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Rock-Physics and Seismic-Inversion Based Reservoir Characterization of AKOS FIELD, Coastal Swamp Depobelt, Niger Delta, Nigeria

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Abstract*: A rock-physics and seismic inversion study have been completed to assist in the prediction of rock and fluid properties in AKOS Field using well logs and high resolution 3D seismic data. Rock attributes were derived from well logs using rock physics models. These derived rock attributes were analyzed in cross-plots space and used to determine which of them constitutes better indicator of pore fluids and lithology. Acoustic impedance versus velocity ratio crossplots showed that clustering models converged to four classes namely; brine, gas, oil and shale zones. Inversion of the post-stack seismic data was also carried out to generate horizon slices of acoustic Impedance and velocity ratio away from the wellbore. Very low values of acoustic impedance andvelocity ratio indicating the presence of hydrocarbon bearing sands were observed in the slices. The outputs from inversion confirmed the observations in the cross plots involving velocity ratio versus acoustic Impedance. In conclusion, results of this study can be used can be used in predicting hydrocarbon prospectivity, delineate lithology, reduce drilling risk and to make economic decisions.*

Keywords*: Attributes, Impedance, Inversion, Post-Stack, Rock Physics.*

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I. Introduction

The cost and complexity of oil field development is so great that a very limited spatial sampling of the target reservoir is achievable with well data. Thus, the quantitative use of seismic data becomes paramount. Seismic inversion is the process of using the principles and theories of seismic method of geophysics to reconstruct a qualitative model of the earth space by providing solution to an inverse problem based on seismic measurement. It unravels underlying models of the physical characteristics of rock and fluid from seismic and well data. Seismic Inversion methods has been very useful in deriving quantities such as density, shear wave velocity, compressional wave velocity, S-impedance, P-impedance and elastic impedances from seismic and well log data.[5]. These derived quantities give understanding and enhanced information on lithology and fluid contents beneath the earth subsurface [4]. Seismic inversion methods have found wide application in locating hydrocarbon bearing strata in the earth's subsurface [5]. Post stack seismic attribute and modelling are frequently employed to perform quantitative prediction of reservoir properties from surface seismic data [12]. Several authors have shown that both absolute and relative acoustic impedance derived from post-stack seismic amplitude inversion can be useful for quantitative estimates of summary reservoir properties such as average porosity, net-to-gross, and others.[12]. Rock physics analysis is the key to relating the seismic properties to reservoir properties and high quality seismic reservoir characterization requires well log data that are consistent between formations and wells over the entire vertical interval of interest and represent the true undisturbed rock properties.[11].

This case study is taken from Akos Field, Coastal Swamp Depobelt, Niger Delta, Nigeria. The ultimate deliverable of this study was to obtain reliable quantitative estimate of relevant reservoir rock and fluid parameters in the area. The major components of our study are: (a) Well log analysis to define different lithofacies, rock physics analysis including lithofacies and pore fluids (b) Seismic inversion to obtain volumes of impedance and wave velocity ratio$\left(\frac{V_P}{V_S}\right)$ attributes of the field. Cross plotting of rock properties from well logs is one very convenient and effective way of looking at two rock properties or their attributes at the same time [7]. This aids in giving more insight into seismic inversion results. Inversion for Acoustic impedance and Vp/Vs cross-sections and volumes enhanced by 2 and 3D cross plot analysis is routine in the exploration and Production (E & P) operations.

II. Geology & Location Of Study Area

The study area falls within the Niger Delta Basin of Nigeria. The oil field for the study is situated some kilometers Southeast of Port Harcourt Nigeria of the Niger delta (Fig.2.1). Well logs and 3-D seismic data were acquired from oilfields within the study area shown on the base map in (fig.2.2). The Niger Delta lies between latitudes 4° N and 6° N and longitudes 3° E and 9° E. [13]. The Niger Delta is a coarsening upward regressive sequence of Tertiary clastic sediments which is divided into three lithostratigraphic units representing prograding depositional facies[1,3,9]. These units are distinguished mostly on the basis of sand-shale ratios as follows, the Akata Formation at the base of the delta, Agbada Formation overlying the Akata Formation and the Benin Formation overlying the Agbada Formation. The Akata Formation is a marine sedimentary succession laid in front of the advancing delta. It consists of undercompactedshales. The Agbada Formation is characterized by paralicinterbedded sandstone and shale with a thickness of over 3,049 m[7]. The Benin Formation is the youngest lithostratigraphic unit in the Niger Delta. It is Miocene-Recent in age with a minimum thickness of more than 6,000ft (1829m) and made up of continental sands and sandstones (>90%) with few shale intercalations.

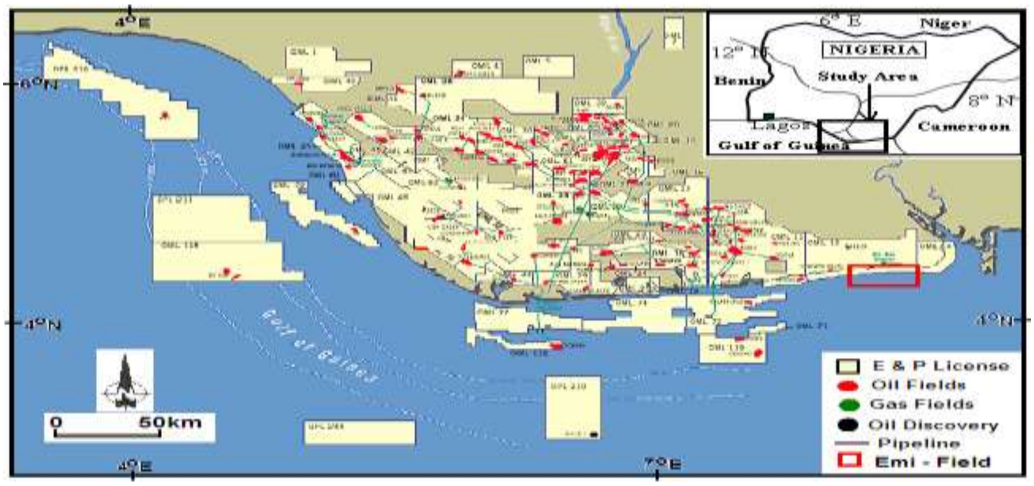

Figure 2.1: Location of the Field in the Niger Delta [6]

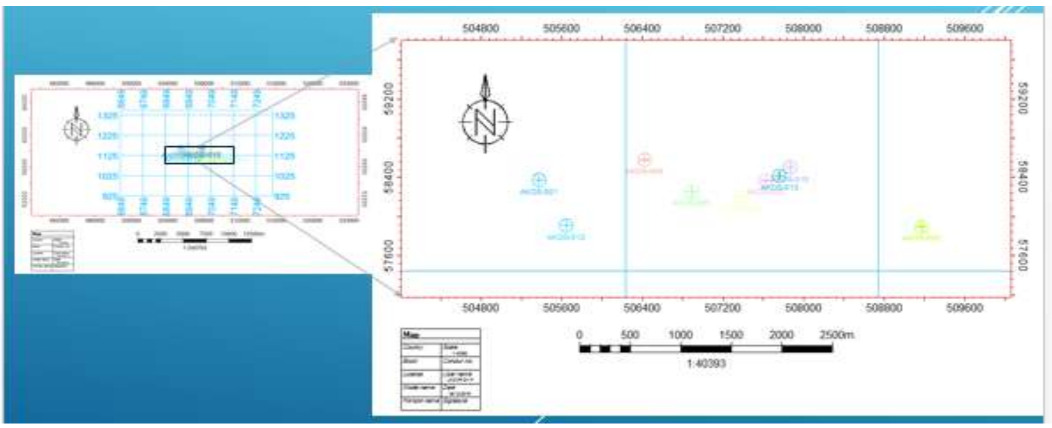

Figure 2.2: Base Map showing well position in the field.

III. Methodology

The data used for this work include well logs from and a High-resolution 3D post-stack seismic data from AKOS field, in the coastal swamp depobelt of Niger Delta basin. The methodology consists of the following stages; Well-log editing and modelling, Rock properties derivation and cross plotting, Seismic modeling and attribute generation from seismic data using model-based inversion.

3.1 Well- Log Editing

Well log editing is the first stage of the pre-interpretation process. In this step, the zones of interest representing the producing interval is mapped out using the resistivity log, gamma ray log, P-wave velocity log and density log curves in some selected wells. The logs are then passed through a series of log editing operations. The log editing operations applied in this work include mainly median filtering and check shot correction. Using the LOG MATH (*special tool used to de-spike logs*) Function of the Hampson Russell's eLOG tool, a median filter with an operator length of 6 was applied in order to reduce the spurious effect caused by high frequency noise appearing as an anomalous spike in the log curves. The aim of this is to reduce the scatter in the lithology, fluid and other cross-plot analysis.

Check shot correction was applied to the sonic log in order to correlate well log data with seismic data (Fig. 3.1). The check shot correction operation modifies the depth-time curve associated with a sonic log in order to improve the tie between a synthetic and real seismic data. This is necessary because the program extrapolates the first compressional or primary wave velocity (V_p) value to the surface, which usually overestimates the near surface velocity.

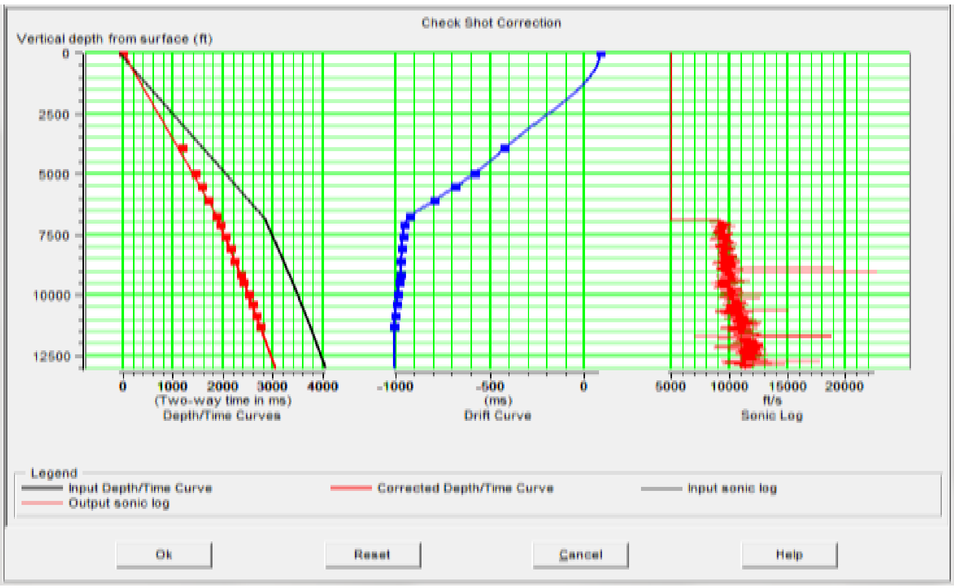

Figure 3.1: Checkshot correction applied to sonic log data. The sonic curves at the far right show the origin. Curve in red and the effect of the correction shown in black.

3.2 Rock Physics Analysis

Rock physics analysis provides the means by which geophysical measurements can be inverted for rock and fluid properties. It is usually focused on the measurement, modelling and interpretation of elastic wave propagation in sedimentary rocks. Most frequently, this involves the analysis and interpretation of compressional and shears wave velocity behavior, the velocity ratio, examination of anisotropic effects and also the analysis of attenuation and dispersion. Before creating seismic attributes for the entire 3D seismic volume as hydrocarbon reservoir indicator, it is very essential to note that its sensitivity was significant enough to resolve the gas zones at the target locations from the well logs. This is because sensitivity of seismic attributes and rock properties responding to pore fluid and lithology contrast are two important issues for defining a reservoir. Lithology contrast and sensitivity of reservoir rocks with respect to pore fluid is a function of porosity, fluid type and rock composition such as shale volume in sandstone. This was done via rock physics basically using density and velocity. Rock attributes were estimated from the input log data using rock-physics algorithm. These attributes include P- impedance and compressional to shear wave velocity ratio$\left(\frac{V_P}{V_S}\right)$. Castagna's relation (1) for S-wave used was to calculate the shear wave velocity. Cross plots of the velocity ratio $\left(\frac{V_P}{V_S}\right)$ versus P-impedance were then carried out. Cross plotting of rock properties from well logs is one very convenient and effective way of looking at two rock properties or their attributes at the same time [7].

$$v_s = c_1 v_p + c_2 \qquad (1)$$

P-impedance was calculated using density ρ, Compressional wave velocity Vp,

Where

$$I_p = v_p \rho \qquad (2)$$

V_p/V_s was computed from V_p and V_s log

Where v_s = shear wave velocity

v_p = compressional wave velocity

$I_P = V_P \rho$ P-Impedance

$c_1 \& c_2$ = fluid discriminant or constants.

3.2 Seismic-Inversion

The post stack inversion was performed using Hampson-Russell Suite HRS version 10.0.2.package. The inversion requires an input information about the seismic wavelet, the geometric structure from structural seismic interpretation, interpreted horizons and a prior model based on well log impedance. The prior model was created by extrapolation of well data along the defined structural horizons. A reliable estimate of the wavelet for the inversion was obtained through the software package, based on the amplitude spectrum of a selected time window, and a scan of the phases to pick one that best matches synthetic and true seismic traces. A density volume was also computed, but in accordance with common practice was treated as a byproduct and not used further.

A model-based deconvolution was used to invert the stacked sections to pseudo-velocity sections. The model-based inversion derives the impedance profile which best fits the modelled trace and the seismic trace in a least squares sense using an initial guess impedance. Basically, this inversion resolves the reflectivity from an objective function and compares its RMS amplitude with the assumed reflectivity size. The wavelet is then scaled to compensate for the difference. This iterative process for updating the estimated reflectivity requires an initial impedance value. The initial impedance logs were obtained from the sonic and density logs of the wells. Each value of the mean impedance log obtained from thewells corresponded to the arithmetic sum of the individual impedance values for each well divided by a factor that corresponds to the total number of wells used. During this process each well was stretched for matching the principal impedance contrasts with the formation tops associated with the Sands 1 & 2 Formation at the tie location. The flowcharts of the model-based inversion approach is shown in (Figs. 3.2, 3.3, 3.4). The work flow in figs. 3.3 and 3.4 is explained in stages interms of equations. Stage 1: shows how acoustic impedance derived from sonic and density logs is used to derive the reflectivity coefficient using the simplified Zoeppritz equation. Stage 2; Wavelet extraction process requires that the reflectivity is convolved with wavelet. The convolution is repeated to extract the most accurate or suitable wavelet by comparing the synthetic seismogram and the original seismic. Stage 3: An initial impedance assumption, this assumption is constrained by well log, seismic data and other geological information. Stage 4: The inversion process, the initial impedance model is fed into the software (HampsellRussel) and the output is compared and contrasted to the original seismic impedance. The initial impedance is modified and the inversion is repeated until the contrast between the inverted impedance and the original seismic is minimized.

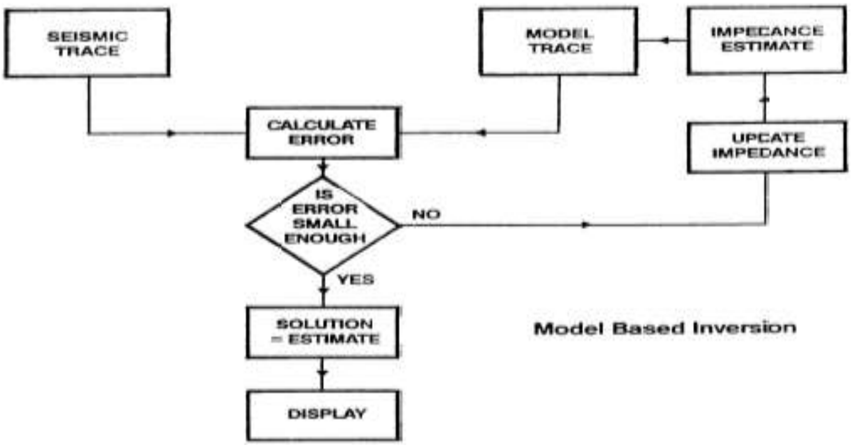

Figure 3.2: Flowchart of the model-based inversion approach [9]

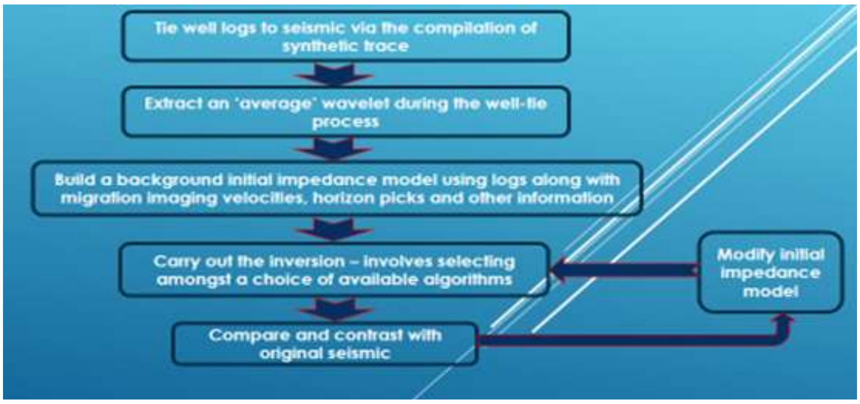

Figure 3.3: Flowchart of the model-based inversion approach [1]

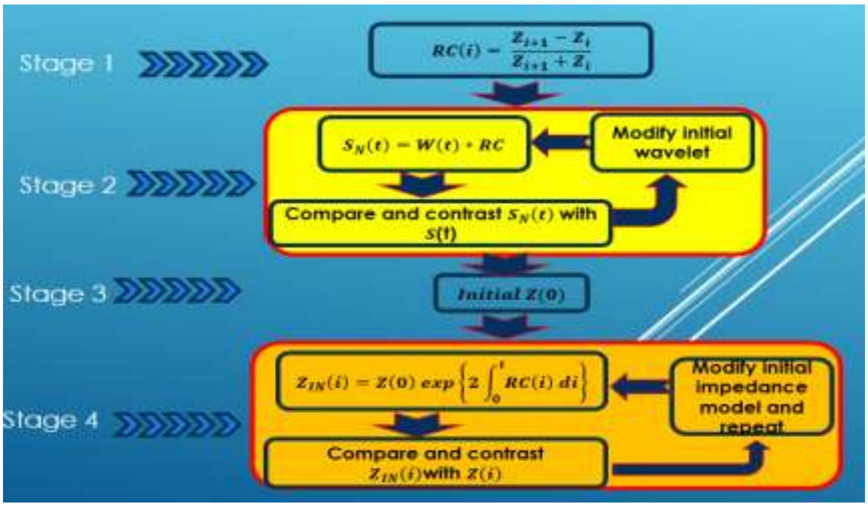

Figure 3.4: Equation Flowchart of the model-based inversion approach [1]

Where RC = Reflectivity coefficient
Z_i= Original impedance
$Z_{IN}(i)$= Inverted impedance
$S_N(t)$= Original seismogram (seismic)
$S(t)$= Synthetic seismogram
$W(t)$= Wavelet

IV. Results

A critical factor to achieving good inversion results is the seismic-to-well tie. The correlation coefficients associated with the wells used in the inversion are shown in (Fig.4.1) at which a very good correlation is obtained (0.76).

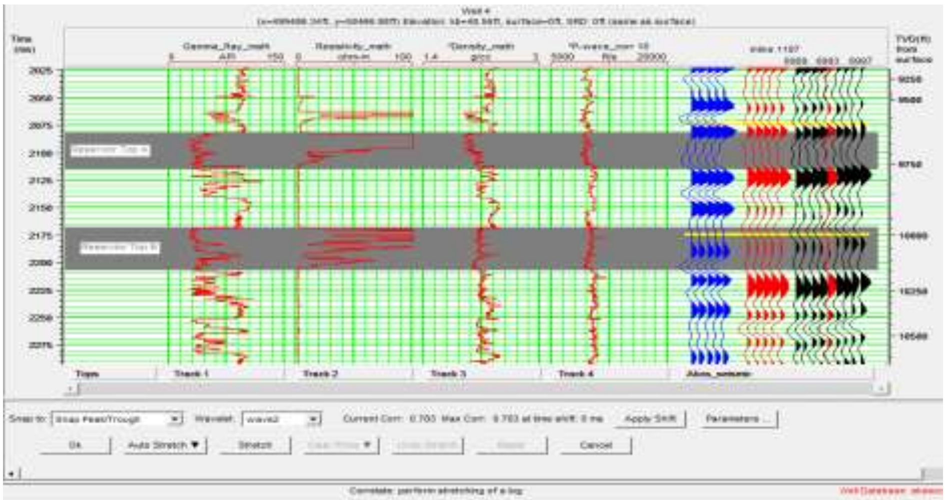

Figure 4.1: Well to seismic tie showing; GR log, Resistivity, density, P-wave, synthetic trace (blue) extracted from the baseline seismic, composite trace (red) and seismic trace (black).

4.1 Velocity ratio $\left(\frac{V_P}{V_S}\right)$ versus P-Impedance Cross Plot

The primary logs used include gamma ray, resistivity, caliper, and density logs which exhibit dominantly shale/sand/shale sequence. Other logs required were derived and crossplotted. The cross plot of $(\frac{V_P}{V_S})$ ratio against P-Impedance (Fig.4.2 and 4.3), distinguishes reservoirs (Sand 1 and 2 respectively) into four zones namely; gas zone (brown ellipse), oil zone (yellow ellipse) brine zone (black eclipse) and shale zone (blue ellipse). This cross plot shows better fluid as well as lithology discrimination along the acoustic impedance axis, indicating that acoustic impedance attribute will better describe the reservoir conditions in terms of lithology and fluid content than$\left(\frac{V_P}{V_S}\right)$ ratio. The cross plots of Well AKOS-004 for Sand 1 and 2 are presented herein.

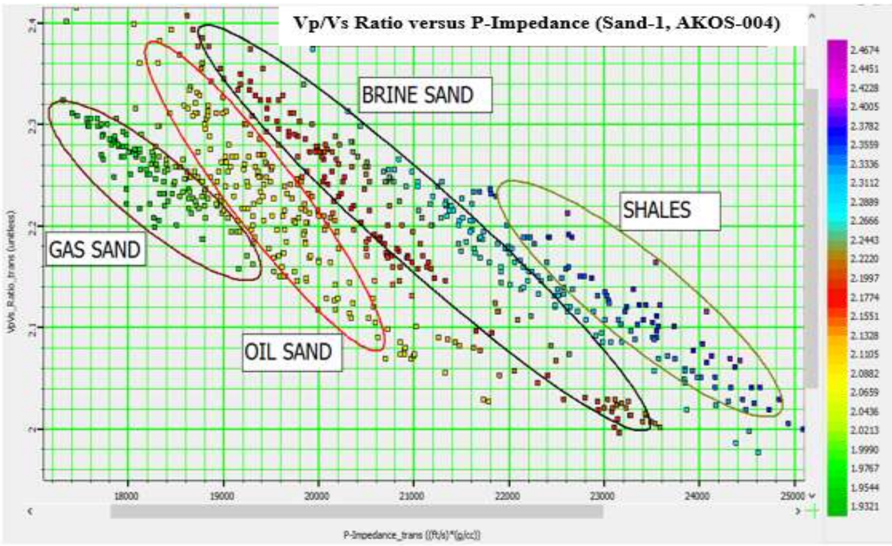

Figure 4.2 AKOS-004$\left(\frac{V_P}{V_S}\right)$ versus P-Impedance colour-coded to density (Sand 1)

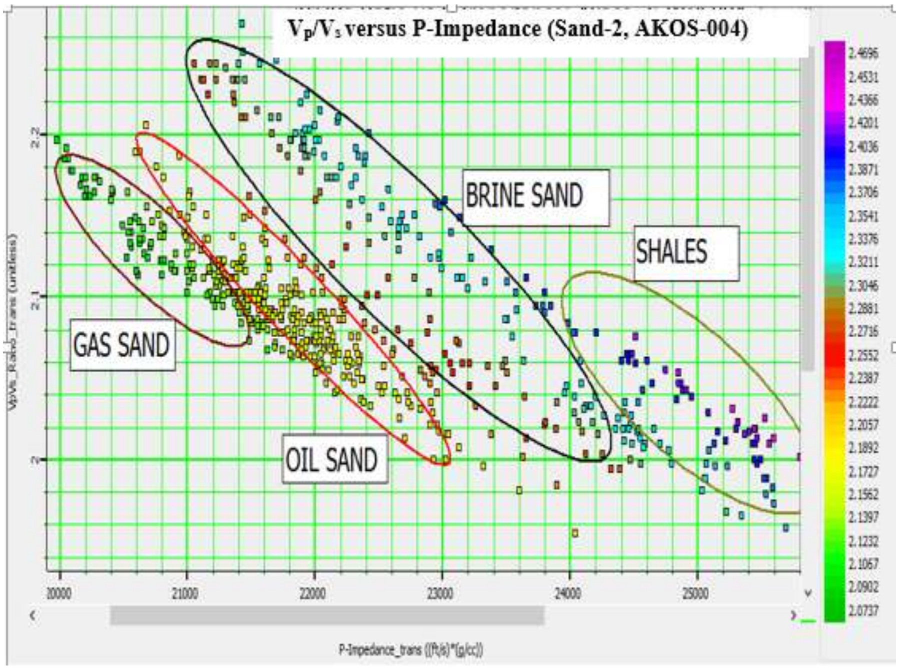

Figure 4.3: AKOS-004$\left(\frac{V_P}{V_S}\right)$versus P-Impedance colour-coded to density (Sand 2)

4.2 SEISMIC INVERSION

4.2.1 Acoustic Impedance Horizon Slice

Inverted rock properties derived from model-based inversion were used to calculate rock attributes. The purpose of this analysis is to confirm the inference of the cross plots and to discriminate between lithology and fluids within the selected reservoir sands. Two horizons were picked in the seismic volume and were used to generate slices. The P-impedance slice was generated for SAND 1 and SAND 2 centred at 2050ms and 2141ms time window respectively. Acoustic impedance values are from low to high and ranges numerically between$(13.8 - 36.0)\ x\ 10^3 kgm^{-2}s^{-1}$. P-impedance generally, is sensitive to lithology and can fairly discriminate hydrocarbon charged sand from brine sand. Very low values of acoustic impedance were observed to the northern part of the field (Fig.4.4 and 4.5). These low values of acoustic impedance are associated with hydrocarbon saturated sands, and probable prospects for by-passed hydrocarbon. Very high acoustic impedance values are observed in the blue circled area, indicating probable depleted zones.

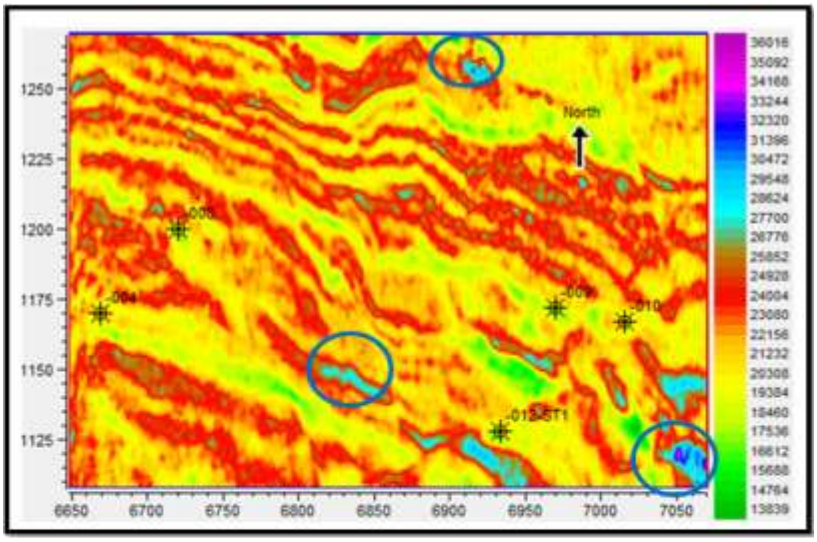

Figure 4.4: P-impedance amplitude slice at SAND 1 (2050ms)

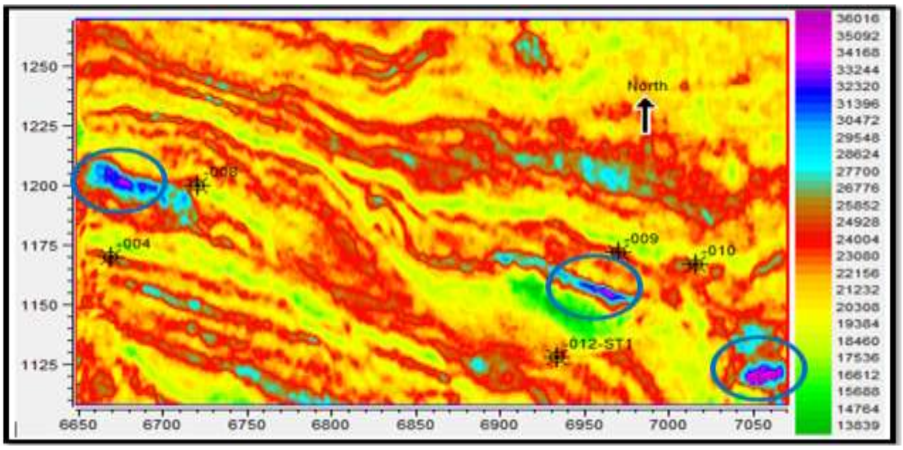

Figure 4.5: P-impedance amplitude slice at SAND 2 (2141 ms)

4.2.2 $\left(\frac{V_P}{V_S}\right)$ Ratio Horizon Slice

$\left(\frac{V_P}{V_S}\right)$ratio values (Figs.4.6 and 4.7) range from low as 1.76 – 1.95 to as high as 2.50 – 2.70. Very low$\left(\frac{V_P}{V_S}\right)$ ratios corresponding to hydrocarbon bearing sand is observed in the slices. The low$\left(\frac{V_P}{V_S}\right)$ratio patches surrounding the producing zone correspond to brine sand, while the regions of moderate to high$\left(\frac{V_P}{V_S}\right)$ ratio at various sections of both volumes correspond to shaly sand. These confirm the observations in the cross plot involving$\left(\frac{V_P}{V_S}\right)$ratio and Acoustic Impedance

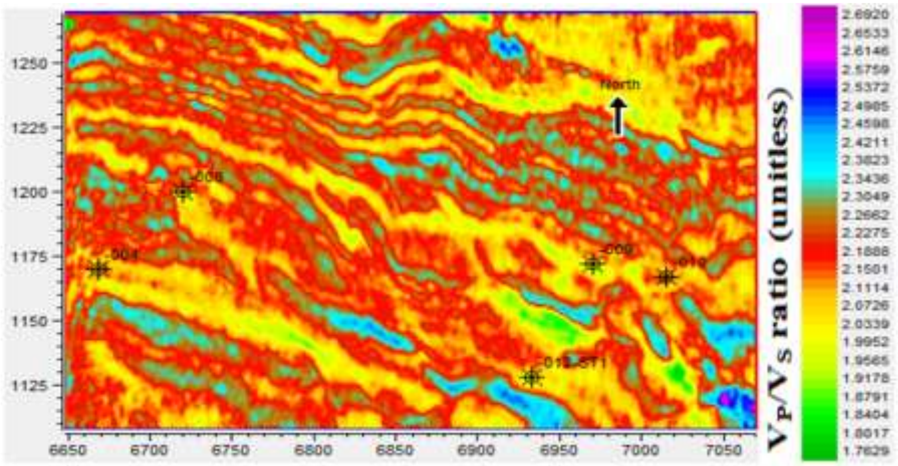

Figure 4.6: V_p/V_s ratio amplitude slice at SAND 1 (2050ms)

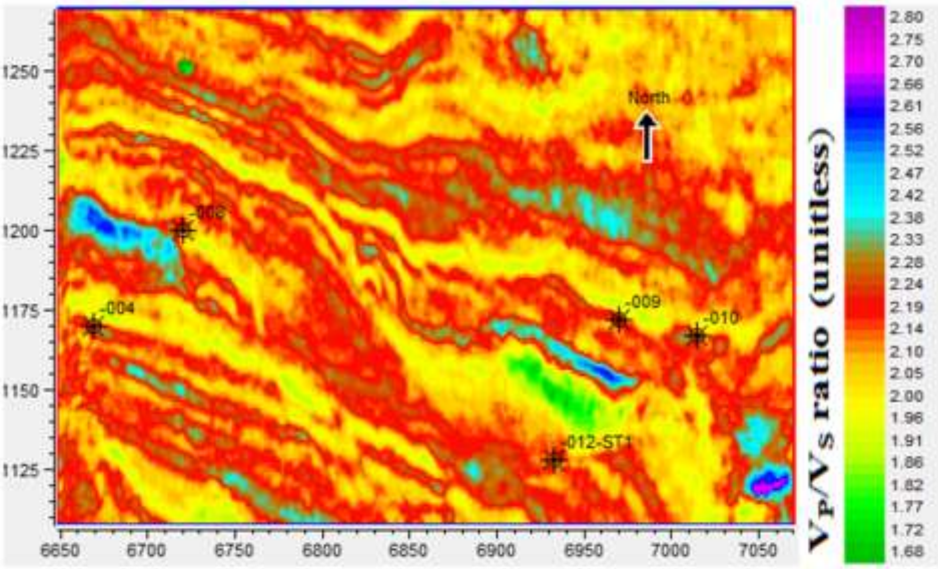

Figure 4.7: V_p/V_s ratio amplitude slice at SAND 2 (2141ms)

V. Conclusion

Well log data and high resolution 3D seismic data acquired in the study area were used in the study. Rock attributes such as Acoustic impedance, S-impedance and $\left(\frac{V_P}{V_S}\right)$ were derived from well logs using rock physics models. These rock attributes were analyzed in cross-plots space and used to determine which of them constitutes better indicators of pore fluids and lithology. Results showed that the cross-plot of acoustic impedance versus $\left(\frac{V_P}{V_S}\right)$ distinguishes the reservoirs into gas, oil, brine and shale zones. Inversion of the post-stack seismic data was also carried out to generate Acoustic Impedance and $\left(\frac{V_P}{V_S}\right)$ sections away from the wellbore. Horizon slices of the inverted volumes were then generated to further study the characteristics of the identified hydrocarbon bearing intervals. Acoustic impedance values are from low to high and ranges numerically between $(13.8 - 36.0)\ x\ 10^3 kgm^{-2}s^{-1}$ Very low values of acoustic impedance were observed in the Northern area of the field. Similarly Velocity ratio values range from (1.76.- 2.70). Very low $\left(\frac{V_P}{V_S}\right)$ values corresponding to hydrocarbon bearing sand were observed in the slices. The results from inversion confirm the observations in the cross plot involving $\left(\frac{V_P}{V_S}\right)$ versus Acoustic Impedance. The summary of the contribution of this research to knowledge is that seismic inversion of the post-stack seismic data plus other conventional geophysical techniques can be used as good indicator of lithology and pore fluid contrasts and to predict presence of hydrocarbon accumulation in the porous gas and oil sands to reduce drilling risk. This has added value to the Exploration and Production industry by avoidance of ambiguous amplitude interpretation that could lead to drilling dry wells and identification of new prospects as an effective economic and decision-making tool.

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References

[1]. Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger Delta. *American Associationof Petroleum Geologist Bulletin,62*(2), 295-300.
[2]. Avseth, P., Mukerji, T., &Mavko, G. (2005) .*Qualitative Seismic Interpretation: Applying Rock Physics tools to reduce interpretation risk.* Cambridge University Press, Cambridge, UK.
[3]. Frankl, E. J., &Cordy, E. A. (1967). The Niger Delta oil province: Recent developments, onshore and offshore, *Mexico City, seventh world petroleum congress proceeding*s, 2, 195-209.
[4]. Horsfall, O. I., Davies, D. H., & Davies, O. A. (2015). Hydrocarbon Reservoir Characterization using Well Log in Niger Delta Basin of Nigeria. *International Journal of Applied and Natural Sciences (IJANS), 4(5),* 55 – 63.
[5]. Maurya, S. P. & Sarkar, P. (2016). Comparison of Post Stack Seismic Inversion Method: A case study from Blackfoot Field, Canada. *International Journal of Scientific and Engineering Research, 7(8),* 1091 – 1101.
[6]. Nton, M. E., &Esan, T. B. (2010). Sequence stratigraphy of EMI fields, offshore Eastern Niger Delta, Nigeria. *European Journal of Scientific Research, 44 (1*), 115 – 132.
[7]. Omudu, L. M., & Ebeniro, J. O. (2005). Cross plot of rock properties for fluid discrimination, using well data in offshore Niger Delta. *Nigerian Journal of Physics, 17,* 16 – 20.
[8]. Reijers T. J. A., Petter, S. W., &Nwajide C. S. (1996). The Niger Delta basin. In T.J.A. Reijers(Eds.), *Selected chapters on Geology: Sedimentary geology and sequence stratigraphy of Anambra basin* (pp. 103-117). Warri, Nigeria: SPDC Corporate Reprographic Services.
[9]. Russell, B.H., 1988. Introduction to Seismic Inversion Methods. *Society of ExplorationGeophysicists,* Tulsa, OK 86pp.
[10]. Short, K. C., &Stauble, A. J. (1967). Outline of the geology of Niger Delta. *Bulletin of AmericaAssociation of Petroleum Geologists,51,* 761-779.
[11]. Tarantola, A. (2005). Inverse problem theory and methods for model parameter estimation. SIAM http://dx,doi.org/10.1137/1. 9780898717921
[12]. Wang, Y. (2001). Approximations to the Zoeppritz equations and their use in AVO analysis. *Geophysics, 64*, 1920 -1927.
[13]. Whiteman, A. (1982). *Nigeria: Its Petroleum Ecology Resources and Potential:* London, Graham and Trotman.

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