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Study on the Imaging Ability of Seismic Exploration to Subsurface Structures and Closed Pores of Hydrocarbon Accumulation

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ABSTRACT

This study demonstrates the ability of seismic exploration to image subsurface structures and closed pores where oil and gas accumulates through a three-dimensional tectonic interpretation of the Ohaji oilfield. In the study area, the Abada Formation is composed of vertically stacked reservoirs, with the thickness of the contrast interval ranging from 25 ft to 250 ft. Base configuration and tectonic movement were deduced from gravity measurements and the development of overlying Tertiary. The various stages of delta development were reconstructed with the help of well data. The petroleum geology characteristic of the delta is the occurrence of multiple reservoirs in the imbricated overlay cycle of offshore strata. The exploration direction in this area is an anticlinal dip closure (annealing trap) with high structural zones on the east and west wings. The northern area is composed of simple overturning structures which are widely distributed, while the growth faults are explained as the deep, overpressure and ductile Marine shale movement, and formed with the assistance of slope instability. The middle zone is dominated by fault tumbling anticline and the southern region is characterized by collapsed roof structure. Because of this complex tectonic model, the growth faults associated with anticlinal traps are segmented by normal faults, which become the potential problems of fault-sealing rupture and insufficient lateral and amplitude support of some reservoirs.

KEYWORDS

Structural interpretation; Agbada formation; Seismic; Reservoir; Growth fault; Anticlinal traps; Faults.

1. Introduction

The oil and gas businesses have witnessed for over the past one decade a quantum leap in effectiveness of geophysics in exploration and production operations. Indeed the industry may never before have witnessed a technological advancement without the overwhelming impact of 3-D seismic. The earth has always been in three-dimensional pattern hence the petroleum reserves are contained in three-dimensional traps. The essence of the 3-D method is a real data collection followed by the processing and interpretation of a closely-spaced data volume. It is in these post-discovery phases that many of the successes of 3-D seismic surveys have been achieved. There seems to be unanimous agreement that 3-D surveys result in a clearer and more accurate pictures of geological details.

The Ohaji Field is located some 45 km from Owerri, Imo State, in OML 21, in the seasonally flooded land area of the Niger Delta. To date 21 wells have been drilled, penetrating seven hydrocarbon-bearing sands (6oil and 1 gas) between 5900 and 8500 ft. It is covered by 3-D seismic acquired in 1994. The field came on stream in 1974. Peak Production reached 35 Million barrel of oil per day in 1980.

1.1 Description of the Study Area

The Ohaji Oilfield is located in Oil Mining Lease (OML) 21. The study area falls within latitude
5o30′N – 5o39′N and longitude 6o40′E – 6o52′E. The field was discovered in 1965 by exploration Well-001 that was drilled to about 9400ft. The field is a large rollover structure with dip closure located to the immediate south of the growth fault that defines the southern macrostructure of OML 21 (figure 1.0). It is within the Northern Niger Depobelt. Within this depobelt, two major east-west oriented macrostructural trends can be distinguished. The trends are separated by a major boundary fault. Ugada field is located in the northern macrostructure while the Ohaji is on the southern macrostructure. Both fields are large rollover structures in the hanging wall of the boundary fault. The Ohaji Field structure is bounded to the north by a major growth fault and dissected by a number of smaller synthetic and antithetic faults. These smaller faults have relatively small throws and are not expected to result in reservoir compartmentalization but may act as baffles to fluid flow.

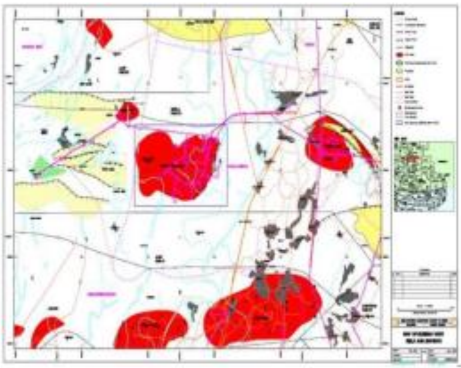

Figure 1. Map of Ohaji Field and Environs

1.2 Area Main Objectives of the Study

1) To obtain the general subsurface structure of the field

2) To get a detailed information on the structural and stratigraphic framework of reservoirs

1.3 Geology of the Area

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta Province (Klett and others 1997). From the Eocene to the present, the delta has prograded southwestward forming depobelts that represent the most active portion of the delta at each stage of its development. These depobelts form one of the largest regressive deltas in the world with an area of some 300,000km2(Kulke, 1995), a sediment volume of 500,000 km3 (Hospers, 1965), and a sediment thickness of over 10 km in the basin depo-center (Kaplan and others, 1994). The Niger Delta Province contains only one identified petroleum system (Kulke, 1995; Ekweozor and Daukoru, 1994), this system is referred to here as the Tertiary Niger Delta (Akata –Agbada) Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province (Petroconsultants, 1996a).

Currently, most of this petroleum is in fields that are onshore or on the continental shelf in waters less than 200 meters deep and occurs primarily in large, relatively simple structures.

In the Niger Delta province, the delta is formed at the site of a rift triple junction related to the opening of the southern Atlantic starting in the Late Jurassic and continuing into the Cretaceous (Lehner and De Ruiter, 1977). The delta proper began developing in the Eocene, accumulating sediments that now are over 10 kilometers thick in the basin depo-center (Kaplan and others, 1994). The primary source rock is the upper Akata Formation, the marine-shale facies of the delta, with possibly contribution from interbedded marine shale of the lowermost Agbada Formation. Oil is produced from sandstone facies within the Agbada Formation, however, turbidite sand in the upper Akata Formation is a potential target in deep water offshore and possibly beneath currently producing intervals onshore. The type sections of these formations are described in Short and Stäuble (1967) and summarized in a variety of papers (e.g. Avbobvo, 1978; Doust and Omatsola, 1990; Kulke, 1995)

2. Methodology

On land, 3-D seismic data array is often acquired by swath shooting with receiver cables laid out in parallel lines, and the shot points run in a perpendicular direction. In the ocean, 3-D seismic exploration technique is often run with line shooting in closely spaced, parallel lines from a single ship towing several arrays of air guns and streamers. There are many different patterns of sources and geophones that can be used for 3-D seismic data acquisition. In undershooting, the sources and geophones are not even located on the land being surveyed. The source is located on one side, and the geophones are located on the other side of the land. The 3D seismic survey is divided into horizontal squares called bins. All reflections whose midpoints fall within a particular bin are combined for common-midpoint (CMP) stacking. The CMP fold is the number of mid-points in each bin. Bins are commonly 55 by 5ft, 110 by 10ft, 20 by 20m, or 30 by 30m. After computer processing, a 3-D view of the subsurface is produced. Rock layers are migrated more accurately, and details are shown better than on a 2-D seismic image. 3-D seismic image on a computer monitor can be rotated and viewed from different directions (Bone and Tegland, 1983). A time or horizontal slice of the subsurface is flat seismic pictures made at a specific depth in time (milliseconds).

Advantages of 3D includes close sampling in X,Y and Z, correct positioning of events, more reliable interpretation, no faults aliasing while the disadvantages include more time for acquisition and data processing, higher acquisition costs particularly on land.

3. Results and Interpretation

The interpretation was done on every 16th inline and 16th cross line. Arbitrary lines were taken where the fault pattern did not show clearly on the inline or trace. The interpretation was then checked and validated on selected semblance time slices and semblance drapes on surfaces. The faults were identified, correlated and aliased. Fault heaves were calculated based on the polygons that were generated. Illumination, dip and azimuth extracted on the horizon surface all conformed to the interpreted fault pattern. Figure 4a, b, c and d show the faults growth in the study area.

3.1 Seismic Data (Time-Depth)

Time map is a map showing areas with equal time. Time map shows the structure of a horizon in the subsurface. When the times are posted on the base map, areas of equal time are contoured to obtain the time map. However, structure is a subject of depth and the map is in travel time of sound waves. Depths are calculated from the time –depth graph and contoured. A velocity survey was acquired in the study area and the T-Z relationship for time to depth conversion is shown in Figure 2.0. The quality of the seismic data was considered good up to 2.4 seconds but deteriorates towards the west and below 2.4 seconds.

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 cross-line 345. This event is a minimum event. Growth faulting dominates the structural style which is interpreted to be triggered by the movement of deep-seated, over pressured, ductile marine shale and aided by slope instability. Faults flatten with depth into a master detachment plane near the top of the over pressured, marine shale sequence.

About ten faults were identified (F1, F2, F3, F4, F5, F6, F7, F8, F9 and F10) see Figure 14a-d. These faults are regularly spaced and rotational. F3 and F7 form a back–to-back fault which is interpreted to be the 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. The -7480ft sand is cut by all the faults except F7. F3, F2 and F4 faults are typical growth faults which are contemporaneous with sedimentation. These faults are associated with anticlines, called roll-over, which develop as a result of bending of the hanging wall fault block as it conforms to the curved-surface (Suppe 1985). These roll over anticlines are one of the most important hydrocarbon traps associated with listric growth faults. Hanging wall roll over anticlines developed on F4 as a result of listric fault geometry and difference of deltaic sediments above ductile shale. They are listric because of their curved shape.F1, F6, F5, and F4 are secondary faulting associated with F2 which is a growth fault. F1, F6, and F5 are antithetic (dipping towards F2) while F4 is synthetic (dipping parallel to F2). F1 and F6 are collapsed crested faults.

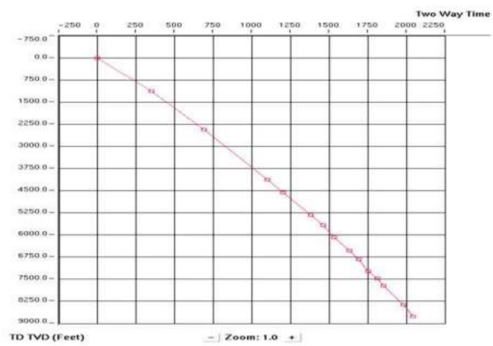

Figure 2. Checkshot data T-Z relationship of Ohaji Oilfield

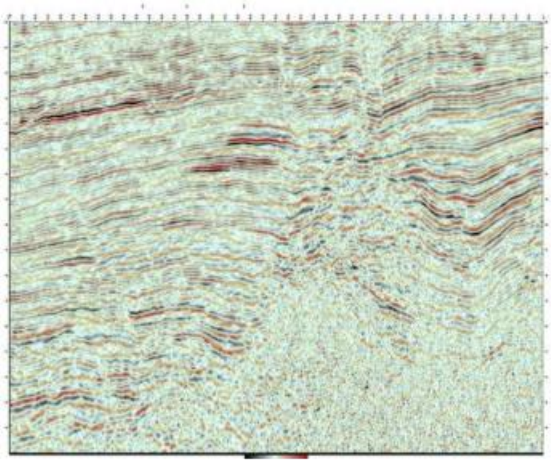

Figure 3. Seismic section showing

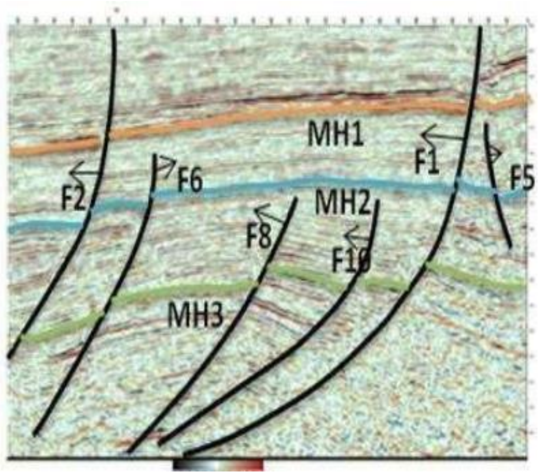

Figure 4a.

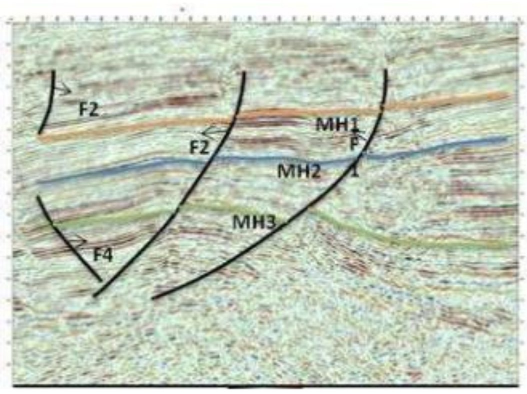

Figure 4b.

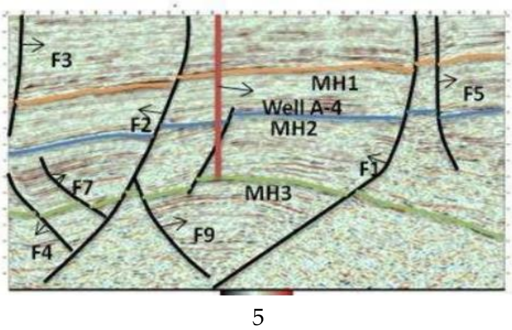

Figure 4c.

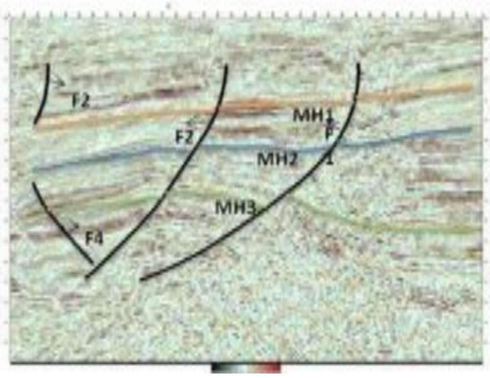

Figure 4d.

Figure 4a-d: Seismic section showing different faults growth in Ohaji Oilfield

Horizon MH1 is the shallowest horizon that was picked at two-way time interval of 1191milliseconds after converting the depth value of the top of the reservoir rock found, with the aid of the check shot curve. This horizon was picked because of its hydrocarbon content of about 40%. The range of reflection times picked for this horizon on both inlines and crosslines is 1171ms to 1325ms. This horizon is relatively shallow and probably occurs close to the top of the Agbada Formation. This is due to the fact that thickness of the Benin formation in the Northern depobelt is less than its thickness in other depobelts.

Horizon MH2 is the intermediate horizon that was picked at two-way time of 1450ms, after converting the depth value of the reservoir rock interpreted in the well log with the aid of the TZ curve. This horizon was picked because of its occurrence in the well log for correlation and its relatively good hydrocarbon content. The range of reflection time picked for this horizon on both inlines and crosslines is between 1380ms and 1623ms. It has a sharp contact with the interpreted shale unit above it. This horizon occurs close to the middle of the Agbada Formation because of the high acoustic impedance contrast.

Horizon MH3 is the deepest horizon that was picked at two-way time of 1800 milliseconds after converting the depth value of the interpreted reservoir rock in the well log within the aid of the T-Z curve. This horizon was picked because of its relatively high hydrocarbon saturation percentage. The range of reflection times picked for this horizon on both inlines and crosslines is between 1720ms and 2150ms. MH3 horizon has the sharpest contact with the interpreted shale unit above it. The overpressure noticed within the reservoir is believed to have occurred as a result of the very thick shale unit overlying the sand reservoir. This horizon occurs close to the top of the Akata formation.

3.2 Mapping

Three velocity models were created for the time to depth conversion exercise. Checkshot data from the wells and seismic velocity was calibrated with velocity in Depth Team Express (a Landmark application). Seismic Migration velocity was used to create a velocity cube. A third volume was created from the checkshot as a realization. Average velocity map (Figure 9.0) was extracted for the surfaces from the two velocity volumes and checked for velocity misties. Depth grids for the different horizons were built in TDQ (a Landmark Application) by multiplying the velocity extracted for sand complex surface with the time map (figure 7.0) for the same surface. This was exported to petrel (Schlumberger software) where top structure depth maps were generated for the reservoir.

The grids were generated using the convergent algorithm, contoured, and smoothened using a maximum of 2 smoothing passes. Sand tops were correlated in Petrel and used to match the depth maps. The depth differences between the sand tops and the maps at the well points were contoured and used to correct the map by a single surface operation to produce final depth maps (Figure 10). The map generated from the combination of checkshot, seismic migration velocity and pseudo velocity gave the lowest residual on back interpolation with well data and thus was used as the base case depth map.

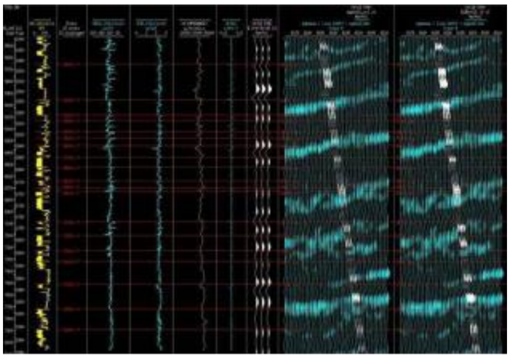

Figure 5. Seismic Cross Section-semblance volume

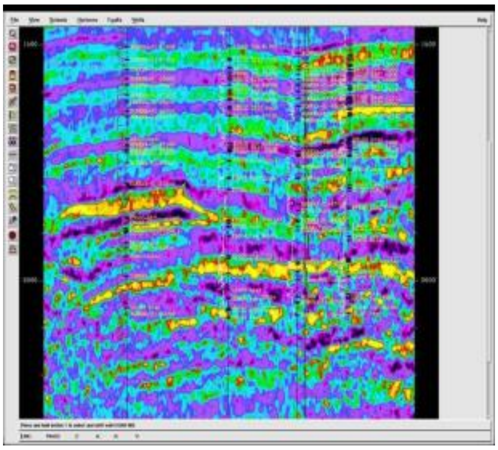

Figure 6. Well to Seismic Tie

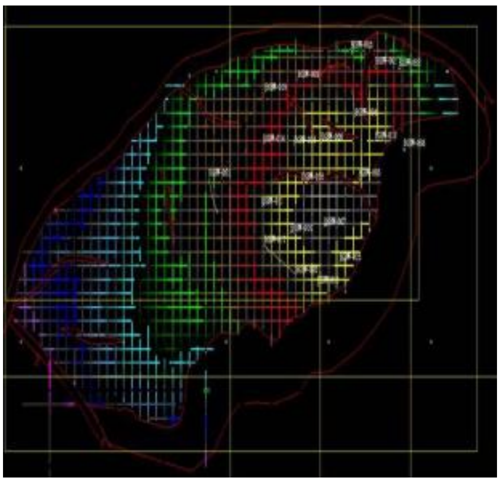

Figure 7. Time Interpretation of Ohaji Oilfield. Colours showing areas with the same average time

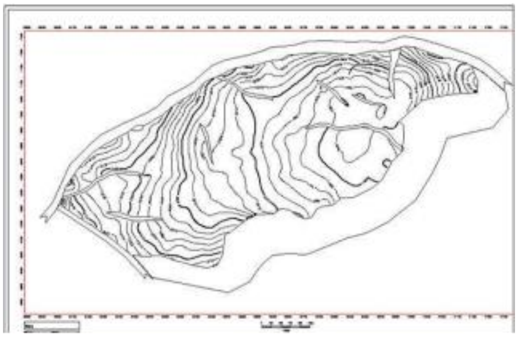

Figure 8. 3D Structural Map of Ohaji Oilfield showing the faults

3.3 Seismic and Structural Uncertainties

The key uncertainties in seismic interpretation are associated with time picks of the selected seismic event, and accuracy of the velocity model used for time-to-depth conversion. Using Acoustic impedance volume minimized uncertainties associated with horizon tracking. Also arbitrary lines were taken to check for misties in the horizon interpretation. Generally, the resolution of the seismic data around sand complex loop was poor; consequently the semblance cube generated using the seismic was not clear and could not be used to resolve the positions and trends of the small faults.

However the Sand complex is faulted and the position of the major faults were clear on seismic. Uncertainty in velocity and depth conversion was considered minimal because all the 21 wells in the field provide good control of both formation depths and lateral velocity variability over the Sand Complex reservoir. Depth maps were tied to the Sand Complex horizon picks in all the wells covering the entire E-W (strike), N-S (dip) extent of the main block. Though the clay channel at the Eastern flank of the reservoir was identified on acoustic impedance seismic data, its exact position and trend could not be delineated and thus it was carried as a major uncertainty. This was built into the static modeling sensitivities in order to quantify the impact on static volume.

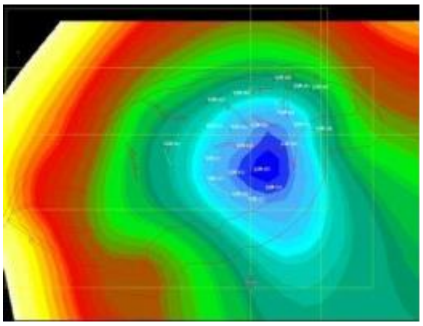

Figure 9. Average Velocity Map of Ohaji Oilfield. Colours showing area with the same average velocity

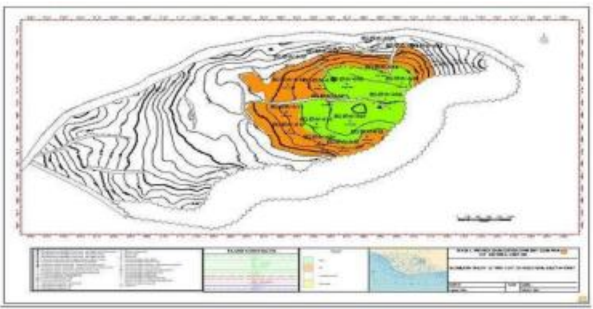

Figure 10. Depth Map of Ohaji Oilfield

3.4 Summary

Ten (10) different faults were mapped as F1, F2, F3, F4, F5, F6, F7, F8, F9 and F10; see figure 4a-d. All these faults are growth faults which are believed to be syn-depositional. The F4 and F7 faults are antithetic showing no growth, and are the conjugate compensation faults for overburden extension. In plan view, they are concave seaward, which is opposite the curvature of the depobelts themselves. Their degree of curvature ranges from rather linear to crescentshaped. Apart from the two above mentioned oil field structures (growth faults and antithetic faults), Inline 375 shows clearly a collapsed crest structure on the South and the back to back faults at the northern end of the section. There is also a clear appearance of crestal faults (F6 and F8) on inline 385. These are faults that show less curvature in the horizontal plane, are generally steeper than the structure building faults (growth faults) and display less growth than the growth faults. The results and interpretation above are in accordance with the known structural styles.

Another structural feature mapped were anticlines, which form potential traps for hydrocarbons in Niger Delta. There are two anticlinal closures observed on the time and depth structural maps. Evidence from the well logs especially logs from well-004 (A4) and well-006(A6) show that the anticlines are good hydrocarbon traps with a good number of oil/gas pools. The trapping mechanism is largely by means of simple closure independent of faults. Three types can be distinguished from the seismic sections (inlines): - unfaulted simple dip rollover, dip closures where faults, though present, contribute less than 50ft to the closure; and faulted anticlinal closure where a dip closure is dissected by synthetic and/or antithetic but non-sealing faults so that closure is limited to the dip element.

3.5 Observation

The origin of the Niger Delta appears to be well understood following the rifting that separated South America from Africa. Basement configuration and structural movements have been deduced from gravimetric measurements and the development of the overlying Tertiary. The various stages of the delta growth have been reconstructed with the aid of the well data. The petroleum geology of the delta is characterized by the occurrence of multiple reservoirs in the imbricated and superimposed offlap cycles of the paralic interval. Typically, in a rollover structure virtually all available sands contain at least some hydrocarbons over an interval ranging from 1500 to 6000 ft, provided the caprock shales overlying the sands are sufficiently thick.

The major growth faults flatten with depth into a master detachment plane near the top of the overpressured marine shale sequence. The hanging-wall roll-over anticlines developed as a result of listric-fault geometry and differential loading of deltaic sediments above ductile shales. But as sediment loading in the depobelt ceased the depocenter shifted seaward and loaded the displaced thick mobile shale, and a new depobelt was formed.

4. Conclusion

The Ohaji field occurs in the Northern depobelt (Northern Delta) of the Niger Delta basin. It can be observed that the Northern delta can be sub-divided into a northern area with predominantly rather widely spaced simple rollover structures, a middle zone in which faulted rollover anticlines prevail and a southern area characterized by collapsed-crest structures. It is important to note that there is an important relationship between the style of the field structures and the volume of reserves.

However, from the time and depth map, it can be deduced that the prospect is an anticline dip closure (annealment phase trap) flanked to the east and to the west by structurally high areas. Structural deformation of top of -7480ft sand can be attributed to high energy deposition of fluvial sand 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.

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