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DERIVED ROCK ATTRIBUTE ANALYSIS AND INVERSION OF LAMDAMURHO FOR FLUID AND LITHOLOGY PREDICTION IN NEMBE FIELD ONSHORE NIGER DELTA, NIGERIA

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Abstract

Prediction of pore fluid and lithology using well log derived rock attributes alone are often associated with higher uncertainties. This could lead to inaccurate determination of formation properties. In this paper, integration of derived rock attributes and Prestack seismic inversion of Lame parameters reduced the uncertainties. The goal was to effectively discriminate fluid and lithology in the reservoir and predict hydrocarbon charged sand zones that could be revived for further drilling decisions. To achieve this goal, elastic attributes were generated from the well logs and appropriate pair of these attributes was cross-plotted to discriminate fluid and lithology. To improve the confidence of delineating bypassed hydrocarbon zones away from the current produncing zones, angle gather generated from the super gather of the prestack seismic data was inverted and data slices of lame impedances along the horizon of interest was extracted and analysed. The results of crossplot of velocity ratio versus Poisson's ratio and acoustic impedance successfully distinguished between fluids and lithology in the area. Gas and oil charged sand exhibit low velocity ratio, Poisson's ratio and acoustic impedance values. The results were also validated by the crossplot of LambdaRho versus MuRho from well logs. To delineate bypassed hydrocarbon away from well locations, data slices of the LambdaRho, and MuRho volumes were generated along HD2 reservoir. The results capture the hydrocarbon prospects at the known well locations and bypassed hydrocarbons away from the known locations which could be revived to increase production in the field.

Keywords: Lithology; Seismic inversion; Reservoir; Lambdah-Rho and Mu-Rho.

1. Introduction

Analysis of pore fluid and lithology are vital elements for effective exploration and production of hydrocarbon because of their importance in delineation of porosity, saturation and permeability in the reservoir. Accurate predictions of lithology and pore fluid in reservoirs that needed natural pressure gradient for extraction of hydrocarbon and those that simply required special recovery operations have continued to pose serious challenge to hydrocarbon exploration and development. But since hydrocarbon economic viability in the field is dependent on the quality and accuracy of the lithology and pore fluid, integrating well log derived attributes and inversion of Lamdah-Mu-Rho in the analysis of these important reservoir properties is hoped to create more confidence in their predictions. However, there has been a growing interest in determining lithology and pore fluid using well log data which is cheaper, and economical but also associated with higher uncertainties [11]. This could lead to erroneous prediction of lithology, pore fluid and delineation of other petrophysical properties such as porosity and permeability. Usually, at the location of a drilled well, we have measurements that give us an idea of the elastic and physical properties of the subsurface rocks [2]. But relying on this information alone for reservoir performance and developments analyses may not effectively give the expected results. Therefore, integrating prestack inversion of Lamdah-Mu-Rho (λ- μ-ρ) and derived well log attributes can offer more insight and confidence in reservoir studies. Goodway *et al.* [4]

proposed Lambdah-Mu-Rho techniques as good tools for pore fluid discriminator which has has its origin in the hard rock exploration areas of Canada. Hilterman [6] stated that this attribute (λ-ρ) is a good approximation of Gassmann's bulk modulus of pore fluid effect. Seismic inversion of these attributes provide additional look at the reservoir properties and its performance. The objective was to predict fluid, lithology and delineate hydrocarbon bearing sand intervals for new exploration and development using rock physics principle. Chopra *et al.* [9] stated that well log properties can be link to seismic data through rock physics studies so that one can infer their variation in a lateral and vertical sense.

2. Location and geologic setting

Nembe Field is located in the northern parts of Port Harcourt province in the Niger delta region of Nigeria (Fig.1).

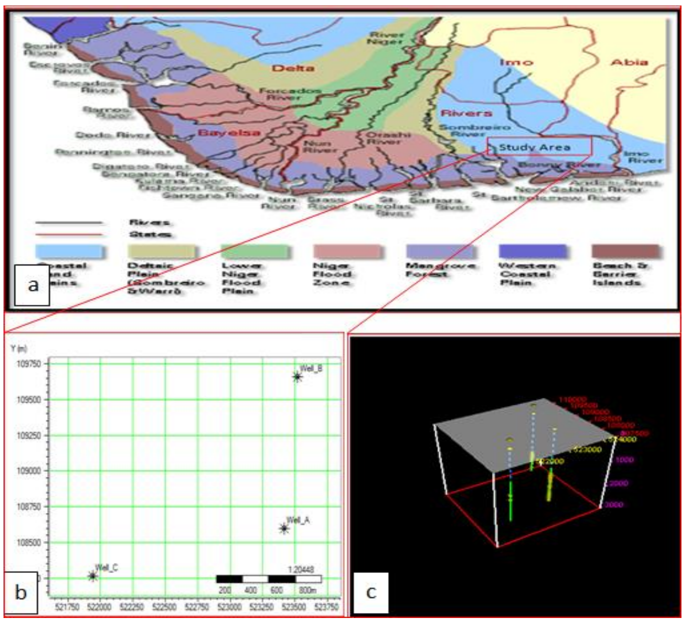

Fig.1. Location of the study area; (a) Map of Niger delta showing the location of the study area as modified after (b) The base map of the study area (c) The 3-D view of the well spots

Niger Delta is situated on the continental margin of Gulf of Guinea in equatorial West Africa, at the Southern end of Nigeria bordering the Atlantic Ocean between latitude 3° and 6° and longitude 5° and 8° [10]. The northern boundary is the Benin flank, an east-northeast trending hinge line south of the West Africa basement massif. The north-eastern boundary is defined by the outcrops of the cretaceous on the Abakaliki high and south east by the Calabar flank, a hinge line bordering the adjacent Precambrian. The offshore boundary of the Niger delta is defined by the Cameroun volcanic line to the east, the eastern boundary of the Dahomey basin. The province covers about 300,000km and includes the geologic extent of the tertiary Niger delta (Akaka- Agbada) petroleum system [12].

The sedimentary basin of the Niger delta encompasses a very large region than the geographical extent of the modern delta as evidenced by the Niger- Benue drainage system [1]. It includes Cross river delta and extends eastwards into the continental margins of neighbouring Cameroon and Equatorial Guinea [8].

3. Materials and method

The data used in this study include suites of well logs and Pre-stack seismic data processed through super gather process to create a uniform offset distribution and to enhance signal to noise ratio. But since Pre-stack inversion perform better in incident angle domain; the super gather (offset) was converted to angle gather where we carried out subsequent processes. Well log correction such as media filtering was carried out on the well logs to minimise anomalous high frequency spikes while errors arising from gaps were corrected using spline interpolation which created interpolated new wells (new Vp and gamma ray log). Shear wave log was not available but was however generated empirically using Castagna relation which applying linear transforms to input p-wave log. Check shot correction was finally applied to improve the match between synthetic and seismic data by modifying the depth –time curve connected with sonic log. This was necessary because of the extrapolation of the initial Vp value to the surface by the program which usually overestimates the near surface velocity. In well log analysis, the first step is usually to differentiate hydrocarbon charged sand from shale using gamma ray log. In absence of gamma ray log, P wave velocity logs can also perform similar functions (lithology prediction) but they are usually influenced by density, bulk and shear moduli. Kearey *et al.* [7] stated that velocity ratio is independent of density and can be used to derive Poison's ratio which is much more diagnostic of lithology. These well log attributes (velocity ratio and poison's ratio) and other elastic rock parameters such as lamdah-Rho and Mu-Rho were generated from well log using transform menu of E-log program (Fig.2). The generated well log attributes were crossploted for quantitative analysis of well logs. The knowledge of the cross-plot populations were used to discriminate fluid and lithology at well locations. The trends of the cross-plot pattern was also used to determine the attribute(s) that have more robust indicator of pore fluid. To predict fluids and lithology (potential bypassed hydrocarbon zones) away from the well locations, Prestack seismic inversion of Lamdah-Mu-Rho was carried out basically to generate Acoustic Impedance, Shear Impedance and Density (Rho) volumes. Rock physic parameter such as LamdahRho ($\lambda\rho$) and MuRho ($\mu\rho$) volumes were generated. Lamda-Rho was derived from the square of the difference of P-Impedance and S-Impedance (P-Impedance^2 - S-Impedance^2). MuRho was also derived from the square of S-Impedance (S-Impedance^2). Data slices were Created to predict the behaviour of hydrocarbon bearing intervals at known well locations and potential bypassed hydrocarbon away from the well locations.

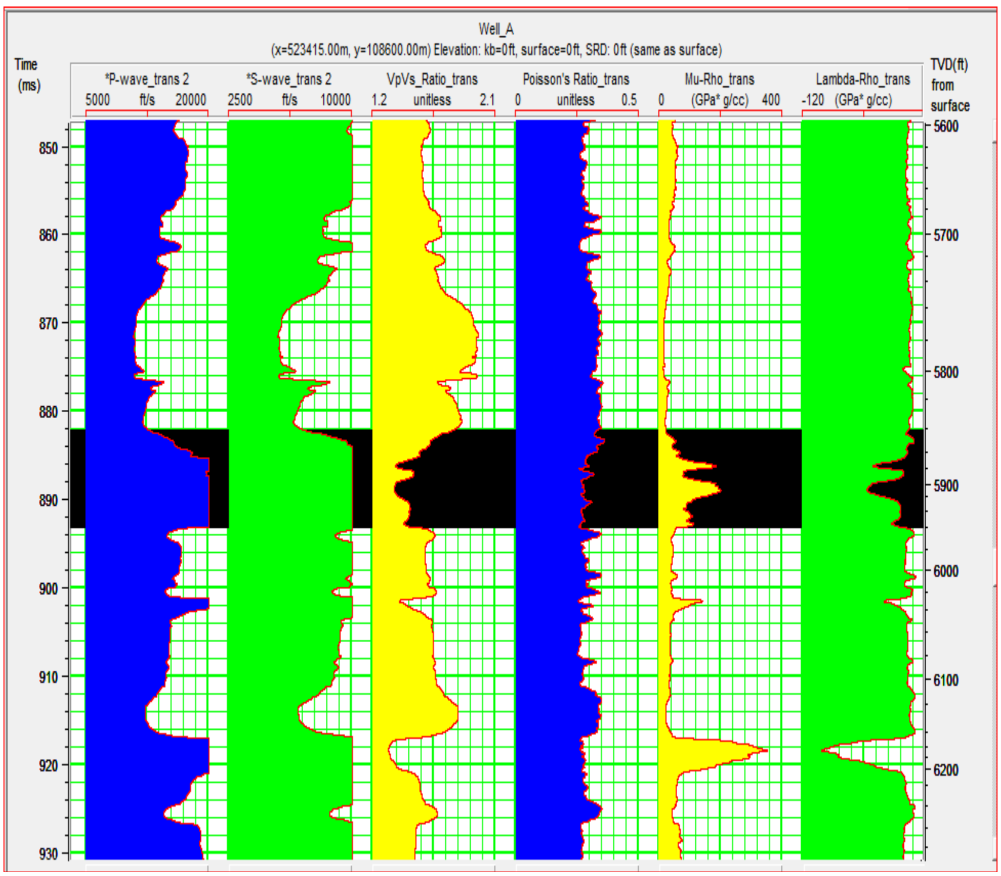

Fig.2. The generated well log attributes indicating HD2 reservoir

3. Results and discussion

Prediction of lithology and pore fluid saturation has been undertaken by analysing the cross-plot populations of the well log attributes (Velocity ratio, Poisson's ratio, LamdahRho and MuRho). The crossplot of Velocity ratio versus Poisson's ratio differentiate the reservoir into three distinct zones as indicated by green, yellow, blue and pink polygons (Fig.3). The green zone represent gas sand, yellow zone is oil sand, blue zone is brine charged sand while the pink zone represents shale zone. The attribute cross-section presents fluids and lithology tresponse to velocity and Poison's ratio (Fig.4).

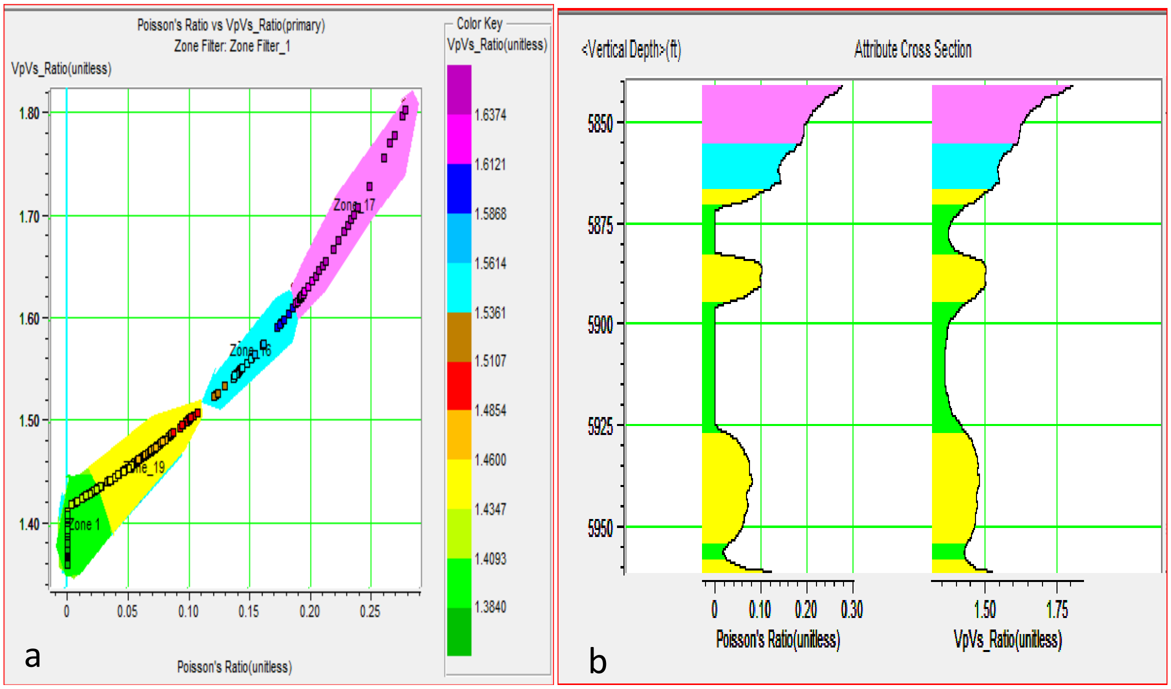

Fig.3. (a) Crossplot of velocity ratio and Poisson' ratio (b) Attribute Cross-Section showing hydrocarbon, Brine and Shale intervals

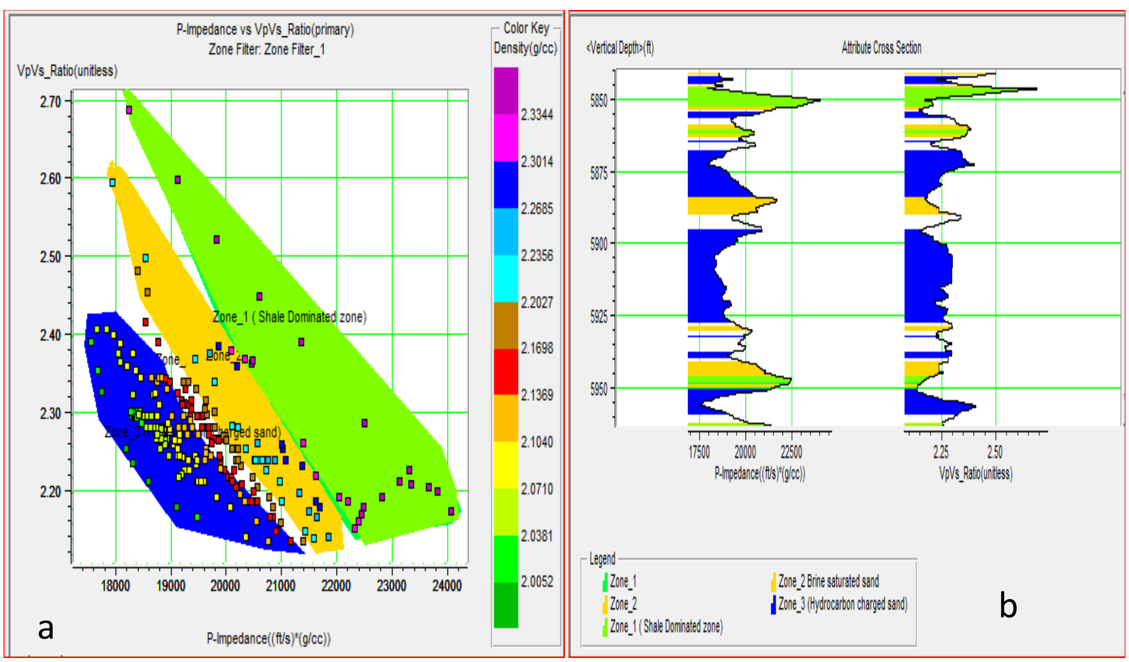

Fig.4. (a) Crossplot of velocity ratio and P-Impedance (b) Attribute Cross-Section showing hydrocarbon, Brine and Shale intervals

Gas and oil charged sand have lower poisons and velocity values while brine and shale are associated with higher values. The attribute cross-section of the velocity ratio revealed that shale has velocity ratio value above 1.75 (Fig.3b). This indicates that that velocity ratio may not be used to discriminate shale and carbonate because both share similar range of velocity ratio values. The crossplot analysis of velocity ratio and acoustic impedance also discriminate lithology and pore fluid in a very similar manner (Fig.4). Low velocity ratios in blue polygon indicate hydrocarbon saturated zone and also correspond to low acoustic impedance. The brine saturated zone in yellow polygon and shale layer in green polygon both correspond to high velocity ratio and acoustic impedance. The acoustic impedance cross-section revealed that hydrocarbon saturated sand has low acoustic impedance, brine saturated sand exhibit relatively high acoustic impedance while shale has very high acoustic impedance (Fig.4). The results revealed that acoustic impedance and velocity ratio were not only used to delineate lithology but also to evaluate the presence of hydrocarbons in pores. Other well log attributes that sensitive to sedimentary rock's pore fluids are Lame parameters. The use of relationship between lame parameters such as λ (incompressibility), μ (rigidity), and ρ (Rho) in pore fluid and lithology discrimination was encouraged by [4]. The crossplot of these two attributes delineate gas saturated zone (green polygon), brine filled sand (blue polygon) and shale zone indicated in pink polygon (Fig.5).

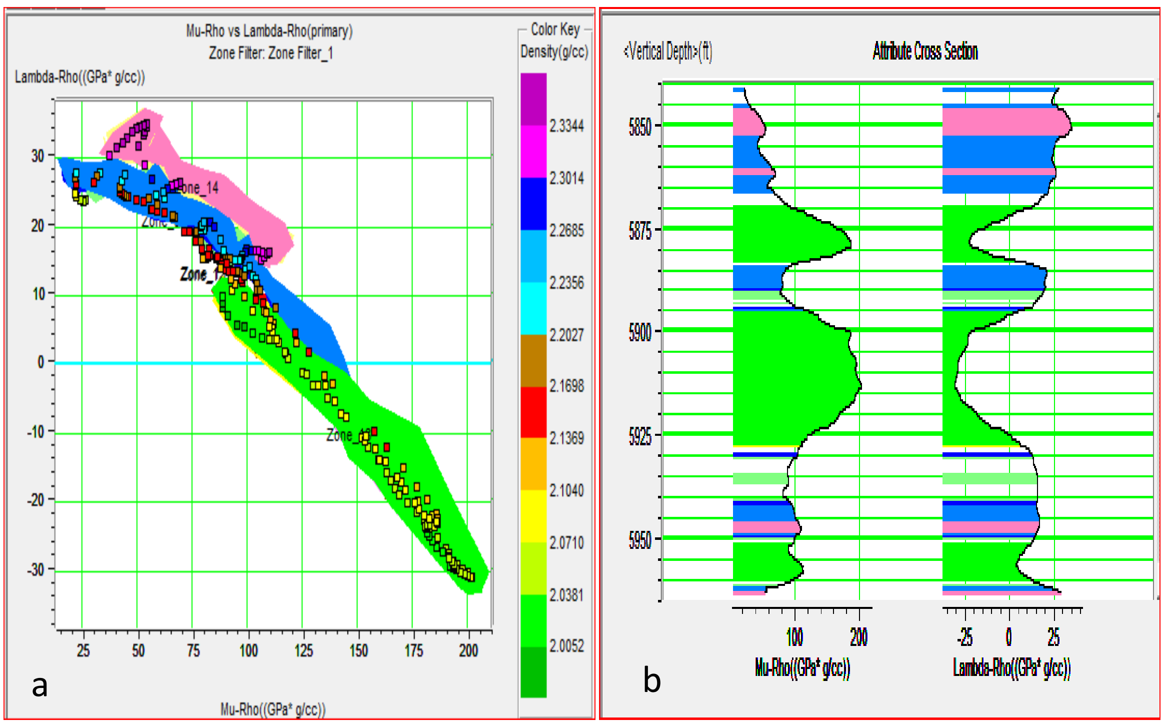

Fig.5. (a) Crossplot of LamdaRho (λ *ρ) and Mu-Rho (μ* ρ) (b) Attribute Cross-Section MuRho (μ* ρ) and LamdaRho (λ *ρ) showing Gas, Brine and Shale intervals

The interesting and unique result of the LamdaRho (λ *ρ) and MuRho (μ* ρ) crossplots and their attribute cross-sections is that sand dominated zone indicates higher MuRho (μ* ρ) values than shale. The high MuRho (μ* ρ) values correspond to very low LamdaRho (λ *ρ) values which are indication of hydrocarbon filled sand sandstone (5b). The increase and decrease in λ *ρ values in water and hydrocarbon filled sandstone respectfully is probably due to its response to the dense media. Hydrocarbon filled sand stone is less dense than water filled sandstone thus leading to decrease in λ *ρ values. Various responses of the well attributes and their crossplot's populations revealed that λ *ρ, Velocity ratio, Poisson's ratio, acoustic impedance and density values are much lower in hydrocarbon saturated layer but characterised by higher (μ* ρ) values (Fig.6). The study has shown that pore fluid and lithology of the well can be predicted by analysing the relationship that exists among the well log derived attributes. But to create much greater insight in fluid and lithology discrimination beyond the well locations, Lambda-Mu-Rho inversion from the prestack 3D seismic data of the study area was undertaken (Fig.7).

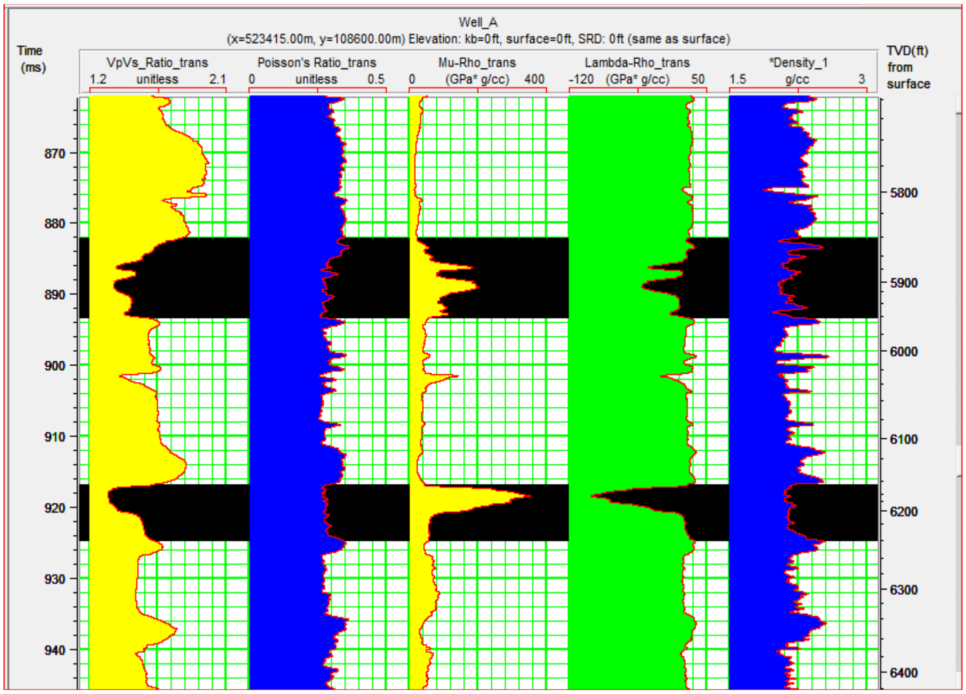

Fig.6. Generated well log attributes indicating their various responses to fluid and lithology

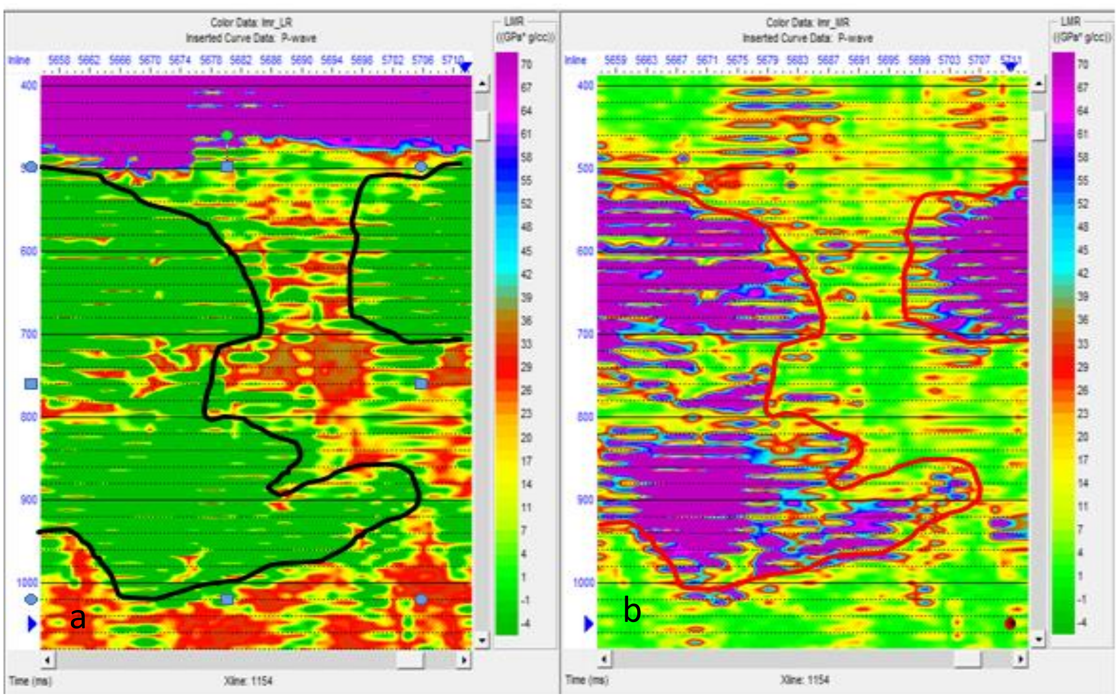

Fig.7. Lambda-Mu-Rho (LMR) inversion (a) Inverted LambdahRho volume (b) Inverted MuRho volume

In the inverted volume, sand dominated zones (green color bands) are characterised by lower $\lambda*\rho$ values (Fig.7a). The same zones are also characterised by higher $\mu*\rho$ values as indicated by pink color band (Fig.7b). This is an indication of hydrocarbon sand reservoirs. Data slices of $\lambda*\rho$ and $\mu*\rho$ were isolated to capture and delineate hydrocarbon charged sand channels away from the well locations (Fig.8). Lower and higher λ *ρ and μ* ρ values of data slices at the well locations are indication of the presence of hydrocarbon. This represents the Known hydrocarbon prospects that were predicted through well attribute cross-plots. The data slices of the λ *ρ and μ* ρ were created from along the horizon (HD2) of interest. Very low values of LambdahRho (λ *ρ) were observed around the well locations (producing zones) in the central, far Northwestern and eastern parts of the slice (Fig.8a).

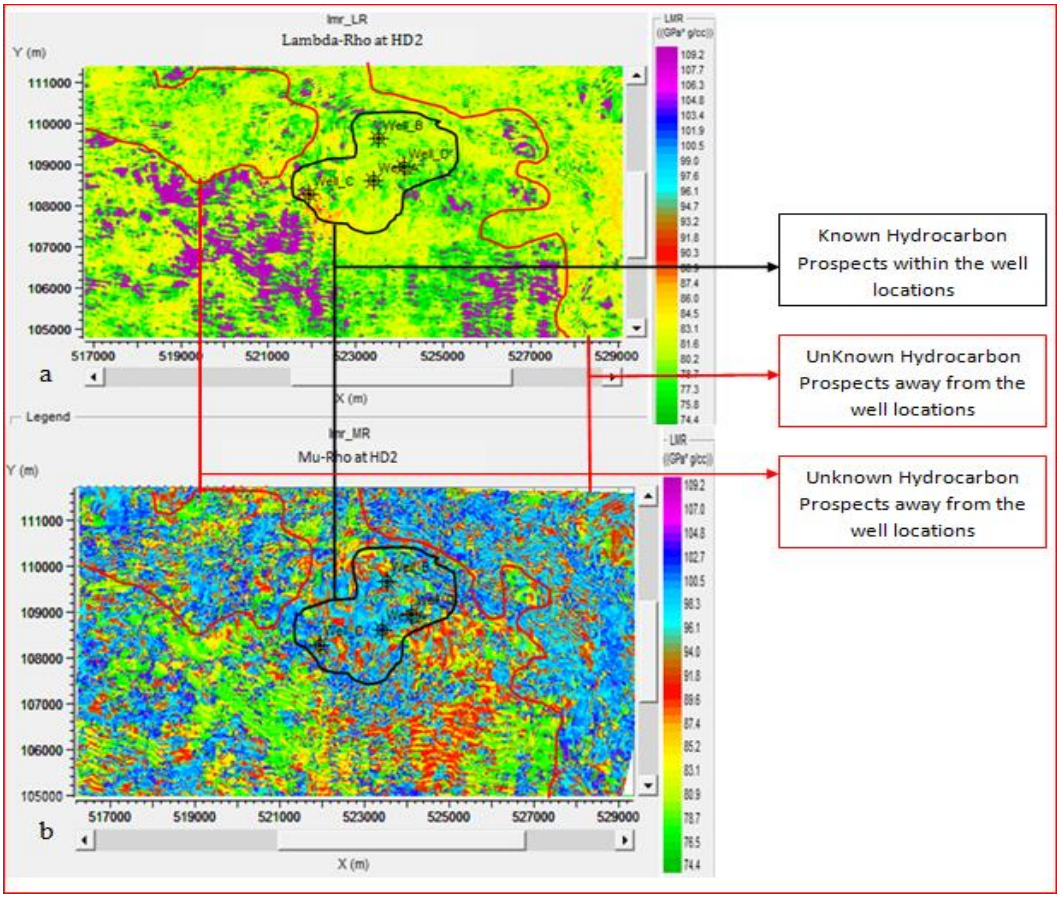

Fig. 8. HD2 reservoir data slices of the inverted (a) LambdahRho (b) MuRho

The lower values of LambdahRho outside the producing zones are the hydrocarbon sand-charged channels. This is unknown hydrocarbon prospect areas. This result was also validated by the data slice of the MuRho (μ* ρ) extracted from the same horizon (Fig.8b). These unknown sand channels areas could be revived to increase more hydrocarbon production. However, derived well log attributes provide useful information on the reservoir condition through the distribution of the fluids and lithology. The knowledge of the lithology and porefluid content of the reservoir is very important in reservoir analysis and development. Hami-Eddine *et al.* [5] stated that the economic viability of a hydrocarbon field is reliant on the quality and accuracy of lithology and pore fluid. Although, the prediction of fluid and lithology using well log derived attributes alone are may not give useful information of the reservoir status beyond the well locations. This is one the major uncertainties associated with this traditional method of lithology and pore fluid prediction. But integration of the well log attribute and Prestack seismic inversion of the Lame parameters (Lambdah-Mu-Rho) offered unique results by providing vertical and lateral information of the reservoir condition beyond well locations. Like velocity ratio, Poison's ratio and P-impedance, Lame parameters derived from the well logs also aid in determination of lithology and pore fluid content of a formation. Goodway [3] proposed the use of relationship between lame parameters to differentiate lithology and gas sand. This is because of their sensitivity to pore fluid and rock matrix. Mu-Rho (rigidity) is sensitive to rock matrix. Sand has higher Mu-Rho values than shale. LambdaRho (compressibility) is sensitive to pore fluid and useful in fluid discrimination. This knowledge was useful in the analysis of reservoir status and mapping of the hydrocarbon charge sand channels beyond the well locations.

4. Conclusion

The Cross-plots of the appropriate pairs well log derived attributes such as velocity ratio, Poison's ratio, P-impdeance and lame parameters have been used to delineate reservoir pore fluid and lithology contents. Clean sands exhibit Low velocity ratio values that range from 1 to 1.7 which is also associated with low Poisson's ratio and acoustic impedance values. Non reservoirs with streaks of shale have higher P-impedance and velocity ratio values with the range of 1.75 to 2.13. The cross-plot of Lame parameters ($\lambda*\rho$ and $\mu*\rho$) also provide huge understanding of reservoir pore fluid and lithology by isolating hydrocarbon filled sand from brine filled sand. Hydrocarbon filled sand exhibit very low Lambda-Rho ($\lambda*\rho$) and high MuRho ($\mu*\rho$) values while brine filled sand showed relatively high $\lambda*\rho$ and low $\mu*\rho$ values. Prestack seismic inversion of the Lame parameters was performed and data slices of Lame impedances were extracted along the horizon of interest (HD2). With this, hydrocarbon charged sand within the (known) well locations and away from the well locations (unknown) were delineated with confidence. The unknown isolated sand channels can be revived to add to the current production output in study area.

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