Determination of Reservoir Properties from Poisson Impedance Pre-stack Inversion

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***Abstract* - In this study Poisson impedance pre-stack seismic inversion has been extensively studied to determine reservoir properties in Gamma field Niger Delta, from high resolution seismic data and well logs. Three main classifications of lithogy (sand, sandy-shale and shale) were discriminated based on the well log Crossplot between gamma ray and Poisson impedance. Also, well log Crossplot between density and Poisson ratio, formed three major clusters which are probably shale, brine and hydrocarbon zones. The sand lithofacies shows low values of gamma ray (< 57 API) and PI (< 5200 ft/s*g/cc) while shale lithofacies possesses high values of gamma ray (> 57 API) and PI (> 5600 ft/s*g/cc). Hydrocarbon zones show low values of PI (< 4995 ft/s*g/cc) while brine and shale zones have intermediate PI (Between 5100 to 5388 ft/s*g/cc) and high values PI (> 5508 ft/s*g/cc) respectively. The value of scale factor, c was calculated to be 1.38, which was obtained from the inverse of the slope of the regression line between the P-impedance (I_p) and a scaled version of the S-impedance (I_s). The scale factor was used in calculation of Poisson impedance. Inversion of the seismic data was also carried out to generate horizon slices of Poisson Impedance away from the wellbore. Results show that anomalously low values of Poisson impedance (Between 4862 to 5168 ft/s*g/cc) were observed in both cross-sections and horizon slices indicating the presence of hydrocarbon sands.**

***Key words:*Poisson Ration, Poisson Impedance, Pre-Stack, Crossplots, Seismic Inversion**

I. INTRODUCTION

As the demand for the consumption of oil and gas products increases globally, the quest by the major players in the exploration and production industries to explore and characterize new reservoirs in an all-encompassing state of the art technology also increases [1, 2]. One of the challenges encountered in achieving this is the differentiation of lithology and fluid within the reservoir [3]. Inversion of elastic impedances (P- and S- Impedances) and other rock physics attributes such as bulk modulus(k), Young modulus (E), shear modulus(u), Mu-rho (μ_ρ) and lambda-rho(λ_ρ) has been extensively used to delineate lithology (mainly sandstones and shales) and fluid contents (gas, oil and water) [4, 5].

Seismic inversion methods have played key role in deriving these elastic parameters while rock physics relates seismic properties to reservoir properties[6, 7, 8]. The Poisson Impedance inversion is specifically used in this study. Several researchers have made outstanding contributions by showing that the Poisson impedance derived from prestack seismic inversion is very important in deriving reservoir properties[1, 9, 10, 11]. Sharma and Chopra [1] in their study of Poisson Impedance (PI) inversion for characterization of sandstone concluded that the PI is very favourable attribute for sandstone reservoir characterization, deriving two attributes of the PI using the target correlation coefficient analysis (TCCA). The two attributes are the Lithology impedance (LI) and Fluid Impedance (FI).

Quakenbush et al. [10] contributed that PI is a seismically derivable attribute that combines the discrimination characteristics of Poisson's ratio along with density, both of which are useful parameters in delineating reservoirs.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

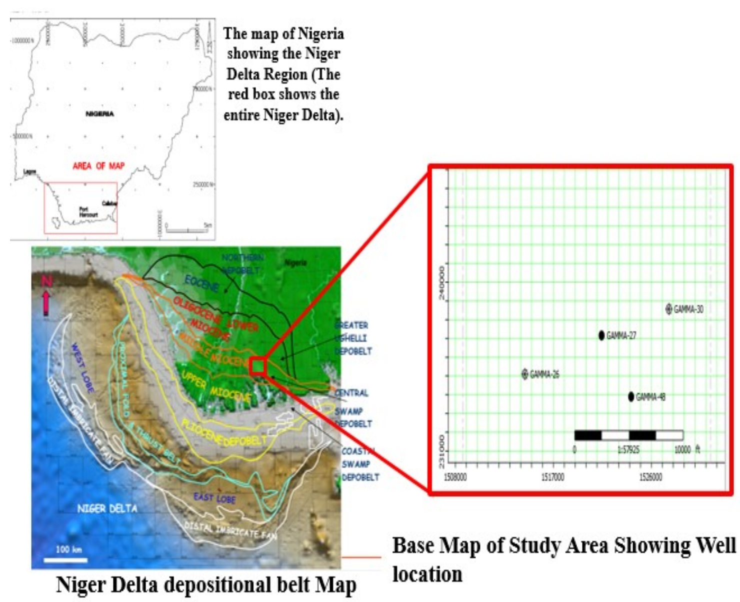

Fig. 1: Map of Niger Delta showing location of the Study

Gamma field is located in the Coastal Swamp of the Niger Delta, about 40km South-west of Port Harcourt which is within the Niger delta, as seen in Fig. 1. The Niger Delta Basin, situated at the apex of the Gulf of Guinea on the west coast of Africa, is one of the most prolific deltaic hydrocarbon provinces in the world[12]. The sedimentary basin occupies a total area of about 75,000 km^2 and is at least 11 km deep in its deepest parts. Current daily oil production is 2.1 million bbl, and daily condensate production is 85,000 bbl[13]. The latitudinal and longitudinal dimensions of the delta lie along the coordinates 4°N - 9°N and 4°E - 9°E [14]. Only one petroleum system has been identified to be associated to the Niger Delta basin and it is known as the (Akata-Agbada) petroleum system [15, 16].

III. METHODOLOGY

The work presented here is a quantitative interpretation(QI) study which integrates rock physics diagnostic and Pre-stack seismic inversion. The integrated methodology includes:

a) Rigorous quality control of available well log and seismic data,
b) Rock physics diagnostic (RPD) conducted at well log data using more than one attribute extracted over the vicinity of the targeted hydrocarbon zone
c) Simultaneous pre-stack inversion.

In practice, well logs contain several inherent problems, especially problems of spikes. The logs were despiked and edited to remove spurious events and reduce the scatter in the lithology and fluid crossplots.

In rock physics planes, from cross plotting, we assessed the elastic seismic attributes within their proper geologic context, alienated the attributes that constitute the best indicators of the subtly differing lithologies and fluids of the studied reservoir. Finally, we conducted simultaneous pre-stack inversion to obtain 3D P-impedance (I_p), S-impedance (I_s), and density volumes to identify and validate the potential hydrocarbon anomalies. Poisson Impedance map is estimated for the targeted reservoirs using the inverted volume by generating a cardinal elastic relationship observed in well log cross plot. The value of scale factor, c was calculated to be 1.38, which was obtained from the inverse of the slope of the regression line between I_p and I_s (Fig.3).

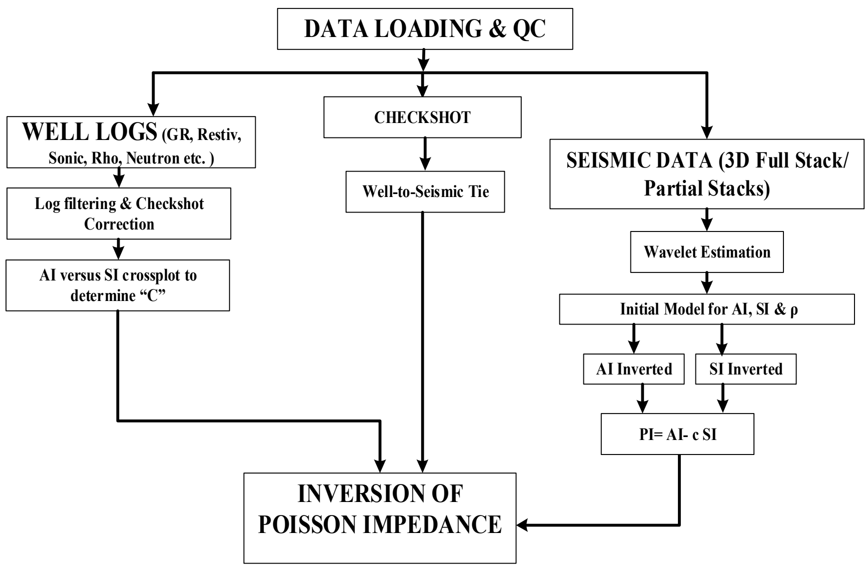

Fig. 2: Work flow for Pre-stack inversion

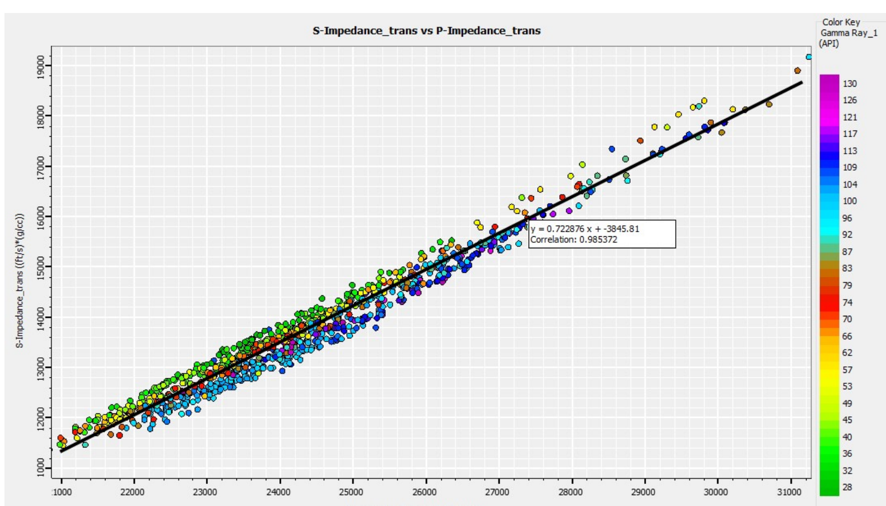

Fig. 3: Determination of Scale Factor "C''

4. RESULTS AND DISCUSSION

4.1 Reservoir delineation & Well Correlation

Ten feasible hydrocarbon-bearing zones are identified from wells Gamma 26, 27, 30 and 48 using conventional log analysis. Curves with low gamma ray and high resistivities are sand lithologies. Shale lithologies were defined by the high gamma ray value. Gamma ray logs measure the radioactivity of formations in the well which connected to clay mineral, oil source rock, organic matter and shale in reservoir rock [17]. Shale-free sandstones normally have low radioactive concentrations representing relatively low gamma ray response. Resistivity is the property of a material or substance to resist the flow of electric current. The resistivity log response against hydrocarbon-bearing zones as observed from the reservoirs were relatively high. Water saturation, Volume of Shale and porosity curves were calculated for wells Gamma 26 and 30 as shown in figure 3a and 3b respectively. Water saturation values were relatively low indicating that the proportion of void spaces occupied by water is low consequently high hydrocarbon saturation and high hydrocarbon production. Volume of shale curves were relatively low which have resulted from less shale content and high sand volume in the reservoirs. The reservoirs total porosity was estimated from density log (RHOB) using porosity formula and curves are relatively high indicating a very good reservoir quality and reflecting probably well sorted coarse grained sandstone reservoirs with less cemented grains. The Fig.4 shows the litho-stratigraphic correlation which provides information on the over-all stratigraphy of the study field. Using the resistivity and gamma ray log, lithologic correlation of equivalent strata across the four wells was performed by matching for similarity the intervals of logs from different wells. At the same time, the potential hydrocarbon reservoirs in the various wells were correlated using the gamma ray and resistivity logs to determine their lateral extent, possible existence of faults, dips and/or unconformities.

Table1: Reservoir Top, Base and thickness

WELL	RESERVOIR NAME	TOP (FT)	BASE (FT)	THICKNESS (FT)
Gamma26	G3000	10483	10682	199
	G5000	11077	11160	83
Gamma 30	G3000	10539	10681	142
	G5000	11061	11122	61
Gamma 27	G3000	10564	10747	183
	G5000	11102	11203	101
Gamma 48	G3000	10720	10882	162
	G5000	11042	11218	176

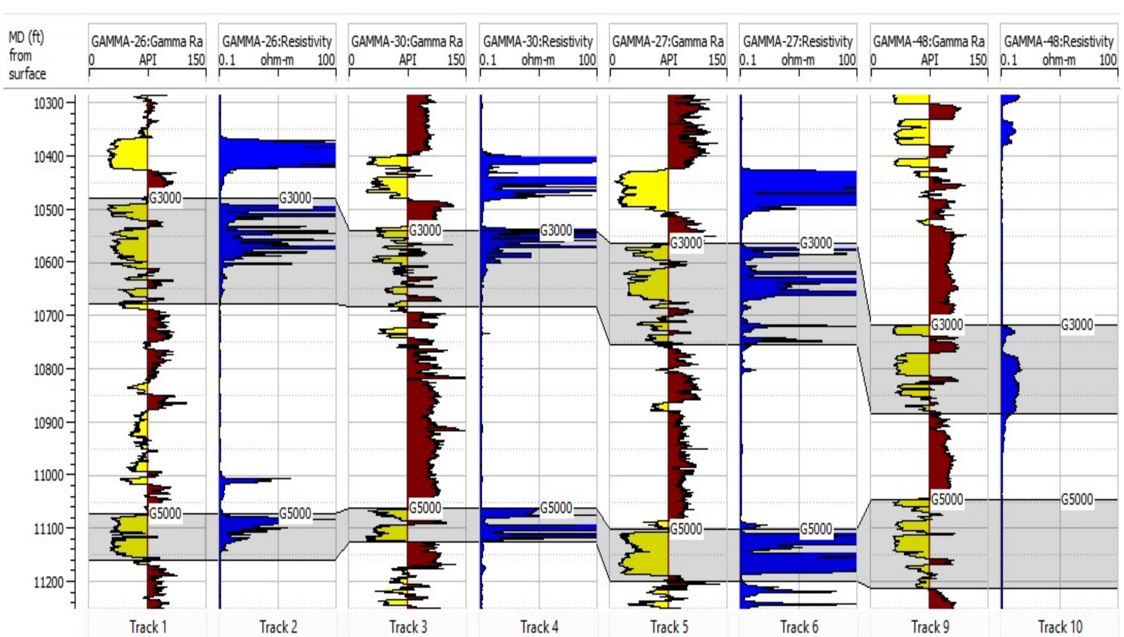

Fig. 4: Lithostratigraphic zones of the delineated reservoirs on the well section

4.2 Rock Physics Diagnostics

Rock-physics diagnostics (RPD) rock-physics model that quantitatively explains the well data. It guides the interpreter toward which of the existing models to use and with which model parameters. Once such a model is established, it can be used to assign elastic properties to a synthetic geology-driven earth model to generate synthetic seismic data. It also aids in the interpretation of seismic data, especially the interpretation of seismically derived impedances[18]. Crossplot of Density versus Poisson Ratio colour coded by Poisson Impedance distinguishes reservoirs G3000 & G5000 into three zones namely; Hydrocarbon zone, brine zone and shale zone as seen in the enclosed eclipse. This Crossplot show better lithology and fairly fluid discrimination along the acoustic impedance axis, indicating that Poisson impedance attribute will better describe the reservoir conditions in terms of lithology and fairly fluid. Crossplot of Poisson Impedance versus Gamma Ray distinguishes the reservoirs G3000 & G5000 into sand, shale and sandy shale (or shaley sand) zones. This means the crossplot is a good lithology discriminator.

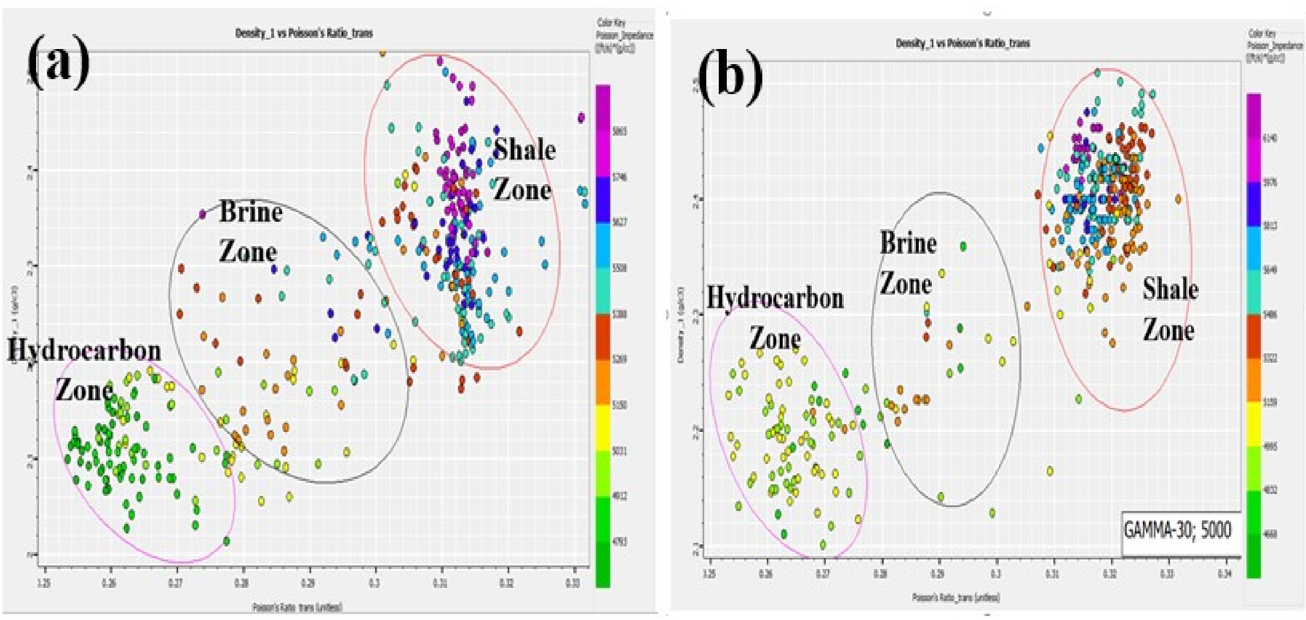

Fig. 5: Well Gamma 30. Density versus Poisson Ratio in reservoir intervals colour coded by Poisson Impedance (a) Well 30, Reservoir G3000 (b) Well 30, Reservoir

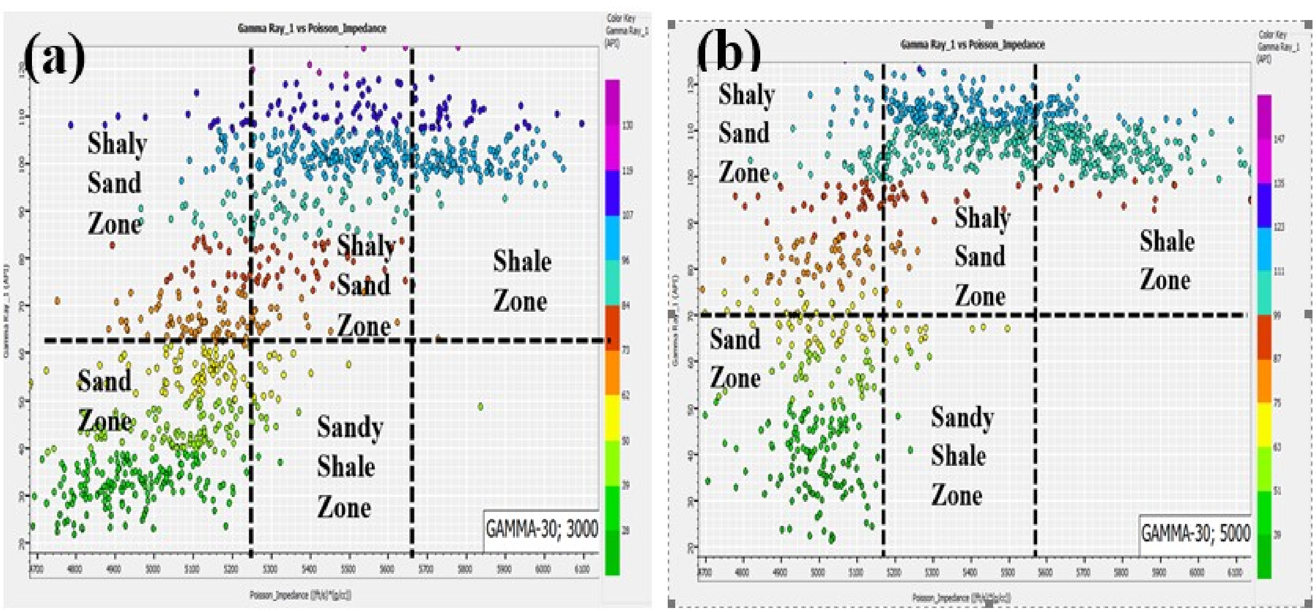

Fig. 6: Gamma Ray vs Poisson Impedance Colour coded with GR (a) Well 30, Reservoir G3000 (b) Well 30, Reservoir G5000

4.3 Poisson Impedance Cross-section

Poisson Impedance attribute is the difference between P-Impedance and scaled S-Impedance arising from the difference of two squares of the lambda-rho (λρ) attribute. According to Quakenbush et al. [10] and Omudu and Ebeniro [19], Poisson impedance attribute is more sensitive to gas effect than oil effect, also with relative sensitivity to oil effect relative to the Vp/Vs ratio attribute. It has been found to be a good discriminator of fluid, being more sensitive however, to gas than oil effect. Hydrocarbon zones show low values of Poisson Impedance (4995-5092 ft/s*g/cc) while brine and shale zones have intermediate PI (between 5100 to 5388 ft/s*g/cc) and high values PI (5508-5702 ft/s*g/cc) respectively. The high Poisson impedance regions are interpreted as brine-saturated sands. Just below the pick horizons, there is the presence of very low Poisson impedance indicating hydrocarbon-saturated sands. There is a good match between the features on the Poisson impedance cross-section and those in the gamma ray log (GR log is the black curve). The areas of low gamma ray values match areas of low Poisson impedance in the section. The cross-section is a good reflection of what is obtainable in typical Niger Delta geology which is dominantly shale/sand/shale sequence. The sand in this case is either hydrocarbon-saturated or brine-saturated.

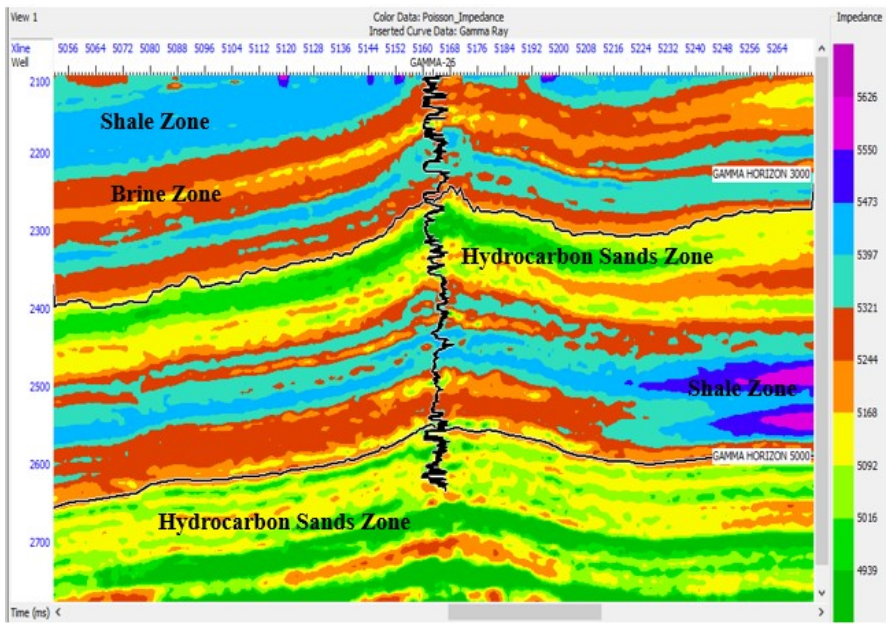

Fig. 7: Inverted Poisson Impedance attribute slice with Gamma Ray Log of Well Gamma 26 Inserted showing three Horizons (G3000 & G5000).

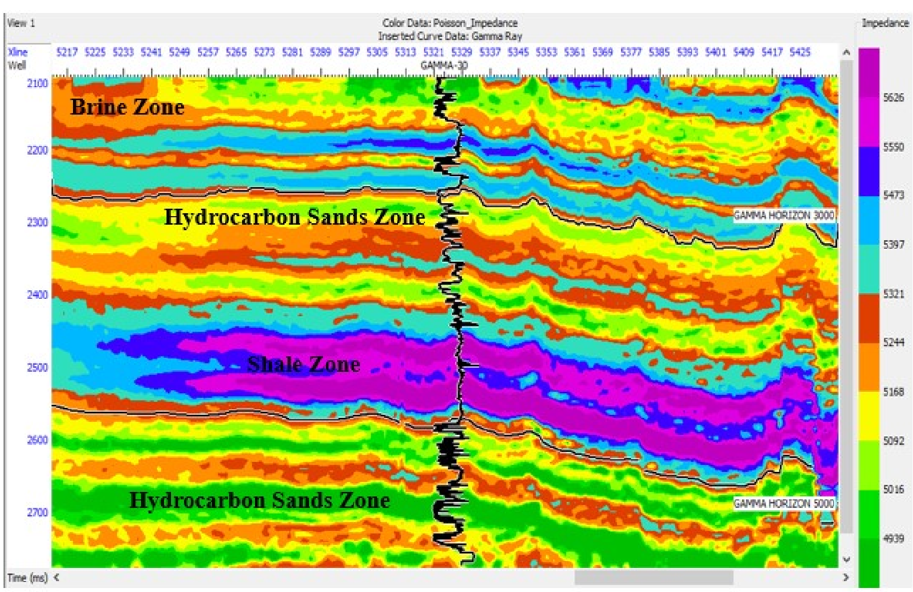

Fig. 8: Inverted Poisson Impedance attribute slice with Gamma Ray Log of Well Gamma 30 Inserted showing three Horizons (G3000 & G5000).

4.4 Poisson Impedance slice

The horizon slice shows low values of Poisson Impedance (4995-5092 ft/s*g/cc) while brine and shale zones have intermediate PI (Between 5100 to 5388 ft/s*g/cc) and high values PI (5508-5702 ft/s*g/cc) respectively. The high Poisson impedance regions are interpreted as shale zones. The central parts of the two horizon slices are located in the region of relatively low poisson impdence values. Relatively high poisson imdeace values are seen the south western parts of the first horizon whereas it is not the case in the second horizon. The second horizon has brine saturated sands surounding the hydrocabon sands in the central part of the field. This suggest that the hydrocarbons is gradually being replaced by water as a result of production. Also the producing wells are concentrated around rgegions with relatively low poisson impedance values. This confirms results obtained from the crossplots.

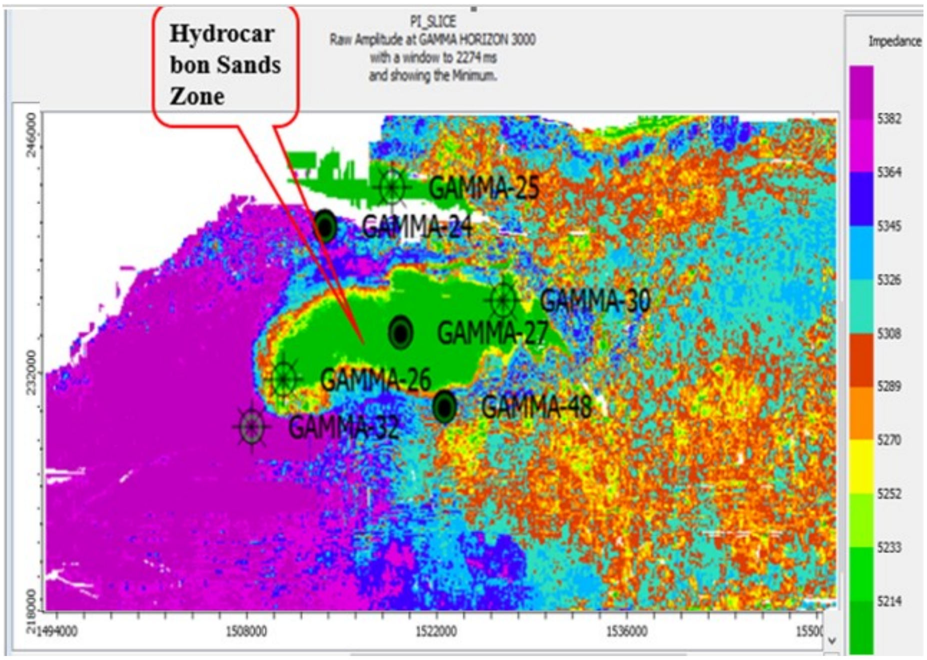

Fig. 9: Poisson Impedance attribute slice showing Gamma 30

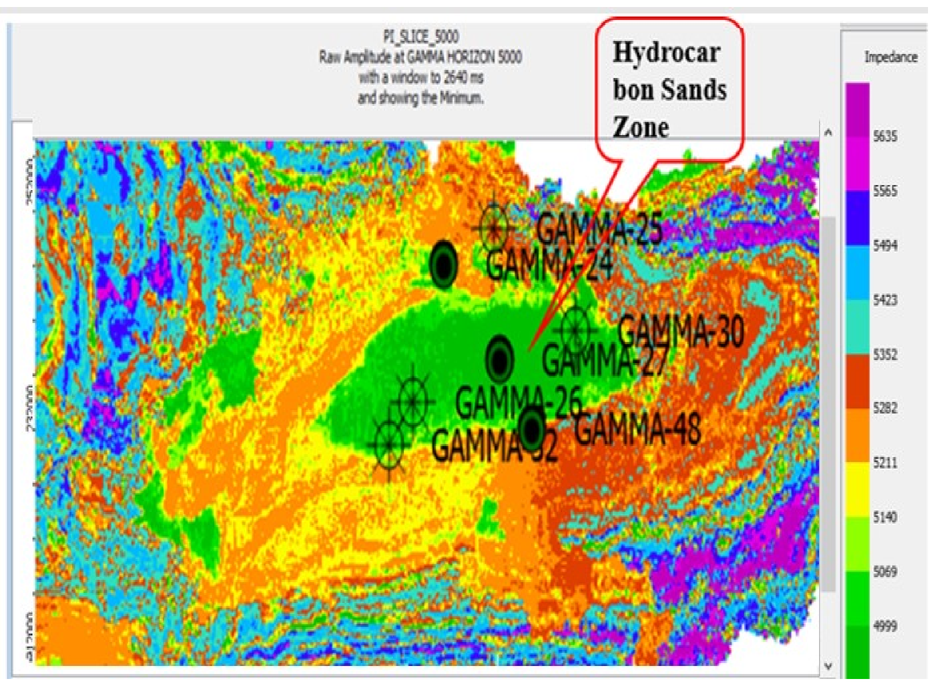

Fig. 10: Poisson Impedance Amplitude Slice at Sand A

V. CONCLUSION

Three main classifications of lithogy (sand, sandy-shale and shale) were discriminated based on the well log Crossplot between gamma ray and Poisson impedance. Also, well log Crossplot between density and Poisson ratio, formed three major clusters which are probably shale, brine and hydrocarbon zones. The sand lithofacies shows low values of gamma ray (< 57 API) and PI (< 5200 ft/s*g/cc) while shale lithofacies possesses high values of gamma ray (> 57 API) and PI (> 5600 ft/s*g/cc). Hydrocarbon zones show low values of PI (< 4995 ft/s*g/cc) while brine and shale zones have intermediate PI (Between 5100 to 5388 ft/s*g/cc) and high values PI (> 5508 ft/s*g/cc) respectively. The value of scale factor, c was calculated to be 1.38, which was obtained from the inverse of the slope of the regression line between I_p and I_s. The scale factor was used in calculation of Poisson impedance. Inversion of the seismic data was also carried out to generate horizon slices of Poisson Impedance away from the wellbore. Results show that anomalously low values of Poisson impedance (Between 4862 to 5168 ft/s*g/cc) were observed in both cross-sections and horizon slices indicating the presence of hydrocarbon sands. The effective application of crossplot and seismic-based impedance inversion will be helpful in defining lithofacies and prediction of fluids for precise location of new wells for ideal production from the field.

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