STRUCTURAL PATTERNS AND LITHO-STRATIGARPHY OF 'DIOK' FIELD, EAST NIGER DELTA, NIGERIA AND ITS IMPLICATION FOR HYDROCARBON GENERATION

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Abstract

Integration of 3D seismic data with well log information has been employed in determining the stratigraphy and structures within 'Diok' field, a Niger Delta hydrocarbon-bearing field. Four distinct seismic facies are recognized in the study area. They are seismic facies 1, which consists of transparent facies that are characterized by lack of acoustic impedance contrasts, it is interpreted to be the continental lithofacies of the Benin Formation. Seismic facies 2, which comprises discontinuous and occasionally inclined internal reflectors, they are found between 0.6 and 1.3s on the seismic sections of the study field, it mimics the transition between the continental and paralic lithofacies. High frequently occurring and continuous parallel reflections characterise seismic facies 3, which is between 1.3 and 3.0s on the seismic sections. They are interpreted to be the well-defined paralic lithofacies of the Agbada Formation. Seismic facies 4 are chaotic reflections found below 3.2s on the seismic sections and they represent thick shales of the Akata Formation. Structurally the field is interpreted to be a faulted anticline within a structural complex that involves series of basinward dipping normal faults. Two main fault blocks (A & B) that are further compartmentalized to smaller blocks at deeper levels and separated by series of small synthetic faults are observed in the field. Consistent and reliable fault interpretation was achieved in the study area through the use of seismic attributes and the pattern of faulting in the field indicates high degree of inter-block communications.

Key Words: 3D Seismic, Structures, Seismic Facies, Stratigraphy, Faults. .

Introduction

Diok field is located within the Central Swamp depobelt of the Eastern Niger Delta, Nigeria (Figure 1). The Niger Delta has long been recognized as a classic example of a continental-margin structural collapse under sediment loading (Rensbergen et al., 1999; Edwards, 2000; Rensbergen and Morley, 2000). It has distinctive basinward variations in structural style that defines (1) an inner extensional zone of listric growth faults beneath the outer shelf; (2) a translational zone of diapirs and shale ridges beneath the upper slope; and (3) an outer compressional zone of imbricate toe-thrust structures beneath the lower slope (Damuth, 1994; Hooper et al., 2002). These areas of contrasting structural style are linked on a regional scale by slow gravity collapse of the thick deltaic prism (Damuth, 1994). The Niger Delta shows structural evolution controlled by large prograding deltaic depocentres that have been deposited on overpressured prodelta shales and/or salt. It has an extensive gravity-driven decollement fold belts, which are of distinctive non-orogenic character. Deposition in the basin are complicated by syndepositional listric normal faults that formed as prograding deltaic sediments loaded within the underlying undercompacted marine shales.

Most recent stratigraphic studies on the sediments of the Niger Delta based on modern 3D seismic records have focused on relationships between depositional patterns within the compressional toe of the clastic wedge along the base of the continental slope (Morgan, 2004; Adeogba et al., 2005; Corredor et al., 2005).

The Niger Delta is one of the most prolific hydrocarbon provinces in the world. Estimates of the ultimate recoverable hydrocarbon from the basin, which is at least 12km thick in its central part is about 35 billion barrels of oil (BBO) and 120 trillion cubic feet of gas (tcf) (Ekweozor and Daukoru, 1994), making it one of the highest global concentrations of petroleum per unit volume of basin fill.

This study, therefore, attempts to delineate and classify the subsurface litho-stratigraphic units in the study field using seismic profiles and well log data. Also, the structural styles and pattern within the field shall be highlighted. This will aid in understanding the hydrocarbon prospectivity of the field.

Geology

The Niger Delta is situated on the continental margin of the Gulf of Guinea (Klett *et al.*, 1997). It occurs at the Southern end of Nigeria between latitudes 3^0 and 6^0N and longitudes 3^0 and 9^0E (Fig. 2) and covers an area of about 75,000km^2. Stable mega tectonic frames such as the Benin and Calabar flanks mark the northwestern and eastern boundaries of the delta respectively, while the Anambra Basin and the Abakaliki high mark the northern boundary. The delta is bounded in the south by the Gulf of Guinea.

The Tertiary wedge of sediments in the Niger Delta consists of three diachronous units, which show an overall upward transition from marine prodelta shales (Akata Formation) through sand-shale paralic sequence (Agbada Formation) to continental sands and gravels (Benin Formation).

The Akata Formation consists of uniform shale, which is dark grey to black with sand and silt lenses. It is undercompacted in most places in the delta and is rich in microfauna, thus, suggesting deposition in shallow marine shelf. Its thickness is about 600-6000m and ranges in age from Late Eocene to Recent (Avbovbo, 1978).

The Agbada Formation comprises shales interbedded with fluviatile, coastal and fluvio-marine sands, which become more prominent and thicker towards the top. Its thickness reaches about 4,500m and the sands constitute the main hydrocarbon reservoirs in the delta. The age of the formation is late Eocene to Recent (Short and Stauble, 1967).

A succession of Oligocene to Recent, massive, poorly compacted sandstones, thin shales, which thicken towards the base and gravels make up the (Benin Formation). It is about 2,100m thick at the basin centre where there is maximum subsidence (Avbovbo, 1978).

Data set/ Methodology

The data sets available for this study include a reprocessed 3D Pre-stack depth migration (PSDM) seismic volume and geophysical well logs.

The seismic sections were initially investigated using seismic facies analysis approach. This involves examination of the seismic characters to identify seismic facies and predict the stratigraphy of the field. The seismic facies units were defined from reflection configuration patterns, continuity, amplitude and attributes as well as their boundary conditions (Mitchum *et al*, 1991). These facies were thereafter, correlated with the associated well log characters (Magbagbeola and Willis, 2007). After generating the results for the seismic facies analysis, the structural interpretation of the field was carried out using the Landmark Seisworks application software. Three horizons (Diok D4000 Top, Diok E5000 Top and Diok J6200 Top) were also interpreted using the same application. Faults were picked on the basis of abrupt termination of reflection, change in pattern of events and dip of events on every 4th line interval on an orthogonal seed line for better positioning (Sheriff and Geldart, 1995). The interpreted faults were validated with the aid of a semblance volume. The seed grids of the interpreted horizons and fault sticks were loaded to the PETREL software for further interpretation. The Time-Depth conversion of the horizons was done in PETREL using a polynomial function that was generated from the checkshot data. The polynomial function used is as shown below,

$$TVD = 0.00053(TWT)^2 + 2.7548(TWT) + 22.55$$

Where: TVD is the true vertical depth

TWT is the two-way-time on the seismic profile.

RESULT AND DISCUSSION

Stratigraphy of Diok Field

The seimic facies analysis of the field shows that the area is characterized by four distinct seismic facies, namely seismic facies 1, 2, 3 & 4 (Fig. 2).

(a) Seismic facies 1: comprises transparent facies that have parallel, nearly horizontal and less continuous reflections with low amplitudes. They are characterized by lack of impedance contrasts. In the gamma ray logs they are shown by blocky sand intervals with interbedded shales that are less than 30ft thick. These facies mimic the continental lithofacies of the Benin Formation.

(b) Seismic facies 2**:** consists of low to medium amplitude, discontinuous and occasionally inclined internal reflectors. They are found between 0.6 and 1.3s on the seismic sections. The interval mimics the transition between the continental Benin and Paralic Agbada lithofacies.

(c) Seismic facies 3**:** is made up of low to high amplitude, high frequency and continuous reflections. On the gamma ray log they are shown to be sands interbedded with shales, which mimic the well-defined paralic (Agbada) lithofacies of the Niger Delta.

(d) Seismic facies 4**:** is composed of chaotic reflections that are well defined below 3.2s on the seismic sections. They probably represent thick shales of the Akata Formation or the extent of the vertical resolution of the seismic data.

The stratigraphy of the field as penetrated by the wells in Diok field reflects the regression of depositional environments within the Niger Delta. Depositions are observed to change broadly from coarse - fine grained with depth. This observation is inferred from the gamma ray log values and/or signatures. The top of the Agbada Formation is defined as the first appearance of salt water sands about 4000ft below sea level. This interval is marked by low gamma ray and sharp decrease in the resistivity log values (Fig.3). The base of the formation, not penetrated by the wells, lies greater than 10,000ft below sea level. Thus, the Agbada Formation is somewhat over 6000ft thick under 'Diok' Field. Gamma-ray logs of Diok field show tens to a few hundred feet vertical variations, which shows alternation of sand and shale successions. Based on standard log interpretations, log successions that show gradual decrease in gamma-ray value and then an abrupt increase (i.e. gradual coarsening and then abrupt fining) are interpreted to be prograding delta deposits. Also gamma ray logs that show abrupt decrease in gamma ray value and blocky form or gradually increasing trends are interpreted to be channel deposits. Serrated high gamma ray values are characterized by mudstone with varying amounts of thin sandstone beds. Generally, gamma ray log signatures from 'Diok' field suggest channel sands and prograding delta (Weber, 1971; Orife & Avbovbo, 1982; Owoyemi & Willis, 2006). It is pertinent to note that studies on facies and environment of deposition from well logs are usually carried out in conjunction with core data if available. For this study core data for 'Diok' field were not available.

Structure of Diok Field

Structural interpretation of the study area clearly reveals eight basinward-dipping normal faults and one counter regional fault. Diok field falls within a structural complex that involves three other adjacent fields, Bele and Maku to the south and Okpu to the east respectively (Fig. 4). Although several small-scaled faults were interpreted, the area around the field contains four major synthetic faults, J, K, L and M (Figs. 5 and 6). The structure of the field is described as a faulted rollover anticline. Diok field contains two main fault blocks (A and B) that are further separated into smaller compartments at deeper level by series of smaller synthetic faults. Figure 6 shows that several faults are converging towards a point at deeper levels within Diok field. This pattern of faulting could possibly introduced noise and caused the poor resolution observed on the semblance volume.

Deposits on the down thrown blocks generally thin for a few distances away from the major faults and then progressively thicken basinward across the remaining part of the fault block. This pattern reflects the syndepositional development of rollover anticlines within the hanging wall. Also, stratas within the hanging wall block dip towards the up thrown block directly adjacent to the fault, thus, showing rise in elevation towards the crest of the anticline.

Structural closures were observed around the fault blocks A & B for D4000 & E5000 (Figs. 7 & 8) and a cross-section (K – L) taken for the two horizons revealed anticlinal structures within the fault blocks.

Horizon interpretation

Well synthetics (well-to-seismic tie) were generated for wells with sufficient and reliable data using SynTool application. Three horizons (Diok D4000 top, Diok E5000 top and Diok J6200 top) were interpreted using SeisWorks application software (Figs. 7 – 9). The interpretation focused on establishing a fault framework over the study field. Seismic seed grids were generated for each of the interpreted horizons on every 4th inline and cross-line at the seismic loop corresponding to or close to the reservoir top. This close interpretation grid was adopted for high confidence zapping. The zap grids were used for amplitude extraction. Impressive amplitude map was generated for D4000 (Fig. 10) using the StratAmp application. The method employed for the extraction is the maximum positive analysis. Prospects around the fault blocks (A & B) with conformable amplitude anomaly are candidates for future appraisals. The intersected faults and horizons for the seed grids were used to define the fault polygons for each of the interpreted horizons. The velocity models for each of the horizons were determined using PETREL software. The horizons in time, fault polygons and the generated velocity models were used to produce the time-depth contour maps (Figs. 7 - 9).

Appraisal/hydrocarbon possibilities

A consistent and reliable fault interpretation was achieved through the use of seismic attributes and semblance slice which supported the fault position and lateral extension interpretation. A discontinuous and open fault pattern has been mapped, thus suggesting high degree of inter-block communications and the amplitude anomaly map show bright spots, suggestive of gas prospects.

Conclusion

The integration of 3D seismic data with geophysical well logs to attempt an interpretation of the structural pattern and litho-stratigraphy of Diok field has been carried out. The conclusions from the study show that:

1. Four distinct seismic facies that reflect the three different litho-stratigraphic units namely, from bottom Akata, Agbada and Benin Formations of the Niger Delta were identified.
2. The study field is inferred as channel sands and prograding Delta based on the studies on facies and environment of deposition using the gamma ray log signatures.
3. Eight basinward-dipping normal faults and one counter regional fault were interpreted using the seismic profile of the study area.
4. The field is a faulted anticline, which falls within a structural complex that involves three other adjacent fields.
5. The study field contains two main fault blocks (A & B) at shallow depths. These blocks are further separated into smaller compartments at greater depth by series of smaller synthetic faults.
6. Discontinuous and open fault pattern exist in the mapped area, suggesting inter-block communication.
7. The observed amplitude anomalies within the main fault blocks are candidates for future appraisal.

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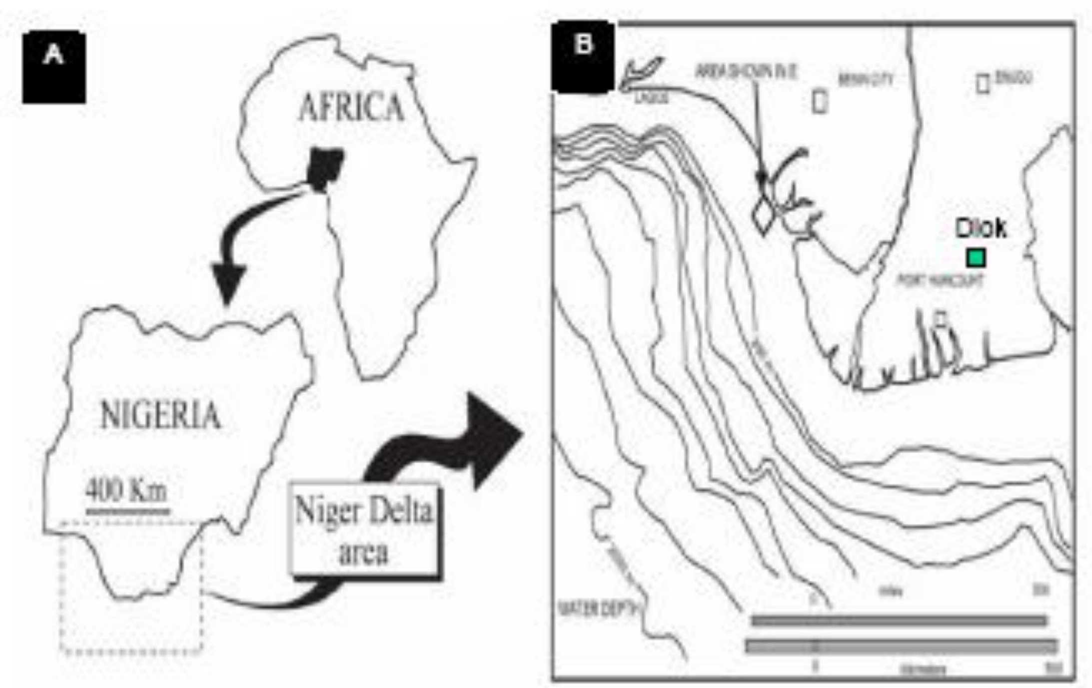

Fig. 1: Location Map of the Study area. (A) Position of Nigeria in Africa and Niger Delta Basin. (B) Diok field within the Niger Delta.

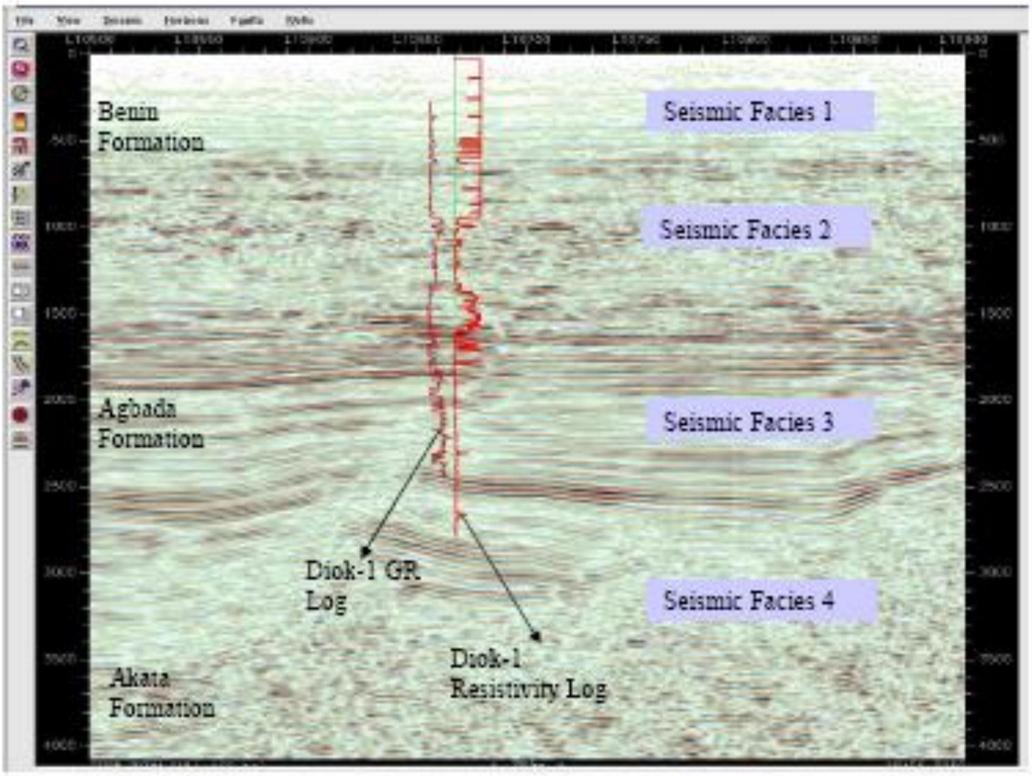

Fig. 2: Seismic section showing different seismic facies in the study area

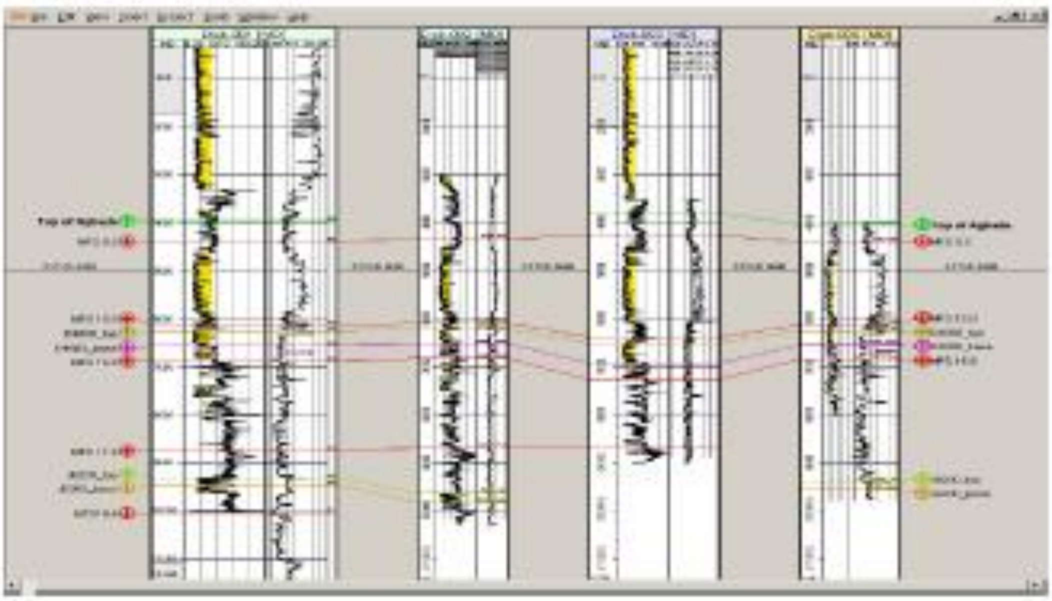

Fig. 3: Cross Section of Wells showing interpreted horizons

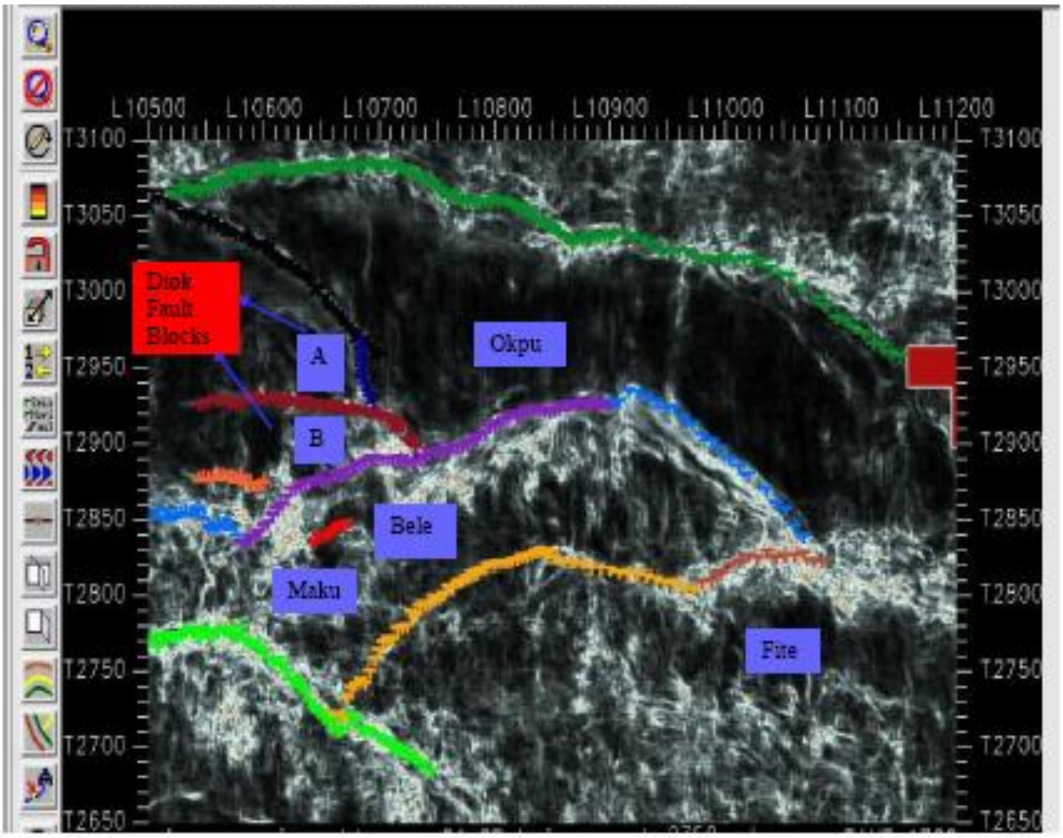

Fig. 4: Semblance Time Slice showing different faults and fault blocks in the Study Area

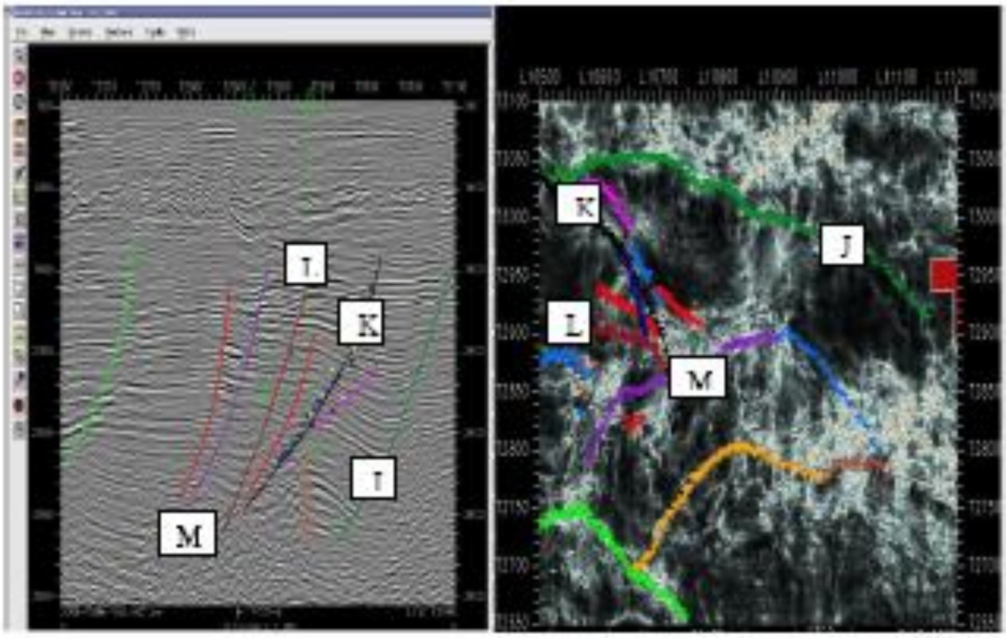

Fig. 5: Section of Seismic line and Semblance Time slice showing interpreted faults at deeper

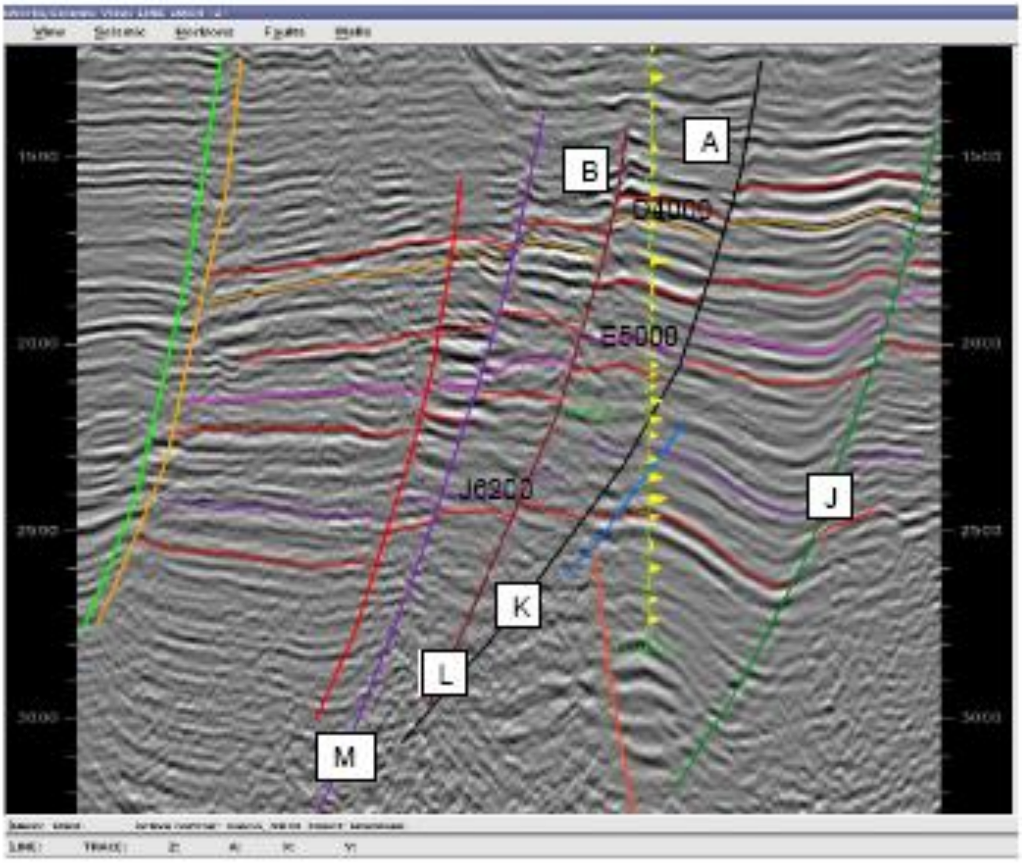

Fig. 6: N-S Seismic Line showing interpreted faults and horizons.

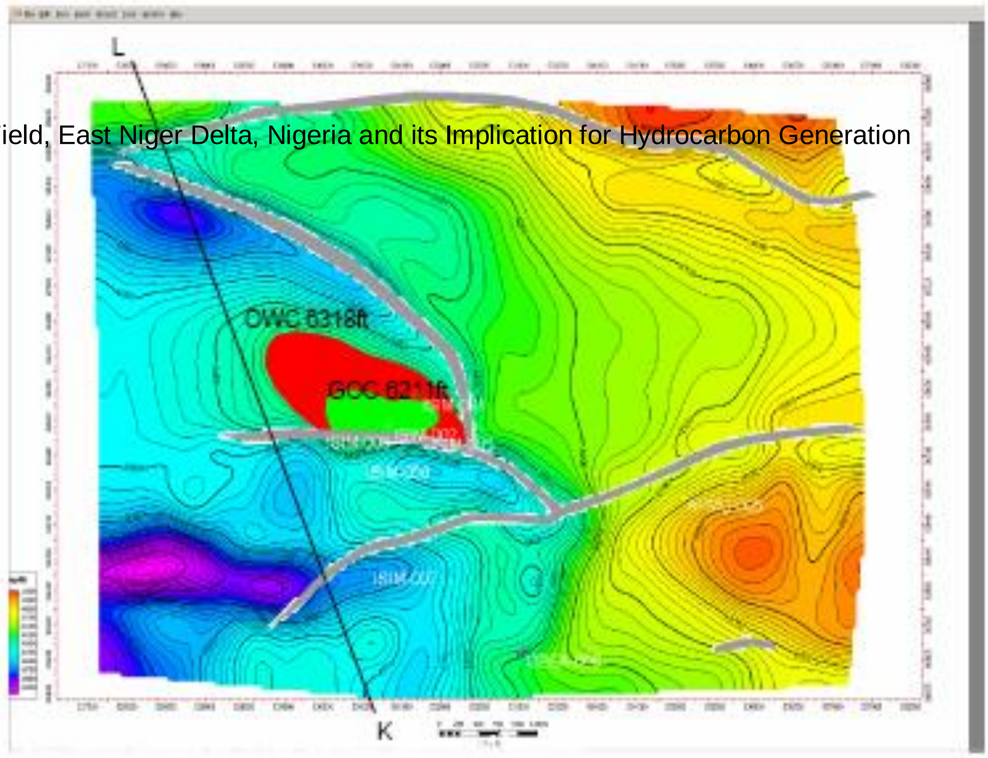

Fig. 7: Diok D4000 Top Structure Depth

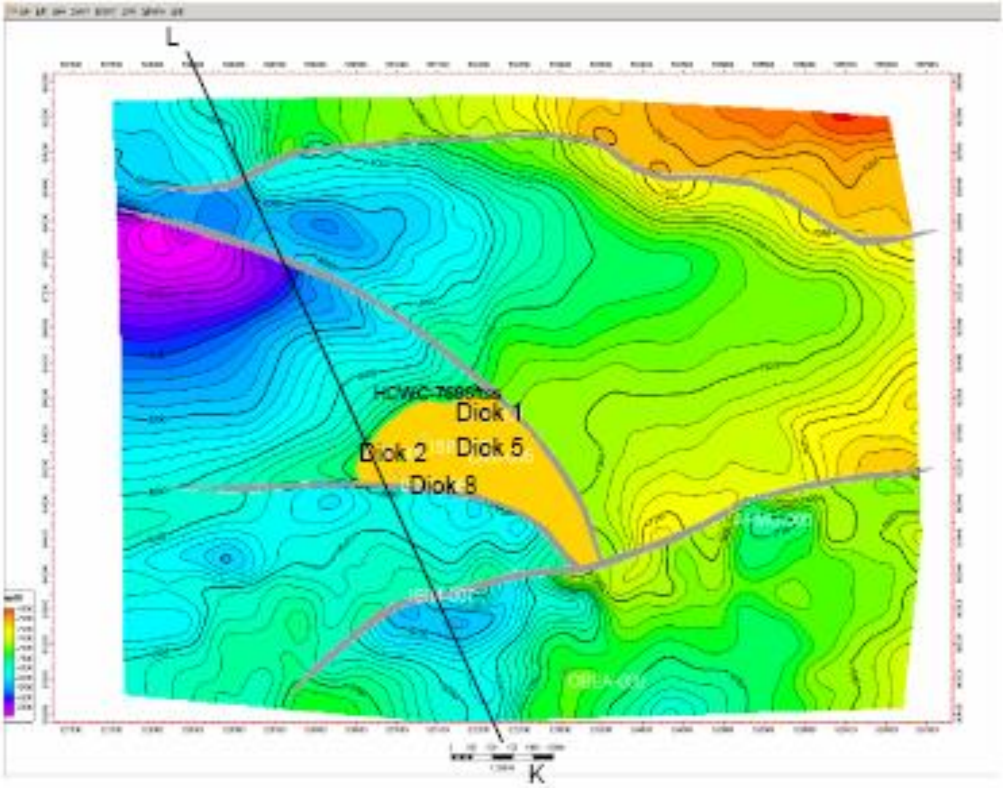

Fig. 8: Diok E5000 Top Structure Depth Map

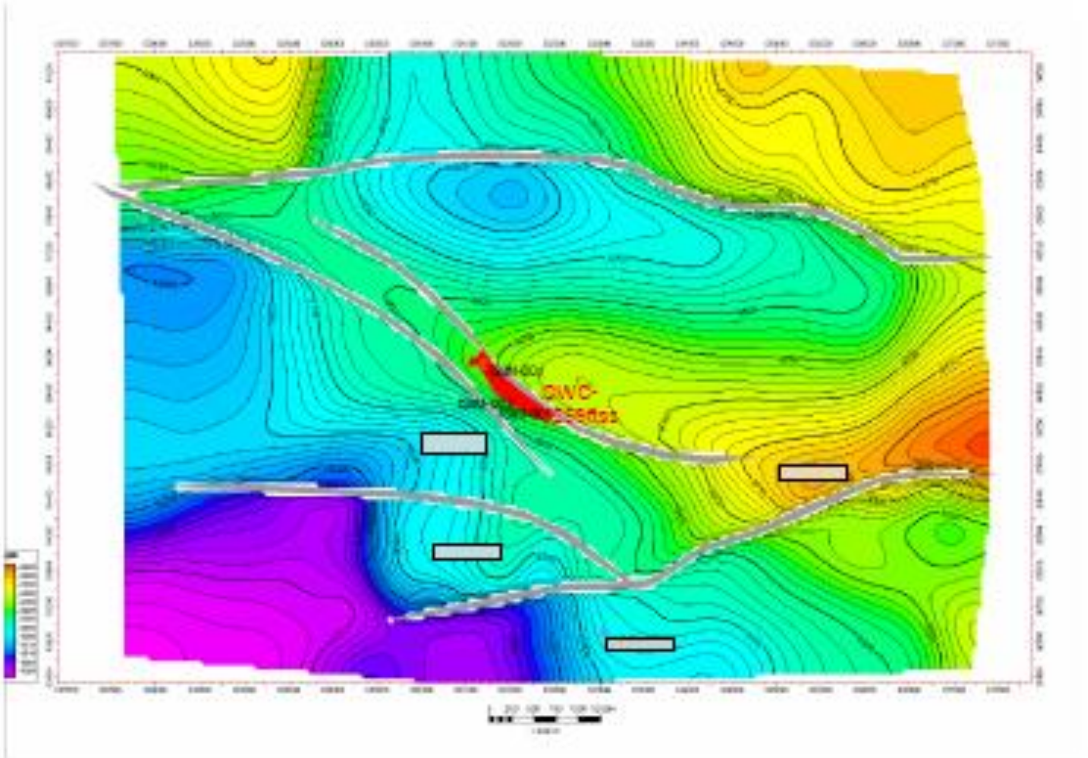

Fig.9: Diok J6200 Top Structure Depth Map

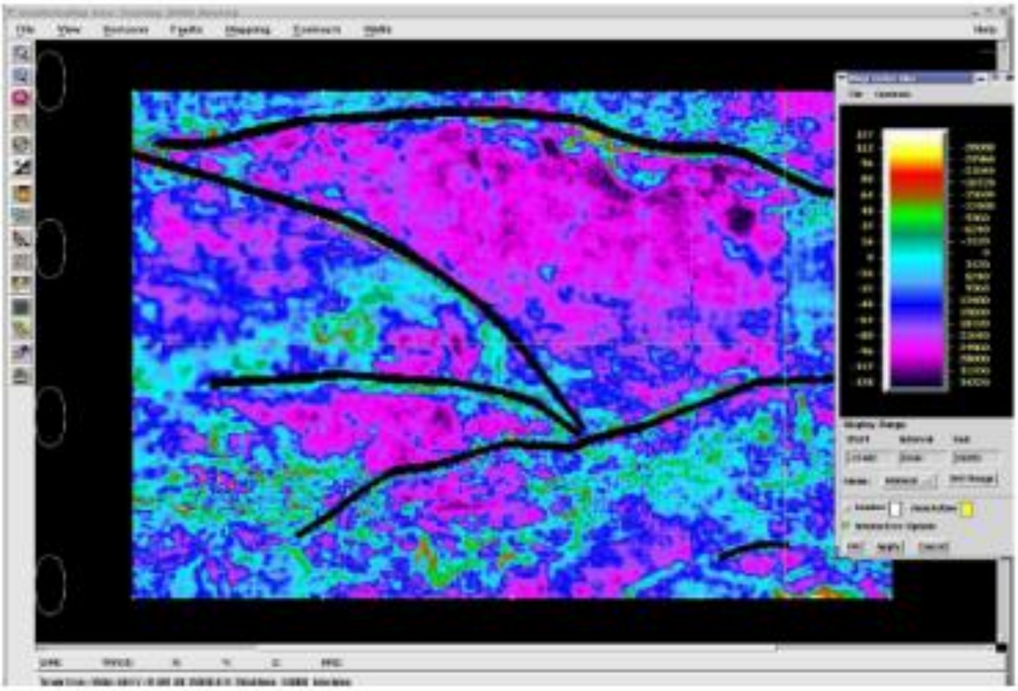

Fig. 10: Amplitude Extraction on Diok D4000 Top