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Research Article

EVALUATION OF SEISMIC ATTRIBUTES OF APO FIELD, ONSHORE NIGER DELTA, SOUTHERN NIGERIA

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ABSTRACT

The evaluation of the seismic attributes of Apo Field, Onshore Niger Delta, Southern Nigeria using 3D-seismic data was undertaken. Six shale and five reservoir sand units were identified. All of these units were penetrated by three wells. The results revealed that the rock properties are variable and are controlled by environments of deposition during Oligocene – late Miocene. The Shales had high acoustic impedances, high transmission coefficients and low reflection coefficients compared to sands. The Seismic attributes analysis also revealed rock properties in terms of fluid content and depositional environments with moderate - high amplitude and strong reflection strength with continuity being continuous to chaotic and truncated by faults. From seismic attributes and gamma log motif, depositional environments of fluvio-deltaic plain, deltaic front and open shelf margin are inferred. The oil and gas yield of the field is high and can be exploited at profit.

INTRODUCTION

Seismic facies analysis takes the interpretation process a step beyond seismic sequence analysis by examining within sequences smaller reflection units that may be the seismic response to lithofacies. In seismic facies analysis, seismic parameters such as; Reflection configuration ,Reflection continuity, ,Reflection amplitude and frequency Interttributesval velocity, Bounding relationship (types of reflection termination or lateral change) ;are used to identify seismic facies unit. Since seismic facies are responses to lithofacies, then reflection within seismic facies represents stratal surfaces or unconformities of stratigraphic significance. Hence, seismic facies analysis involves the recognition of these distinctive packages through their different physical characteristics. Reflection configurations could be parallel/divergent, prograding, mounded/draped or onlap fills.

Location of the Study Area: The study area (Apo field) is situated in the eastern part of the onshore Niger Delta, about 223km SW of Port Harcourt (Fig. 1). It has a total area of about 1969km2.

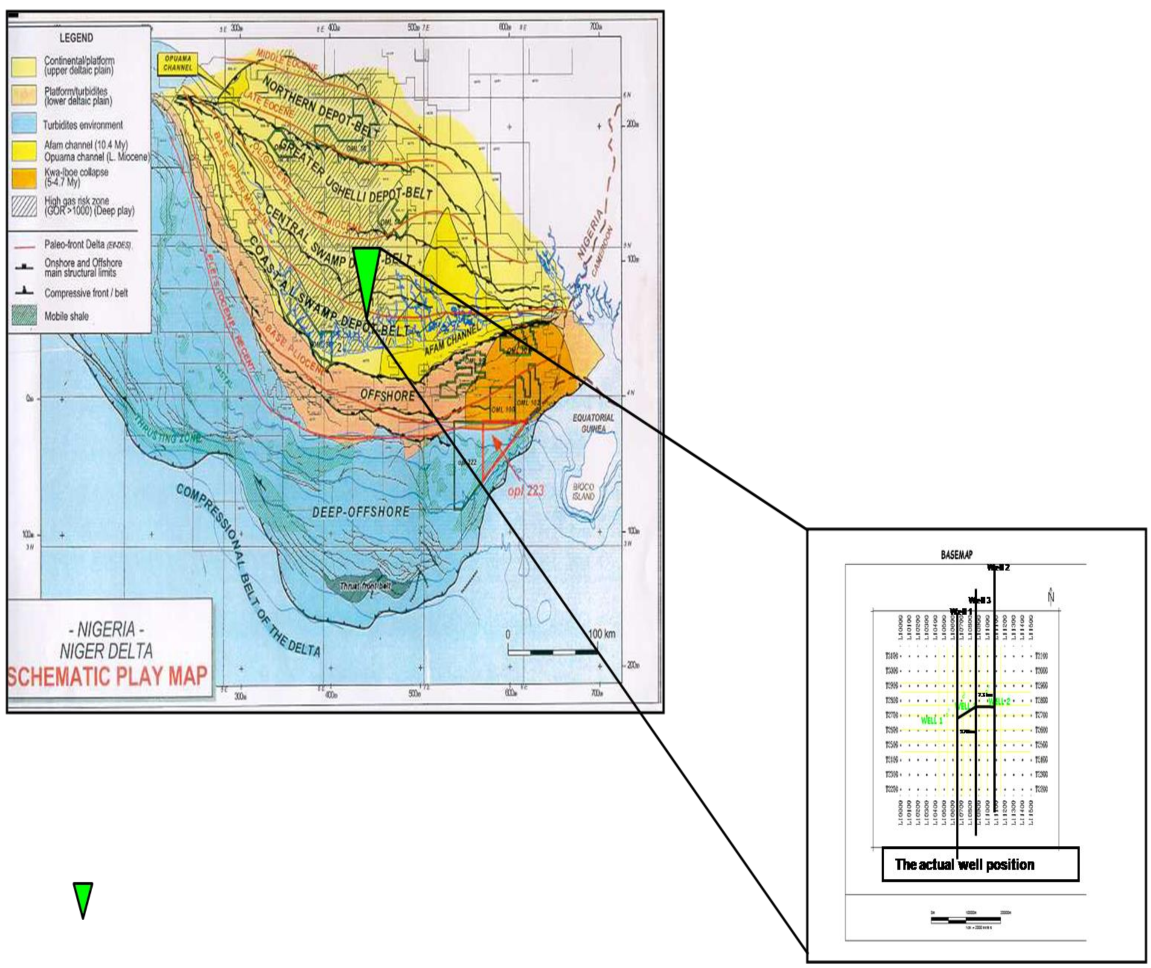

Figure 1: Location of study area (Apo Field) with respect to coordinates, fluvial and deltaic systems of the Niger Delta, Southern Nigeria.

OBJECTIVES OF THE STUDY

The objectives of this study include, but not limited to the: Determination of the seismic attributes of the Apo Field , Identification and definition of potential reservoirs and key hydrocarbon horizons useful for field development Determination of variables that influenced variation in rock properties of Apo Field.

The Geology of Niger Delta: Niger Delta is a large arcuate Tertiary prograding sedimentary complex deposited under transitional marine, deltaic, and continental environments since Eocene in the North to Pliocene in the South. Located within the Cenozoic formation of Southern Nigeria in West Africa, it covers an area of about 75,000 Km2 from the Calabar Flank and Abakaliki Trough in Eastern Nigeria to the Benin Flank in the West, and it opens to the Atlantic ocean in the South where it protrudes into the Gulf of Guinea as an extension from the Benue Trough and Anambra Basin provinces (Burke and Whiteman, 1970; Burke et al, 1972; Tuttle et.al 1999; IHS, 2010).

The Niger Delta as a prograding sedimentary complex is characterized by a coarsening upward regressive sequences. The overall regressive sequence of Clastic sediments was deposited in a series of offlap cycles that were interrupted by periods of sea level change (Etu-Efeotor, 1997; Bouvier et al, 1989; IHS, 2010). These periods resulted in episodes of erosion or marine transgression.

Stratigraphically, the Tertiary Niger Delta is divided into three formations, namely Akata Formation, Agbada Formation, and Benin Formation (Evamy et al, 1978; Etu-Efeotor, 1997; Tuttle et al, 1999). The Akata Formation at the base of the delta is predominantly undercompacted, over pressured sequence of thick marine shales, clays and siltstones (potential source rock) with turbidite sandstones (potential reservoirs in deep water). It is estimated that the formation is up to 7,000 meters thick (Bouvier et al, 1989; Doust and Omatsola, 1990). The Agbada Formation, the major petroleum-bearing unit about 3700m thick, is alternation sequence of paralic sandstones, clays and siltstone and it is reported to show a two-fold division. (Evamy et al, 1978; Etu-Efeotor, 1997; Tuttle et al, 1999). The upper Benin Formation overlying Agbada Formation consists of massive, unconsolidated continental sandstones. The deposition of the three formations and the progradation of the Niger Delta has been dependent on the interaction between rates of subsidence and sediment supply, and modified by faulting. Several growth-fault-bounded sedimentary units (depobelts) are present. These depobelts succeeded one another as the delta prograded through time under the influence of offlapping siliciclastic sedimentation cycles (Stacher, 1995; Tuttle et al, 1999).

There are 11 proven plays in the Niger Delta Basin, the Agbada group of plays being the main contributors of reserves. Agbada Stratigraphic-structural Play accounts for 58% of the basin.

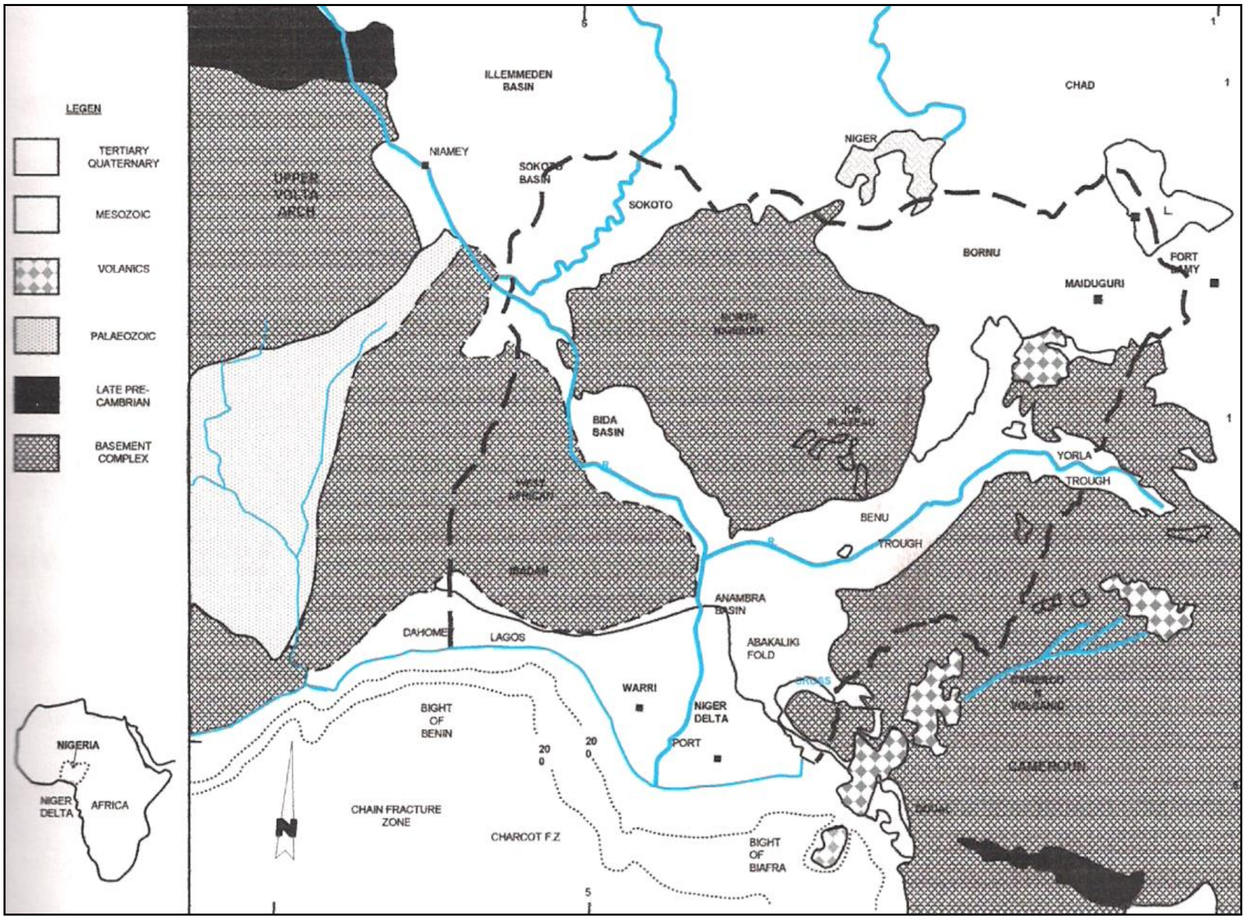

Figure 2: Simplified geological map of Nigeria and surrounding areas showing main drainage into the Gulf of Guinea

LITERATURE REVIEW

Seismic Attributes Chambers and Yarus (2002) considered seismic attribute as any seismically derived parameter computed from pre-stack or post-stack data before or after migration. For seismic attributes to have geological significance, they should have physical basis for their correlation with properties measured at the wells. Sheriff (1980) identified amplitude, phase, frequency, polarity, and velocity as attributes useful as hydrocarbon indicators whereas acoustic impedance, reflectivity and transmissitivity are useful for boundary conditions, hardness and nature of surfaces. Anomalies due to variation in seismic attributes often appear in section as *bright spots, flat spots*, and *velocity sags.*

Sheriff (1980), Chambers and Yarus (2002), and Schlumberger (2009) highlighted the geological significance of seismic attributes as useful in defining lithological contrast, bedding continuity, bed spacing and thickness, depositional environment, geologic structures, gross porosity, fluid content, abnormal pressure, temperature, and polarity of seismic. While the structural attributes can help in picking horizons and faults, seismic attributes relating to log and rock properties help in defining a better petrophysical and facies model, thus reducing uncertainty.

METHODOLOGY

Data Sets:

The following data sets were obtained and used for this study: 3D Seismic sections Structure Contour Map check shot data

Seismic Sections: For this study, 5-profile lines of a 3D-Seismic section of APO Field were obtained. The section included 1 X-line (Strike line) section and 4 In-line (Dip line) sections. The X-line section shows reflected events at time window of 1,500 – 3,300 msec and between T1000 and T1350 offsets, with well locations between T1160 and T1220 while the 4-Dip line sections (Traces 1153, 1169, 1185 and 1201 show the events between L5700 and L6440 offsets

The seismic section and the traces were used for overall sub-surface appraisal of structural features tracking lateral variation and changes in lithofacies The analysis of the seismic attribute Evaluation of the field in combination with geophysical logs.

FACTORS IN INTERPRETING SEISMIC FACIES:

The parallel/divergent type, which is the most common, comprises the following;

i. High amplitude/high continuity
ii. Low to moderate amplitude and continuity
iii. Variable amplitude/low continuity

Seismic Facies Parameters	Geologic interpretation
Reflection configuration	Bedding pattern, depositional processes, Erosional and paleo-topography, fluid contact
Reflection continuity	Bedding continuity, Depositional processes
Reflection amplitude	Velocity density contrast, bed spacing, fluid content
Reflection frequency	Bed thickness and fluid contact
Interval velocity	Estimation of lithology and porosity, fluid
External from and areal association of seismic facie unit	Gross depositional environment, sediment source and geologic setting

Table 1: Principal seismic parameters used in seismic stratigraphy and their geologic significance (Adopted from Mitchum et al., 1977)

Progradational (sigmoid and hummocky) reflection configuration or offlap reflections are typical of outbuilding stratal commonly from shallow water into deeper water, as along the Delta front or by infilling of channels. Progradational configuration could be oblique, sigmoid, shingled or complex/composite (Mitchum et al., 1977). Differences in configuration of clinoforms represent variation in sediment supply or rates of rates of basin subsidence or changes in sea level, water energy of the depositional environment, or water depth. Oblique configuration is associated with high energy deltaic due to rapid sedimentation rate; it has a toplap termination which could vary considerably from high angle to tangential, while sigmoid seismic facies result during progradation of a shelf of low energy deposition, it lack toplap terminations and the reflection could be traced into parallel/divergent reflections. Along the strike direction, progradational seismic facies exhibit parallel to hummocky clinoforms and mounded configuration.

Mounded and draped configurations may be caused by biogenic carbonate build up example reef or bank, proximal turbidites caused by slumping and superimposed strata which drape over mounds. Clastic mound usually of poor layered reflections and poor continuity is commonly composed of sand and shale, and onlap against eroded slopes or in front of slopes

RESULTS AND INTERPRETATION

Seismic Attribute Interpretation:

From Figure 3 , three (3) seismic reflection packages labeled A, B, and C, from top to bottom, was identified based on their reflection patterns. Between shot points T1000 and T1350 and between the time windows of 1500msec to about 2500msec, the beds in Unit A tend to be continuous with parallel – sub-parallel, strong reflection strength, uniform frequency and high amplitude

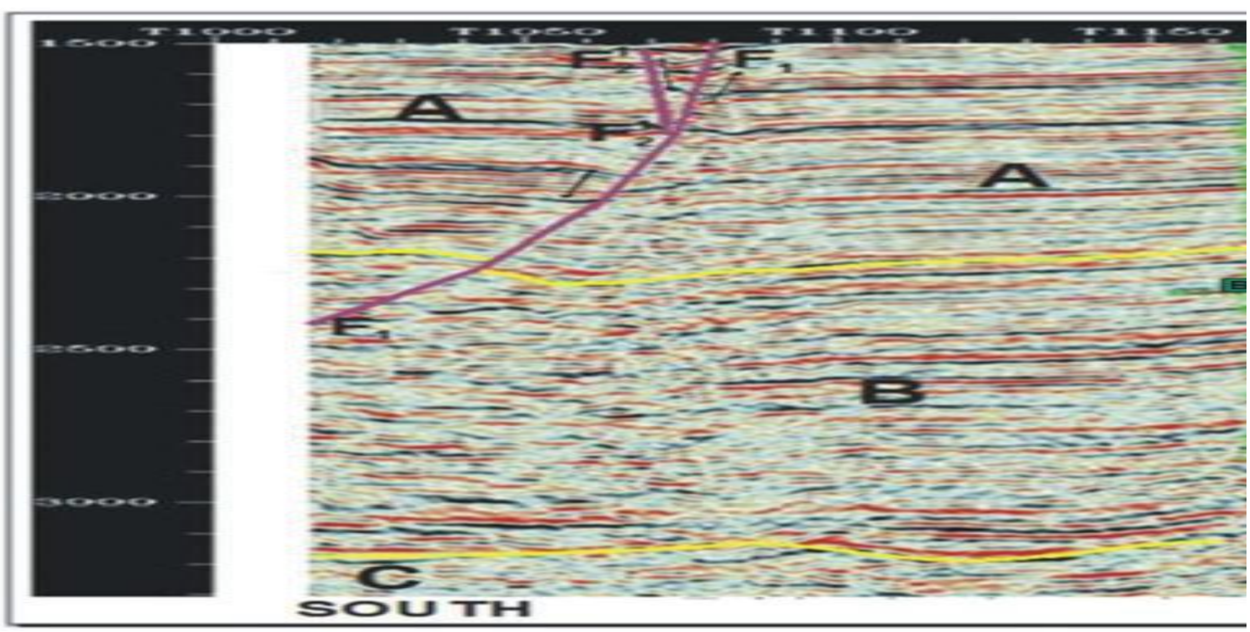

Figure 3: Faults (F), seismic packages / facies (A, B and C) and diapiric structure (S) mapped on X-line section. Bold upward arrow indicates direction of diapiric intrusion.

This unit is interpreted as massive sand body with shale intercalations deposited in a low energy deltaic plain / platform and shelf margin shoreface. folding and faulting. Six faults identified were designated

F1, F2, F3, F1, F2, and F3. Fault F1, F2, and F3 are synthetic (growth) faults that dip in the basinward direction while faults F1, F2, and F3 are antithetic faults dipping in landward direction.

Unit B, just below Unit A, is characterized by sub- parallel (variable parallel to divergent) reflection pattern, poor to moderate continuity and low-medium amplitude. This Unit also displays weak to moderate reflection strength and downlap on yet another package. It extends from time window of about 2200msec to about 3150msec.

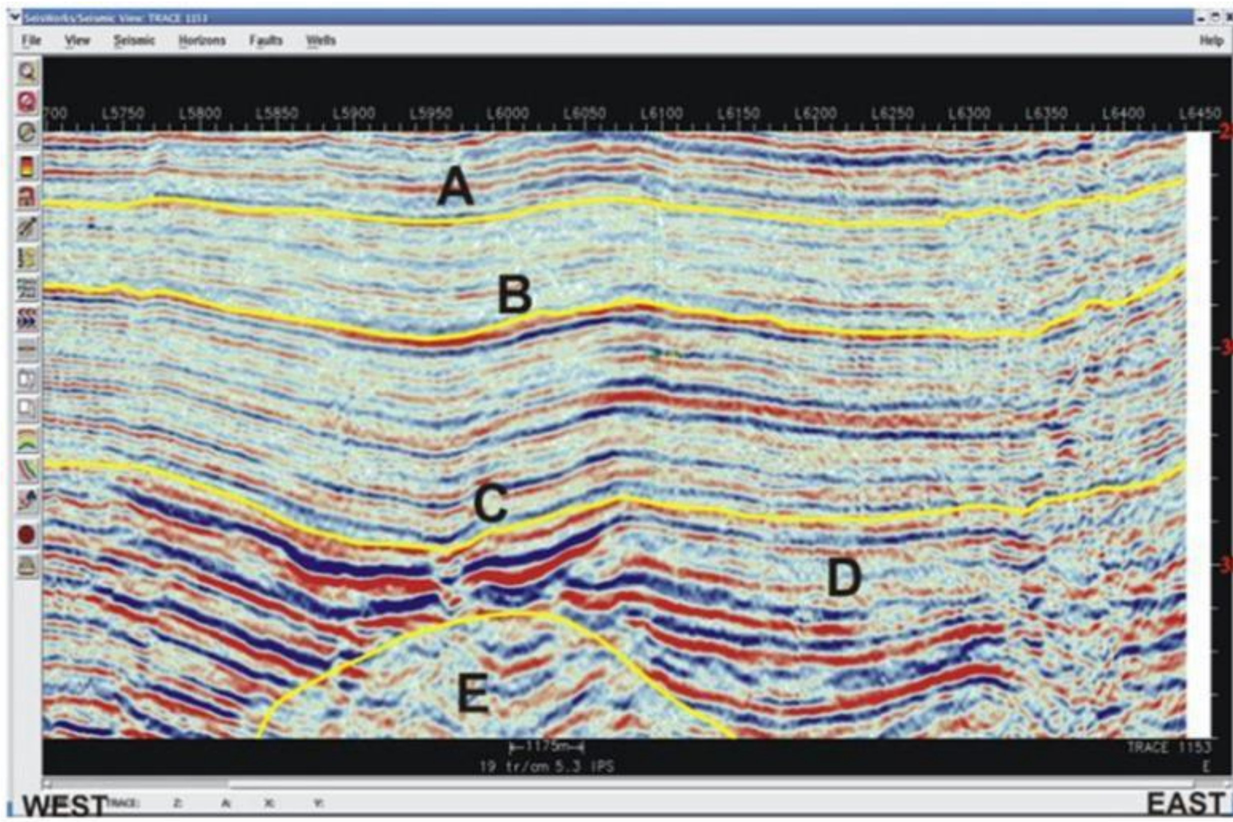

Figure 4: Seismic reflection attributes in terms of seismic packages on Trace 1153

This unit is interpreted as thick sand body with inter-bedding shales deposited in a low – medium energy deltaic front; inner - middle neritic shelf margin. Well-logged intervals are within this Unit. That is, within the time slice of about 2650 - 3150msec. The seismic reflection package labeled Unit C displays hummocky to chaotic configuration, with weak reflection and low amplitude. Reflection continuity is poor to very poor.

From the In-line sections (traces 1153, 1169, 1185 and 1201), five (5) seismic reflection packages / units labeled A, B, C, D and E, from top to bottom, were identified. An overall view of these sections / traces reveals a parallel and wavy reflection patterns which become discontinuous, discordant and weakly chaotic with variable reflection strength easterly from about shot point L6350. The parallel and wavy reflection patterns suggest a uniform condition of deposition on uniformly subsiding substratum.

Unit A shows both the vertical and lateral facies variation and shift in time windows. Between 2500-2600msec), the reflection are very continuous with moderate reflection strength and medium amplitude. The high continuity suggests widespread and uniform deposition along the strike direction. High amplitude suggests that the beds are relatively thick. Moderate reflection strength implies a relatively mo derate variation in acoustic impedance contrast in lithofacies of the unit A.

From the In-line sections (traces 1153, 1169, 1185 and 1201), five (5) seismic reflection packages / units labeled A, B, C, D and E, from top to bottom, were identified (Figures 3 and 4). An overall view of these sections / traces reveals a parallel and wavy reflection patterns which become discontinuous, discordant and weakly chaotic with variable reflection strength easterly from about shot point L6350. The parallel and wavy reflection patterns suggest a uniform condition of deposition on uniformly subsiding substratum.

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The Unit B which lies between the time windows of 2600 – 2840msec (trace 1153); 2550 -2800msec (trace 1169); 2500-2700msec (1185); and about 2500-2700msec (trace 1201) shows high continuity but weak reflection strength and low amplitude. The high continuity again suggests widespread deposition of various lithologic units while low amplitude suggests thin beds and/or gradational contacts between the lithologic units. Weak reflection is an indication of low acoustic impedance contrast between the various lithologicunits. Between 2700-3700msec (Unit C), though continuity was high, the amplitude variation is rather low to moderately high, with reflection strength being weak to moderate. High continuity implies widespread and uniform deposition whereas the weak-moderate reflection and low-moderately high amplitude could indicate sharp sand-shale boundaries and their alternating successions. However, the reflection is much stronger within the anticlines than in the synclinal part of the folded / wavy sequence. The amplitude is higher within this zone as well than in the synclinal zone and it gradually reduces towards the West. Thus, low-moderately high amplitude is interpreted as indication of alternating thick and thin lithologic units of low and high energy environment and/or relatively high fluid content. The weak – moderate reflection implies low and moderately high acoustic impedance contrasts of the lithologic units and variable hydrocarbon content within the reservoirs. The high reflection strength of the anticlines possibly indicates hydrocarbon accumulation within the structure.

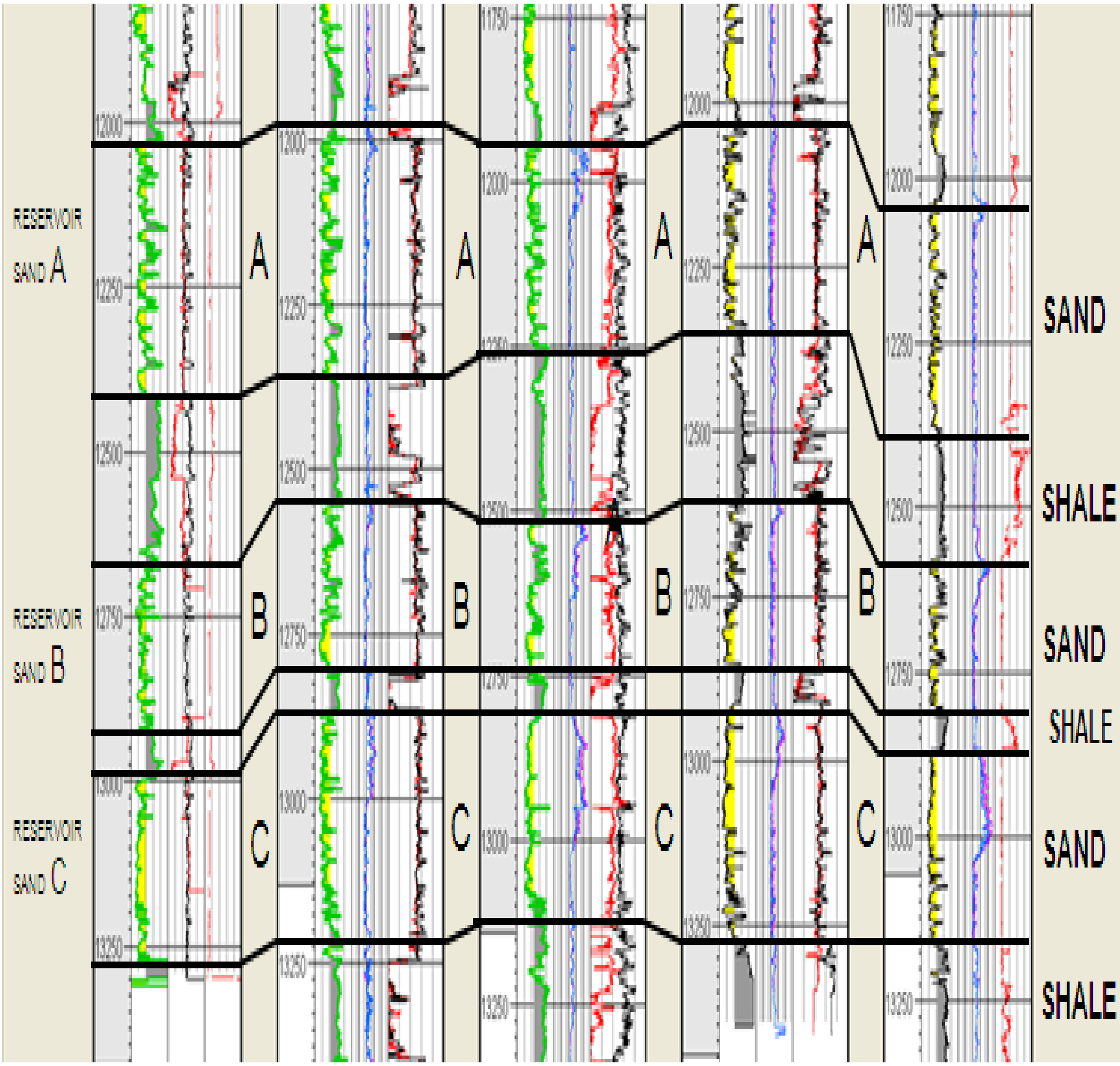

Figure 5: Correlation of Reservoir sands

Between 2700-3700msec (Unit C), though continuity was high, the amplitude variation is rather low to moderately high, with reflection strength being weak to moderate. High continuity implies widespread and uniform deposition whereas the weak-moderate reflection and low-moderately high amplitude could indicate sharp sand-shale boundaries and their alternating successions. However, the reflection is much stronger within the anticlines than in the synclinal part of the folded / wavy sequence. The amplitude is higher within this zone as well than in the synclinal zone and it gradually reduces towards the West. Thus, low-moderately high amplitude is interpreted as indication of alternating thick and thin lithologic units of low and high energy environment and/or relatively high fluid content. The weak – moderate reflection implies low and moderately high acoustic impedance contrasts of the lithologic units and variable hydrocarbon content within the reservoirs. The high reflection strength of the anticlines possibly indicates hydrocarbon accumulation within the structure.

The Unit D, lying below Unit C and between time windows of 2850 – 3900msec across the four seismic traces of the In-line section show a relatively very high amplitude, very strong reflection strength, and high continuity of seismic facies which are truncated against diapiric structure (Unit E). Unit D seems to have the strongest reflection strength and the highest amplitude. The diapirc structure (Unit E) has low amplitude and variable weak reflection strength. It is characterized with hummocky-chaotic internal configuration pattern typical of plastic materials such as clay which flowed into the overlying structure upon gravitational loading. This unit also shows both vertical and lateral variation in size across the Field. Unit E could have resulted from deformation and flowage of initially continuous strata possibly the clay materials within the designated Unit E.

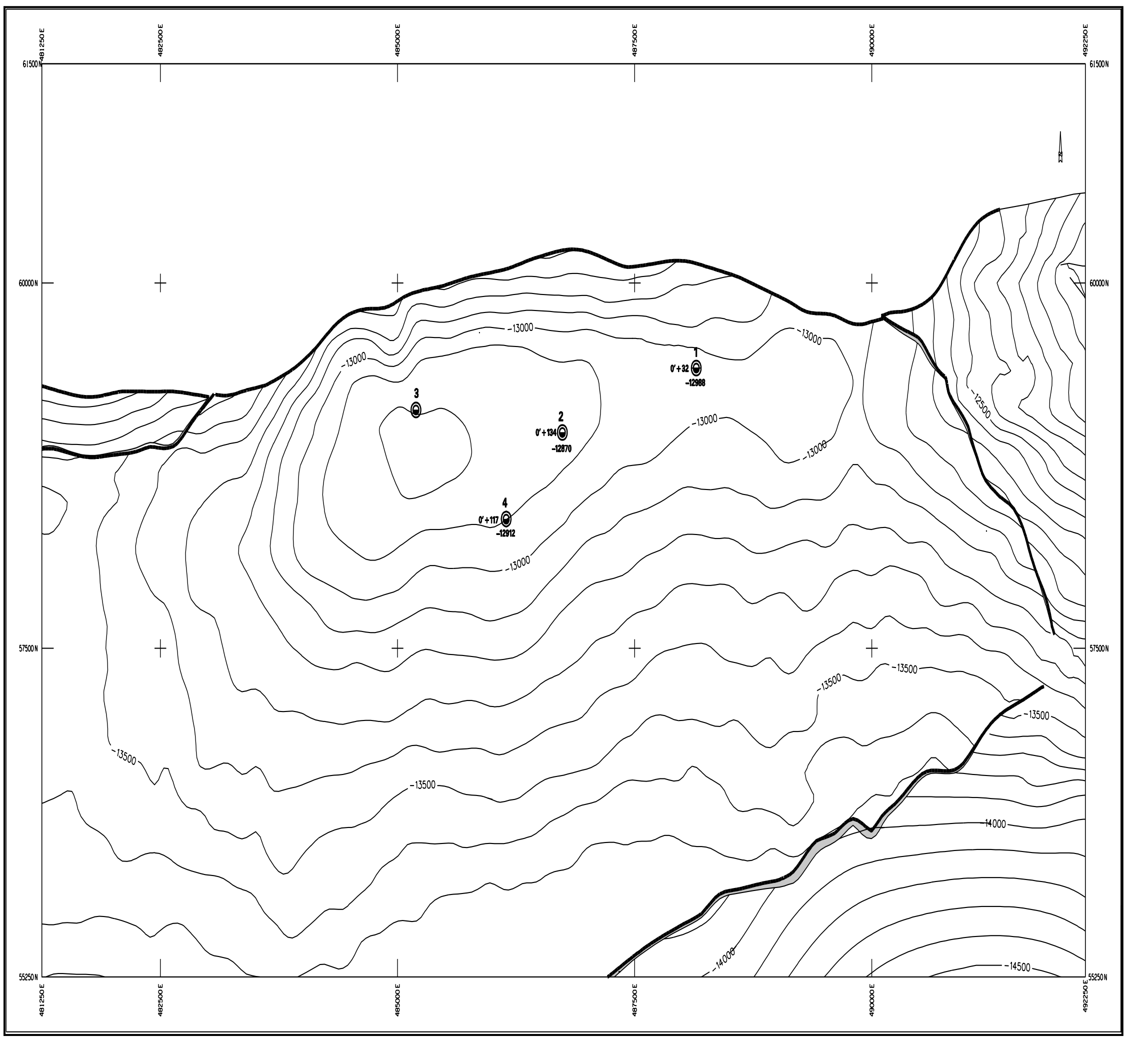

Figure 6: Showing Contour Map of the Study Area

The structural section through the field reveals the anticlinal structure with fault that is hydrocarbon and water bearing. The high amplitude contrast on top of this anticlinal structure implies it is overlaid by shale which serves as seal or cap rock. High amplitude and strong reflection strength along the margin of the faults are indication of the smearing of the faults and sealing of the reservoirs by clays or shales, thus trapping the hydrocarbons migration within the closures. The top seals are provided by field-wide marine and continental clays/shales whereas lateral seals are provided by juxtaposition of impermeable units of shales/clays against the hydrocarbon-bearing sandstones along the fault planes (Bouvier et al, 1989).

Clay or shale smears along the fault planes during faulting provided a seal to migrating gas and oil. The abundance of hydrocarbon distribution within the field could possibly be associated with lateral spill-points at the termination of discontinuous faults and seals, or lack of seals along fault planes (Bouvier et al, 1989).

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