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Lithofacies Identification and Porosity Prediction through Acoustic Impedance Inversion

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Summary

The compressional and shear wave velocities (Vp and Vs), bulk density, acoustic impedance (AI) and Vp/Vs ratio are key elements in lithofacies identification. Rock physics model like Vp/Vs vs. AI as well as lamda-mu-rho (LMR) plot has been used to detect the presence of gas bearing zones. By creating relationships between the seismic attribute and logged petrophysical property, it is possible to produce porosity image of post-stack seismic data. Predicting lithology, porosity, clay content, saturation and fluid content are the key problems in reservoir characterization. Thick shale in combination with silty sand are characterized by low resistivity, high gamma ray, low Vp/Vs, low rigidity values. In this study we demonstrate the inversion of 2D post-stack seismic data incorporating well log measurement for prediction of porosity of overpressured formation.

Introduction

Analysis of post-stack seismic data has been used as an effective method of hydrocarbon exploration in many areas around the world, including offshore parts of east coast basins of India. The unconsolidated Tertiary sediments of the Krishna-Godavari offshore basin create geologic conditions that are particularly favorable to the existence and detection of seismic "bright spots" associated with gas hydrate and gas deposits (Bastia, 2006). The typical gas sand in the basin has lower acoustic impedance than the sealing shales and will produce a negative reflection coefficient. Figure 1 is showing the 2D post-stack seismic section with a well. Figure 1 shows faulted structure in left side of 2D post stack seismic section along NNW-SSE direction between 500 and 800 ms. To understand the physical link between seismic properties and reservoir properties (e.g., lithology, porosity, pore type, clay content, fluid type, and saturation), rock physics models computed from well log data along with the inverted seismic data, can be used to detect the presence of hydrocarbon bearing rocks (Avseth et al., 2008 and Goodway et al., 1997). In this paper, rock physics models have been used to predict porosity from the well logs, to interpret the seismic data away from the well. Poststack seismic inversion generates 2D acoustic impedance section which further mathematically transformed from well data to derive porosity of this section.

Lithology from well log Data

Well logs play the important role of linking rock parameters to the seismic data. Crossplots are the visualization of the relationship between two variables. The compressional and shear wave velocities, bulk density, and gamma ray logs are available for the present study for lithofacies identification. The discovery of conventional gas and gas hydrate deposits along the eastern continental margin of India provide the major impetus to study Krishna-Godavari (K-G) basin located in this part in greater detail (e.g. Bastia 2006). The K-G offshore comprises predominantly claystone with minor sand and siltstone bands (Ramana et al., 2009). This study is carried out over a field in east coast basin that has gas bearing clastic reservoirs that range in age from Miocene to Pliocene. High sedimentation rate ranging from 0.07mm/y to more than 2mm/y (Singha and Chatterjee, 2014) and a total organic content of 1.5 to 2.0% serves favorable conditions for appreciable amount of methane generation in K-G basin. Estimated pressure coefficients demonstrate that there is a rather widespread overpressure zone in the study area than hitherto anticipated, with maximum pressure coefficient of 1.31 or more (Singha and Chatterjee, 2014). The well shown in figure 1 has porosity ranging from 7 to 30%. There is a sharp change in decrease of P wave velocity around 1250 m depth. This change in P wave velocity is also associated with the decrease in density values. Neutron porosity log indicates more than 40% for the entire well with decrease in porosity values around 1310m. This well is penetrated the overpressured Shale in this part of the study area and this is in close agreement with the pore pressure study for other wells in offshore K-G basin (Chatterjee et al., 2011). Overpressured shale could also generate low Vp/Vs, low μρ values. Rock physics crossplots in these overpressured sediments are used to identify trends which may indicate multiple populations within the same dataset. Crossplots are made by visualizing different combinations of the measured well-log parameters such as: Vp, Vs, density (ρ). The information on Vp is very useful in identifying lithology, porosity and pore fluids. Shear wave velocity data are also useful for fluid identification. Combination of both compressional and shear wave data will help to identify fluid especially for gas reservoir. To identify the fluid and lithology by the visualization of log-derived parameter in crossplot space, the derived parameters are as:

Acoustic Impedance (AI) = ρVp and Shear Impedance (SI) = ρVs

Lambda-Rho(λρ)=AI^2-$2SI^2$

Mu-Rho(μρ) =SI^2

Rock physics cross-plots between various elastic moduli such as: Vp/Vs ratio vs. AI (Figure 2a) and Vp/Vs vs. μρ (Figure 2b) show the best discrimination between the gas bearing silty sand (zone-1), shaly sand (zone-2), shale (zone-3) and cemented sand (zone-4). The gas bearing silty sand with varying porosity 17 to 22 % is corresponded to low λρ and μρ values as identified in λρ vs. μρ crossplot (Figure 2c). Overpressured Shale with sand corresponding to zone-2 in λρ vs. μρ cross plot characterizes moderately low λρ (18- 28 GPa*gm.c.c) and μρ (11-25 GPa*gm/c.c). Zone-3 may be shale identified in this plot is showing comparatively high λρ whereas zone-4 indicated the cemented sand with high values of λρ and μρ. The impedance vs. porosity plot is showing the range of sediment porosity from 7 to 35% for this well. Gas accumulation in zone-1 is observed at 1310-1315m at a corresponding time of 690 ms.

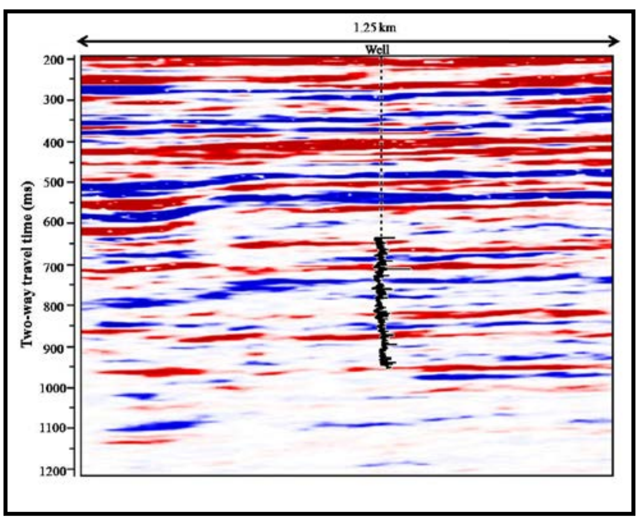
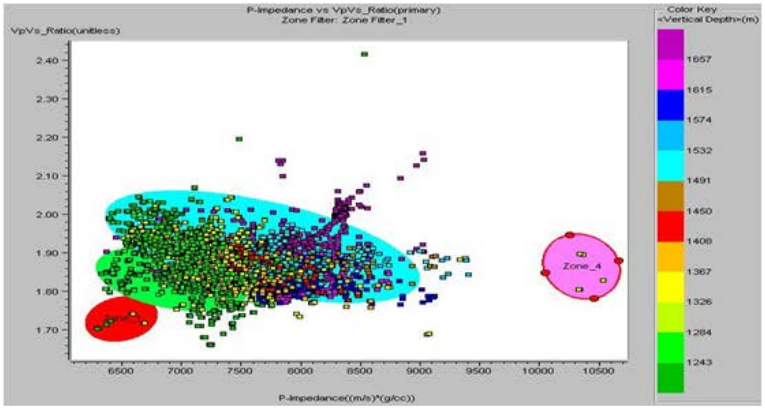
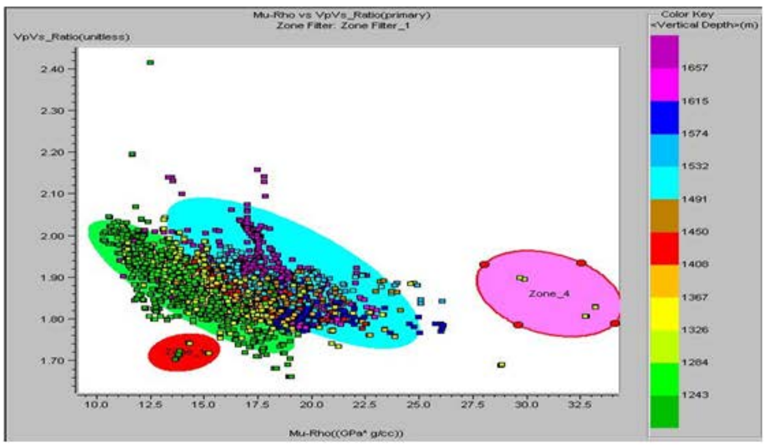


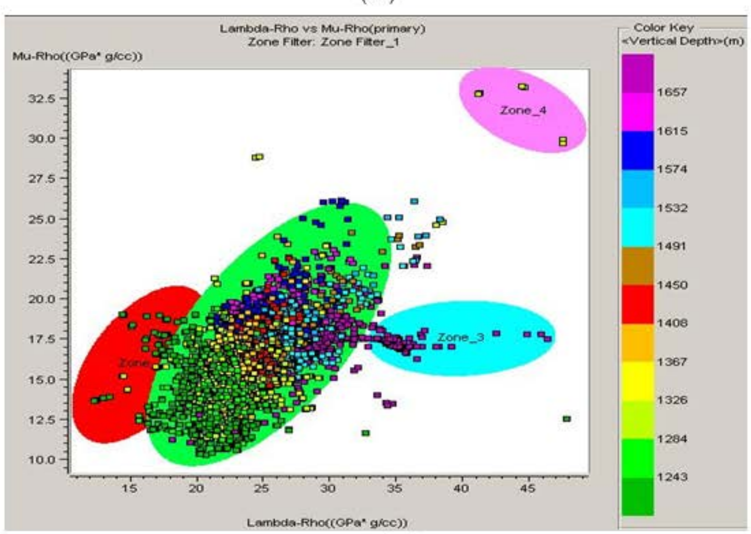
Figure 1: Showing the post-stack Seismic section with a well. The faulted structure at left side of this section is noticed between 500 and 800 ms.



(a)



(b)



(c)

Figure 2: Cross plots between (a) Vp/Vs and AI indicating sand-shale lithofacies with gas bearing zones. Zones are referred in text (b) Vp/Vs and μρ, identifying gas bearing zone-1, shaly sand and shale. and (c) λρ and μρ with varying porosity in silty sand (zone-1), shaly sand (zone-2), shale (zone-3 and cemented sand (zone-4).

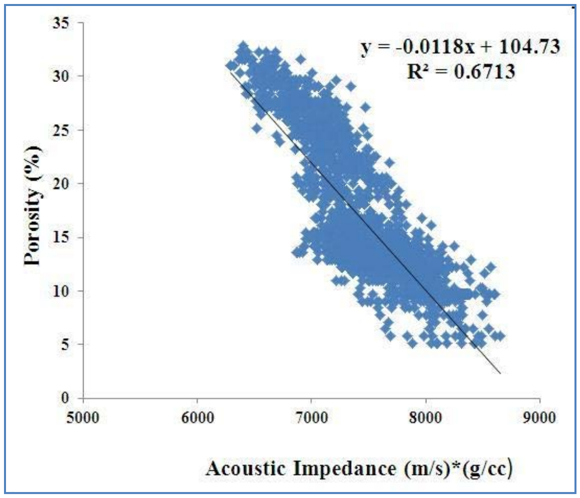


Figure 3: The variation of impedance with the total porosity derived from density log.

Acoustic Impedance Inversion

Different methodologies can be used for post-stack acoustic impedance inversion of seismic data, including band limited, sparse spike, and model based inversions. Band limited inversion commonly uses recursive inversion algorithm which ignores the effect of the seismic wavelet and treats the seismic trace as a set of reflection coefficient (Russell and Hampson, 1991 and Berge et al., 2001). The acoustic impedance at i^{th} layer

$AI_i = (R_{i+1} + R_i)/(R_{i+1} - R_i)$, where R_i = Reflection coefficient of i^{th} layer and R_{i+1} Reflection coefficient of $(i+1)^{th}$ layer

Band limited inversion ignores the effect of the seismic wavelet, and treats the trace as a set of reflection coefficients, with the low-frequency component added from the well logs. The advantage of this technique is its simplicity, short computation time, and robustness in the presence of noise, but thin layer interference is not accounted for since the wavelet is ignored.

This inversion requires the initial value of impedance. Basically band limited inversion is derived by picking the major reflectors on the seismic data and providing the detailed velocity information at selected points on the line. The advantage of this inversion is that the low frequency component missing in the seismic is added from the sonic logs to get more realistic result. We have utilized the band limited inversion technique as reliable well-log data are available with the 2D post stack seismic data. An initial model for the inversion was generated using the P-impedance logs calculated at the well location (Figure 3). The inversion algorithm modifies the impedance-log to minimize the misfit between the measured and synthetic seismic data. As it is to be expected with impedance inversion, a good match between seismic and synthetic data can be achieved. Figure 4 is showing the match between the inverted impedance and well log data for the study area. The inverted impedance for this section of about 1.25m length is illustrated in figure 5a. Figure 5a shows the low impedance zone varying between 650 and 950ms. A thick homogeneous lithology with no lateral impedance contrast can produce a low impedance seismic facies. Low impedance contrast is most likely to be expected in overpressured zone as in prodelta mudstone in this area. The porosity section (Figure 5b) has been obtained from mathematical transformation from log derived AI vs. porosity plot. The gas and water bearing zone are identified within 650 to 950ms. This zone characterizes porosity of 17 to 22%.

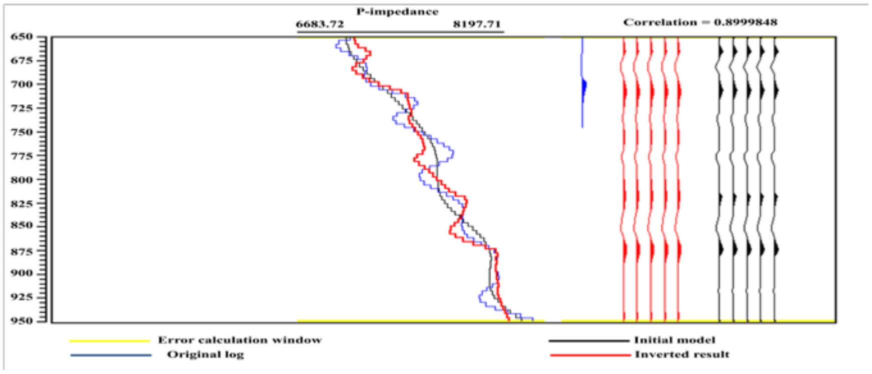
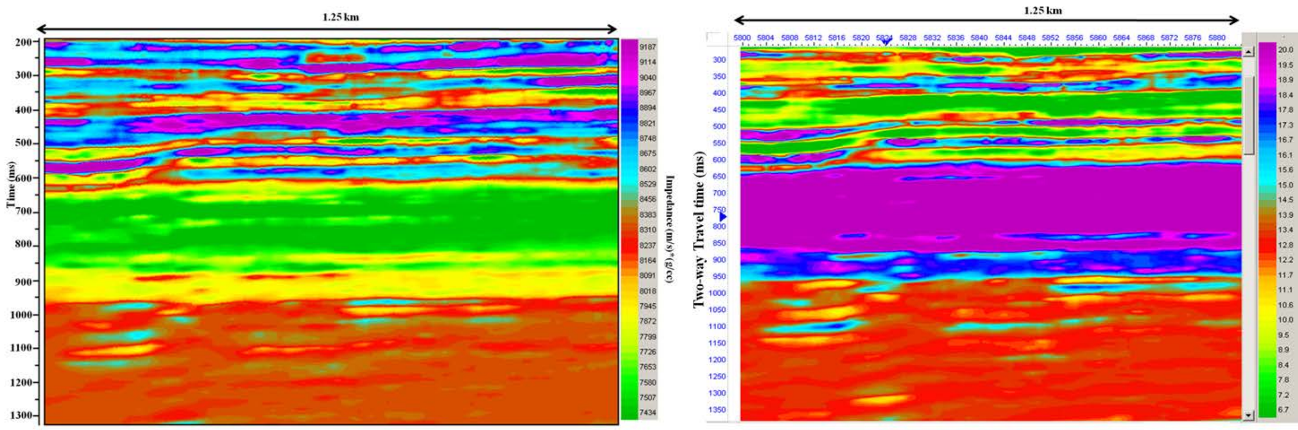


Figure 4: Error window displays the initial model, well log and inverted impedance with correlation.



(a) (b)

Figure 5: (a) Inverted acoustic impedance (AI) section, (b) Inverted porosity mapping for a seismic line located at offshore, east coast basin of India.

Conclusions

This study demonstrates the integration of rock physics and petrophysics from well log and seismic data. Band limited inversion method works well for this dataset. Well log data are available for a selected depth interval corresponding to time interval 620 to 920 ms. This technique is able to identify gas bearing sediment and sand/shale in overpressured sahle..

Acknowledgement

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