Pre-stack Simultaneous Inversion for identification of fluid and lithology in Wadu Paliyad area of Cambay Basin.

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Summary

In this study, simultaneous inversion was carried out to identify and delineate hydrocarbon charged reservoirs in Kalol sequence of Wadu Paliyad area of Cambay Basin, India. This inversion methodology along with other geological and geophysical analysis, significantly reduces the risk of exploratory and development well locations.

The study begins with detail well log analysis on the basis of petrophysics and rock physics modelling and pre-stack time migrated seismic data that provides partial angle stacks from CRP gathers. The PSTM gather data were pre-conditioned to remove existing noise and multiple before partial stacking. The method is based on the information of Constrained Sparse Spike (CSS) of the reflectivity with the angle of incidence embedded in the partial angle stacks using the Knott & Zoeppritz formulations.

The volumes generated through this simultaneous inversion are P-impedance, S-impedance, Vp/Vs, Density, Lambda-Rho, Mu-Rho and Poisson's Ratio. The distinctive response of these volumes, according to the lithology and fluid contents, allows a better definition of reservoir and fluids content when analyzed in combination. Hydrocarbon charged geo-body units of Kalol formation were captured, delineated and subsequently validated with wells in this area and additional prospective locations were identified.

Introduction

The study area, Wadu Paliyad is located in Cambay Basin of India (**Figure 1**), producing oil and gas from about 118 wells. However several dry wells are also drilled in different structural positions. The target reservoir of this study is in Kalol Formation. The facies of arenaceous unit of this formation are grossly classified into sandstone, shale and coal. This formation is overlain by the cap rock of transgressive Tarapur shale. The distribution of oil and gas in this reservoirs unit is very complex and the abrupt facies changes in sand bodies lose their reservoir character within short distance.

The challenge in differentiation of prospective porous sandstone from shale is due to the similarity in their impedances. Another problem is the high amplitude contamination due to coal obscuring the pay sand seismically. So only impedance could not discriminate pay sand from non-pay. Hence, other inverted properties are required to achieve the desired discrimination by exploiting the contrast in rigidity of sandstone-shale. In this case we take S-wave related combination of Vp/Vs and P-impedance volumes.

The technique applied for this seismic inversion was Simultaneous AVA Constrained Sparse Spike Inversion (CSSI) that uses multiple angle stacks. The goal of simultaneous inversion is to convert seismic amplitudes into rock property of lithology and fluid and extracts more dynamic range of information from partial seismic stacks as compared to traditional seismic AVO analysis.

The objective of this study was to characterize and delineate the producing reservoirs on the basis of results derived from simultaneous inversion and to determine the extent, geometry and fluid content of these sands for exploration as well as development.

The work-flow adopted for this simultaneous Constrained Sparse Spike Inversion CSSI) as narrated below.

Pre-conditioning of PSTM Gathers

The PSTM gather data used for this study is the PP component of acquired 3D-3C seismic data. These data were pre-conditioned to remove the existing noise and multiples. Four partial angle stacks were generated from offset gathers in the range of 5º – 12º, 12º – 19º, 19º– 26º and 26º - 32º. Gather data were largely aligned.

Log editing, processing and modelling

Rock physics modelling is the important and essential part for simultaneous inversion. Feasibility study with these is vital to understand the expected angle dependent effects of seismic reflection data. Prior to rock physics analysis, the logs were edited, conditioned and processed. The rock physics modelling provides a link between the petrophysical properties (water saturation, porosity and clay content) and the elastic properties (Vp, Vs and density) of the rocks. Rock physics modelling help in obtaining shear sonic log when it is missing or poorly recorded and to assure an reliable wavelet extraction process. A relationship between recorded shear sonic logs and other logs are determined to compute model shear sonic logs at wells where they were not acquired. After having elastic logs and their transforms (Vp/Vs, Lambda-Rho, Mu-Rho and

Poisson's ratio), cross-plot between them are used to study the lithologies and fluids discriminating sensitivity. The cross-plot between P-impedance and Vp/Vs or P-impedance and S-impedance, Lame parameters Lambda-Rho and Mu-Rho are the best combination to diagnose the fluid effect and lithology discrimination.

the wavelet to match synthetics and corresponding angle-limited stacks. These wavelets are direct input into the inversion algorithm. This enables the inversion to compensate for angle dependent phase, bandwidth, and tuning.

Wavelets extracted from well to seismic tie for each angle stacks performed separately and then multi wells wavelets were calculated for each angle stacks. QC was performed at the time of wavelets extraction. The four wavelets extracted from four angle stacks are stable and consistence with a linear phase shift and slight variation in frequency content. The final wavelets used for this inversion are calculated from six wells and four stacks, **Figure 2**.

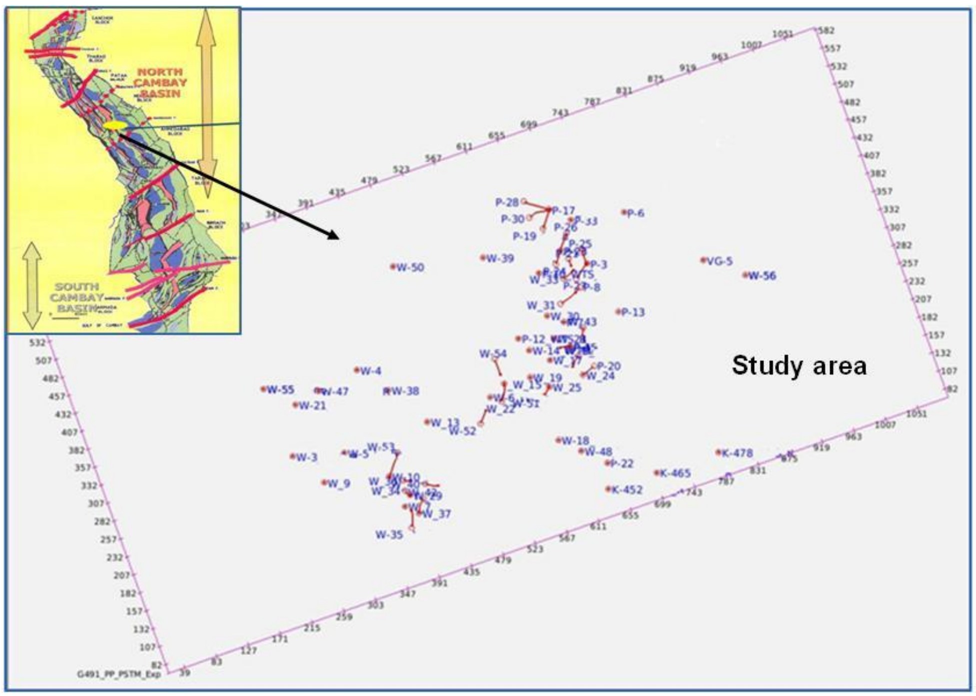

Figure 1: Base map of study area, Wadu Paliyad, Cambay Basin with some well positions. Inset is showing Cambay Basin, India.

In this study area, about 173 exploratory and development wells are drilled and the hydrocarbon reserves were established in multiple pays of Kalol Formation (K-IV, K-V, K-VI+VII, K-VIII, K-IX, K-X and K-XI). Rock physics modelled were performed in six numbers of wells for this inversion in which recorded shear sonic logs are available in three and other three were generated through rock physics modelling. Twenty one processed wells and thirty two conditioned wells were used for the validation of the inversion result in this study.

Wavelet Estimation

A key point of inversion is the estimation of the stable seismic wavelets. Usually logs are in depth and seismic is in time scale, hence a perfect time-to-depth relation is established through interactive well-to-seismic tie method. Separate wavelet for each angle stack was derived matching the seismic amplitudes with the synthetic traces modelled by the Aki-Richards equations in available wells. This incorporates AVO modelling to properly account for AVO effects. The wavelets are estimated by shaping

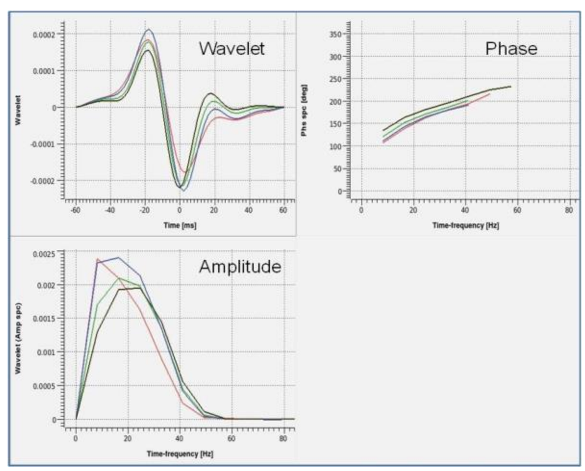

Figure 2: Multi-well wavelet, phase and amplitude spectra, extracted for four angle stacks are stable and consistence.

Low Frequency Model

Quantitative interpretation of seismic inversion requires absolute elastic properties. To achieve this, inversion must include the low frequency component as background model which is below the bandwidth of seismic data. An earth model is generated to constrain and stabilize the inversion and to generate the low frequency content. The model biases the inversion results and their interpretation and honour all the available information such as well logs, stratigraphy and geology. The 3D geological models of the area were generated from the P-sonic, S-sonic, and density at the well logs which have been integrated to time and drift-corrected horizons, then interpolated for the whole volume according to the seismic interpreted horizons of the full-stack seismic amplitudes.

In our study, model volumes of compressional, shear impedance, Vp/Vs and density are created and the low frequency components of these models are used to stabilize the inversion, **Figure 3**. Additional constraints are added to stabilize the S-wave impedance result and P-wave and density relation because, the data angle range used were not enough to give reliable density information.

expected geological results and are defined separately for compressional and shear impedances and density. Other constraints are to control the relations between density and compressional velocity and also compressional and shear velocity. The density component is poorly resolved from the input seismic data which is upto 32 degree angle. To reduce this instability, Gardner equation was invoked as a soft constraint.

Seismic Inversion

Simultaneous inversion of partial angle stacks following a "Constrained Sparse Spike" approach (Pendrel et al., 2000) the compressional, shear impedance and density, along with the volume of Vp/Vs, Lambda-Rho, Mu-Rho and Poisson's Ratio were obtained. The solution of the inversion is established by minimizing a combination of L1 norms on reflectivity and L2 norms on the data fit.

The seismic data of Wadu-Paliyad area that used for inversion consists of 515 lines and 1076 CMP's. The bin size is 17.5 x 17.5m and offsets ranged from 25 to 3714 m. The inversion was run for this study is

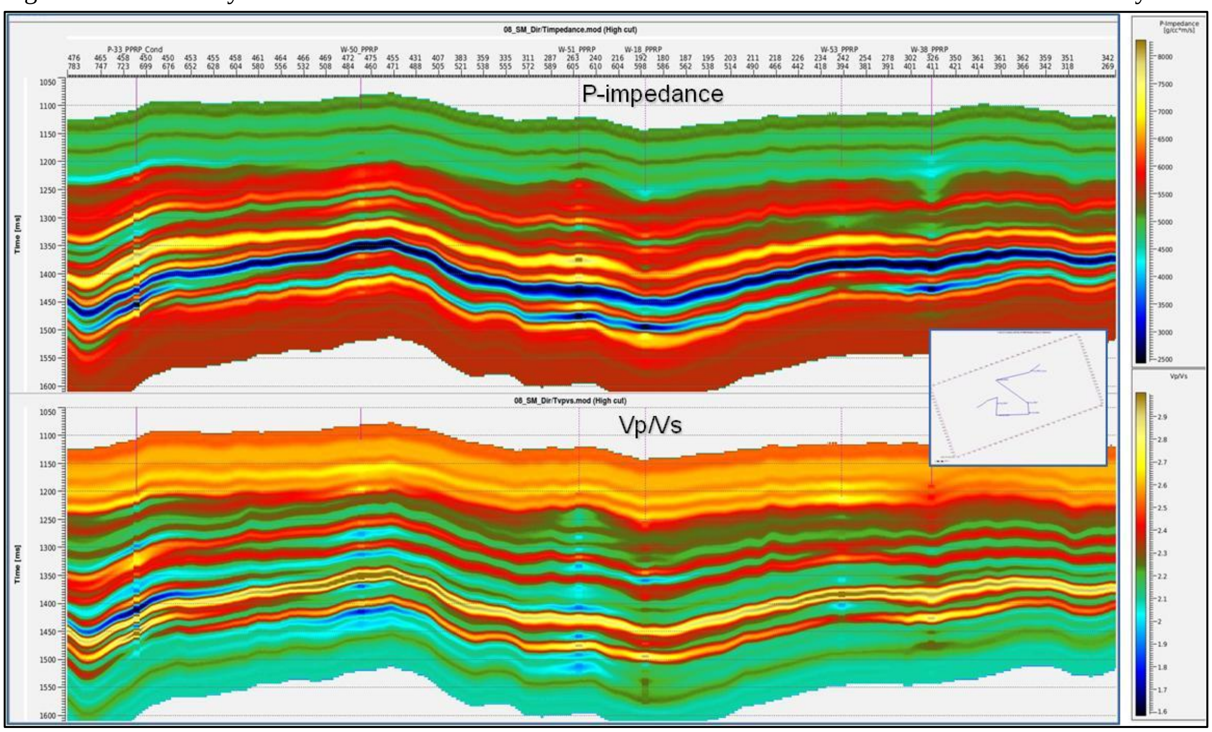

Figure 3: Example of two low frequency trend model of P-impedance and Vp/Vs passing through six Rock Physics Model (RPM) wells. Inset showing RC line orientation.

Setting of Inversion Parameter

To control, stabilize and constraint the inversion parameters there are about thirty primary and advance parameters that should be optimized before running a simultaneous inversion. The choice of few parameters depends upon data quality. The constraints are designed to admit the possibility of all

169 Sq.Km.

The output of inversion is both absolute and relative. The relative volume contains impedance information in the seismic band only. These data are largely uninfluenced by the model or any assumptions made to construct it. The inversion generally reduces the tuning and offset dependent tuning. The inverted volumes are more reliable and resolvable for quantitative interpretation than that achieved from interpreting seismic data. The advantage of the inversion products are layer based rock property cubes rather than seismic reflection cubes. Hence, the interpretation of the inverted volumes can be directly linked to well observation.

QC the Inversion Results

The simultaneous inversion produce the output of P-impedance, S-impedance, and Density volumes and in addition derived volume of Vp/Vs, Lambda-Rho, Mu-Rho and Poisson's Ratio were also computed, (**Figure 4**). The inverted volumes indicate that the matching of both amplitude and events between seismic and wells are very accurate, as shown in **Figure 5** where logs were filtered to seismic bandwidth. Since the results of the inversion are not derived from well data, the well to seismic match indicates the good quality of simultaneous inversion. The values of P-impedance and Vp/Vs derived from well data can now directly and quantitatively compared to the results of inversion.

claystone, carbonaceous/coaly shale and coal. The hydrocarbon accumulation in the area depicts both structural and stratigraphic plays.

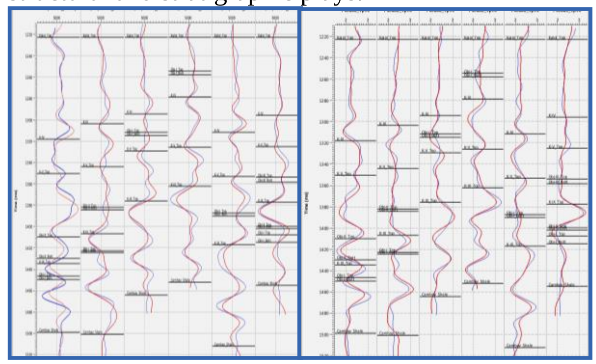

Figure 5: Logs of P-impedance and inverted P-impedance (left) and Vp/Vs and inverted Vp/Vs (right) of six wells, showing perfect match with logs.

To interpret the inversion volumes, a relationship from the well logs are established and then applied it

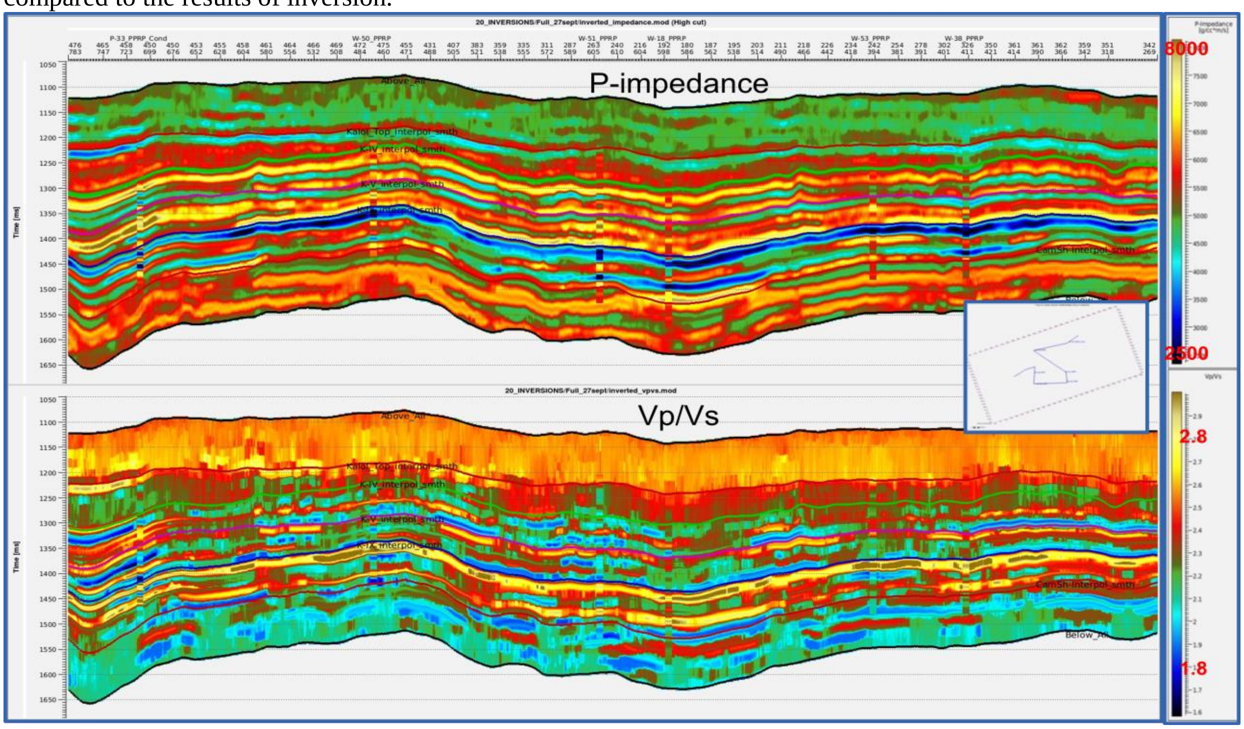

Figure 4: Inverted P-impedance and Vp/Vs superimposed with corresponding well logs. Inversion result shows good match with log data. Inset showing RC line orientation through wells.

Lithology and Fluid Characterization

The distribution of oil and gas reservoirs in this area is very complex. Abrupt facies changes are common. Sand bodies lose their reservoir character within short distance. The thick reservoir unit of Kalol formation are developed at different part of the area. The dominant lithologies, which make up this formation, are sandstone, silty shale, siltstone, sideritic

to the 3D volumes to automatically find all points meeting the well log derived criteria, that lead to calibrate the seismic derived rock property cubes to wells. These connected spatial points generate Geobodies.

The information of reservoir acquire from shear wave velocity significantly increased the ability to identify fluids and lithology in simultaneous inversion. Cross-plot of P-impedance versus Vp/Vs or P-impedance vs. S-impedance or Lambda-Rho vs. Mu-Rho from well logs and inversion result are used for the characterization of fluids and lithology. The P wave velocity is affected by fluid content in the reservoir and so do P impedance and Vp/Vs, however shear wave does not change. So the combination of these two parameters can be used for defining the change of reservoir characters from no-reservoir. The polygons derived lithology can define from these cross-plots. K-VIII hydrocarbon bearing reservoir sand is medium impedance and low Vp/Vs. The lithofacies of coal, shale, brine sand and hydrocarbon bearing sand are detectable from this cross plot. However, there are overlapping of hydrocarbon sand with brine sand, brine sand with shale and shale with coal. The increasing porosity and increasing water saturation is plotted in the **Figure 6.** It is observed that gas sand are more porous than oil sand.

Lambda-Rho and Mu-Rho cross plot can be used for fluid and lithology discrimination where Lambda-rho is a pore fluid indicator with low values indicate hydrocarbons and mu-rho is a lithology indicator with high values indicates the sands.

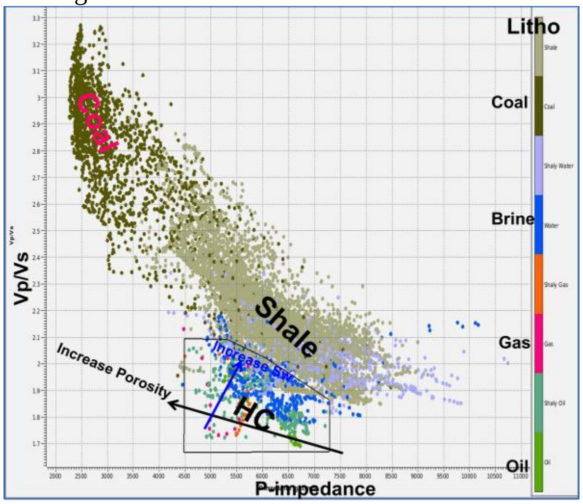

Figure 6: Cross-plot of P-impedance and Vp/Vs of **K-VIII** unit of wells W-18, 38, 50, 51, 52, 53, 55, 56, P-19, 20, 23, 33. Colours are coded with lithology.

The above discrimination of fluid in the cross plot of P-impedance vs. Vp/Vs is in well logs. To test the averaging effect of seismic, the logs are filtered to seismic frequency band by applying high-cut filter where the fluid discrimination is still possible, **Figure 7**. Due to averaging effect, the sand points are slightly sifted.

Geo-body Capture

The inverted volumes are calibrated with well log and layer based rock property volumes leads to the

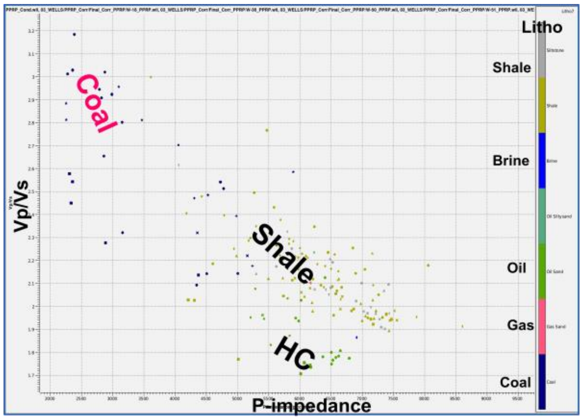

Figure 7: Cross-plot of Figure 6 filtered to seismic frequency band. Discrimination of hydrocarbon bearing sand still exists.

application of a very powerful, volume-based interpretation. Hydrocarbon bearing sand was identified from the well data through the cross-plot of P-impedance and Vp/V sand were used to the CSSI output volume by slightly modifying the polygon to isolate the cells of pay zones. Geo-bodies were subsequently captured by applying minimum size and connectivity criteria. (**Figure 8**). Once the geo-bodies of interest were selected, structural top and base and thickness maps were generated. The volume of each geo-body was then obtained by adding those cells which honour pay sand and face connectivity criteria.

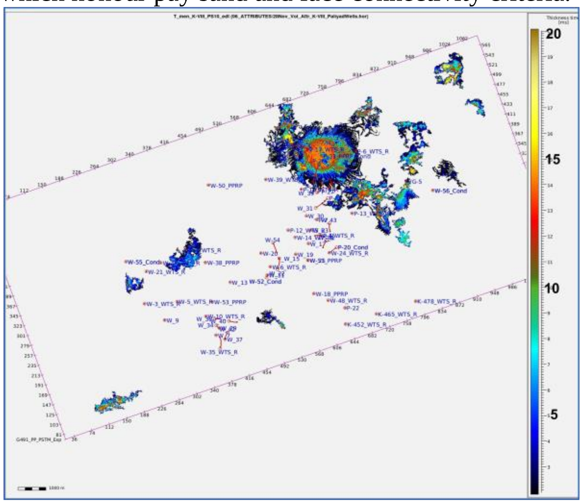

Figure 8: Time Thickness map of Geo Bodies for K-VIII sand. Colour scale indicates time thickness.

These connected points geobodies can be viewed in 3D to understand their geometry and extent and how they relate to the depositional and structural environment. Geo-bodies were validated by analysing their consistency with respect to the geological model, hydrocarbon migration and volumetric. Finally, the results were used to define exploratory prospects. Average gross thickness of the producing reservoir in the study area is 22 m and net reservoir is around 14 m with good porosity values which is nearly in match with our inversion results. These results support volumetric analysis of potential hydrocarbon reservoirs.

Conclusion

The resolution of the layer model derived from Simultaneous Inversion provides a better well to seismic tie to support reservoir characterization. The variability of shear wave velocity derived from the inversion substantially increases the ability to define fluid and lithology.

The reservoir sand distribution inferred from lithology indicators is consistent with the interpreted depositional system and relates to a sedimentary source. Well production data coincides with the fluid and lithology indicators derived from the inversion.

Using the combination of P-impedance and Vp/Vs volumes, most probable hydrocarbon sand are delineated. The most prospective hydrocarbon bearing sand of Kalol sequence is in higher side of medium P-impedance and low Vp/Vs. The inversion results significantly improve the imaging and discrimination of different litho-facies.

A successful seismic inversion depends on favorable rock physics and on seismic data quality and resolution. In spite of all these studies, it is required to be further augmented by other G&G analysis to derisk the location for drilling as these results are partially affected by overlapping properties of pay and brine sands and thinness of reservoir sands.

Refferences

1. Avseth Per, TapanMukerji and Gary Mavko, 2005, Quantitative seismic interpretation, Applying rock physics tool to reduce interpretation risk.
2. Pendrel, J., Debey, H., Pedersen, R., Goodway, B., Dufour, J., Bogaards, M., Stewart, R., Estimation and interpretation of P and S impedance volumes from simultaneous inversion of P-wave offset seismic data, SEG Annual conf, 2000.
3. Veeken, P. and Rauch-Davies, M., 2006, AVO attribute analysis and seismic reservoir characterisation, First Break, vol. 24, p.41-52.
4. Hampson Russell knowledge base.
5. Frugro Jason training manual.
6. Ikon Science RokDoc manual.
7. Aki, K., and Richards, P.G., 1980, Quantitative seismology: Theory and methods, v.1: W.H. Freeman and Co.
8. Xu S. & White R., 1995, A new velocity model for clay sand mixtures. Geophysical Prospecting. V.43, p.91
9. Dufour, J., Goodway, B., Shook, I., Edmunds, A., AVO analysis to extract rock parameters on the Blackfoot 3C-3D seismic data, 68th Ann. Int. SEG Mtg., p.174-177, 1998.
10. Dufour, J., Squires, J., Edmunds, A., and Shook, I., Integrated geological and geophysical interpretation of the Blackfoot area, Southern Alberta, 68th Ann. Int. SEG Mtg., p.598-601, 1998.

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