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Mapping of Reservoir Sands within Cambay Shale Formation Using Simultaneous Inversion

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Summary

Use of traditional interpretations of seismic data to map reservoir geometry and extent are often quite challenging due to presence of noise, besides intrinsic limitations caused by tuning arising out of band limited nature of the surface seismic data. Inversion of seismic data provides elastic properties which have lesser noise with tuning effect reduced significantly. Thus, inverted elastic properties give a clearer picture of the subsurface. It also provides a platform for quantitative interpretation from a rock physics standpoint. In this study we inverted simultaneously six angle stacks from a block in Cambay basin to derive acoustic impedance (AI) and the ratio of compressional and shear wave velocities (V_p/V_s). Cambay shales are characterized by high AI and low V_p/V_s . Simultaneous Inversion was able to discriminate lithology, i.e. reservoir sands and their spatial distribution through geo-body capture. Sand thickness map generated from geobodies extracted from the inverted elastic properties provided valuable information about the reservoir architecture.

Keywords: Cambay basin, Simultaneous inversion, Sand thickness map

Introduction

The area under study is from Cambay basin in Gujarat. The study area contains only one well, XX-1. In this area three major sand bearing formations i.e. Ankleshwar formation, Cambay Shale formation and Olpad formation are encountered. In general, the first two formations, viz. Ankleshwar and Cambay Shale are good regional producers of hydrocarbon. The well XX-1 also tested small amount of oil in the Cambay Shale.

The objective of the study is to map the extension of this reservoir rock known as XX pay away from the well. This entrapment is stratigraphic in the form of up-dip pinch out of sands. The oil pay in the offset is only 1m and close to OWC. The extension of this entrapment was mapped using the inverted elastic rock properties. Seismic angle stack data, well log data and seismic velocity data were integrated to produce elastic rock properties of the reservoir and surrounding rocks. These elastic properties were quantitatively interpreted in terms of facies variations to gain a better understanding of the sand distribution of XX pay.

Methodology

Figure 1 shows a schematic work flow for inverting multiple seismic angle stacks through integration with well data, horizon interpretation and seismic velocity to yield the absolute elastic properties, viz. AI and V_p/V_s of the reservoir and surrounding rocks. These elastic properties are then interpreted in terms of lithology and fluid distribution and reservoir properties based on a petro-elastic/ Rock Physics model built from well data and other relevant information/knowledge about this area.

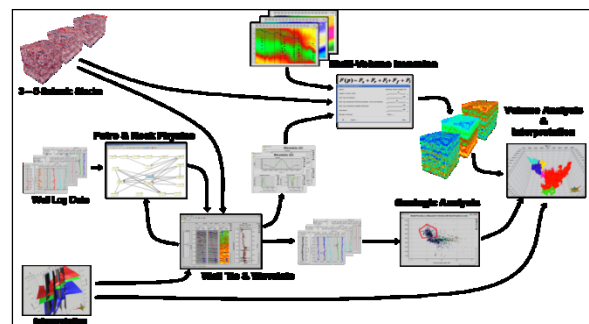


Figure 1: Simultaneous Inversion Workflow



Six seismic angle stacks were used in this study ranging between 5-40 degrees. The frequency bandwidth for near and far angle stacks were found to be from 8- 45 Hz and 8-35 Hz respectively

There is only single well drilled in study area in which P-Sonic and density have been measured along with other regular measurements. But no shear sonic data is available in the well which is required for simultaneous inversion. Petro physical analysis was carried out after required conditioning of well log data to remove the effects of borehole wash out effects and to fill gap in measurement within the vertical zone used for inversion. Using petrophysical analysis, a rockphysics model was built for prediction of shear sonic data. Predicted shear sonic and other logs are shown in Figure 2.

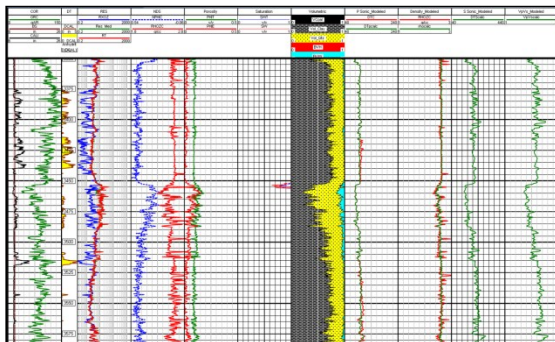


Figure 2: Prediction of shear sonic data. Panels from left to right are: caliper (black) and gamma ray (green); differential caliper; resistivity (RT: red, RHOX: blue); Neutron (blue) and density (red), Porosity (total: green, effective: red); water saturation; volumetric fractions; p-sonic (measured: red) and modeled (green); density (measured: red and modeled: green); modeled shear sonic modeled and calculated Vp/Vs logs.

A combination of low frequency from checkshot data and high frequency from integrated sonic data provided a very good time-depth (TD) relationship to establish well to seismic ties and wavelet estimation at the well XX-1 for each seismic angle stacks. For AVA (amplitude variation with angle) wavelet estimation, rock physics modeled P-sonic, S-sonic and density logs have been used. Figure 3 shows the correlation between the seismic and synthetic data displayed in gather mode for easy understanding of well to seismic ties and wavelet character variation across different angle stacks.

Well ties are good for near stack and moderate for far angle stack. Extracted wavelets for all angles have the phase rotation of 30 degree and consistent in seismic

amplitude and frequency ranges. It can also be seen that the rockphysics modeled shear-sonic used for AVA wavelet estimation captures the true overall AVA character across the measured angle stacks. This provides a validation of rock physics modeling used in this study.

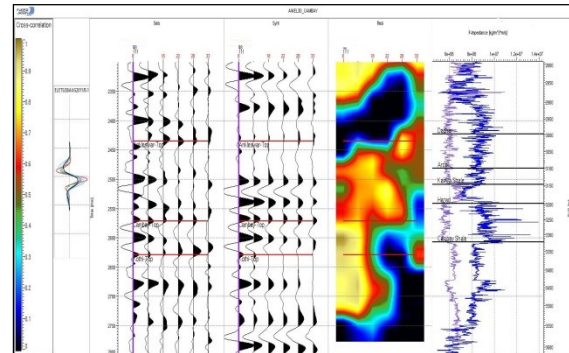


Figure 3: Final well ties for well XX-1. The panels show from left to right: the wavelets used, seismic angle gathers, synthetic angle gathers along well path, correlation panel and P-impedance (blue) and Vp/Vs (grey) logs. Colour bar in the left represents cross-correlation

Constrained Sparse Spike Inversion (Debye and van Riel, 1990; Contreras et al., 2006) was carried out using six angle stacks to obtain a broadband model of the elastic properties of the subsurface. The output of the inversion is controlled by constraints and settings that are optimised based on comparisons at the well locations and several other measures of quality control.

Results

Figure 4 and Figure 5 show a section view of inverted P-Impedance and Vp/Vs along a well line. The output volumes of P-impedance and Vp/Vs exhibited good match at the wells substantiating the accuracy of inversion results. Figure 6 shows the comparison of P-impedance and Vp/Vs logs extracted from the inverted volumes, popularly known as pseudo logs, with the corresponding wire line elastic logs. The match between the inverted and wire line elastic logs is very good.

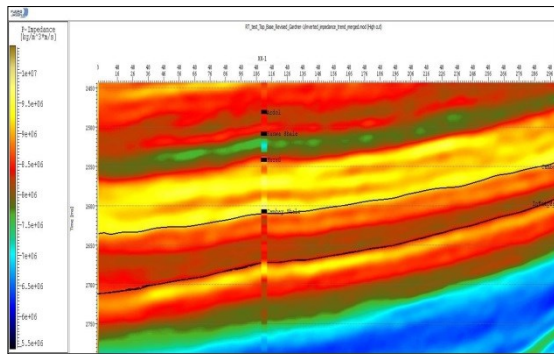


Figure 4: Inverted P-Impedance along a section passing through the well XX-1.

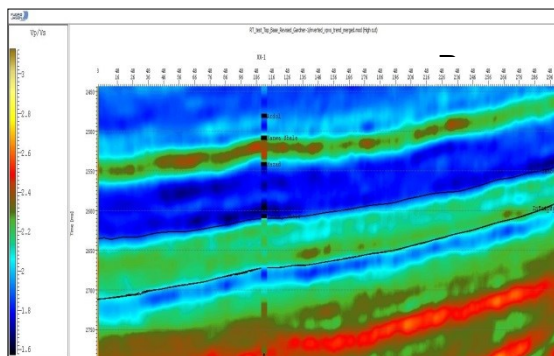


Figure 5: Inverted Vp/Vs along the same section as in Figure 4.

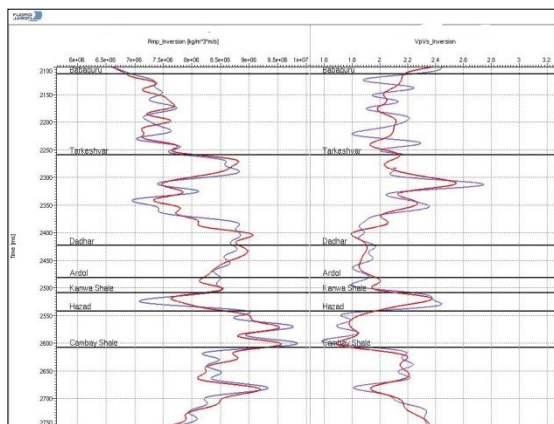


Figure 6: Comparison of pseudo logs extracted from inverted elastic properties (red) with wire line log (blue): P-impedance (left) and Vp/Vs (right).

Interpretation

Elastic property volumes are excellent datasets for interpretation. With the wavelet effects removed, the elastic property volumes do not contain tuning artefacts that always pose risk of misinterpretation. Since elastic

properties are layer properties, the elastic property volumes can be directly related to the well logs. In many instances, the log data shows a unique relationship between lithology and/or porosity and impedance. When this occurs, the log data can be used to identify elastic property cut-offs for reservoir rocks. Such cut-off values can be used for traditional mapping, layer extractions or for 3D body capture. For interpretation of inverted results, 3D sand geobodies can be captured in different geological intervals using a polygonal cut-off on the elastic properties defined in a cross-plot (Figure 7) with the shape and size of sand geobodies dependent on the geometry of the polygon used for capturing the sand on P-impedance and Vp/Vs cross-plot (Latimer et al., 2000). In this study discrimination of fluids through fluid substitutions model has inherent limitations due to thin pay, lack of recorded shear logs, resolution limits and limited offset well data. Therefore effort was made to capture the total reservoir sand.

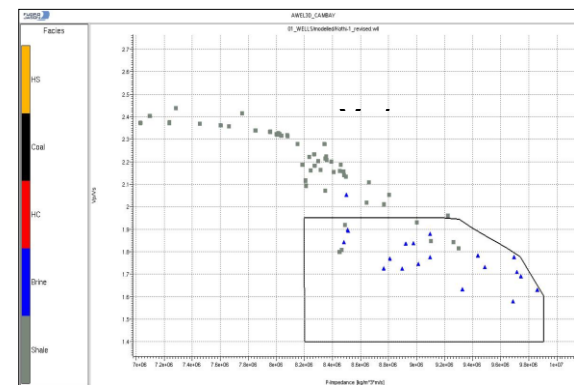


Figure 7: Crossplot of P-impedance and Vp/Vs log data at seismic resolution. Polygon used for capturing the reservoir sands

In this case a polygon using rock physics trend was used to capture sand bodies for the XX pay zone. Figure 8 shows the sand captured on inverted P-Impedance and Vp/Vs section view using a polygon on P-Impedance and Vp/Vs cross plot. Using the same polygon sand bodies were captured in 3D to get the extension and thickness of sand distribution. The thickness map of the largest captured sand body is shown in Figure 9. The sand thickness map is conformal with geology of study area and also shows that sand is pinching out up dip.

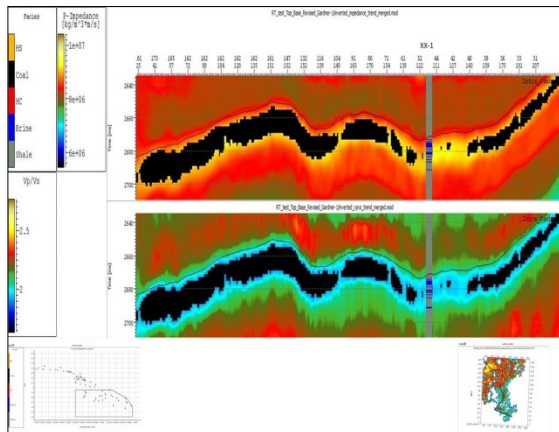


Figure 8: Sand bodies captured on inverted P-Impedance (upper panel) and Vp/Vs section (lower panel) view using a polygon on elastic properties cross plot (left inset)

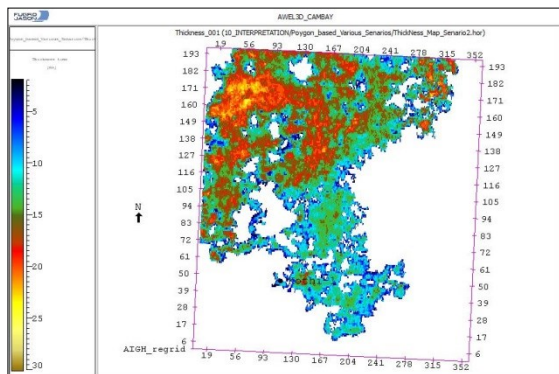


Figure 9: Time thickness map of sand distribution for XX pay zone

Conclusions

Partial angle stack seismic data, well log data, horizon interpretation and rock physics relationships have been combined within the framework of simultaneous inversion to produce a model of elastic properties. These models are consistent with the well log data within the seismic bandwidth. These models have been successfully used in mapping the sand distribution of XX pay. Areas of better reservoir development inferred from inversion results coupled with structural model had helped in evolving an appropriate appraisal program.

Acknowledgements

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