Fluid and Lithology Discrimination Using Rock Physics Modelling And Lambdamurho Inversion: An Example from Onshore Niger Delta, Nigeria*

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Abstract

Rock physics modelling and LambdaMuRho seismic inversion have been applied in an integrated approach to identify and delineate hydrocarbon charged reservoirs in an old producing field in the Niger Delta basin. Shear wave logs were generated empirically from the Castagna mud rock line relationship while fluid substitution was used to obtain correct log values over hydrocarbon bearing intervals. Common depth point (CDP) super gathers were generated to improve fidelity of pre-stack seismic data while cross-plots of elastic rock properties were generated to determine which of them constitute better pore fill and lithology indicators. Volumes of P-impedance, S-impedance, Vp/Vs, LambdaRho ($\lambda\rho$), MuRho ($\mu\rho$) and density(ρ) were calculated through a LambdaMuRho (LMR) inversion process while data slices of LambdaRho, MuRho, Vp/Vs and Lambda/Mu were generated to capture, delineate and validate a known prospect located on a structural high and containing five wells within a four way dip closure. The cross-plot of LambdaRho versus MuRho from wells successfully distinguished between fluids and lithology in the area while a similar cross-plot from the inverted seismic volume validated the results from wells. A combination of LambdaRho and MuRho data slices was used to delineate hydrocarbon charged sand compartments in the study area. The results show that high values of MuRho ($\mu\rho$) were indicative of clean sands and lower values of LambdaRho ($\lambda\rho$) correlated well with areas containing hydrocarbons. Using similar capture technique as applied to the known prospect, three other zones of exploration interest were identified.

Introduction

The onshore Niger Delta has gradually assumed the status of a matured oil and gas producing province. A lot of bypassed reservoirs could still be won from these old oilfields using newer approaches. One of such tools is rock physics and one of its primary goals is to enhance the understanding of the physical properties of the reservoir. Usually, at the location of a drilled well, we have measurements that give us a good idea of the elastic and physical properties of the subsurface rocks (Velocity, Density, Lithology, Porosity, etc.). However, to understand these properties away from the well, we have to rely on seismic data volumes. Rock physics studies now help us to link these properties to the seismic data and infer their variation in a lateral and vertical sense (Sayers and Chopra, 2009). In effect, by studying the physical rock properties at known hydrocarbon bearing intervals at well locations, one can use the results to delineate other potential hydrocarbon zones away from wells. Numerous approaches which derive lithology and fluid indicators from Amplitude Variation with Offset (AVO) equations have now been published (e.g. Gray and Anderson, 2000; Pelletier, 2009; Gray and Anderson, 2001, Burianyk, 2000; Chopra et al., 2003; Royle, 2001; Omudu and Ebeniro, 2005; Goodway, 1997; Ujuanbi et al., 2008). In this study, our main aim was to integrate rock physics and seismic data inversion to identify bye-passed hydrocarbon bearing sands in parts of an old oil field, away from existing wells so as to create new exploration and development opportunities in the field.

Methodology

After empirically generating shear wave data from the available logs and verifying same by fluid substitution using the Biot-Gassmann method, cross-plots of elastic rock properties: Lambda (λ), Mu (μ), Rho (ρ) from logs and their combinations ($\lambda\rho$, $\mu\rho$, λ/μ, etc.) were then generated. Knowledge of cross plot patterns at known wells was then used to further investigate cluster patterns at other well locations and at potential locations beyond. A Lambda (λ) -Mu (μ) -Rho (ρ) inversion of the pre-stack seismic data was carried out to generate Acoustic Impedance (AI), Shear Impedance (SI) and Density (Rho) volumes. With these, rock physics parameters such as LambdaRho ($\lambda\rho$) = $AI^2 - 2SI^2$ and MuRho ($\mu\rho$) = SI^2 were computed and the generated cross plots used to determine which of them constituted better indicators of pore fluids. Data slices of the elastic rock parameter volumes were then used to study the characteristics of hydrocarbon bearing intervals and also assist in locating other potential hydrocarbon bearing areas away from wells.

Examples

<u>Crossplots</u>

Crossplot display of Vp/Vs ratio versus P-Impedance showing a cluster of points away from the wet background trend. (Figure 1)

Well attribute cross-section of Vp/Vs ratio shows that the anomalous data points corresponds to a hydrocarbon bearing interval. (Figure 2)

Lambda-Rho versus MuRho crossplot at well location. (Figure 3)

Lambda-Rho versus MuRho crossplot from the seismic volume. (Figure 4)

Attribute cross section showing hydrocarbon intervals from the LambdaRho versus MuRho crossplot. (Figure 5)

Zoning shows that the anomalous data points correspond to the W5000 hydrocarbon zone. (Figure 6)

<u>Inversion</u>

Acoustic Impedance (Zp) volume (from pre-stack inversion) with Well A superimposed. (Figure 7)

Data slice of acoustic impedance along W9500 reservoir interval. A well developed sand channel is seen in an area away from well control. (Figure 8)

LambdaRho data slice. Lower values around well locations confirm hydrocarbon presence. (Figure 9)

MuRho data slice. Medium to high values around well locations indicate hydrocarbon bearing sands. (Figure 10)

W9500 MuRho and LambdaRho data slices showing values at well locations and other prospectable locations (Prospects X, Y& Z) away from well control. (Figure 11)

Conclusions

The generated acoustic impedance volume gives a fairly good representation of the geology of the area. Cross-plots of acoustic impedance versus depth of the wells in the area showed that the shallow and deeper sections contain sands of higher impedance than the surrounding shales. The reverse was the case at the middle section; shales in this section have higher acoustic impedance than the sands. The switch of impedance values between sands and shale have been attributed to compaction, presence of fluids, lithification and increasing pressure as a result of increasing depth of burial. The P-impedance data slice along the W9500 hydrocarbon reservoir interval successfully isolated the reservoir zones using their low impedance values. Vp/Vs values calculated from P-sonic and S-sonic curves were used to delineate the different lithologies and fluids. Vp/Vs values lower than 1.9 indicates clean sandstone reservoirs while reservoirs with tiny streaks of shale have Vp/Vs values ranging from 1.9 and 2.2. The cross-plot of P-impedance versus Vp/Vs facilitated the discrimination of gas sands from brine filled sands as well as the discrimination between sands and shales. Results from Lambda-Mu-Rho (LMR) inversion provided greater insight into rock properties for pore fluid and lithology discrimination by isolating Lamé impedances (LambdaRho ($\lambda\rho$) and MuRho ($\mu\rho$)) from the seismic reflectivity response. The combined interpretation of LambdaRho ($\lambda\rho$) and MuRho ($\mu\rho$) data slices from the pre-stack 3D seismic data set in the study area enhanced the identification and delineation of hydrocarbon charged sands with greater confidence. Low values of LambdaRho ($\lambda\rho$), associated with moderate to high values of MuRho ($\mu\rho$) indicate the presence of hydrocarbons within the sand reservoirs. These results now confirm that we can use this approach with confidence in delineating bye-passed hydrocarbons in mature fields within the Niger Delta basin and thereby revive or increase production from such fields.

Acknowledgements

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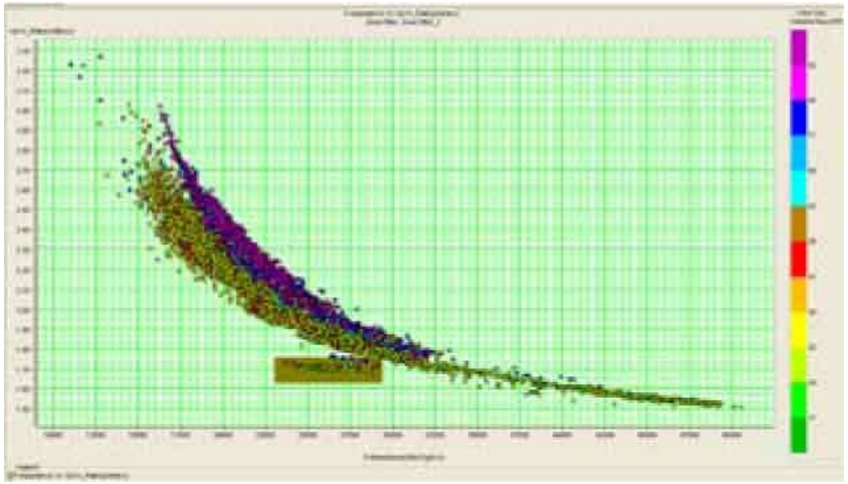

Figure 1. Crossplot display of Vp/Vs ratio versus P-Impedance showing a cluster of points away from the wet background trend.

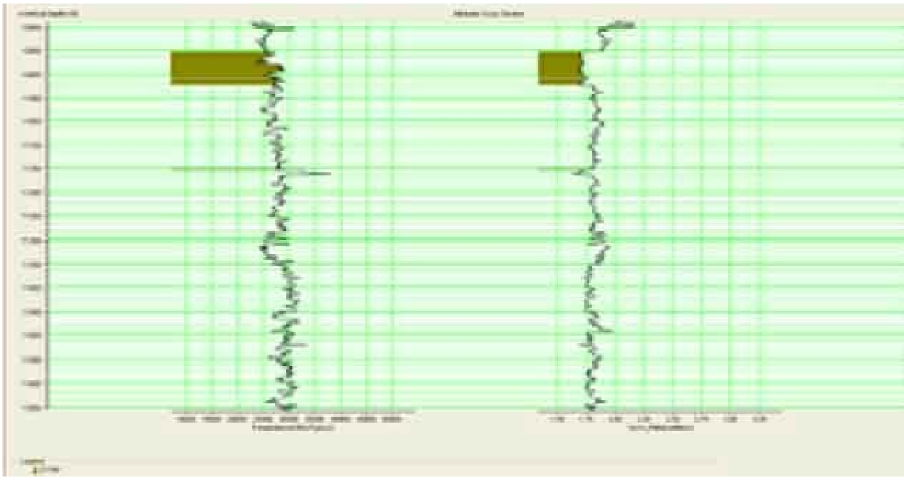

Figure 2. Well attribute cross-section of Vp/Vs ratio shows that the anomalous data points corresponds to a hydrocarbon bearing interval.

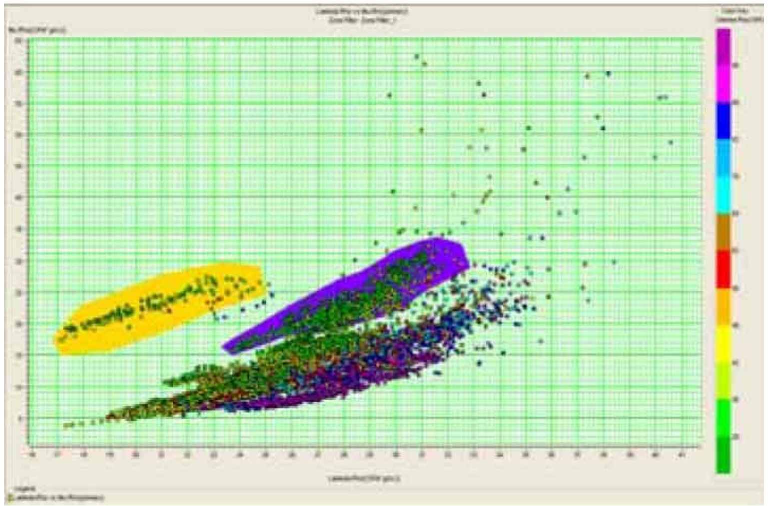

Figure 3. Lambda-Rho versus MuRho crossplot at well location.

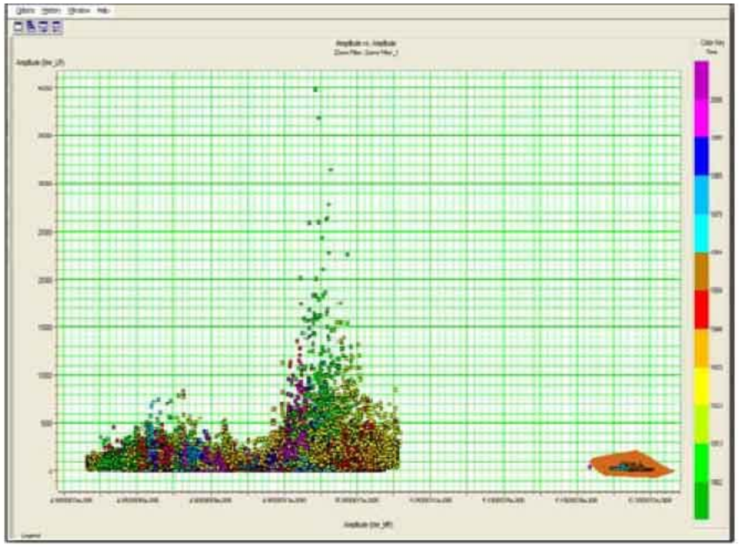

Figure 4. Lambda-Rho versus MuRho crossplot from the seismic volume.

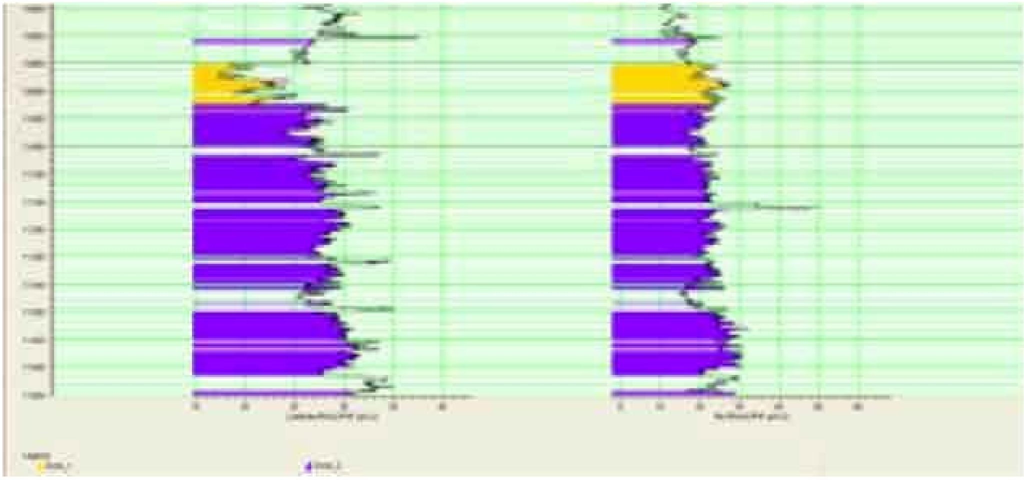

Figure 5. Attribute cross section showing hydrocarbon intervals from the LambdaRho versus MuRho crossplot.

Figure 6. Zoning shows that the anomalous data points correspond to the W5000 hydrocarbon zone.

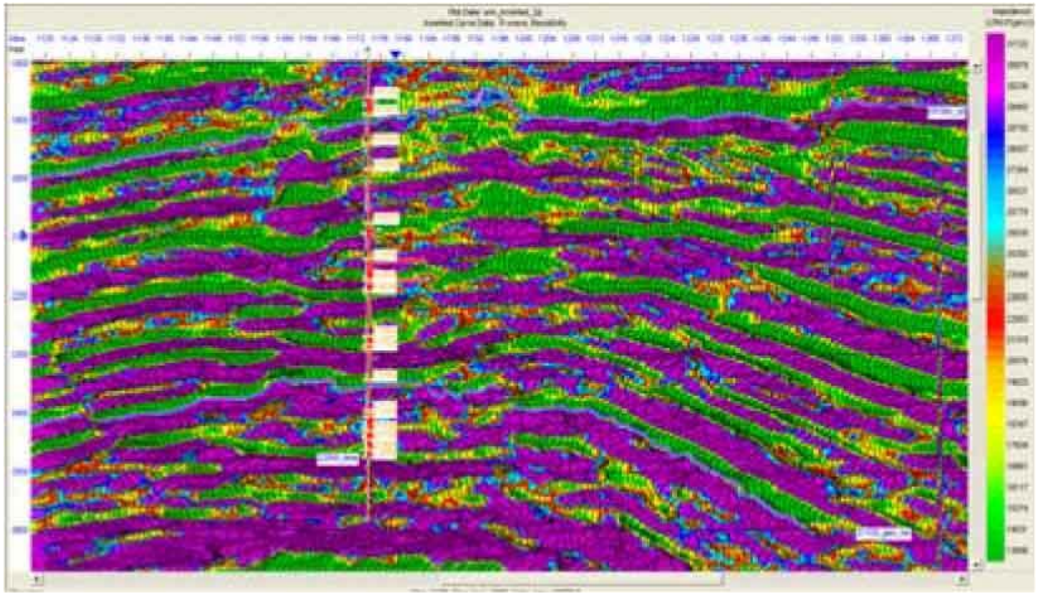

Figure 7. Acoustic Impedance (Zp) volume (from pre-stack inversion) with Well A superimposed.

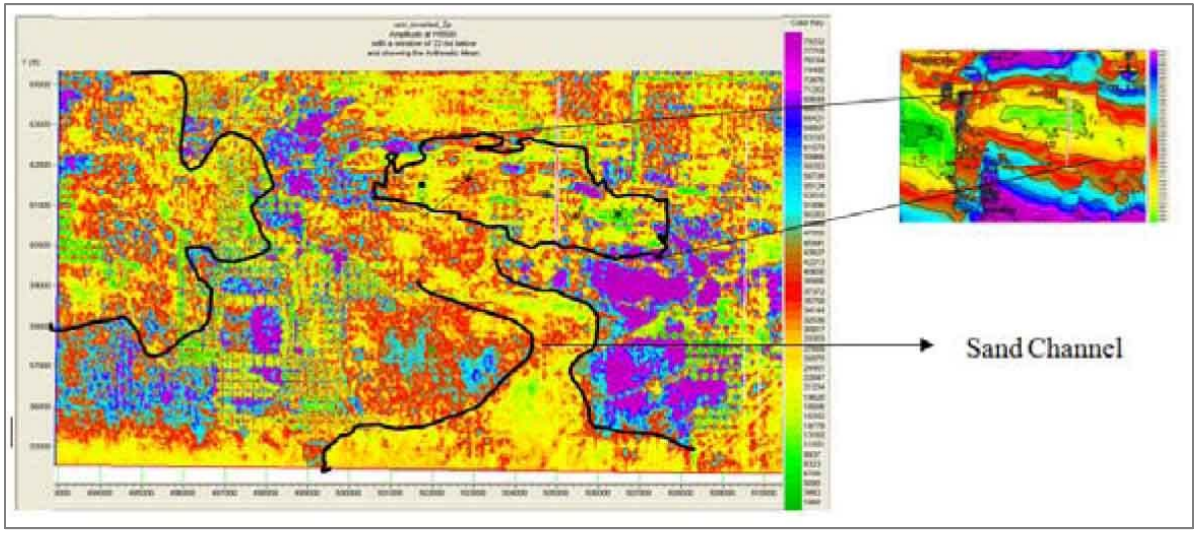

Figure 8. Data slice of acoustic impedance along W9500 reservoir interval. A well developed sand channel is seen in an area away from well control.

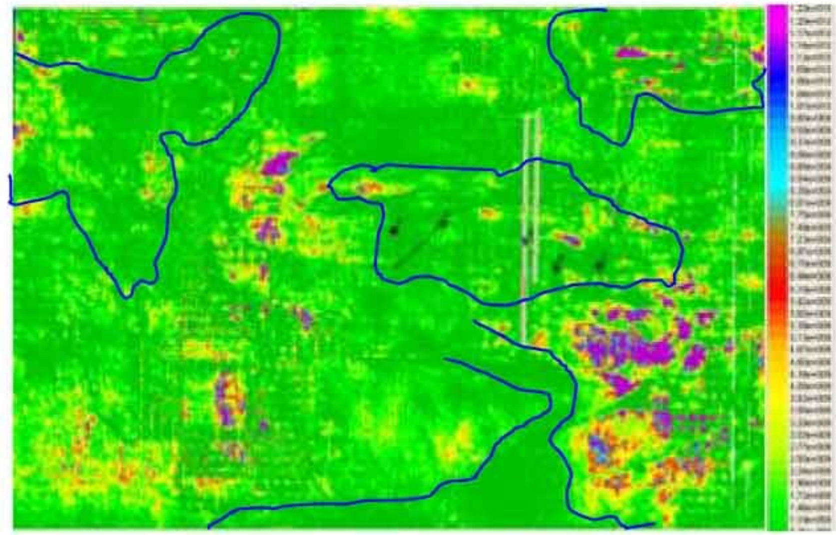

Figure 9. LambdaRho data slice. Lower values around well locations confirm hydrocarbon presence.

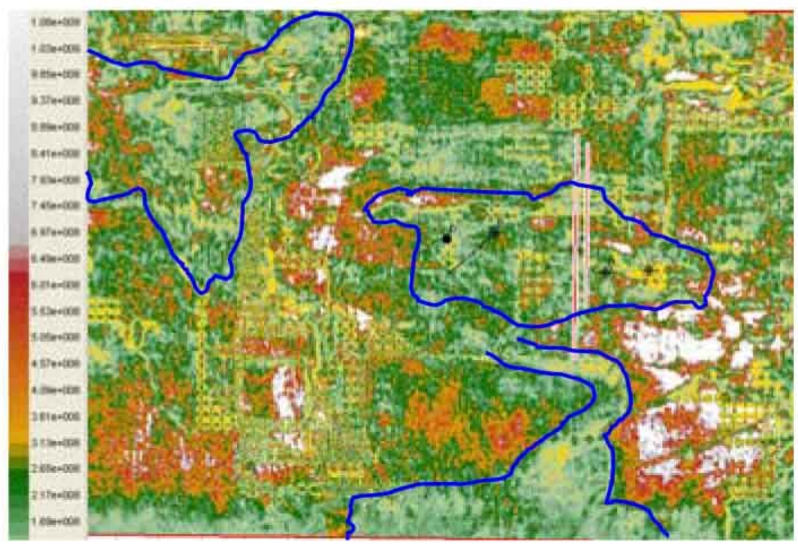

Figure 10. MuRho data slice. Medium to high values around well locations indicate hydrocarbon bearing sands.

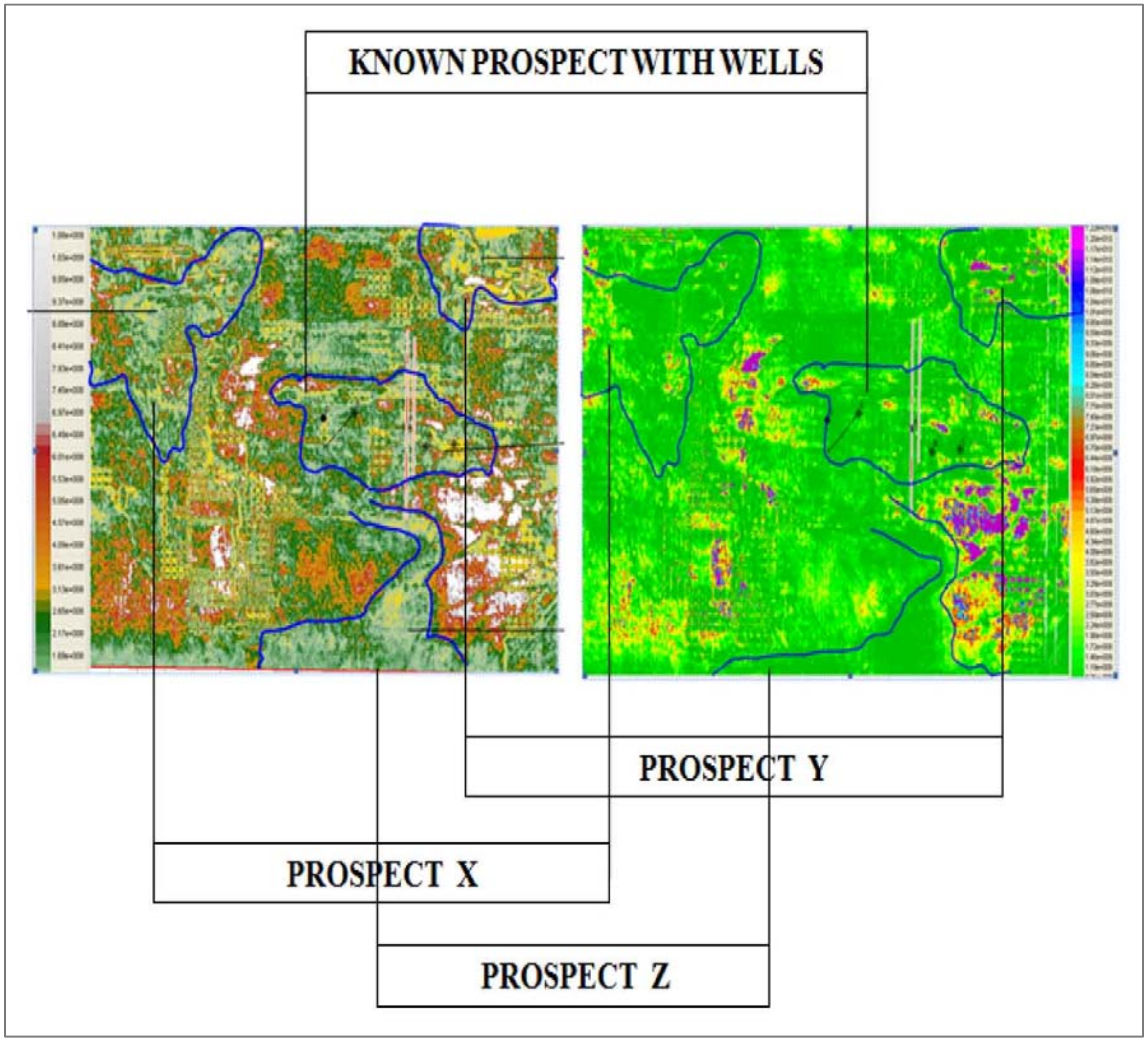

Figure 11. W9500 MuRho and LambdaRho data slices showing values at well locations and other prospectable locations (Prospects X, Y& Z) away from well control.