International Journal of Research
Available at https://journals.pen2print.org/index.php/ijr/
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 06 Issue 03
March 2019

Fault Modeling and Seismic Attributes Of Nana Field, Niger Delta Nigeria

Emudianughe J. E & Michael M. Inyang
[1] Department of Earth Sciences, Federal University of Petroleum Resources, Effurun,Nigeria
[2] Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria

ABSTRACT

This study examined the application of 3-D seismic and well log data for proper optimization and development of hydrocarbon potential in " NANA " field of Niger-Delta Province. The data were conditioned for interpretation using Petrel software. These delineated reservoirs found in each well were then correlated across the field. A well-to-seismic tie was done using Seismic attributes (Frequency, RMS amplitude, Acoustic Impedance and Variance) and property modeling (Facies, net-to-gross, porosity, water saturation, hydrocarbon saturation and permeability) were distributed stochastically within the constructed 3-D grid. The reservoir structural model shows a system of differently oriented growth faults are quite extensive). The trapping mechanism is a fault assisted anticlinal closure.. This study demonstrated the effectiveness of 3-D static modeling technique as a tool for better understanding of spatial distribution of discrete and continuous reservoir properties, hence, has provided a framework for future prediction of reservoir performance and production behavior of the reservoir..

(I) INTRODUCTION

In most exploration and reservoir seismic surveys, the main objectives are, first, to correctly image the structure in time and depth and, second, to correctly characterize the amplitudes of the reflections. Assuming that the amplitudes are accurately rendered, a host of additional features can be derived and used in interpretation. Collectively, these features are referred to as seismic attributes. The simplest attribute, and the one most widely used, is seismic amplitude, and it is usually reported as the maximum (positive or negative) amplitude value at each sample along a horizon picked from a 3D volume. It is fortunate that, in many cases, the amplitude of reflection corresponds directly to the porosity or to the saturation of the underlying formation.

attribute analysis also help to identify faults missed using the conventional methods of interpretation Seismic attributes have been used for many years to delineate faults and stratigraphic features that are difficult to map using standard amplitude seismic data Though the seismically resolvable faults may be interpreted using traditional diagnostic criteria (e.g., abrupt reflector cut off, kinks, etc.), the subtle faults like sub-seismic faults which are of immense exploration significance are usually not visibly imaged by the conventional seismic sections and time slice displays. The poor imaging of sub-seismic faults is because they have smaller throws relative to the resolution limit of the seismic survey, which is a factor dependent on the frequency content, signal to noise ratio of the dataset and the depth to the reflecting horizon. Identification of these subtle traps are therefore, essential for effective identification and characterization of very complex reservoirs, hence this research is conducted to unravel the reservoir characterization of some of this complexities.

Statement of Problems

The quest for optimum method of hydrocarbon production has been an issue which many oil and gas companies are interested in. Alvarado and Manrique (2010) have stated that the effdgort of industries to increase production by the use of large capital investments to enhance oil recovery sometimes proves futile. This hitch needs to be proffered with a sustainable solution. One of the major ways of resolving this issue is through seismic attributes hydrocarbon reservoir properties modeling. These shortcomings have resulted in poor evaluation of target reservoir sand bodies, structures and stratigraphic development, and overall geologic resolution due to inadequate mapping and interpretation of the subsurface rock properties and seismic attributes, even where favourable structures exist. The realization of problems stated above, and the usefulness of seismic data, necessitated the researchers to undertake the investigation of sub-surface rock properties of NANA Field using seismic attributes, possible cause of their complexities, and their possible fluid contents and types as can be revealed by seismic attributes in seismic section.

Location and Geology of the study area

The NANA FIELD is located in the coastal swamp region of the western onshore Niger Delta, Nigeria. The actual location is concealed because of proprietary reason

Aim of the Study

The aim of this study is the Determination of the seismic attributes of the of Nana Field and Identification and definition of potential reservoirs and key hydrocarbon horizons useful for field development

Geology of the Study Area

The Niger Delta is located in the Gulf of Guinea, from where it extends through the entire Niger Delta Province.(Klett, Ahlbrandt, Schmoker, & Dolton, 1997). It is situated between latitudes 4° N and 6°N as well as longitudes 3°E and 9°E. The delta has prograded southwestward thus forming depobeltsfrom the Eocene to the present.(Doust & Omatsola, 1990) These depobelts now represent the most active portion of the delta at each stage of its development. (Doust & Omatsola, 1990). They form one of the largest regressive deltas worldwide with a 300,000 km^2 area (Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica., 1995)as well as a 500,000 km^{3}ofsediment volume(Hospers, 1965), and a sediment thickness of over 10 km in the basin depocenter.The Niger Delta started to evolve in early Tertiary times when clastic river input increased.(Doust & Omatsola, 1990)

The Niger Delta basin is situated at the extreme south of the elongatedintracontinental Benue Trough.(Dim, 2017). In the west, it is separated from the Dahomey basin by the Okitipupa basement high, and in the east it is bounded by the Cameroun volcanic line. Its margin in the north transects several older Cretaceous agedtectonic elements-the Anambra basin, Abakaliki basin, Afikpo syncline, and the Calabar Flank.(Dim, 2017). The rate at which sediment builds up as well as subsidence rate has been the major developmental factor as well as the balance of the Niger delta.(Doust & Omatsola, 1990).

The Niger delta hinterland is primarily made up of ancient rocks of the African Shield. The position that the Niger delta occupies is as a result of the break-up of the CentralAfrica-South America portion of the Gondwana continent which took place in the Mesozoic along a series of rift zones of different orientations that met in a triple junction in the area that the Gulf of Guinea now occupies.(Doust & Omatsola, 1990)

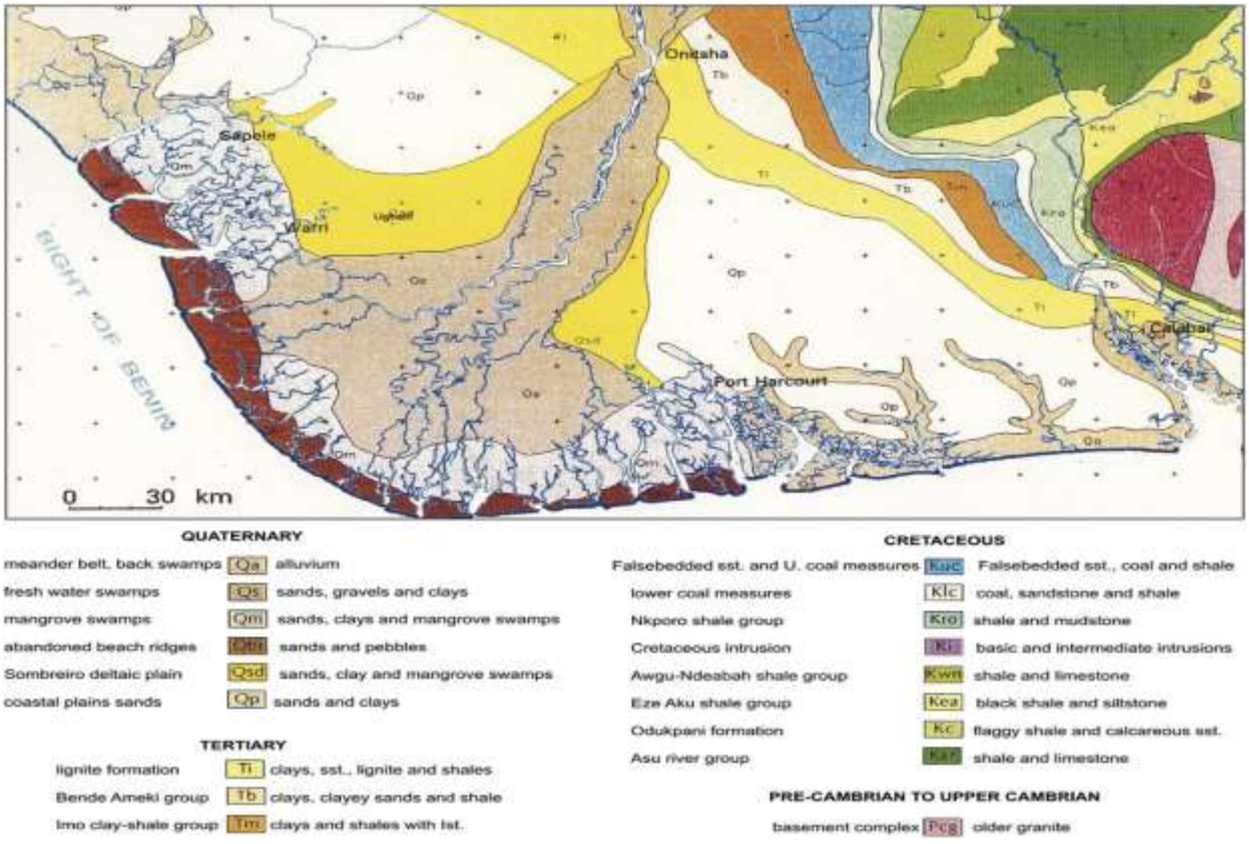

Figure **Error! No text of specified style in document.**: Diagram showing geological map of Niger delta and its environs**(Reijers, 2011)**.

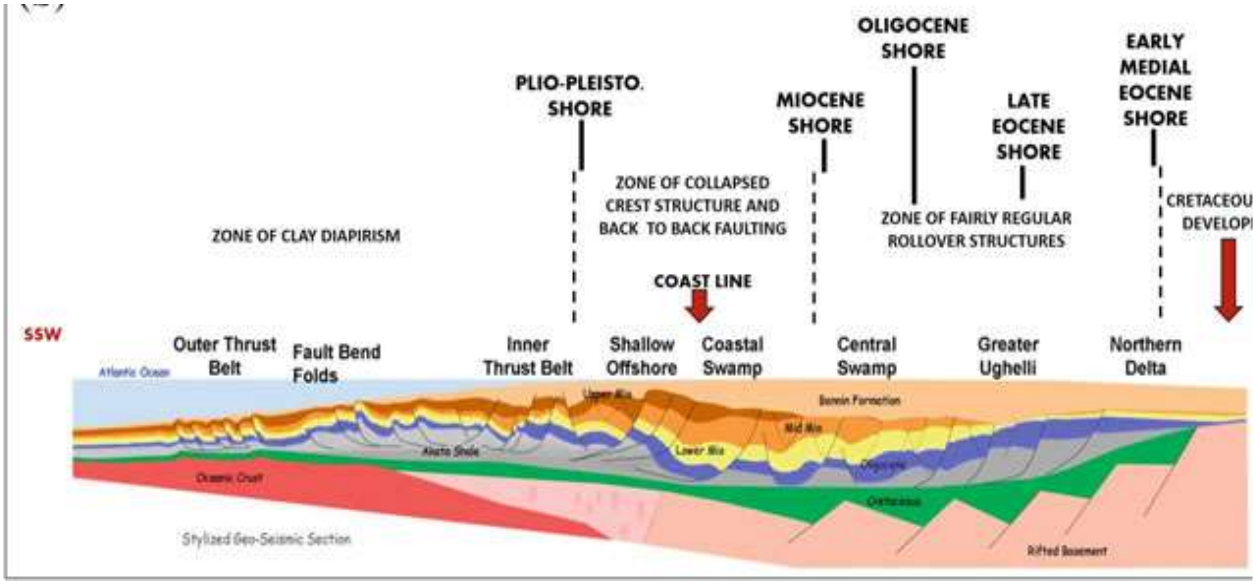

Figure .1: Diagram showing depobelts and dip section of the Niger Delta Basin.**(Frankl & Cordy, 1967)**

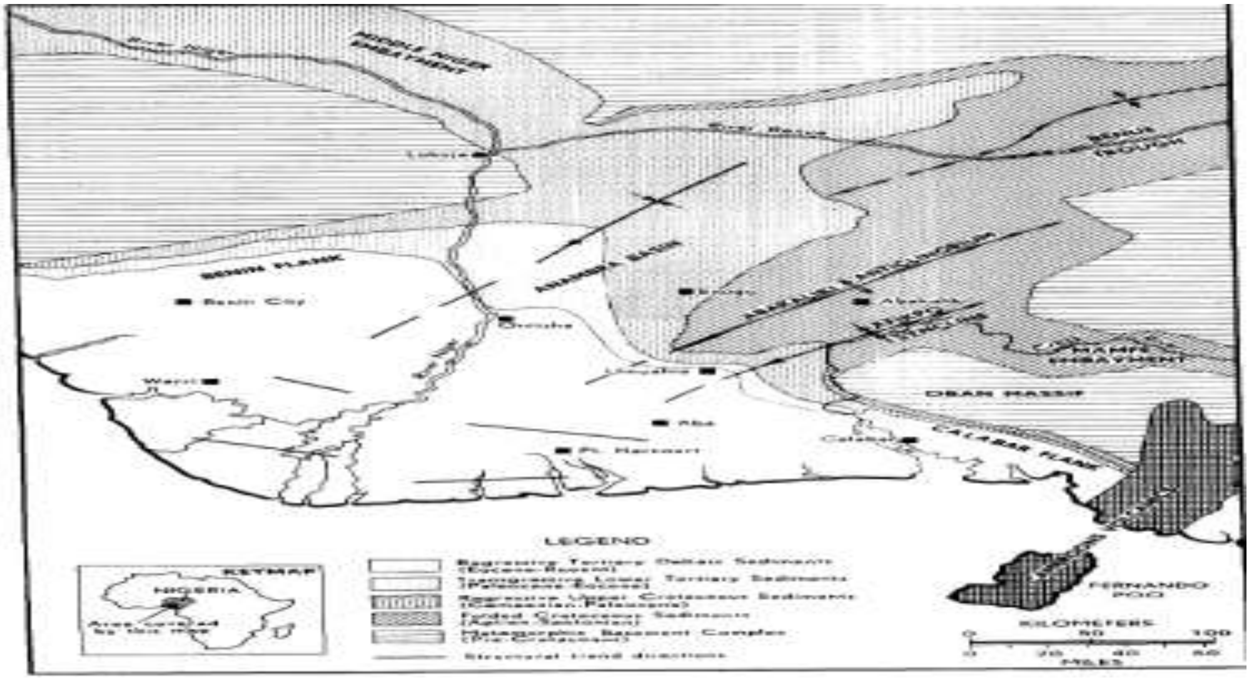

Figure 3: Mapshowing the structural units of the Niger Delta (Short & Stauble, 1967)

(III) LITERATURE REVIEW

Seismic Attributes

Marfurt (2005) defined seismic attribute as any measure of seismic data that helps in visualization or quantification of features of interpretation of interest.

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.

Dopkin and Wang (2008), in a study of seismic-driven reservoir characterization, reported that using seismic data and well data calls for continuous transformation, calibration and interpretation for achievement of accuracy. This is because rock properties affect observed acoustic and elastic behaviour of seismic data e.g. in travel time and amplitude variation with offset (AVO); and through seismic inversion, attributes such as AVO, reflectivity and impedances which often indicate presence of hydrocarbon can be generated.

Okeke (1999) classified Niger Delta amplitude on the basis of reflection strength into three (3) types, namely; low amplitude, middle amplitude, and high amplitude. Combining reflection strength and amplitude, five (5) seismic sequences are identified in the Niger Delta. Describing the sequences, from bottom to top: sequence 1, the deepest section, is faulted, has poor data resolution and fairly weak reflection; sequence 2 is faulted, has medium amplitude facies and continuous alternation of sand and shales; sequence 3 is faulted but relatively continuous, has high amplitude; sequence 4 is of discontinuous beds, low amplitude facies, low continuity reflections, inter-bedded low energy deposits; sequence 5 has poor resolution data, variable amplitude, poor continuity reflection (alluvial deposits). In term of rock unit, sequence 1 correlates with Akata Formation, Sequence 2 and 3 with Agbada Formation while sequence 4 and 5 are those of Benin Formation.

In a study of 3D seismic and fault sealing in Nun River Field, Eastern Niger Delta, Bouvier et al (1989) reported that acoustic impedance contrast is negative for hard shale to soft sandstone and positive acoustic impedance contrast for soft sandstone to hard shale and that in Nigeria, sandstones have comparatively lower acoustic impedance than shales; hydrocarbon bearing sandstones having even lower acoustic impedance than water-bearing sandstones with increased positive amplitude. They also reported of sandstones as having positive amplitude polarity and shales a negative amplitude polarity.

(IV) METHODOLOGY

Data Sets

The following data sets were obtained and used for this study:

☐ 3D Seismic sections
☐ Structure Contour Map
☐ Check shot data

The data set used for this study comprised of 3-D seismic reflection data (255 in lines and 226 cross lines), covering an estimated area of 85 km^2 and suites of composite logs (GR, Sonic, Resistivity, Compensated Density and Neutron porosity logs). Part of the dataset include four vertical wells and their check shot survey data. show the base map of the study area with the appropriate location of the drilled wells within the study area. Schlumberger Petrel 2015 version (a seismic to simulation and interactive petrophysics (IP) software) was used for this project.

The X-line section indicate 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 procedure include the overall sub-surface appraisal of structural features, Tracking lateral variation and changes in lithofacies

And the analysis of the seismic attribute

HYDROCARBON RESERVE

The fluid contacts were delineated for the reservoirs from the neutron-density cross-plot across the reservoir from the NANA well. The hydrocarbon-water contact (HWC) was at the depth of 7509ft (TVDSS).

Therefore, the reserve for hydrocarbon was estimated using the relation

$$N_f = \frac{7758 \times A \times h \times \text{ø} \times S_h \times Rf}{B_{oil}}$$

Where, N_f = volumetric recoverable oil reserve in stock tank barrel (STB)

7758 = barrels per area foot

A = drainage area in acres

h = reservoir thickness in ft

ø = porosity in decimal

S_H = hydrocarbon saturation in decimal

R_f = recovery factor = 0.42 (for oil)

B_{oil} =oil formation volume factor

$B_{oil} = 1.05 + 0.5 \times \frac{GOR}{100}$

GOR (gas-oil ratio) = $\frac{Gas\ in\ cubic\ feet}{oil\ in\ barrels}$

N_f = 136,000,000 STB (stock tank barrels).

Above calculation shows the reservoir A petrophysical properties estimation, this same process was applied in obtaining the petrophysical and volumetric parameters for reservoir B as shown in ta Table .1: Average Petrophysical properties for Reservoir A and B.

Table 1: Averahe petrophysical values of the study area

RESERVOIR	POROSITY (%)	PERMEABILITY (millidarcy)	NTG (%)	WATER SAT. (%)	HYDROCARBON SAT. (%)	STOIIP (m STB)
A	35	1342	90	33.7	68	138
B	26.	1328	91	36.5	65	130

(V) RESULTS AND INTERPRETATION

SEISMIC ATTRIBUTES MODEL

Frequency attribute model: Technically, each individual frequency or band of frequencies could be considered an attribute. The seismic data was filtered at various frequency ranges in order to show certain geological patterns that may not be obvious in the other frequency bands. There is an inverse relationship between the thickness of a rock layer and the corresponding peak frequency of its seismic reflection. That is, thinner rock layers are much more apparent at higher frequencies and thicker rock layers are much more apparent at lower frequencies. This was used to qualitatively identify thinning or thickening of a rock unit in different directions

Frequency attribute has also been widely used as a direct hydrocarbon indicator based on the time-frequency seismic character of the hydrocarbon sand (Adepoju et al. 2013).

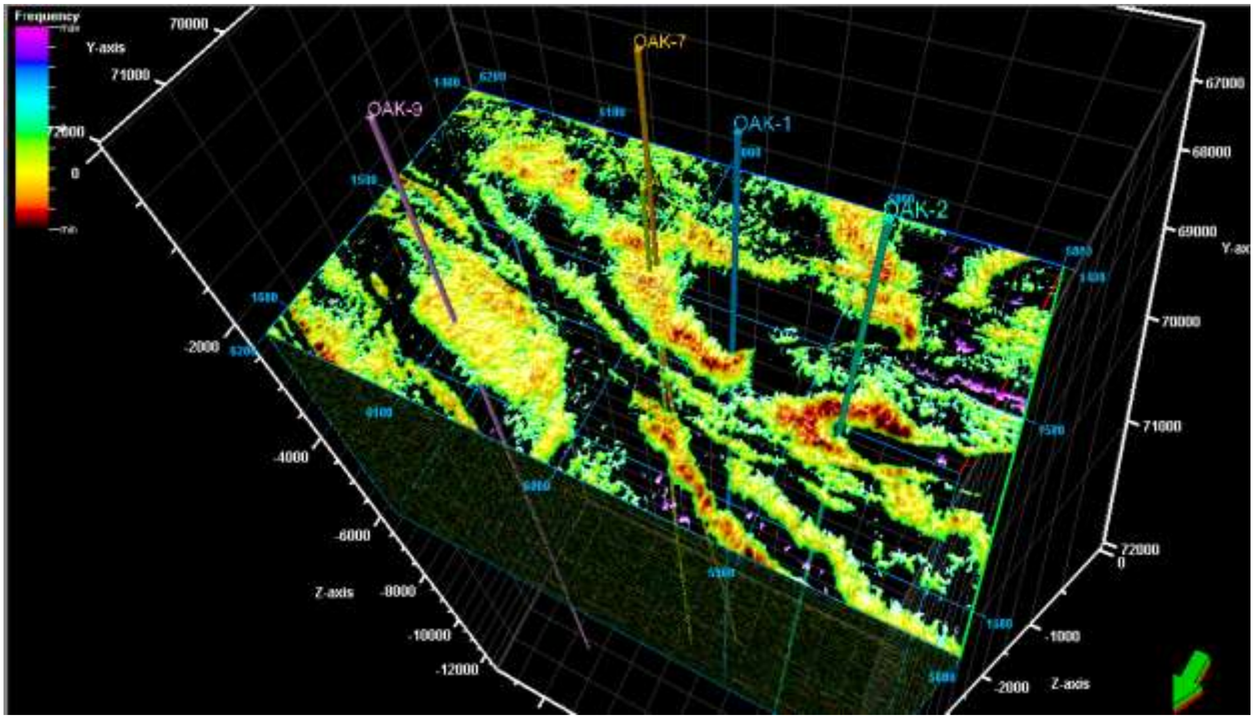

Figure 4 : Frequency Attribute Model showing Sand body in Reservoir A and B.

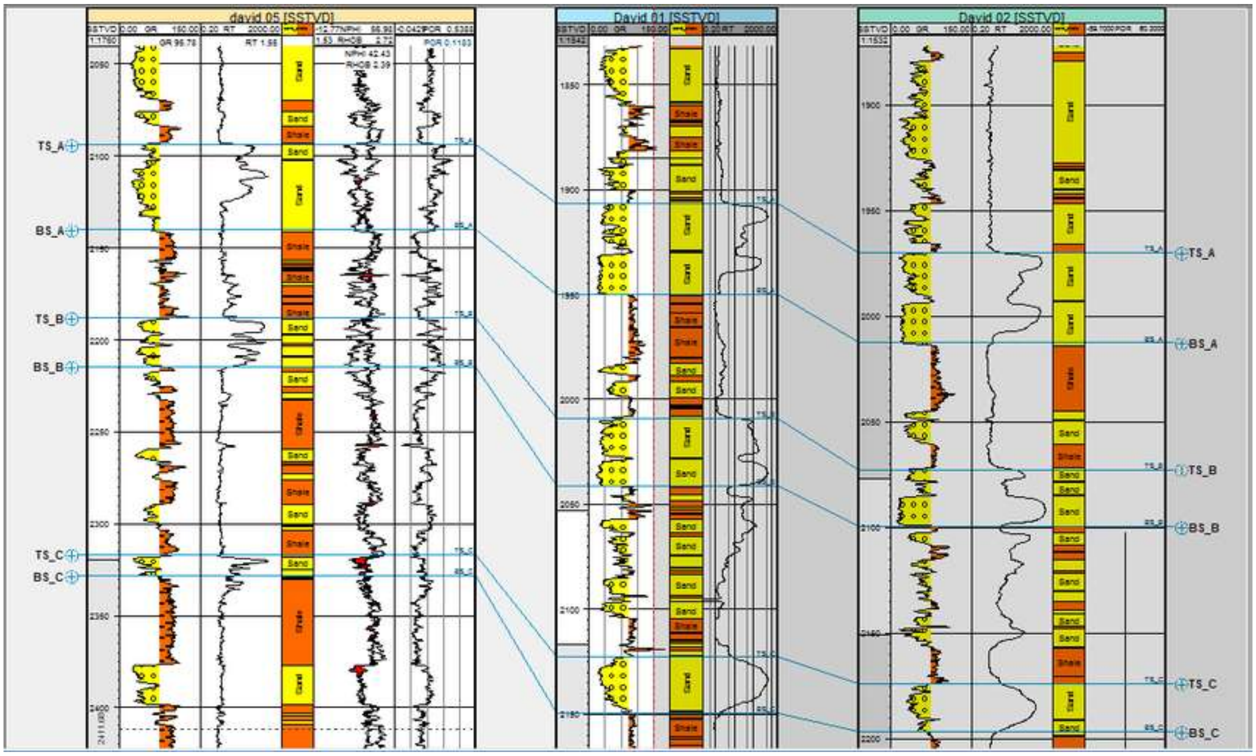

Figure 5: Correlation panel of the well logs

Seismic Attribute Interpretation

The Unit of X which lies between the time windows of 2800 – 2940msec (trace 1153); 2500 -2600msec (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 lithologic Between 2800-3900msec (Unit Y), 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 Z, lying below Unit Y and between time windows of 2750 – 3800msec 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. The seems to have the strongest reflection strength and the highest amplitude. The diapirc structure 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. This could have resulted from deformation and flowage of initially continuous strata possibly the clay materials within the designated Unit

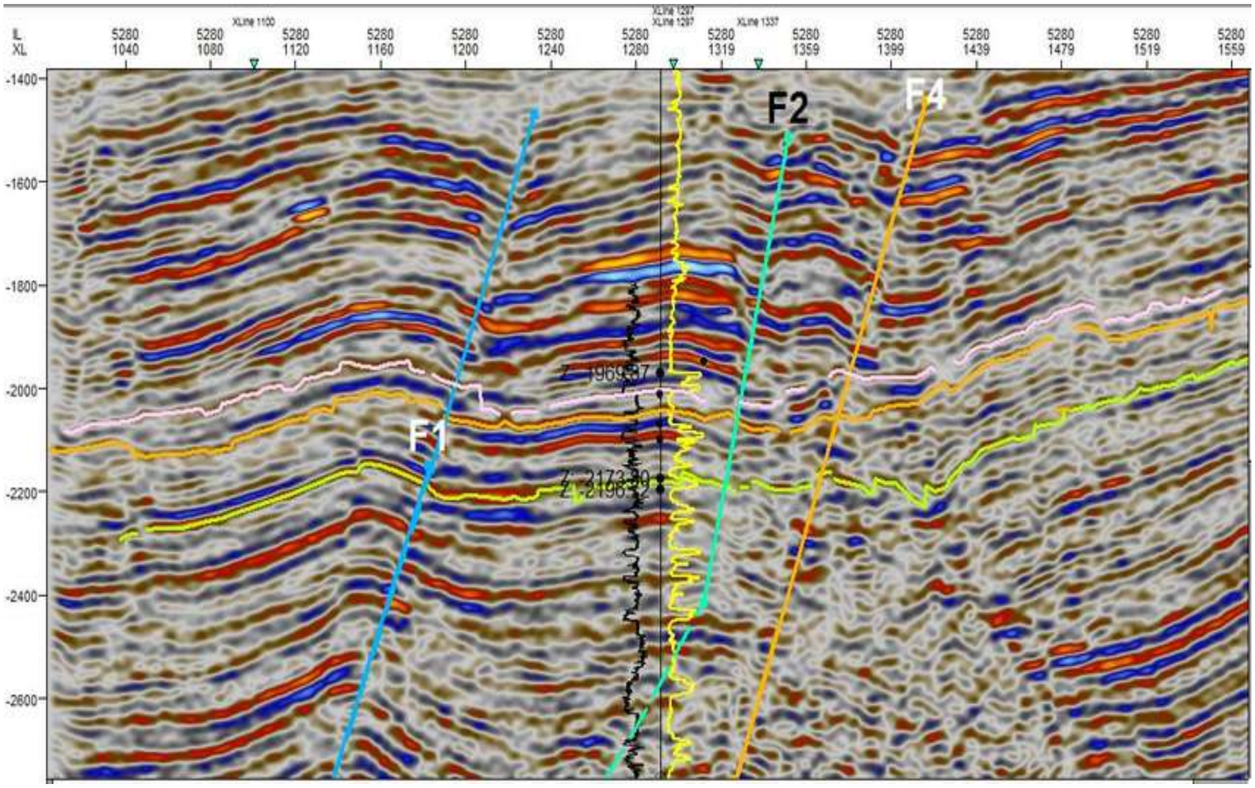

Figure 6: Inline 5788 depicting faults

DISCUSSION

SEISMIC SECTION OF THE MAPPED FAULTS AND HORIZONS

The exact horizons for the tops of the reservoirs were picked and this ensures that the interpretation process is consistent. The field is considered to have complex structures (classification, according to Doust and Omatsola, 1990.) and located in the distal delta. This is in the depobelt range of central swamp II and coastal swamp.

The NANA Field is a complex south-east dipping anticlinal structure, parallel synthetic and antithetic faults. Six faults were mapped with series of colours. Within the major fault blocks numerous subsidiary faults, both synthetic and antithetic, have been recognized but some additional small scale faults which may be present cannot be confidently mapped, especially at the deeper levels, due to relatively poor data quality.

Within the central area of the base map, there is considerable well control therefore, the fault positions are considered to be accurate at the mapped reservoir levels to the base of the B sands.

The structural contour maps were produced for the two horizons defined on top of sand bodies, namely, Horizon A and B. Both types of structural contour maps show similar structural relationship. This linear relationship was also corroborated by the linear curve observed from the plot of depth against time using the check shot data of the well

Faults are significant tools in the trapping of hydrocarbon. A growth fault in the study area regional fault mechanism. The trapping configurations of the faults along with the embedding shale responsible for the creation of multiple reservoir compartments of hydrocarbon bearing formations that is witnessed from one this conforms with displacement of the major and subsidiary growth faults show that the amount of throw of both major and minor faults are small and varied from line to line in the seismic survey but increases in the northern part of the field for all the horizons considered data were tied to the seismic data after the mapped horizons were digitized and this was done with the aid of synthetic seismogram. The reflections that match the depth to top of the hydrocarbon zones on the well logs were noted. The top of hydrocarbon bearing sand tied with horizon picking started on this reflection the depth structural map of the horizon A. The depth map revealed the crest of the anticline at the depth of 7,550ft, which tied with what was obtained on the well logs. The anticline dip closure establishes the trap for the reservoir. Also, antithetic faults are growing and trending in the south-east direction as well as dipping in the direction. There is a two way fault assisted closure which covers an appreciable area for a good prospect for hydrocarbon. The hydrocarbon reservoir was mapped base on their low gamma ray counts and high resistivity values from the well log displayed on "PETREL". The throw of the fault range indicate that these faults are sealing based on (Whiteman, 1982) which postulated that faults are still conductive as long as their throw does not exceed 500ft. Since it is less than 500ft it is adjusted sealing because it will be justaposed by shale which is impermeable and will prevent the migration of hydrocarbon. The overall depth at which the reservoir is located from the depth map ranges from 7500 to 7950ft.

Horizon B depth structural map revealed the crest of the anticline at the depth of 9050ft, which tied with what was obtained on the well logs. The depth map shows that the depth of the reservoir increases in the east-west direction away from the crest of the anticline

The depth structural map is a two way closure (dependent on an antithetic fault) was cut through by a synthetic fault. it can be inferred from the resistivity log that the reservoir is prolific for hydrocarbon accumulation with its characteristic high resistivity value and the fluid differentiation by the neutron-density cross plot.

FAULT MODEL

Fault modeling is the process of generating a faulted 3D grid and inserting the horizons, zones and layers into it, as seen, the faults penetrated the two mapped horizons. The process takes 3 steps:

Fault Modelling - The purpose of this step was to define the shape of each of the faults that should be modeled. This was done by generating "Key Pillars".

Pillar Gridding - This was done in the Pillar Gridding process. The result of the pillar gridding process is a "Skeleton grid", defined by all the faults and all the pillars. This was not associated with any other input than the faults.

Layering - the final step was to insert the horizons into the faulted 3D grid. At this point, the 3D grid was attached to depth by associating it with inputs such as time or depth maps and/or well tops. After the horizons were inserted, the final step was to make the fine-scale layering, suitable for property modelling.

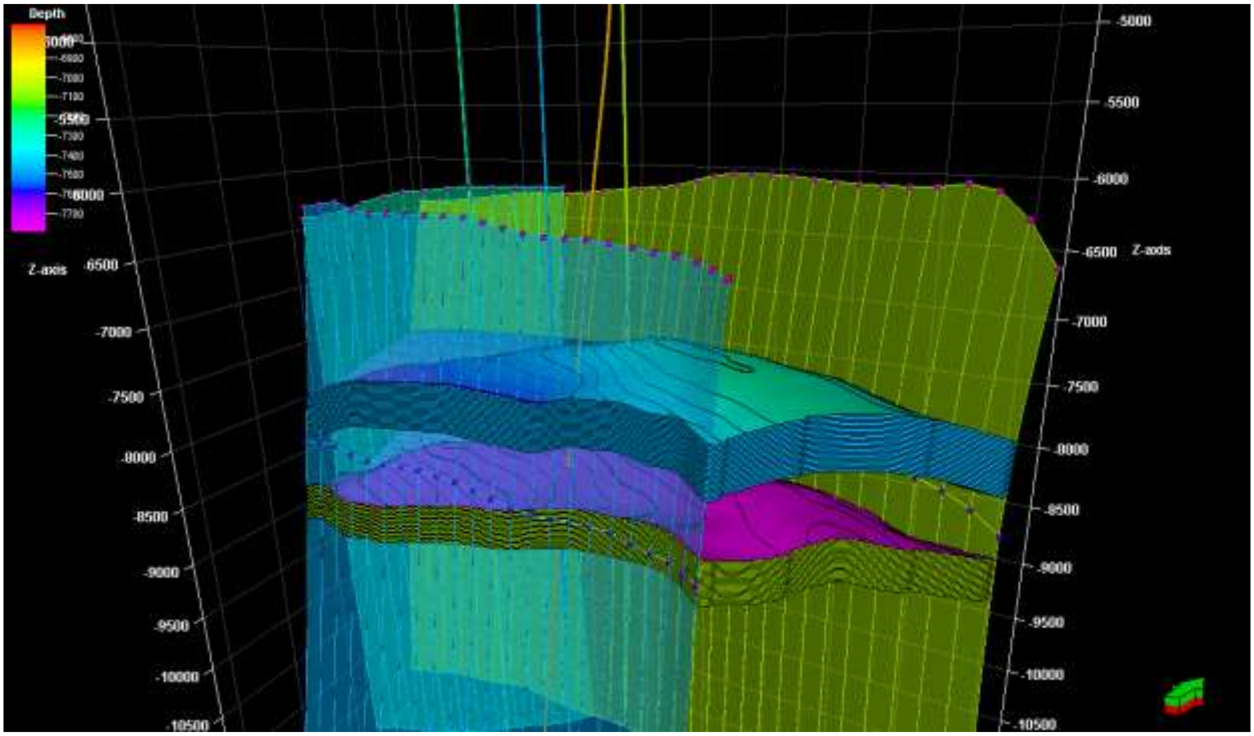

Figure 7; Reservoir Architecture showing Fault Model and reservoirs.

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).

Three seismic attribute maps (RMS amplitude, interval average extraction and instantaneous frequency) were extracted from the structural maps of the various surfaces of the reservoirs. The attribute maps revealed lateral distribution of porous units (reservoir) as a result of the amplitude anomaly of acoustic impedance contrast caused by the underlying non porous, dense formations. The zones of interest were correlated with well log data, with the observed bright spots revealing possible hydrocarbon accumulation around the structurally high areas of the reservoirs. Within the NE-SW area highly porous formation with high hydrocarbon prospect, while the yellow zones are assumed to be porous units but possibly with a different fluid content. The background purple colour was interpreted as a result of lateral change in lithofacies from a porous to non-porous formation. The bright spot areas generally increased from the northeast to the southwest (especially around the H1 and H2 events). This indicated possible direction (NE-SW) of displacement of porous units hence it is believed that the depositional environment is a point bar of a distributary channel. The thicker reservoirs likely represent composite bodies of stacked channels. The interval average extraction maps of the horizons inshowed a great similarity in lateral distribution, lithologic variation and hydrocarbon prospect zones. The bright spots observed in this map are believed to be as a result of decrease in acoustic impedance at the boundary between the sand units and the intercalated shales. The high amplitude areas were observed around the structural high zones (around NE-SW area) which possibly confirmed the choice of location of the wells drilled within the anticlinal structure.

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