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Hydrocarbon exploration in Odo Field in the Niger Delta Basin Nigeria, using a three-dimensional seismic reflection survey

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A three-dimensional seismic reflection survey carried out in Odo Field in the central swamp of the Niger Delta Basin has been interpreted with respect to exploration for hydrocarbons. The Odo Field is marked by a large southwest heading listric growth fault with numerous synthetic and antithetic faults. The two picked seismic events, horizons 1 and 2 indicate four closures each, which are hydrocarbon bearing. The faults in the field thus support hydrocarbon accumulations which are seen to be mainly fault/dip closures. The expectations calculated for the observed fault closures suggest that several in-field appraisal prospects exist. The seismic attributes (amplitude maps) furthermore suggest that horizon 1 is mainly gas bearing.

Key words: Field, faults, Niger Delta, seismic, hydrocarbon

INTRODUCTION

Hydrocarbons such as oil and gas are found in geologic traps, which can either be structural or stratigraphic (Doust and Omatsola, 1990). Hydrocarbon exploration aims at identifying and delineating these structural and stratigraphic traps suitable for economically exploitable accumulations in a field. It also helps in delineating the extent of discoveries in field appraisals and development. These traps could be very multifaceted and subtle, thus mapping it accurately becomes difficult. The geophysicist works with a set of seismic sections and the primary product of the geophysical interpretation is a series of annotated maps indicating presence of prospective highs or other potential trap structures (McQuillin et al., 1984). Petroleum reserves are contained in three-dimensional traps but the seismic method in its attempt to image the subsurface has traditionally taken a two-dimensional (2D) approach (Brown, 2004). The use of 3D interpretation has been reported to yield better results; they have better resolution and have increased fault details as compared to the old 2D surveys.

The Niger Delta Basin is a major geological feature of significant petroleum exploration and production in Nigeria (Whiteman, 1982), now it is Africa's leading oil province (Reijers, 2011). The Niger Delta Basin (Figure 1) accounts for the entire hydrocarbon production at present-day Nigeria and is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 3°N and 6°N and longitude 5°E and 8°E

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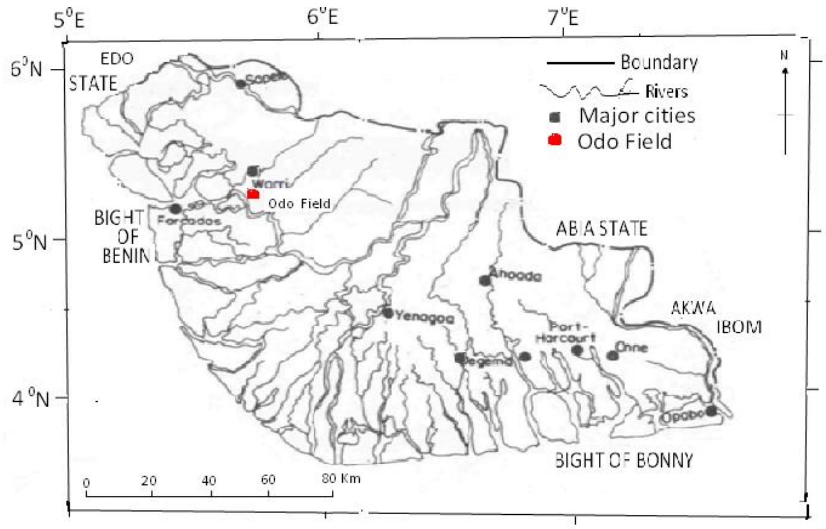

Figure 1. Map of the Niger Delta Basin.

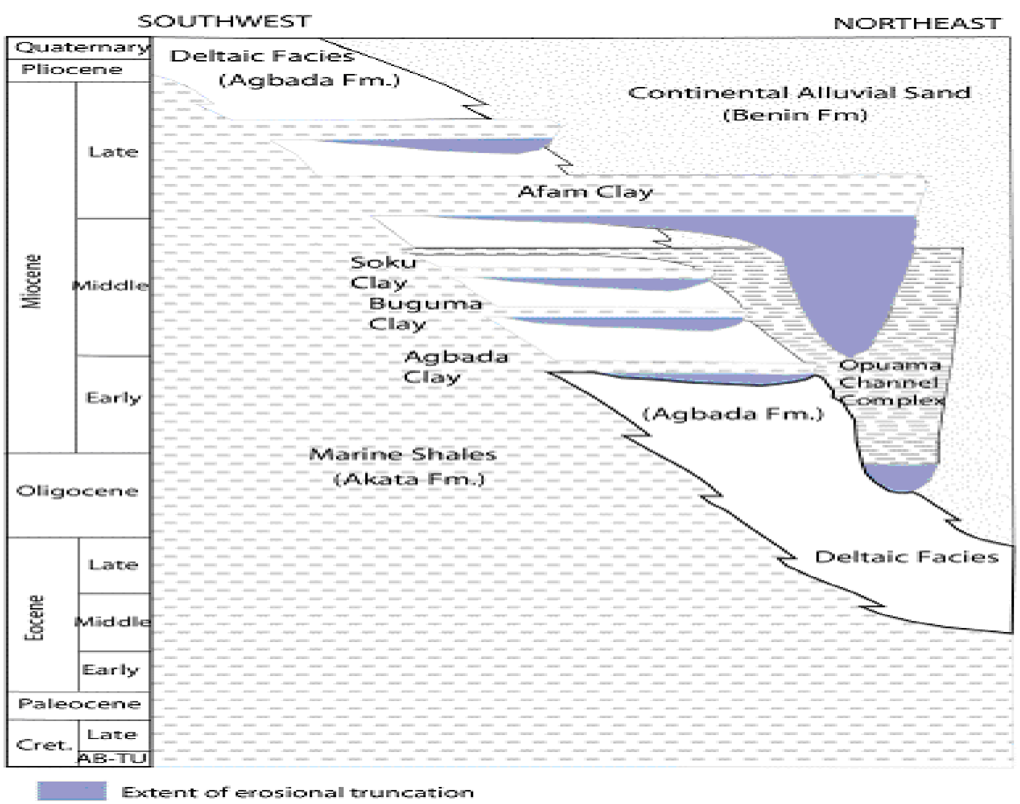

Figure 2. Stratigraphic column showing the three Formations of the Niger Delta, the continental *Benin* sandstone, the paralic Agbada formation and the Marine Akata shale. Modified from Doust and Omatsola (1990).

(Reijers, 1996). The Niger Delta sediments comprise three broad Formations, the Benin, Agbada and Akata Formations (Figure 2). The upper Benin Formation consists predominantly of fresh water bearing continental sands and gravels. The middle Agbada Formation consists primarily of sand and shale and is of fluviomarine origin. The lower Akata Formation is composed of shales, clays and silts (Short and Stauble,

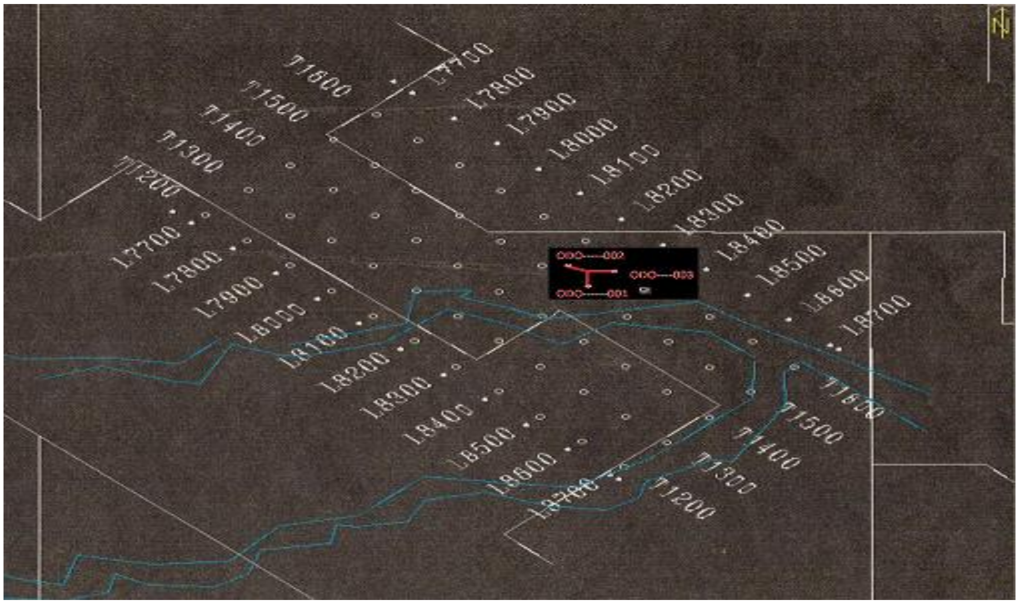

Figure 3. Base map of Odo Field showing the transition areas in blue, the land areas in white and the three existing wells in red.

1967; Magbagbeoloa and Willis, 2007; Owoyemi and Willis, 2006).

The distribution of hydrocarbon in the Niger Delta is complex with gas-to-oil ratio generally increasing southward away from the depocentre within a depobelt (Evamy et al., 1978). The distribution is found to be principally controlled by the quality and thermal history of source rocks, migration, fault sealing quality and the timing of traps formation (Chukwueke, 1997). The source rock for petroleum in the Niger Delta basin is assumed to arise from the marine interbedded shale in the Agbada Formation, the marine shale in the Akata formation and the Cretaceous shale (Doust and Omatsola, 1990; Short and Stauble, 1967; Ejedawe, 1981; Ekweozor and Okoye, 1980; Lambert-Aikhionbare and Ibe, 1984). Intervals with total organic-carbon contents sufficient to be considered as good source rocks exist in the Agbada Formation. These intervals are immature in various parts of the Niger Delta and rarely reach the thickness that is sufficient to produce a world-class oil province. The Akata Formation which is below the Agbada Formation shale is volumetrically sufficient to generate enough oil for a world class oil region such as the Niger Delta. The source-rock potential of the Cretaceous shale has not been ascertained because the Cretaceous shale is at present very deeply buried and has never been drilled (Evamy et al., 1978).

The majority of the traps found in the Niger Delta are structural in nature though stratigraphic traps are not unusual (Doust and Omatsola, 1990). The structural traps developed during syn-sedimentary deformation of the Agbada paralic sequence (Evamy et al., 1978). The syn-sedimentary structures which deform the delta largely beneath the Benin sand facies are the most striking structural features of the Niger Delta complex. These structures are believed to arise from gravity sliding during the course of deltaic sedimentation. They are polygenic in origin and their complexity increases generally in a down delta direction (Merki, 1972). The syn-sedimentary structures which are named growth faults are predominantly trending northeast to southwest and northwest to southeast (Hosper, 1971). They are usually associated with rollover anticlines, shale ridges, and sand-shale diapirs which are caused by shale upheaval ridges. Most of the faults are listric normal; others include structure building growth faults, crestal faults, flank faults, counter regional faults and antithetic faults.

Odo Field is located in the central swamp of the Niger Delta Basin. The field was discovered in 1978. The 3D seismic data were acquired in 1992 and covers 277.11 km^2 of subsurface full fold coverage. Subsurface sampling was 15 fold with a 25 m × 25 m bin size.

The base map or survey block of the field can be seen in Figure 3, the region bounded by the white lines indicates very dry land while the region bounded by the blue lines indicates transition zones. The 3D data were acquired using the usual methods for land and transition zones. The field is partly appraised having three already drilled wells.

The aim of this work is to interpret an already processed seismic reflection data from Odo Field in the Niger Delta Basin in order to explore for hydrocarbons. The seismic data had been processed to zero phase reflectivity and loaded to Halliburton land mark work station. The processed data quality was good but deteriorates below 3 s behind the major faults and within

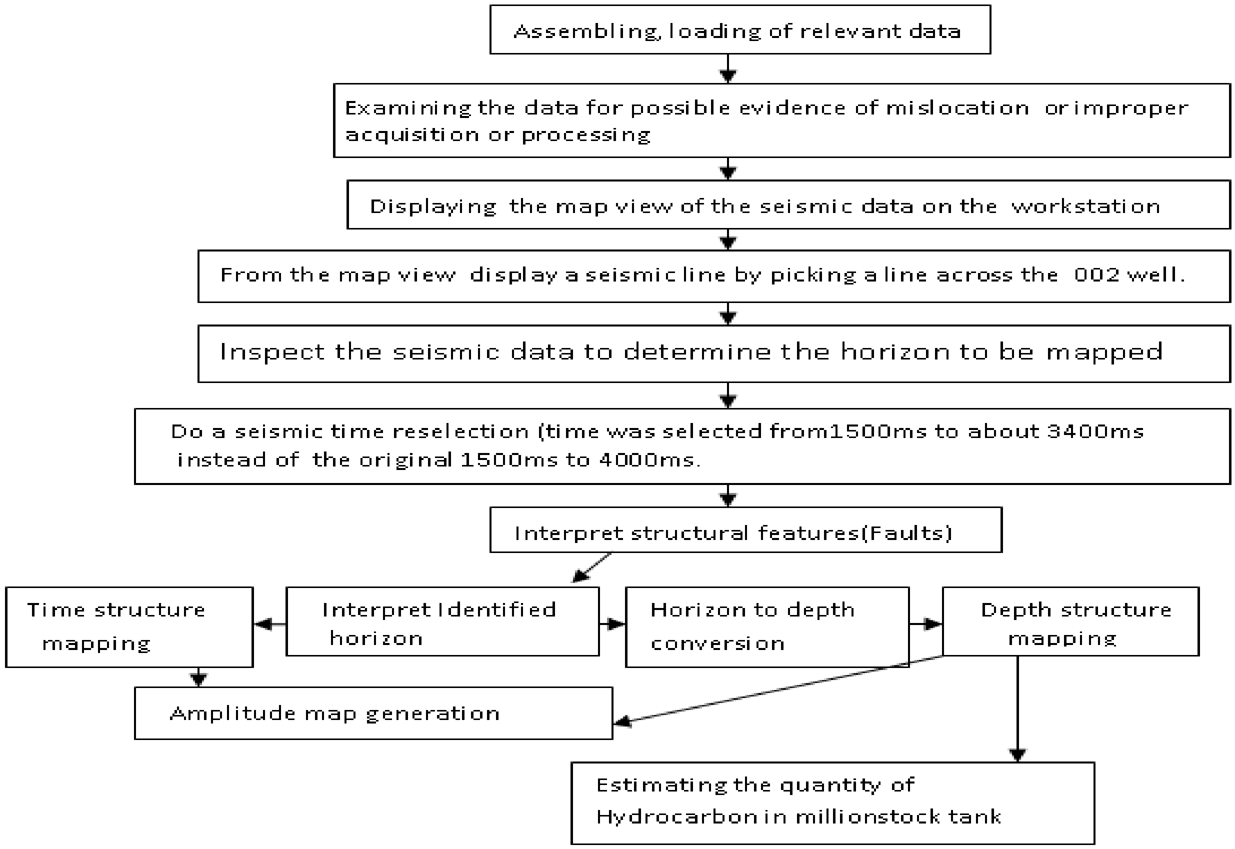

Figure 4. Flow chart of the analytic procedure.

narrow fault blocks. Recommendation for favourable drilling sites is expected to be made if the data suggests economically exploitable accumulations of hydrocarbon.

METHOD OF ANALYSIS

The analysis method followed the flow chart in Figure 4. Faults were interpreted as structures on every eight in line while the seismic events were interpreted on every eight in-lines and sixteenth cross-lines thereby generating an 8 × 16 grid. Several arbitrary lines were also generated to check the correlation. The horizons were identified as horizon 1 (red) and horizon 2 (blue) in Figure 5.

The quantity of hydrocarbon is estimated in million stock tank barrel using

$$STOIIP = \frac{GRV \times 43560 \times \Phi \times \frac{N}{G} \times (1 - S_w)}{5.615 \times FVF \times 1000000} \qquad (1)$$

Where
STOIIP =Stock Tank Oil in Place (in million stock tank barrels),
GRV= Gross Rock Volume (in acrefeet),
N/G= Ratio of clean sand to the total sand, Φ =porosity.
$(1 - S_w)$ = Hydrocarbon saturation,
FVF = Formation Volume Factor.

INTERPRETATION OF RESULTS

The structure shows that the area is an elongated rollover anticline with a collapsed crest. The field is marked by a large southwest heading listric growth fault with numerous but closely spaced northwest to southeast antithetic and synthetic faults which are seen to be discontinuous across the field forming semi-parallel fault blocks (Figure 5). The depth maps (Figure 6) show structural highs against faults, which represent potential traps for hydrocarbons. The synthetic and antithetic faults form the footwall closures of the field. Four closures were identified on both horizons 1 and 2.

The hydrocarbon estimates calculated in million stock tank barrels for the fault closures in horizons 1 and 2 (Table 1) indicates that closures 1, 2, 3, 4 are hydrocarbon bearing. This suggests that several in field appraisals prospects exist in the field. The result shows that more hydrocarbon accumulation can be seen in closure 3 in horizon 2.

3D seismic has made the use of amplitudes an integral part of seismic interpretation. Amplitude related seismic attributes have robust physical relationships to lithology and porosity (Banchs and Michelena, 2002; Dorrington and Link, 2004; Calderon and Castagna, 2005).

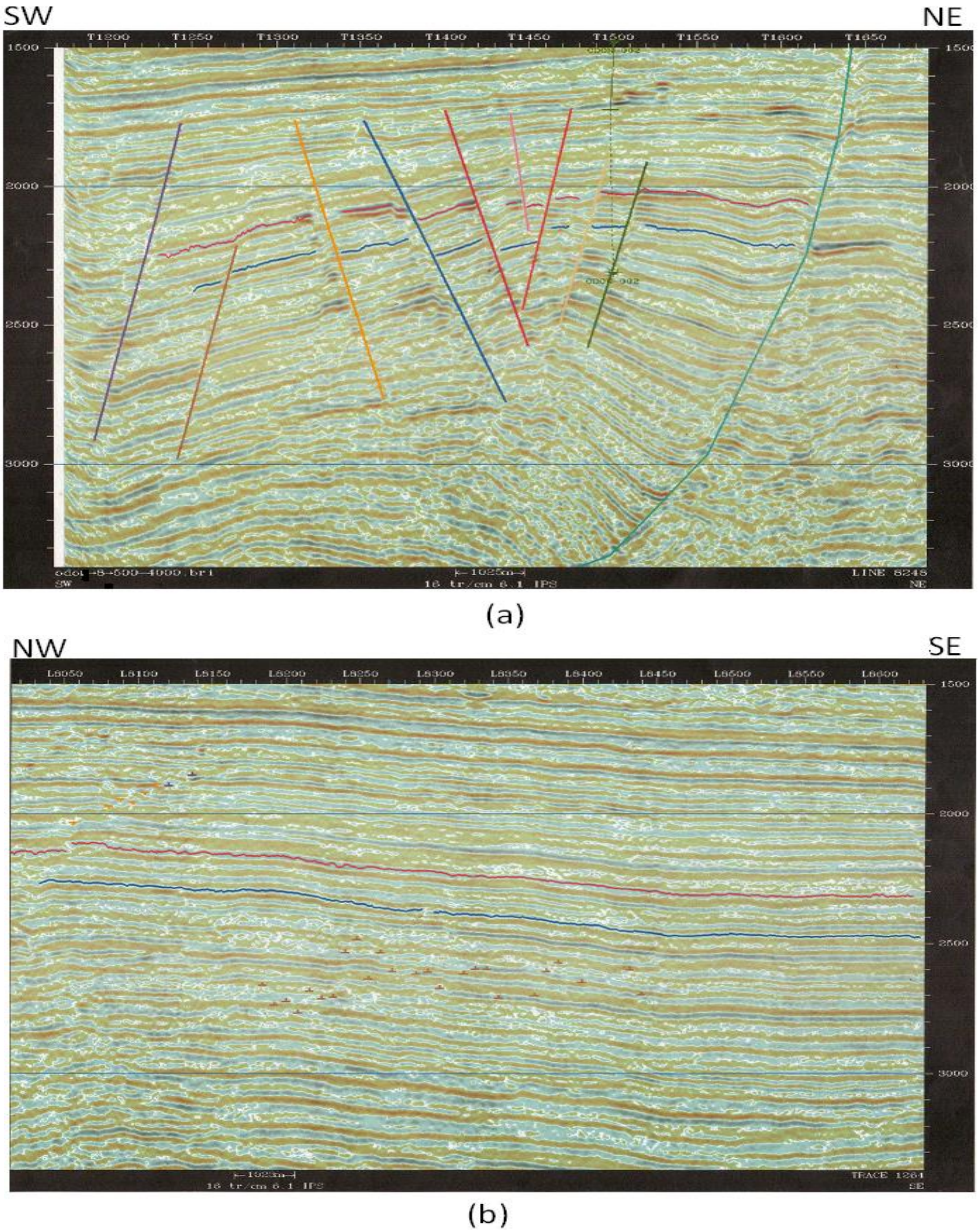

Figure 5. (a) Interpreted seismic in-line showing the faults and two horizons and (b) Interpreted cross line showing the two horizons and the cross posted fault.

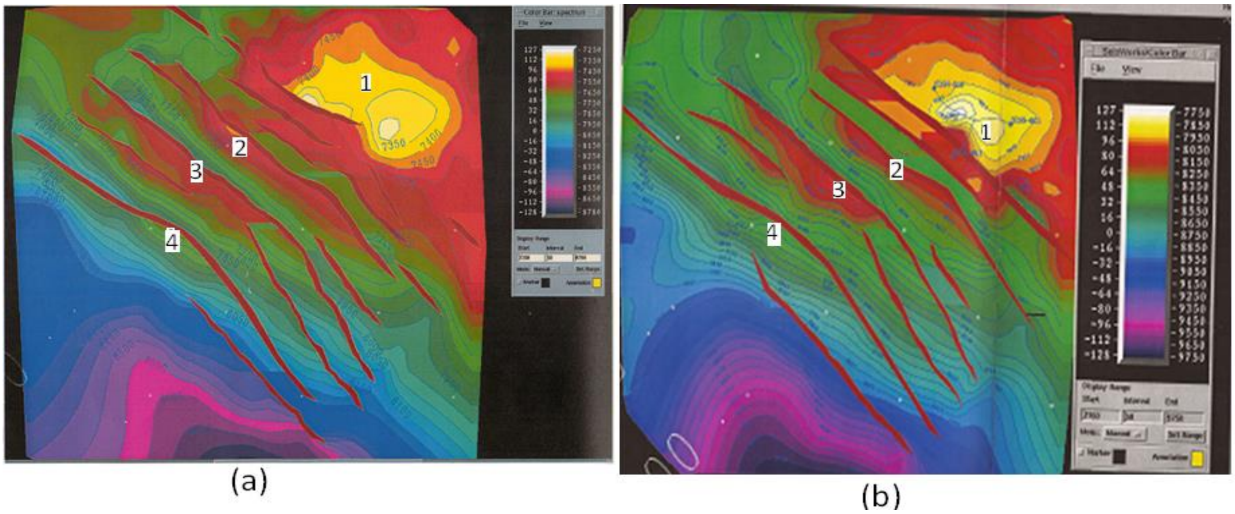

Figure 6. Depth contour map for (a) horizon 1, and (b) Depth contour map for horizon 2, showing the four closures.

Table 1. Estimated quantity of hydrocarbons from the closures.

Closures	Quantity of hydrocarbon in million stock tank barrel	
	Horizon 1	Horizon 2
1	18.871	35.082
2	111.293	43.922
3	30.861	129.665
4	11.661	1.186

The presence of gas in a reservior has often the property of a significant reduction in seismic velocity. The presence of oil does not have such significant effect. More usually the only detectable effect is the production of amplitude anomalies, these being due to the large negative reflection coefficient at the interface between gas-filled reservoirs and the overlying cap rock. Such amplitude anomalies are often termed ‘bright spots’ (McQuillin et al., 1984). Thus bright spots are seen as an indication of hydrocarbon presence; Figure 7 shows the amplitude maps for horizons 1 and 2. It is noted that gas shows clearly where the hydrocarbon is trapped. Thus from Figure 7 it is assumed that horizon 1 is mainly gas bearing.

Conclusions

The results from the hydrocarbon exploration in Odo Field in the Niger Delta Basin Nigeria, using a three-dimensional seismic reflection survey indicates that; Odo Field is an elongated rollover anticline with a collapsed crest which is associated with a growth fault. The picked seismic events (horizons) has four identified structural closures which were mainly fault /dip closures and were found to be hydrocarbon bearing. These hydrocarbon accumulations were seen to be supported by the faults within the field. Following the calculated estimations, several infield appraisal prospects exist. Finally, from the amplitude maps, horizon 1 is assumed to be mainly gas bearing.

It is suggested that drilling should not be carried out now but after a 3D time lapse (4D) has been carried out in the field to determine changes in rock properties to enable qualification and quantification of the hydrocarbons for production planning and well drilling.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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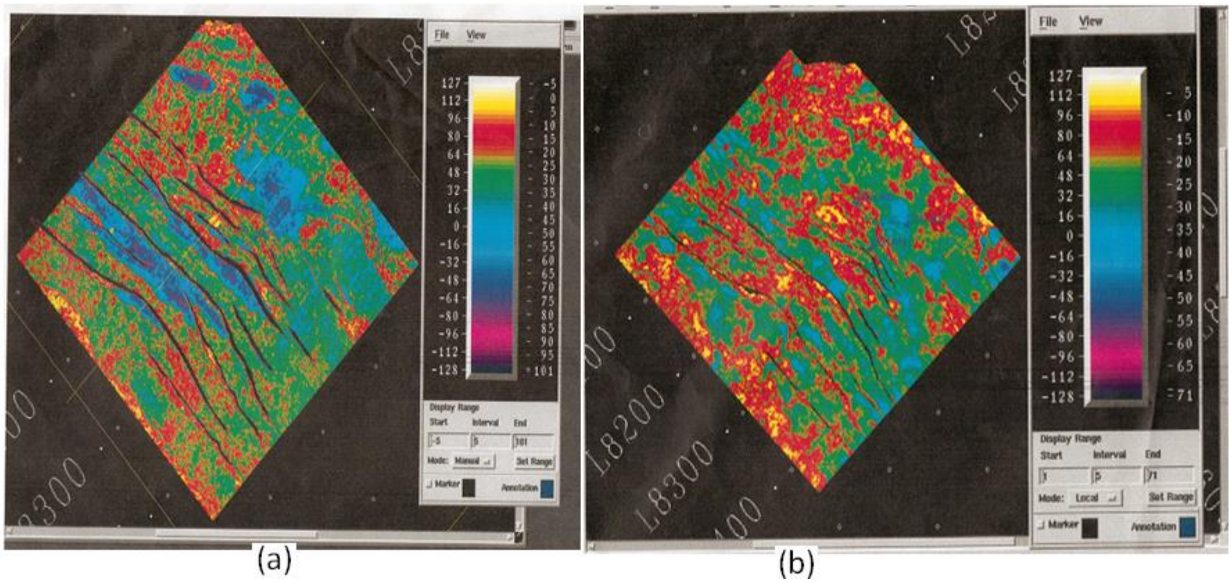

Figure 7. Amplitude map for (a) horizon 1 (b) horizon 2.

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