a sub-aerial exposure of about 75,000km^2 and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences [11]. The Proto-delta developed in the Northern part of the basin during the Campanian transgression and ended with the Paleocene transgression. Formation of the modern delta began during the Eocene.

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank - an east-northeast trending hinge line south of the West African basement massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank-a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west, and the two-kilometer sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest.

Sedimentary deposits in the basin have been divided into three large-scale lithostratigraphic units: (1) the basal Paleocene to Recent pro-delta facies of the Akata Formation, (2) Eocene to Recent, paralic facies of the Agbada Formation, and, (3) Oligocene-Recent, fluvial facies of the Benin Formation [6-8]. These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin. The stratigraphy of the Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits. A series of large-scale, basinward-dipping listric normal faults formed as underlying shales diapered upward. Blocks down dropped across these faults filled with growth strata, changed local depositional slopes, and complicated sediment transport paths into the basin.

Deposition of the three formations occurred in each of the five offlapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea,and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply [9-11]. The interplay of subsidence and supply rates resulted in deposition of discrete depobelts. When further crustal subsidence of the basin could no longer be accommo-dated, the focus of sediment deposition shifted seaward, forming a new depobelt. Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt [9]. Six major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increases their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. Lastly, the distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope.

Petroleum occurs throughout the Agbada Formation in the Niger Delta clastic wedge. Although the distribution of hydrocarbons is complex, there is a general tendency for the ratio of gas to oil to increase southward within individual depobelts [7,14-15]. Stacher [11] developed a hydrocarbon habitat model based on sequence stratigraphy of some petroleum-rich belts within the Niger Delta area, and provides a short summary of basin, trap, reservoir, source rock and hydrocarbon character. Gas to oil ratios within reservoirs was reported by some workers [7, 9, 14]. Reservoirs occur along northwest-southeast "oil rich belts" and along a number of north-south trends in the Port Harcourt area [7]. These belts roughly correspond to the transition between continental and oceanic crust within the axis of maximum sediment thickness [13]. Other authors have related oil-rich belts to structural or depositional controls, to an increase in the geothermal gradient, and shifts in deposition basin-ward within subsequent depobelts [9, 14-17].

3. Methodology

A three pronged approach was used to unravel the structure and hydrocarbon potentials in the prospective sequence (-7489ft sand of well A4) to determine its fair market price. This interdisciplinary approach include seismic interpretation of the field, petrophysical evaluation of the wells (A_1,A_2,A_3,A_4,A_5,&A_6) and reserve estimation using the volumetric method. Figure 3 is the regional well calibration of all the wells in the "Usso" field. The seismic calibration is based on a synthetic seismogram using sonic and density logs from well A-4 with checkshot from the same well. Generally, the seismic-to-well tie is good and has been achieved with a –2ms time shift. This tie formed the first step in picking events, which correspond to the tops of the sands for interpretation. Seismic- to- well ties done for well A-1, well A-2 and well A-4 also show good ties to the seismic data, increasing the confidence in the picked events. Time to depth conversion of the mapped time events was carried out using a velocity model based on the Usso 3-D migration velocities calibrated using T-Z from well A-1, well A-2 and well A-4 . Time-migrated 3-D seismic data obtained from the field was used to develop time and depth maps from which the vertex (representation of the prospect/pay zone) was extracted. With available information from the well logs, the GRV (Gross rock volume or volume of impregnated rock) of the prospect was determined for reserve estimation using volumetric approach.

Deterministic estimation of the volume of hydrocarbon in place involves the application of one or more simple equations that describes the volume of hydrocarbon filled pore space in the reservoir and the way that volume will change from the reservoir to the surface. We considered the weighted mean hydrocarbon saturation of the net pay section and estimated the hydrocarbon in place. This quantity is the Oil in Place, abbreviated to OIIP which is given as:

$$OIIP = GRV * N/G * \varphi\left(1 - Sw_i\right) \quad (1)$$

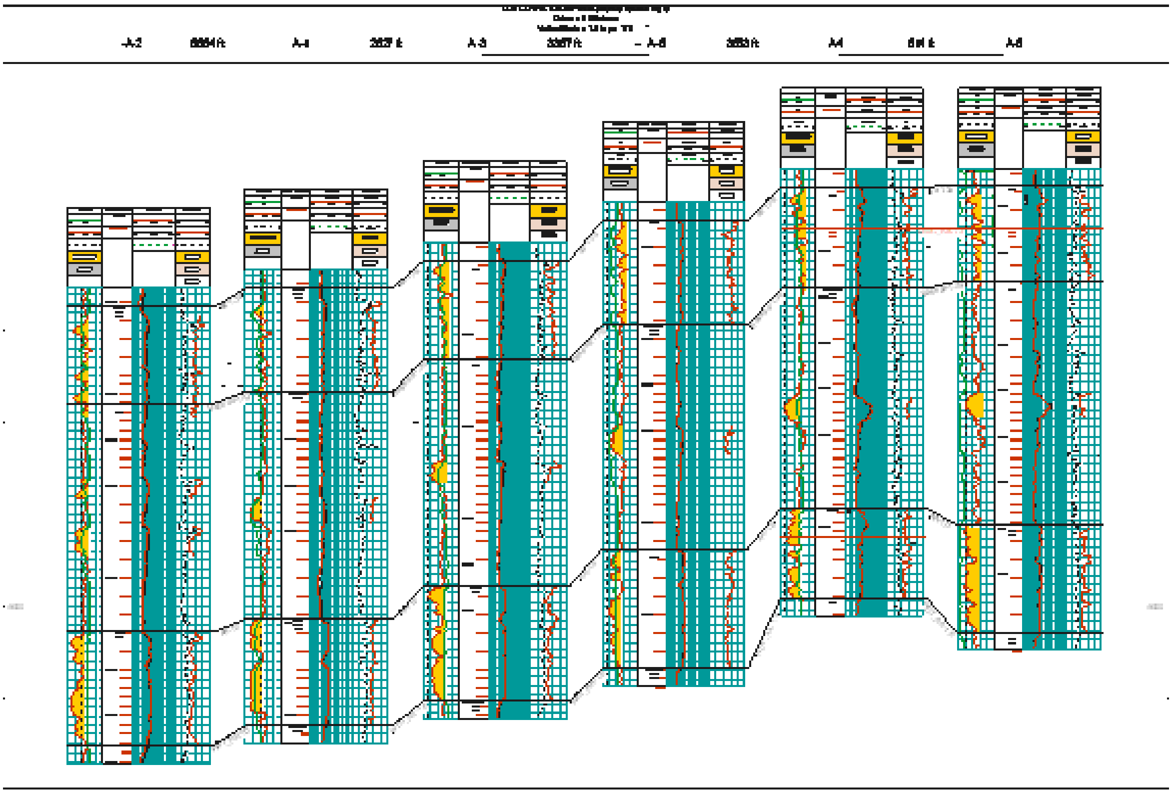

Fig. 3 Regional well log correlation of the "Usso" field, Northern depobelt, Niger Delta.

Where GRV is the Gross Rock Volume, N/G is the net to gross (interval ratio). φ and Swi are the corrected porosity and interstitial water saturation respectively. OIIP was converted into recoverable reserve in terms of stock tank oil initially in place (STOIIP) by applying three additional factors.

$$STOIIP = \frac{7758 * GRV * N/G * (1 - Sw_i)}{FVF}. \qquad (2)$$

where FVF is the formation volume factor estimated from the production data. Recoverable reserve (N) is given as

$$N = STOIIP * RF \qquad (3)$$

where RF is the Recovery factor which depends on drive mechanism, permeability, reservoir depth and hydrocarbon viscosity. RF was estimated using equation (4) below

$$RF = \frac{100(1 - Sw_i - S_{or})}{1 - Sw_i}. \qquad (4)$$

here *Sor* is the oil saturation.

Incorrect porosity value and water resistivity (Rw) can introduce significant error in reserve estimation. In order to quell the probability of an error in Rw, a resistivity-porosity crossplot of the sand section representing the payzone was made (Figure 4a).Choosing $F=0.62/\varphi^m$ chart, since the lithology is sandstone, a scale that adequately covers interval time (Δt) ranges from sonic log was chosen. This crossplot gave us a more accurate value of the water resistivity (Rw). Besides this, the resistivity-porosity cross plot was used to estimate the water cut which showed clearly if the reservoir would be producible or not by taking a quick glance at the cluster of points whether it is below or above the 60% water saturation line. The next step involved constructing a neutron-density cross-plot to determine the corrected porosity and shale volume in percent (Figure 4b). This was done using a linear graph.

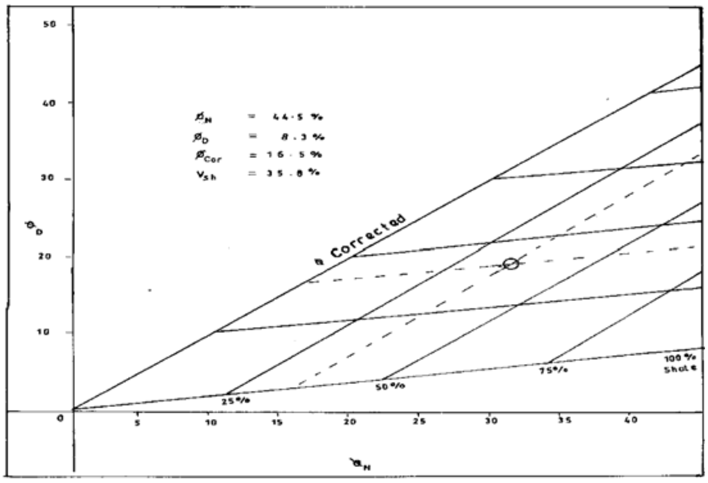

Fig. 4a Density-Neutron crossplot of the payzone of "Usso " field

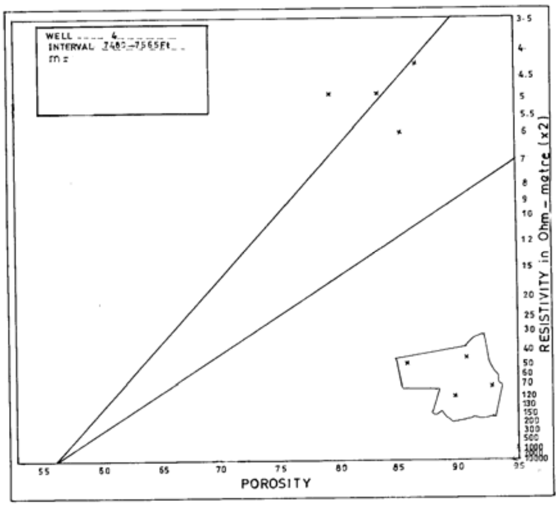

Fig. 4b Resistivity- porosity crossplot of the pay zone with the cluster of the points below the 60% water saturation line encircled

4. Presentation of results

4.1 Seismic data interpretation

After the well to seismic tie, the top of the -7480ft sand fell on an event of 1.8seconds on inline 395 at the point of intersection with crossline 345 (figure 2). This event is a minimum. The structural interpretation of the 3-D seismic data of the study area of the study area is presented in figures 5a and 5b. Growth faulting dominates the structural styles which are interpreted to be triggered by slope instability. About seven faults were identified (F1, F2, F3, F4, F5, F6 and F7. These faults are regularly spaced and rotational. F3 and F7 form a back-to-back fault which is interpreted to be walls or ridges of mobile shale piercing upward from beneath the depobelt. F7 is an antithetic fault with a counter regional dip but of secondary structural importance. It displays no growth and it is a compensating fault for overburden extension. Regular spacing and simplicity of the structures is in line with the structural styles that characterize the Northern depobelt of the Niger delta rich hydrocarbon province [18];see figure 7b.

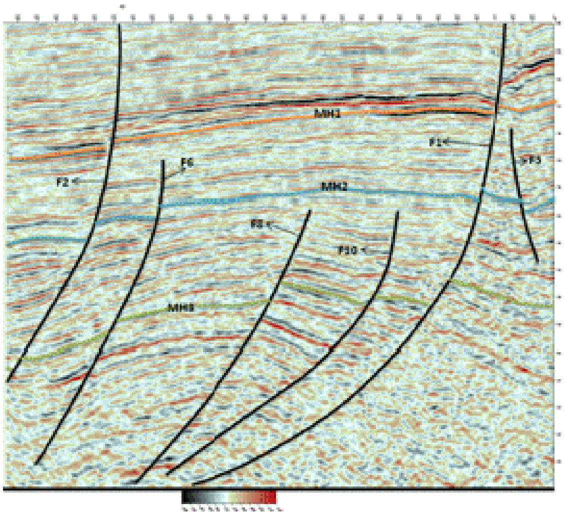

Fig. 5a Structural interpretation of inline 425 showing growth faulting in the "Usso" field

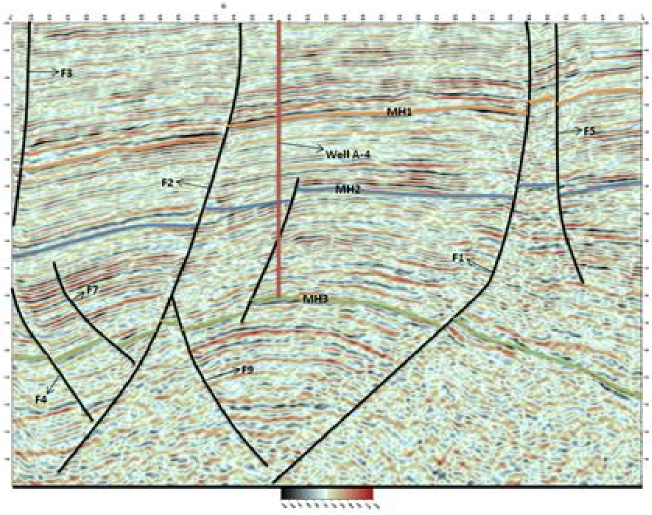

Fig. 5b Seismic interpretation of inline 396 showing growth and antithetic faults the location of well A-4.

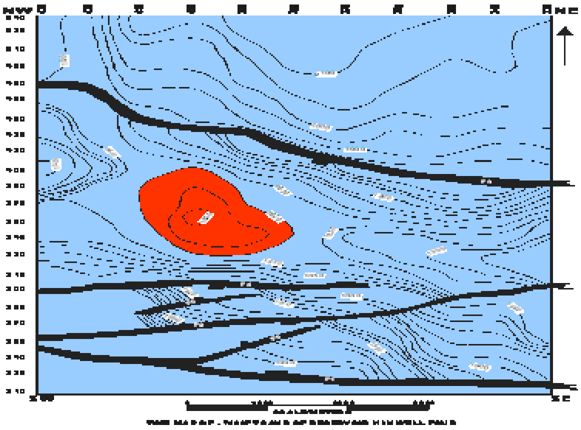

Fig. 6a Structure map (Time) of the top of -7480ft sand

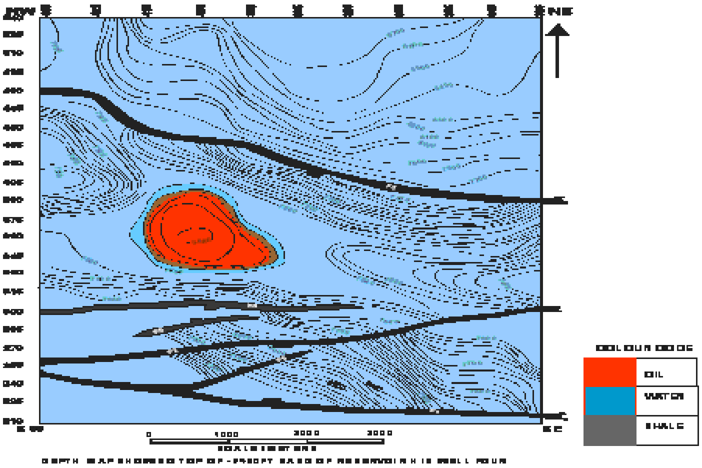

Fig. 6b Structure (Depth) map showing top of -7480ft sand and reservoir H in well A-4

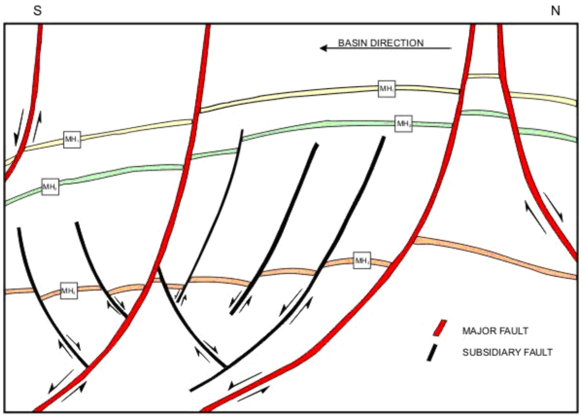

Fig.7a Structural model based on the seismic, well log and geological interpretation showing the effects of the major and subsidiary growth faults on the Agbada Formation in the "Usso" field of OML 124. Deformation is more pronounced in the hanging wall side of the major growth faults

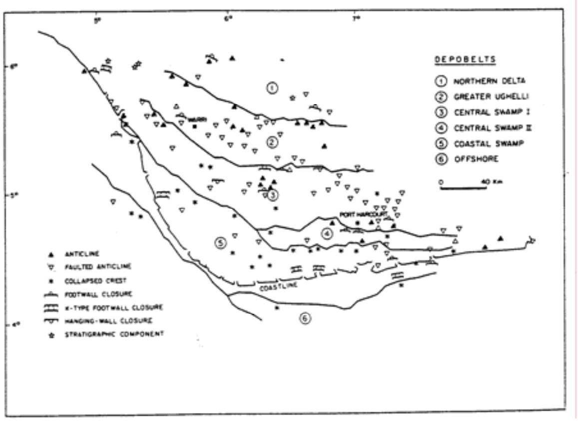

Fig. 7b Distribution of structural types and their relationship to depocentres in the Niger Delta. (after Knox and Omatsola, 1987)

The time and depth maps of the -7480ft sand are shown in figures 6a and 6b respectively. The top of -7480ft sand as deduced from the time and depth maps is dominated by structurally low areas except in the eastern, central and western part of the field with structurally high areas. The top of -7480ft sand as deduced from the maps is dominated by structurally low areas except in the eastern, central and western part of the field with structurally high areas. The prospect is in the central part of the field (colored red). The general trend of the sand is N-S. This can be attributed to high energy deposition of fluvial sand by river Nun. The structure is an anticlinal dip closure independent of faulting (annealment phase trap) flanked to the east and to the west by structurally high areas. These high areas are a good structural lead which requires a more integrated work to define them. This may include acquiring more seismic data to the east and to the west and detailed structural interpretation done to determine if a closure exist. Also 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 drives.

The reservoir limit is defined by the oil/water contact at 5730ft as shown in figure 6b. The faults, F6 and F1 form a bifurcating fault pattern which resulted from the normal faults dipping in the same general direction. The strike direction of each fault is such that the faults merge laterally in the subsurface and continue on as one fault. Structural deformation of the top of -7480ft late Eocene to early Miocene sand can be attributed to high energy deformation of fluvial sand by river Nun and gravitational slumping caused by piercing upward of the depobelt, giving rise to syndepositional faulting and complex structures.

4.2 Petrophysical Evaluation

The Petrophysical result(Table1)revealed that the -7480ft late Eocene to early Miocene sand of well A-4 has a porosity of 19% which was later corrected to 16.5% by the density-neutron cross plot (Figure 4b). A porosity of 16.5% is good for a sandstone reservoir [19]. This porosity value can be justified by considering the effect of compaction due to burial and the shale volume present in the reservoir estimated at 35.8% from the density-neutron cross plot. The question of 'if the reservoir will be producible or not' was answered by the resistivity-porosity cross plot (figure 4a) which showed a cluster of points below the 60% water saturation line. Therefore, the reservoir is producible.

Table1: Summary of the petrophysical evaluation of the reservoirs identified in well A-4.

Reservoirs	Top	Base	NTG	Porosity	S_w(%)	$S_{h=(\%)}$	Contact	Fluid type
A	4790	4820	1.000	48.0	35.50	64.50	GDT	Gas
B	4910	5010	0.700	28.8	62.80	37.20	OWT@4950	Oil
C	5210	5250	0.625	23.9	73.62	26.37	OWC@5230	Oil
D	5380	5410	0.667	24.4	97.45	2.50	ODT	Oil
E	5685	5730	0.625	23.6	52.50	47.47	GOC@5705	Oil&gas
F	5815	6000	0.630	24.1	91.10	8.93	OWC@5890	Oil
G	6580	6830	0.542	22.0	82.70	17.30	GOC@6590	Oil&gas
H	7480	7565	0.642	19.0	43.60	56.40	OWC@7530	Oil

4.3 Volumetrics

Using a volumetric approach, the original oil in place was estimated at 1.2bb as shown in table 2 below. This amount has a surface equivalence of about 862.5mb. With a recovery factor of about 9%, only 77.6mb can be produced from the reservoir. 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 mechanism.

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

SAND	-7480Ft.
Gross, Rock Volume (GRV)	24087.9 acre Ft.
Net-to-gross	64.2%
Connate water (S_{wi})	39%
Formation Volume Factor	1.4
Recovery factor	9%
Oil saturation	55.6%
Original Oil In Place (OOIP)	1207528866.0 barrels/acre feet.
Stock Tank Oil in Place (STOIP)	862,520620.10 barrels/acre feet.
Recoverable Reserve	77,626855.81 barrels

5. Discussion

The petrophysical result revealed that the -7480ft sand of well A4, of "Usso" field has a porosity of 19% which was later corrected to 16.5% by the Density-Neutron Cross plot. Similarly, the well log of reservoir H reveals a funnel-shaped motif which is an indication of a coarsening-up succession. This can be interpreted as a deltaic progradation or a shallow marine progradation in a high energy depositional environment [20].

The structural style is dominated by simple rollover anticlines and collapsed crest faults. This is in line with previous studies in the Niger delta as shown in figure 7b. The subsurface of the Niger Delta basin is extensively deformed by growth fault structures and roll over anticlines [7,21-22]. 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 [7,23]. These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation. However, from the time and depth map, 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.

6. Conclusion

Information extracted from 3-D seismic data volume and well logs resulted in more understanding of the structure, stratigraphy and hydrocarbon potentials of the "Usso" field, Northern depobelt of the Niger delta. The result suggests more development opportunities in the Northern depobelt. The physiography and location of the area is good, since the field is in a low cost environment reducing the logistics, risk and funding challenges often posed by water depth and geology. However, 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.

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