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Full Length Research Paper

Lamda-mu-rho technique as a viable tool for litho-fluid discrimination - The Niger-Delta example

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The focus of this paper is to discriminate fluid and lithology in the tertiary Niger Delta using the Lamda-mu-rho technique. This involves the use of basic rock Physics, Amplitude Variation with Offset (AVO), and seismic amplitude inversion to show the effectiveness of this technique in an oil sand reservoir. The data used in this study include pre-stack seismic data and well log data. The result shows the effectiveness of this technique for litho-fluid discrimination irrespective of the geological setting. For over a decade, there has been a lot of interest in the extraction of information from Amplitude Variations with Offset (AVO) for the determination of fluid content of reservoirs.The work of Goodway et al, 1997, Gray and Anderson, 2000 have shown with great success the Lambda-murho technique for litho- fluid discrimination. This has wide application in exploratory work and development of reservoirs in various geological settings. Despite the robustness of their work, David Gray 2001 suggested the extraction of the fundamental rock properties λ and μ with the exclusion of density term ρ.The work was found to be an improvement on Goodway's method in that it produced data that were less noisy and stable (Quakenbush et al., 2006). Reservoir characterization requires the detection, identification, and quantification of thickness, porosity, permeability, and fluid content. Unfortunately, many of these reservoir parameters are not derivable from seismic data. The only elastic parameters derivable from seismic data are the Lame's Constant (λ,μ), velocity, poisson's ratio and impedances. This is due to the fact that these mentioned parameters are directly responsible for seismic amplitude variation. In this paper, a simultaneous inversion of prestack seismic data was done with a view to obtaining the acoustic and shear impedances. The aim was to verify Goodway et al. (1997) technique as a viable tool for discriminating oil sand from shales within a reservoir in the Niger Delta region of Nigeria.

Key words: Fluid, lithology,Niger Delta, AVO, Lamda-mu-rho, discrimination

BASIC THEORY

For a plane interface as shown in Figure 1.The Zeoppritz equations describe the relations of incident, reflected, and transmitted longitudinal waves and shear waves on both sides of the interface.

Aki and Richards (1980) gave an approximate expression for the Zeoppritz equation in terms of the P- wave reflection coefficient, $R_P(\theta)$ and the angle of incident θ.

$$R_P(\theta)=\frac{1}{2}\left(\frac{\Delta V_P}{V_P}+\frac{\Delta\rho}{\rho}\right)-2\left(\frac{V_S}{V_P}\right)^2\left(2\frac{\Delta V_S}{V_S}+\frac{\Delta\rho}{\rho}\right)\sin^2\theta+\frac{1}{2}\frac{\Delta V_P}{V_P}\tan^2\theta. \quad (1)$$

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It was assumed that $\frac{\Delta V_P}{V_P}$, $\frac{\Delta V_S}{V_S}$, and $\frac{\Delta\rho}{\rho}$ are so small, that the second order terms can be neglected, and that θ is much less than 90^0. Equation (1) can also be rewritten in terms of P- wave and S- wave impedances as

$$R_P(\theta)=\left(1+\tan^2\theta\right)\frac{\Delta Z_P}{2Z_P}-8\left(\frac{V_S}{V_P}\right)^2\sin^2\theta\frac{\Delta Z_S}{2Z_S}-\left[\tan^2\theta-4\left(\frac{V_S}{V_P}\right)^2\sin^2\theta\right]\frac{\Delta\rho}{2\rho}. \quad (2)$$

Where $Z_P = V_P\rho$ is the average acoustic impedance
$Z_S = V_S\rho$ is the average shear impedance

$$\frac{\Delta Z_P}{2Z_P}=\frac{1}{2}\left[\frac{\Delta V_P}{V_P}+\frac{\Delta\rho}{\rho}\right] \quad \textit{is the zero-offset P-wave reflection coefficient and}$$

$$\frac{\Delta Z_S}{2Z_S}=\frac{1}{2}\left[\frac{\Delta V_S}{V_S}+\frac{\Delta\rho}{\rho}\right] \quad \textit{is the zero-offset S-wave reflection coefficient.}$$

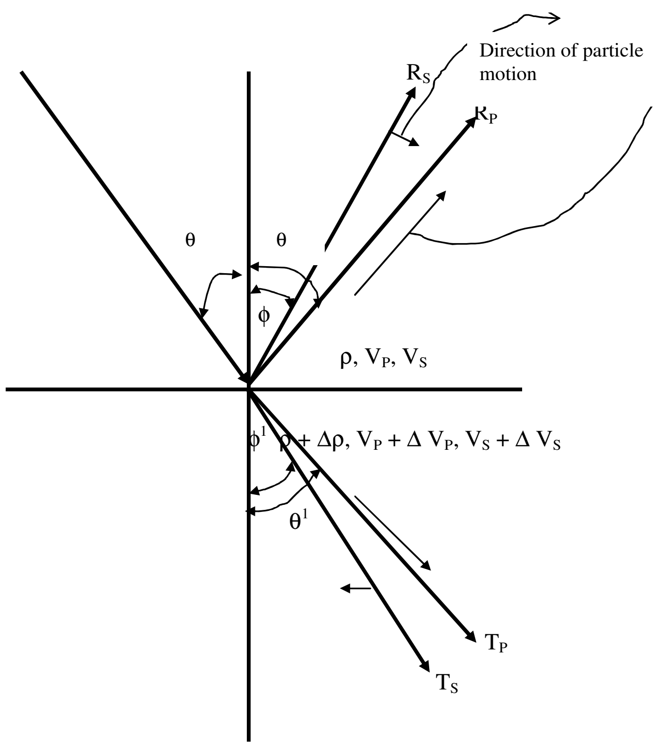

Figure 1. The model parameters and the geometry for the propagating rays, where R_S, R_P and T_S, T_P are the reflection and transmission coefficient or the reflected and transmitted amplitudes if the amplitudes of the incident wave is unity.
V_P is the average P- wave velocity between two uniform half-spaces.
V_S = The average S- wave velocity.
ρ= The average density.

$$\frac{\Delta Z_P}{2Z_P}=\frac{1}{2}\left[\frac{\Delta V_P}{V_P}+\frac{\Delta\rho}{\rho}\right] \quad \text{is the zero-offset P-wave reflection coefficient and}$$

$$\frac{\Delta Z_S}{2Z_S}=\frac{1}{2}\left[\frac{\Delta V_S}{V_S}+\frac{\Delta\rho}{\rho}\right] \quad \text{is the zero-offset S-wave reflection coefficient.}$$

However, the third term in ρ only cancels for V_S/V_P ratios around 0.5 and small angles as applicable to seismic angles below 40^0, so that Equation (2) can be simplified to

$$R_P(\theta)=\left(1+\tan^2\theta\right)\frac{\Delta Z_P}{2Z_P}-8\left(\frac{V_S}{V_P}\right)^2\sin^2\theta\frac{\Delta Z_S}{2Z_S}. \quad (3)$$

This equation has been used successfully by Fatti et al. (1994), Goodway et al (1997) to extract P and S- wave impedance reflectivities by fitting it to the P-wave reflection amplitudes from real common-midpoint (CMP) gathers.

From a given starting model, zero-offset P and S-impedance reflection coefficients at an interface i can be calculated as

$$\frac{\Delta Z_P}{2Z_P}=\frac{Z_P^i-Z_P^{i-1}}{Z_P^i+Z_P^{i-1}} \quad and \quad \frac{\Delta Z_S}{2Z_S}=\frac{Z_S^i-Z_S^{i-1}}{Z_S^i+Z_S^{i-1}}$$

A synthetic offset seismic gather can be calculated by convolving the reflection coefficient $R_P(\theta)$ with predetermined wavelets. These synthetic data are compared with the observed data to form a new earth model, and generate new synthetic data, which are compared with the observation again.

The process is repeated until a sufficient agreement between the observed and the synthetic data is obtained. To reduce the non-uniqueness problem, the inversion algorithm was constrained by low- frequency macro models, which may be obtained from seismic stacking velocities or from log information.

In extracting the fluid term, we have from Russel et al 2003

$$Z_P=\rho V_P=\sqrt{\rho(f+s)}\text{..............................}(4)$$

$$and\ Z_S=\rho V_S=\sqrt{\rho\mu}\text{..............................}(5)$$

From eqn 4 we have $Z_P^2=\rho^2V_P^2=\rho(f+s)=\rho f+\rho s$

where ρf = fluid term and

ρs= matrix term

$$\therefore \quad \rho f=Z_P^2-\rho s\text{..}(6)$$

Again recall from basic physics that

$$V_P=\sqrt{\frac{\lambda+2\mu}{\rho}}$$

$$hence \quad \lambda\rho=Z_P^2-2\mu\rho\text{...............................}(7)$$

Comparing eqn (6) and eqn.(7) ρf = λρ and ρs = 2μρ, where every other symbol have there usual meanings.

Field data example

The prestack seismic data used for the simultaneous inversion using the Jason Work bench soft ware consist of a full stack, near stack and far stack seismic data respectively so as to obtain the inverted impedance and other attributes. The data were acquired within the Niger Delta region of Nigeria in the continent of Africa as shown in Figure 2.

Although there were many well data acquired within the field of interest, only one well penetrated the horizon of interest, which we shall refer to as the X Sand. The well was also deviated. The well log data included P- wave velocity log S- wave velocity log, density log, gamma ray log, caliper log and resistivity log.

These logs and interpreted seismic horizons were used to construct macro- velocity and impedance models The extracted wavelet shown on the extreme left of Figure 3 was used to generate the synthetics, which agreed very

Figure 2. Location of study area

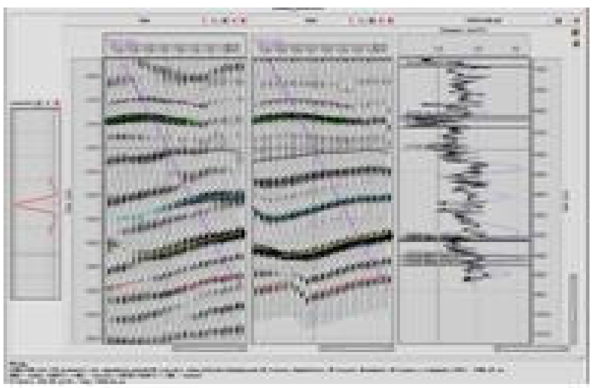

Figure 3. Comparison of seismic gather with the synthetic gather constructed using the wavelet shown on the left hand side of the figure

well with the seismic. The seismic is shown closest to the wavelet whereas the synthetic is on the extreme right of the wavelet.

The inversions were constrained at each time sample by the low frequency P- and S- impedances and V_S/V_P ratios. The outputs from the inversion are the estimated acoustic and shear impedances. The extracted Psuedo P- impedances and the acquired P-impedance log appeared to have a good correlation particularly within our zone of interest as shown in Figure 4. A correlation of 0.620813 was obtained between the inverted P- impedance and well log P- impedance as shown in Figure 5. This is well within acceptable correlation limits of 0.5 to 0.9, having considered the effect of deviation of the well. Figure 6 shows the results for a seismic inline crossing the well, for the P- wave impedance obtained from the inversion. The horizon of interest is the top of the oil sand. Note that the P-wave impedance in Figure 6 indicates that the oil sand shows a drop in P- impedance

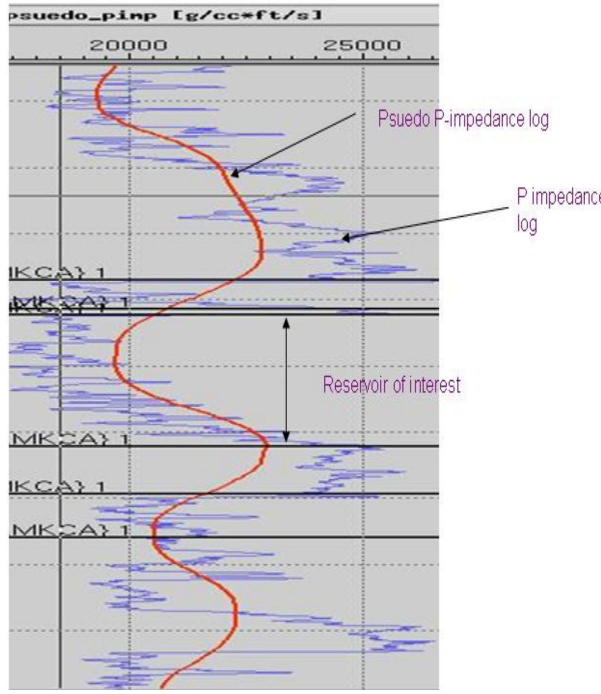

Figure 4. Psuedo impedance log extracted from inverted P-impedance compared with the acquired P-impedance log.

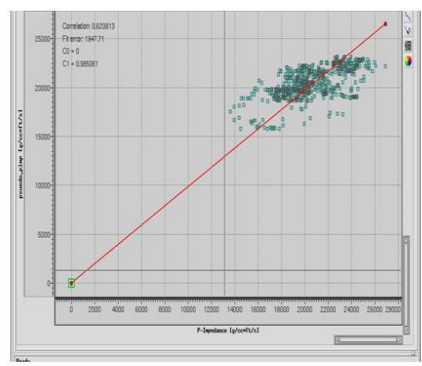

Figure 5. Correlation between P-impedance log and Pseudo acoustic impedance

with respect to the encasing shale. The inserted gamma ray log on the inverted impedance also confirms the delineated sand body within the reservoir of interest. In addition, the acoustic impedance log was inserted at the well location as shown in Figure 7. They both showed quite good matches. The S- impedance in Figure 8 does not show the same decrease as we move into the oil sand. This can be physically understood when we recall that Shear modulus is insensitive to the fluid, but sensitive to the matrix term which in this case is the lithology, whereas the bulk modulus which is the major attribute of P-wave velocity is sensitive to the presence of fluid in a reservoir.

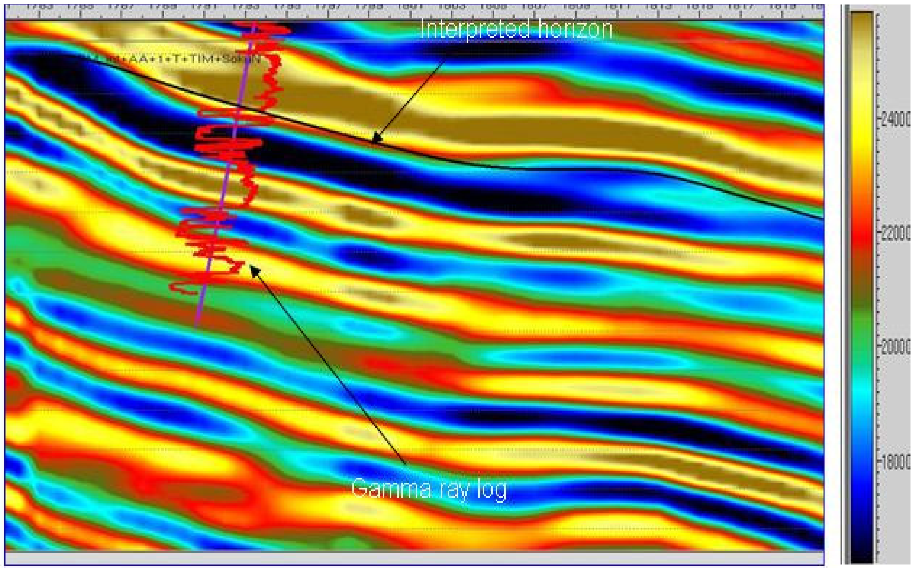

Figure 6. The P-wave impedance,Zp, found by inverting Rp estimate of the oil sand with gamma ray log insert

The fluid factor section found by combining the Z_P and Z_S inversions is shown in Fig. 9 whereas the matrix section is shown in Fig. 10. Fig 9 shows a strong decrease in the impedance value in the oil filled reservoir as highlighted. On the other hand, Figure 10 shows the corresponding matrix term which is associated with high impedance value compared with the fluid term.

Conclusion

This work has confirmed that since impedances are directly responsible for seismic responses, the use of impedances rather than reflection coefficient as model parameters allows reliable and flexible constraints to be included in the inversion algorithm. The work has also shown that the Lamda mu rho technique has also shown to be a good discriminator when applied to oil- sand reservoir delineation.

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