Reservoir Characterization using Seismic Inversion and Attribute Analysis: A Case Study of Niger Delta

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Abstract: *This study demonstrated the effectiveness of 3-D static modeling technique as a tool for better understanding of reservoir characterization using seismic inversion and attributes analysis of the spatial distribution of discrete and continuous reservoir properties, hence, has provided a framework for future prediction of reservoir performance and production behavior of the reservoirs. However, appraisal wells should be drilled within the identified prospect areas to enhance optimization of the reservoirs.*

Keywords: *Reservoir, Niger Delta, Inversion, Seismic, Attribute, Modelling.*

1. INTRODUCTION:

Reservoir characterization is a detailed description of a reservoir using all available data. It involves integration of data to build a spatial representative earth model. This spatial model is then used in flow simulators, which can predict reservoir performance. The purpose of this study will not only be to build a model that is consistent with currently available data, but also to build one that gives a good prediction of its future behaviour. An accurate and reliable reservoir characterization study is crucial and indispensable to production optimization. However, a major challenge in today's reservoir characterization is the integration of different kinds of data to obtain an accurate and robust reservoir model. The concept of data analysis forms the basis of reservoir characterization. Uncertainty and large variety of scales due to the different sources of the data must be taken into consideration. Together with the large size of the data sets that must be available, these issues bring complex problems, which are hard to address with conventional tools. Seismic inversion used in this research study is an innovative tools which involves calculating acoustic impedance contrast- which when expressed mathematically is a product of density and velocity, when correlated with wellbore information, well information may then be extrapolafed across the entire seismic volume This research aims at using model-based inversion technique to extract rock properties and attributes to characterize reservoirs

2. LOCATION OF THE STUDY AREA

The study area under consideration is situated in the coastal swamp of the Niger Delta, as result of proprietary reasons, the location of the wells are concealed

Aim of this research work

The significance of this research is to characterize the reservoir using seismic attribute as this will help to show fluid migration through the structural features found in the field of study, detect hydrocarbon presence and help reduce uncertainties.

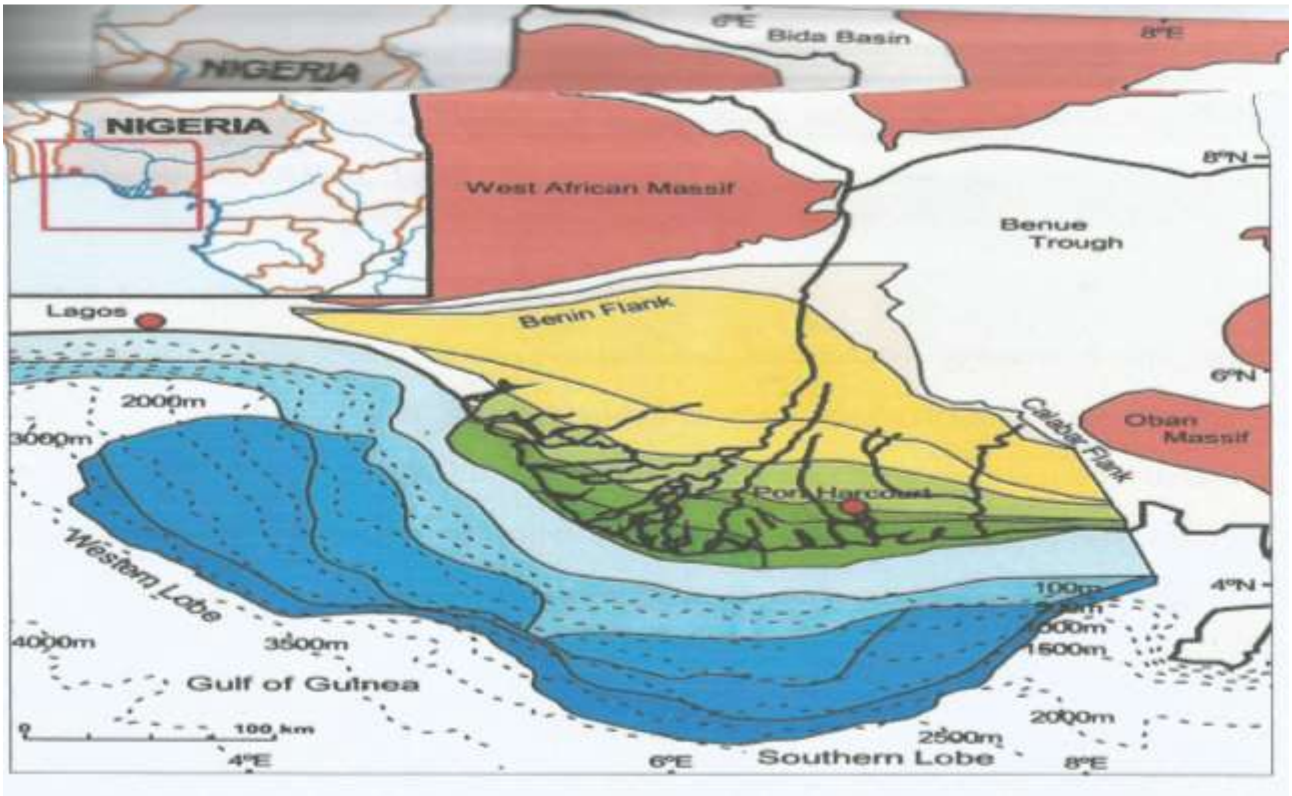

Figure 1: Location map of Niger Delta showing the depobelts and geologic features that bounds the delta

The Stratigraphy of The Niger Delta: The stratigraphy of the Niger Delta clastic wedge has been documented during oil exploration and production. Most stratigraphy schemes remain
proprietary to the major oil companies operating concessions in the Niger Delta basin. The composite Tertiary sequence of the Niger Delta consists, in ascending order, of the Akata, Agbada and Benin Formation.

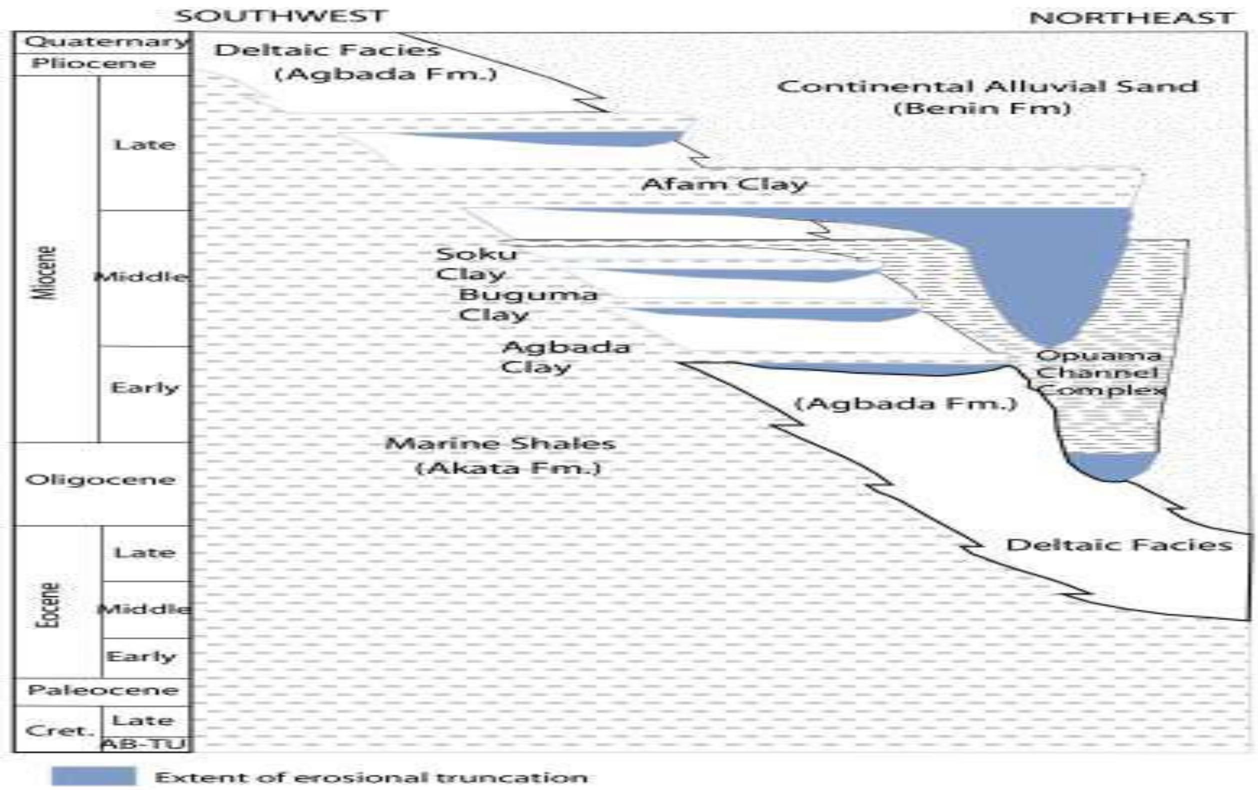

Figure 2: Lithostratigraphy of Niger Delta

They composed of estimated 28,000ft (8,535m) of section at the approximated depocenter in the central part of the delta (Avbovbo, 1978). There is decrease in age basinward, reflecting the overall regression of depositional environment

Short and Stauble (1967) recognized three sub-surface stratigraphic units in the modern Niger delta - Benin, Agbada and Akata formations. These formations were distinguished according to their depositional environments; marine, deltaic and fluvial environments (Weber and Daukoru (1975) and Weber, 1987).

AKATA FORMATION

The Lithofacie is characterized by uniform shale developments as evidence by gamma- ray (GR) and spontaneous potential (SP) logs. It formed the lowermost unit among the three sub-surface stratigraphic units in Niger Delta, consisting of dark grey sandy, silty shale with plant remains at the top .

With sand and silt increasing towards the top of the formation, the shale are under compacted and many contain lenses of abnormally high pressured siltstone or fine grained sandstone, which are possibly of turbidity origin and were deposited in halo marine (delta front to deeper marine) environments. It occurs at the base of the delta and is of marine origin.

The thickness of this sequence ranges from 0m to 6000m and may reach 7,000m in the central part of the delta. Marine shales formed the base of the sequence in each depobelt range from Paleocene to Holocene in age.

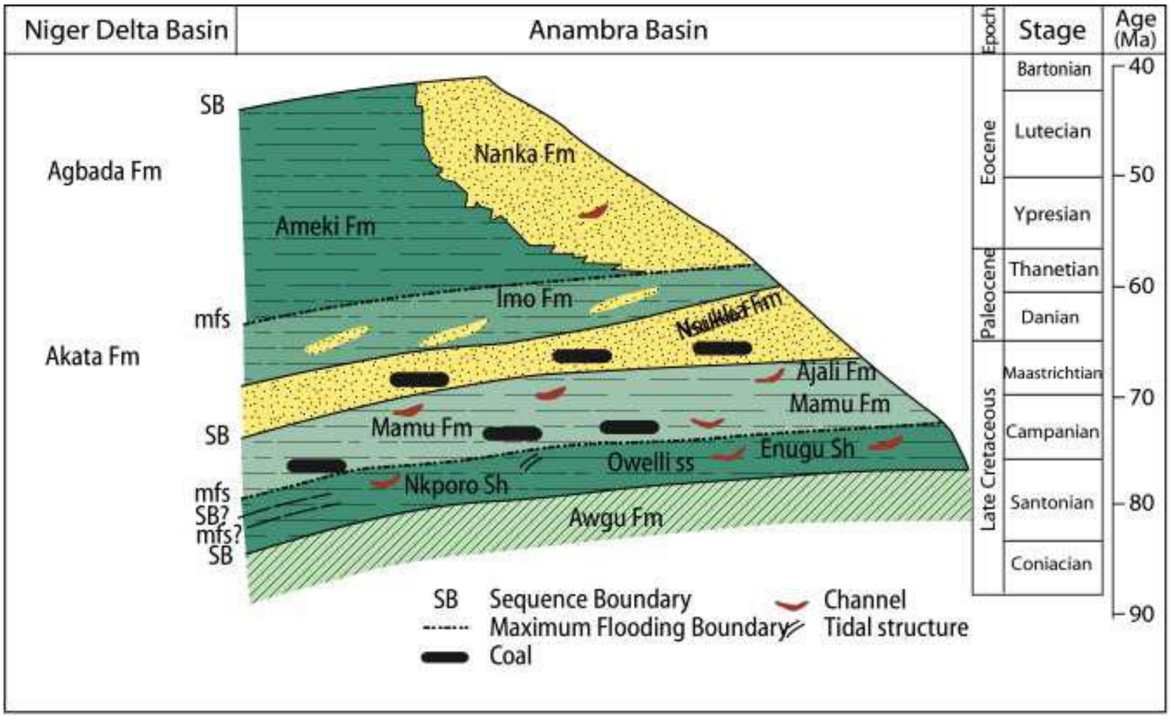

Fig. 3: Stratigraphy sections of time equivalent of Niger Delta Basin and Anambra Basin

AGBADA FORMATION

The underlying Agbada Formation is a sequence of sandstones and shales of delta-front and deltaic plain origins. The alternating sequence of sandstones and shales of the Agbada Formation has been shown by Weber (1971) to be deposited by alternating cycles of marine and fluvial process (offlap units) determined from electric log patterns, well cores and dipmeter log data.

The sandstones are fine to medium grained, fairly clean and locally calcareous, glauconitic and shalely, and consist dominantly of quartz and potash feldspar with subordinate amounts of plagioclase, Kaolinite and illite. The shales are medium to dark grey, fairly consolidated and silty with localized glauconite. They contain mainly Kaolinite (average value 75%) with small amounts of mixed layers of illite and montmorillonite.

The alternation of fine and coarse clastic provided multiple reservoirs seal and therefore, forms the hydrocarbon prospective sequences in the Niger Delta. The shales contain microfauna that are best developed at the base of each shale unit. Petroleum occurs throughout the Agbada Formation of the Niger Delta (Tuttle et al. 1999).

The formation occurs throughout Niger Delta clastic wedge and has a maximum thickness of about 12000ft (4000m). Its outcrops observed in Southern Niger, between Ogwashi and Asaba; is called the Ogwashi – Asaba Formation (Doust and Omatsola, 1990). It is rich in microfauna at the base decreasing upward and thus indicating an increasing rate of deposition in the delta front. A fluviatile origin is indicated by coarseness of the grains and the poor sortin

BENIN FORMATION

Benin Formation extends from the west across the whole Niger Delta area and southward beyond the present coastline. It is over 90% sandstone with shale intercalations. It is coarse grained, gravely, locally fine grained, poorly sorted, sub-angular to well rounded and bears lignite streaks and wood fragments. It is a continental deposit of probable upper deltaic depositional environment.

Mineralogically, the sandstones consist dominantly of quartz, potash feldspar and minor amounts of plagioclase. Most companies exploring for oil in the Niger Delta arbitrarily define the base of the Benin Formation by the deepest fresh water-bearing sandstone that exhibits high resistivity.

However, Short and Stauble (1967) defined the base of the Benin Formation by the first marine Formation as non-marine origin. The oldest continental sands are probably Oligocene although they lack fauna and are impossible to date directly. Off shore, they become thinner and disappear near the shelf edge. Elele 1 well, 39km northwest of Port Harcourt, is the type section of Benin Formation described by Short and Stauble (1967)..

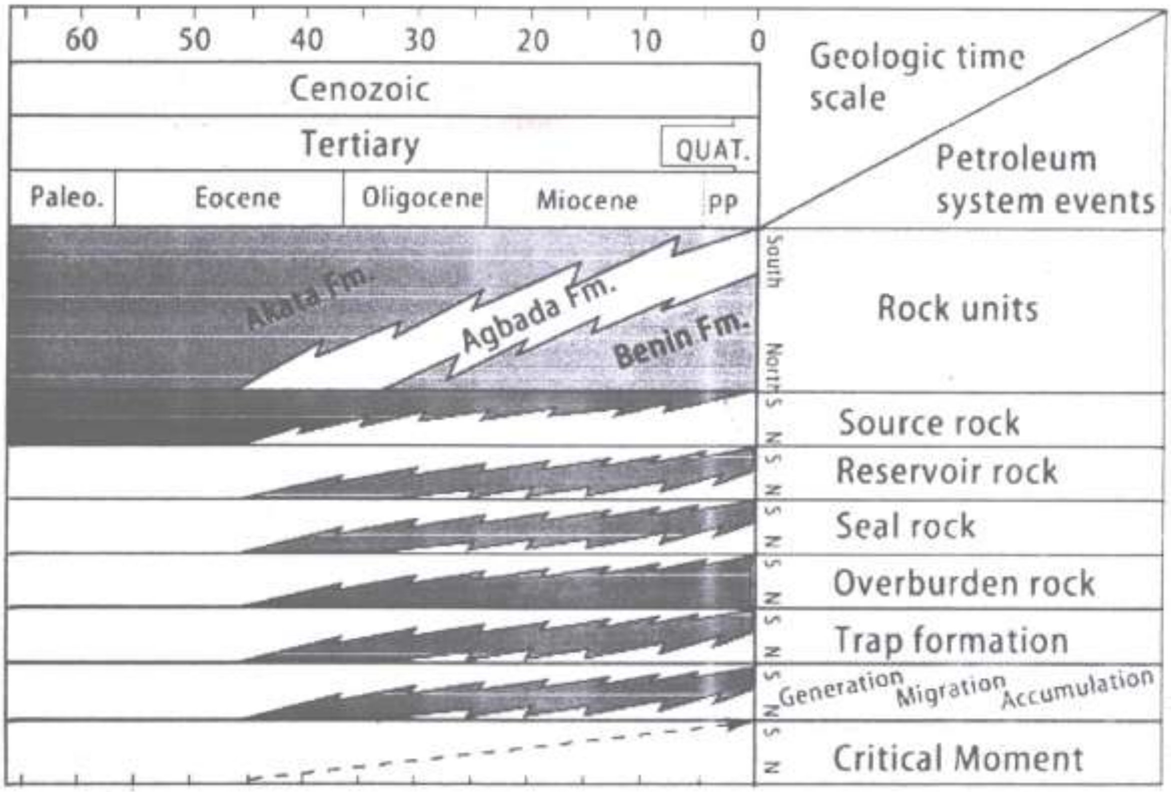

Fig 4. : Events chart for the Niger Delta (Akata/Agbada) Petroleum system

WELL LOGS

Some logs are used to quantify hydrocarbon in place, Gamma ray and Spontaneous Potential logs, known as Lithology Logs. Density, Neutron and Sonic logs are known as Porosity Logs and Laterolog, Induction logs are known as Resistivity Logs. The well logs obtained are in ASCII format. The basic principles and application of these logs are stated briefly:

Gamma ray log: Gamma rays are bursts of high energy electromagnetic waves that are emitted spontaneously by some radioactive elements. Nearly all the gamma ray radiation encountered in the earth is emitted by the radioactive potassium isotope of atomic weight 40 (K 40) and the radioactive elements of the uranium and thorium series. Applications include: Bed Boundaries, Geological correlations, Shale content estimation, presence of radioactive minerals and depth matching of subsequent logs

Resistivity log: The resistivity log measures the resistivities of subsurface formation and fluids contained in them due to passage of electric current. The standard measurements of formation deep, shallow and micro resistivities or the multiple depth of investigation. Laterolog or Induction logs are used to:

a. Detect the presence of hydrocarbon in the reservoirs (Water-HC Contact)
b. Determine the resistivities Rt and Rxo and estimate the invasion diameter Di
c. Determine the hydrocarbon saturation in the virgin zone (She = 1-Sw)
d. Determine the residual hydrocarbon saturation in the flushed zone (Shr = 1-Sxo)

Density log: This tool provides an estimate of the bulk density by measuring the attenuation of gamma ray between a source and a receiver. A radioactive source, applied to the borehole wall in a shielded sidewall skid, emits medium-energy gamma rays into the formation. These gamma rays may be thought of as high-velocity particles that collide with the electrons in the formation. At each collision a gamma ray loses some, but not all, of its energy to the electron, and then continues with diminished energy. This type of interaction is known as Compton scattering. The scattered gamma rays reaching the detector, at a fixed distance from the source, are counted as an indication of formation density The number of Compton-scattering collisions is related directly to the number of electrons in the formation. Consequently, the response of the density tool is determined essentially by the electron density (number of electrons per cubic centimeter) of the formation. Density logs are primarily used as porosity logs.
Other uses include identification of minerals in evaporate deposits, detection of gas, determination of hydrocarbon density, evaluation of shaly sands and complex lithologies, determinations of oil-shale yield, calculation of overburden pressure and rock mechanical properties.
Sonic log: The tool measures the velocity of acoustic wave train in rock formations. It is often expressed in microsecond/foot and sometimes in microsecond/meter (ts/ft or ts/m).

3. METHODOLOGY:

Seismic Attributes

Seismic attribute analysis in hydrocarbon exploration was first used in 1970s and 1990s after the development of complex trace theory (Taner,1979). Seismic atthbutes are the components/inherent properties of the seismic data which is normally obtained by measurement, computation and other methods from the seismic datasets An attribute is defined as a measurement based on seismic data such as envelope amplitude(”reflection strength”, instantaneous phase, instantaneous frequency, polarity, velocity, dip, dip azimuth, etc (Sheriff 1994). Seismic attributes can also be defined as specific measurements of geometric, kinematic, or statistical features derived from seismic data

Figure 5: The workflow for the project study is itemized below

The well logs were loaded and correlated to map reservoir of interest by picking the top and base of the reservoir

⇓

A synthetic seismogram is generated to match created to match the seismic volume.

⇓

Seismic interpretation includes fault mapping, horizon picking and fault polygon were carried out

⇓

Surface and volume attributes for different horizons of reservoirs’ were generated for the wells

⇓

In the final analysis, the Volumetrics procedures was carried out to know the amount of hydrocarbon in place in the reservoirs of the wells.

⇓

Cross plots of lambda-rha and acoustic impedance, porosity and lambda-rho were carried out

Datasets

The data used in this research work among many others include welllogs and post-stack seismic data; these were used at different level of the research work

The data consist of suites of welllogs from two wells, with no unique well name coined as well 01 and well 02. These data were analysed using "Geoview" of the "Harnpson-Russell software (HRS)". The well log data was evaluated using "eLog", and the seismic and rock attribute cross-were created using "STRATA"

4. RESULT:

Seismic attributes can be important predictor of reservoir properties and geometries when correctly used in reservoir characterization studies. The use of high quality 3D seismic data associated with huge developments in seismic interpretation software made seismic attributes reliable solutions to solve ambiguous situations in the seismic interpretation process. However, attributes derived from seismic data cannot be applied as a general recipe even if there are many examples in the literature that try to correlate the attributes with the expected results. These correlations should be done with special care since the output volume attribute depending on the geological background of the dataset may produce unexpected results. The seismic attributes used for this project when properly applied to seismic data can significantly detect subtle lithological variations and also direct hydrocarbon indicators (DHIs).

In the scope of this work, the Petrel software was used to generate the studied seismic attributes and Hampson-Russell was used to cross plot which showed fluid and porosity distribution. The interpretation of the dataset used in this work and the study of the derived seismic attributes shows that the two wells drilled encountered commercial quantities of hydrocarbons. Also, bright spots were observed at the flanks of the anticlinal structure which indicates possible hydrocarbon accumulation. Therefore, this research work has shown the importance of seismic attributes for deriving parameters that are vital to reservoir characterization and how a combination of these attribute maps could aid in selecting targets for drilling activities.

FAULT INTERPRETATION RESULT

The study 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.

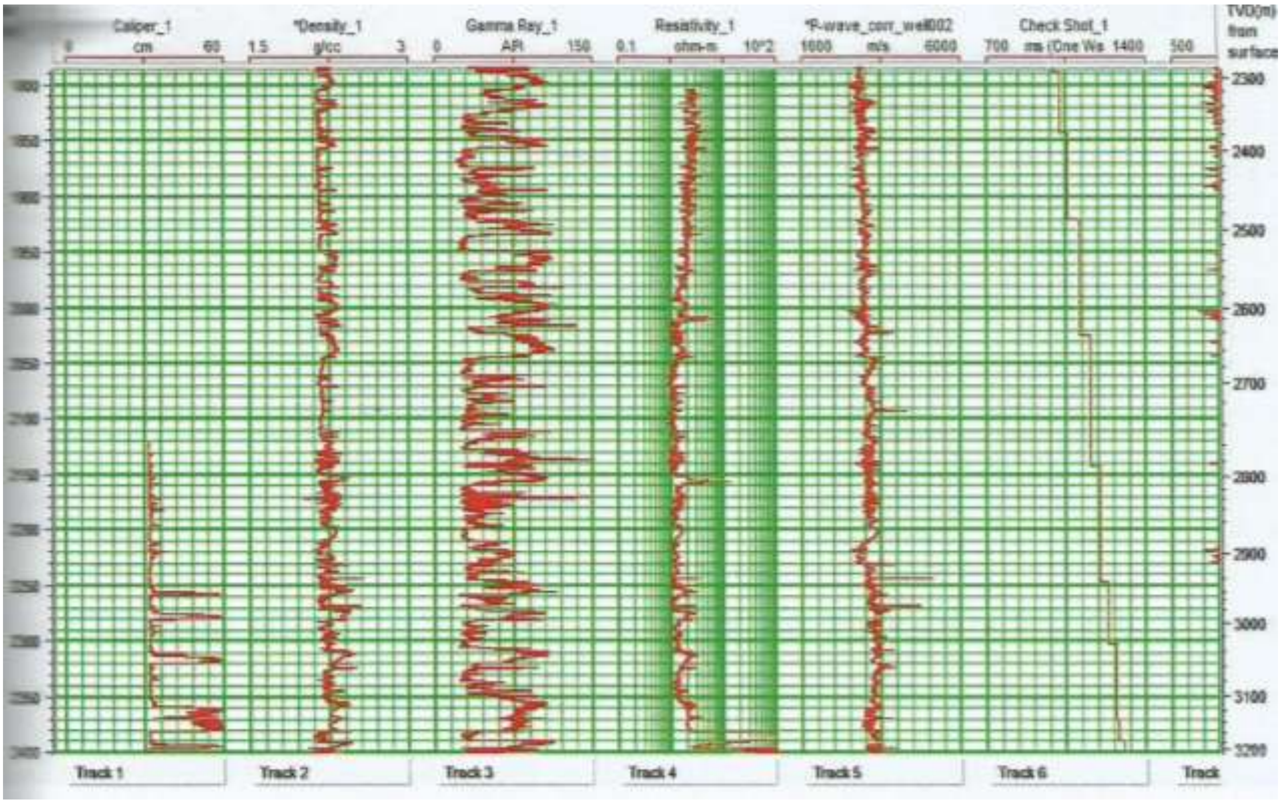

Figure 6: Suites of logs for well 02

ROCK PROPERTIES ATTRIBUTE ANALYSIS

Inverted rock properties obtained from model-based inversion, acoustic impedance and shear impedance were used to generate rock attributes .The purpose of this analysis is to discriminate between lithology and fluids within the selected reservoir sands. The model shows low impedance values around and away from well control. Moving further from well control, there exhibits a reversal in amplitude which is indicative of possible gas sand. This is further illustrated in the inverted P-impedance section. The reservoirs on both sections indicate a low acoustic impedance value. LMR inversion also shows low values around and away from the reservoirs, indicative of spatial distribution of fluid in the reservoir. However, clue to the effect of compaction and pressure with depth, values tend to increase, as also witnessed in the inverted P-impedance volume.

SEISMIC ATTRIBUTES MAXIMUM AMPLITUDE

The amplitude maps show clearly the position of faults in the project area with a general trend of NW-SE by creating a discontinuity in the amplitude pattern around them. High amplitudes-which are indicative of lithologic changes or hydrocarbon presence- on the above two maps are seen on the crest and flanks of the anticlinal structure. As this map is more of sand body, the high amplitude represents more of fluid content than lithologic change. The location of these high amplitudes suggests the presence of fluid accumulation in the anticlinal structure or a migrating fluid navigating through the anticline which tends to act as a trap.

The wells on this field encountered high amplitude which indicates the presence of hydrocarbon in the wells. The wells were drilled away from the flanks of the anticline on the two reservoirs of interest such that if hydrocarbon is encountered, the wells will not have an early water cut/breakthrough.

RMS AMPLITUDE

RMS-Amplitude which is a sum of squared amplitudes divided by number of live samples and it's indicative of hydrocarbon or geologic feature. The RMS amplitude exhibited similar distribution of high amplitude similar to that of maximum amplitude showing the presence of hydrocarbon.

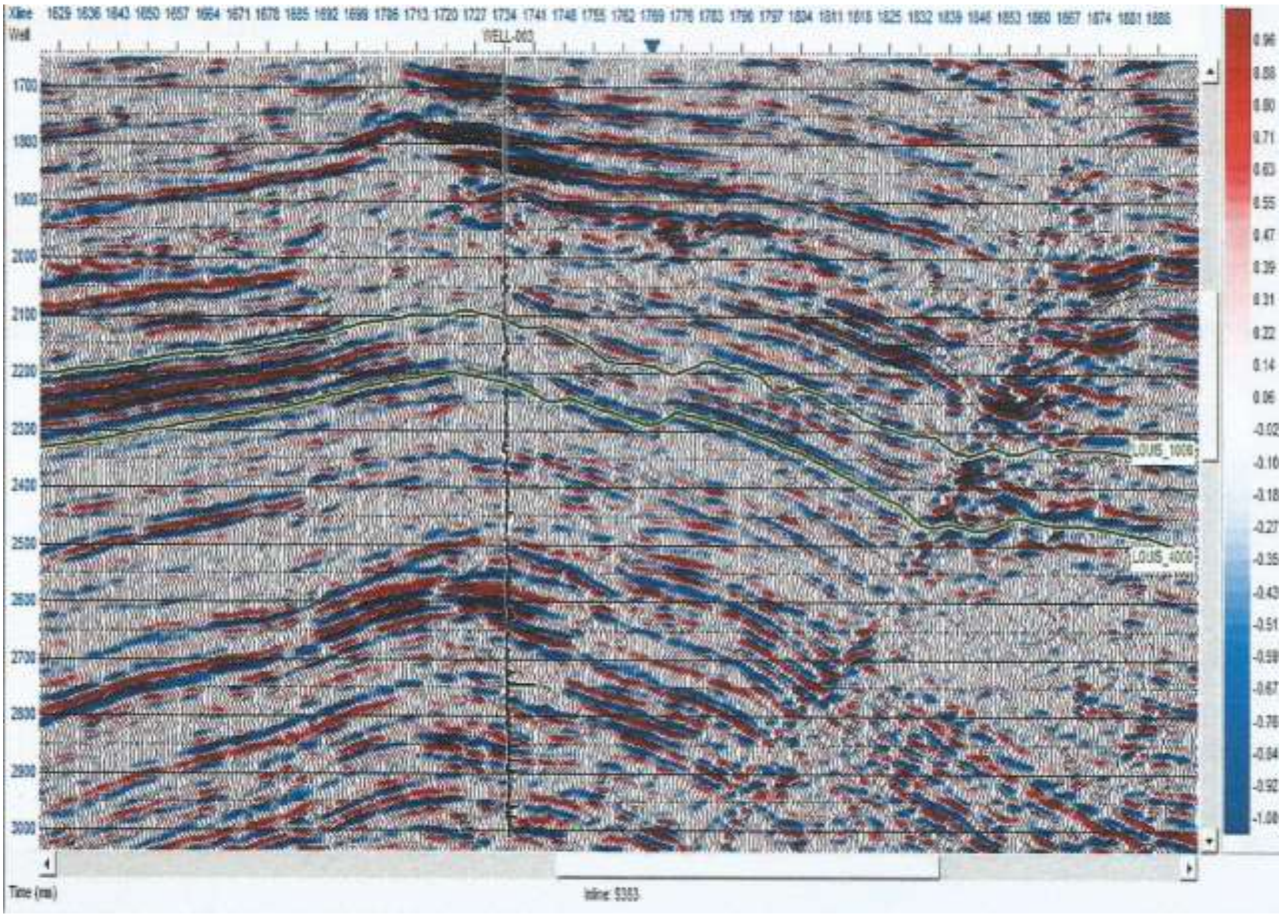

Figure 7: Seismic section showing Cross lines with well-02

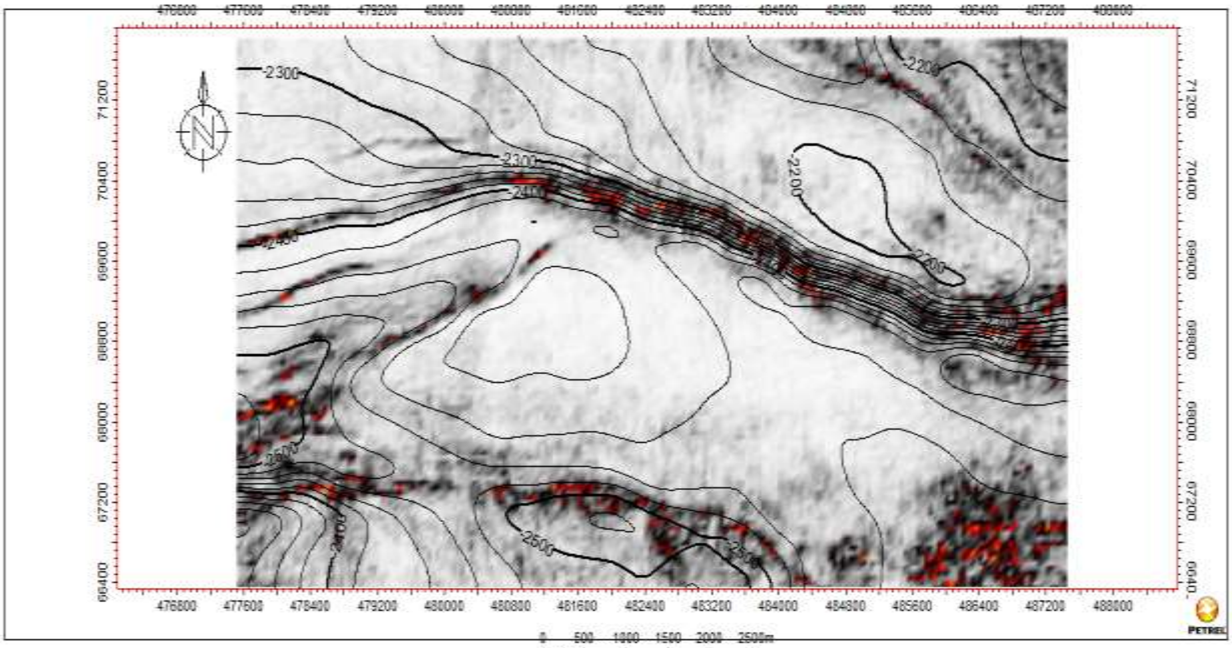

Figure 8 : The Variance Edge Surface Map for Reservoir 02.

TABLE 1: RESERVOIRS PROPERTIES

Reservoir parameters	Well=01	Well=02
A-top	456115.16	46079
A-Base	45721.22	46029
Thickness(ft)	75.02	50.15
0 (fraction)	0.27	0.35
Sw (Fraction)	0.4	0.26
N/G(fraction)	0.81	0.38
STOIIP	192MMSTB	173MMSTB

5. DISCUSSION:

The process of Reservoir characterization of a field is based on the ability of the interpreter to make use of available data in interpreting various parameters with minhnum error margins. The Lithostratigraphic correlation which was done with a gamma ray log across the two wells has helped in the identification of the reservoir with hydrocarbon shows. Resistivity logs, density and neutron logs were used to delineate the presence and type of fluid found in the reservoir. The basis of mapping the two reservoirs used for this project is the sand thickness and indication of hydrocarbon from the log suites used. Vertical displacement of reflections and abrupt termination of seismic events formed the basis for fault interpretation. Time map was generated from the horizon and depth converted using velocity model. Cross- plots of lambda-rho versus acoustic impedance and lambda-rho versus porosity was carried using Hampson-Russell software to delineate fluid type and porosity distribution present in reservoir A using the sand top depth. Seismic attributes were extracted from the 3-D seismic volume which was used for better visualization and interpretation of the morphological and reflectivity characteristics of the reservoir.

Root Mean Square Amplitude extraction was carried out on reservoirs level where the reservoir can be confidently identified on the seismic data from the well-synthetic tie. Amplitude anomalies exist at all levels where it was possible, both within the field itself and the surrounding areas. These anomalies are of two types: those that conform to structure, and those that appear to be appraisal i.e. doesn't conform to any structure. Amplitude being a seismic attribute was superimposed on the time structure map of horizon A and B to check its conformity to structure. Amongst the different types of amplitude which can be extracted (maximum positive and negative, average positive and negative e.t.c.), root mean square amplitude was chosen because of its unique characteristics as a good indicator of the presence of hydrocarbon (Mangal et al. 2004). R.M.S amplitude is obtained by summing all the square of all the amplitudes of the reflection and calculating the roots of the cumulative; high amplitudes with respect to amplitude distribution are direct hydrocarbon indicators

The result of the attributes showed high maximum amplitude, high energy, high RMS amplitude and low relative acoustic impedance which indicate the presence of hydrocarbon in the two reservoirs of interest. Bright spots were noticed at the flanks of the anticlinal structure which can serve as possible target for drilling activities. Using the results from the petrophysical analysis, stock tank oil in place was calculated for each reservoir, the area used was calculated from the depth map by creating a polygon around the oil/water contact (OWC). The formation volume factor (Bo) and dissolved gas was gotten from PVT data.

Well curves used for the analysis are logs of the wells. The logs include caliper, gamma ray, resistivity, density, P-wave and acoustic impedance curves generated through rock property transform. .The wells exhibit a dominantly shale/sand/shale sequence typical of the Niger - delta formation". The hydrocarbon-water- contact (HCWC) occurs which was estimated visually. The wells were analysed for "fluid type", and "lithology". Shale lithologies were defined by "high gamma ray" value and "high acoustic impedance value", responsible for the deflection to the right of the curve and to the left of the resistivity curve due to it being conductive.

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