Quantitative Seismic Interpretation reduces the risk in Hydrocarbon Exploration –A case study from Mehsana-Ahmedabad Block of Cambay Basin, India

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Summary

For any quantitative seismic interpretation, three things are required as structural interpretation, reservoir facies analysis and fluid analysis. In the present study, care has been taken for structural interpretation at the initial phase of prospect evaluation by mapping of different horizons and reservoir tops.

In second phase, seismic inversion for reservoir characterization and AVO analysis for fluid analysis was carried out.

Seismic inversion is one of means to extract additional information from seismic data. It replaces the seismic signature (wiggles) by blocky response, corresponding to acoustic and /or elastic impedance which resembles as layers. It facilitates the interpretation of meaningful geological and petrophysical boundaries in the sub surface. It increases the resolution of conventional seismic in many cases and makes the reservoir as interpretable. It is useful in ranking of prospect/leads and identification of sweet spots.

Seismic data is sensitive to pore-fluid but effect is small in comparison to lithology and porosity. Therefore , after lithology evaluation and reservoir facies analysed from the seismic inversion results, further improvement of lithology is achieved by pre-stack seismic inversion, rock facies analysis and finally fluid effect by AVO analysis .

The integrated approach adopted in this paper demonstrates the effectiveness of the study by mapping of reservoir sands geometries and identification of new prospect based on specialised study with seismic inversion and AVO analysis through a case study of Mehsana-Ahemedabad Block of Cambay Basin.

Introduction

To improve the understanding and drilling of a new well in thin reservoirs is challenging task for which the quantitative methodology was used by integration of 3-D Post Stack Time Migrated data, impedance log and geologic knowledge. The approach used well log analysis, seismic wavelet estimation, well to seismic calibration, horizon tracking, attribute analysis and special study as inverted acoustic impedance and AVO analysis.

Since the author was associated from complete API (data Acquisition, Processing and Interpretation) with quality control to witness the discovery of hydrocarbon, he has special interest to analyse the data. An effort was made to acquire high resolution seismic data (**figure 1)** and process the data (**figure 2)** with intensive care. Procedures are described sequentially in figures. The shot hole gather data after fixation of charge size and shot hole depth and processing parameters are shown with corresponding figures. The main emphasis of study is given for data analysis only without going in detail of data acquisition and processing.

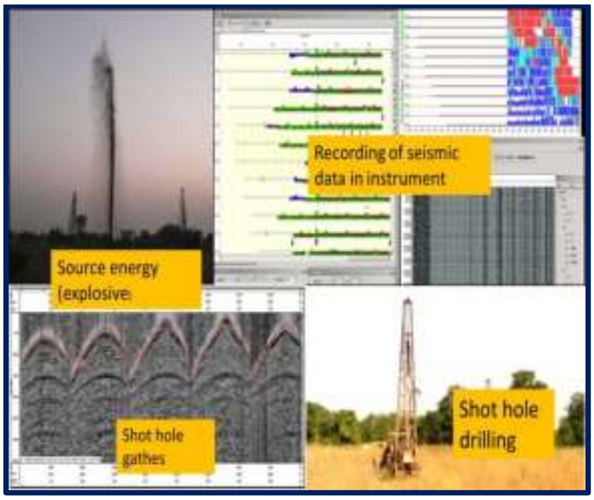

Figure 1: Seismic data acquisition and quality control during parameter fixation and experimentation

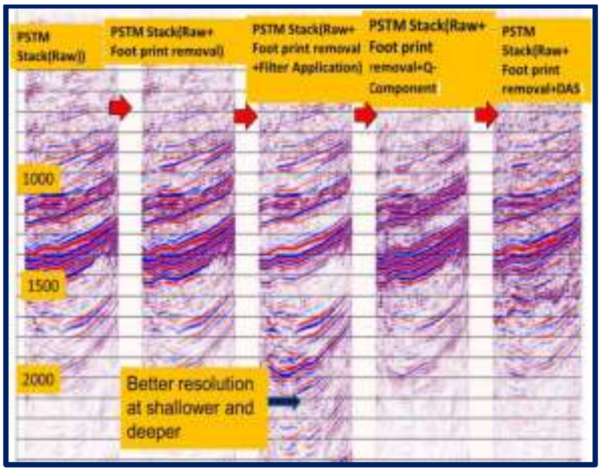

Figure 2: Seismic data processing and parameter fixation

Study area

The study area is covered by a 3-D seismic survey (**figure 3) .**The Kadi and Kalol Formations of early to middle Eocene age are thick clastic wedges in the northern part of the Cambay basin and major producer in the Mehsana-Ahmedabad block. The Kadi Formation has been divided into the Mandhali and Mehsana Members. The formation is restricted areally to the northern part of the Mehsana-Ahmedabad block and was deposited in fluvial, lagoonal, and deltaic environments. Unlike the

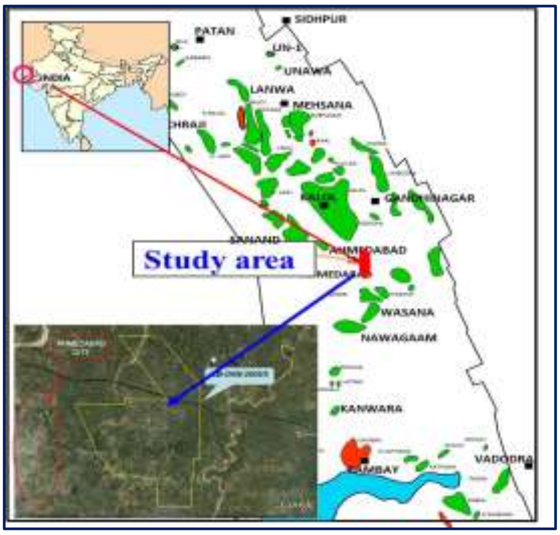

Figure 3: Location map of study area with index map showing neighbourhood field

Kadi, the Kalol Formation is present in a large area from Mehsana in the north to the Dadhar River in the south. The Kalol Formation has been divided into four members. The upper three (Sertha, Kansari, and Wavel) were deposited in an extensive area and the lowermost Chhatral Member is restricted to some part only.

Kalol formation is characterized by intercalation of thin sandstones/ siltstones, shale and coal. In some area, an additional reservoir facies deposited above and below the coals, is the main producer whereas Chhatral and Mehsana sands are secondary reservoir sands.

Methodology and discussions of results

(i) Well to seismic tie and Wavelet extraction

Log values are spurious at many depth intervals especially near casing shoes. Therefore log editing was done using smoothening and filters application. S wave velocity was computed using P wave velocity based on Costagna equation.

The first step in inversion is to extract the wavelets. The wavelets were extracted for angle stacks (near, middle and far stacks) and Post Stack Time Migration (PSTM) data .The raw wavelets has similarity and seems stable for use in simultaneous seismic inversion.

Once the wavelet from stacked data has been estimated, synthetic seismogram was prepared and correlated with seismic and a correlation coefficient of the order of 72% was achieved (**figure 4**)

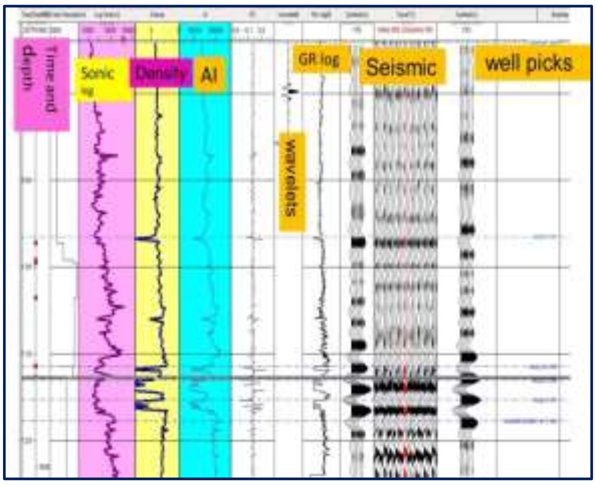

Figure 4: Synthetic seismogram showing correlation and well to seismic tie

(ii) Initial model building and seismic inversion

A model that contains low frequency information from well logs was built by interpolation of well data (impedance log calculated from sonic and density logs), application of low pass filter of 10Hz and interpreted horizons.

We performed the model based inversion process to obtain acoustic impedance volume for the specified window of log availability. In the present case, we used 3 wells as W1 ,W2 and W3 for model building**.** The cross correlation between seismic derived acoustic impedance and well based acoustic log in blind well (drilled new well P) is acceptable. During simultaneous inversion, Vp/Vs ratio and density were also derived and shown in **figure 5.** Computed P wave and S wave impedance used for Vp/Vs ratio computation. Vertical panel of seismic derived P impedance, Vp/Vs ratio and density section superimposed with well based impedance logs have a very good match especially at reservoir Kalol sands and coal alternations.

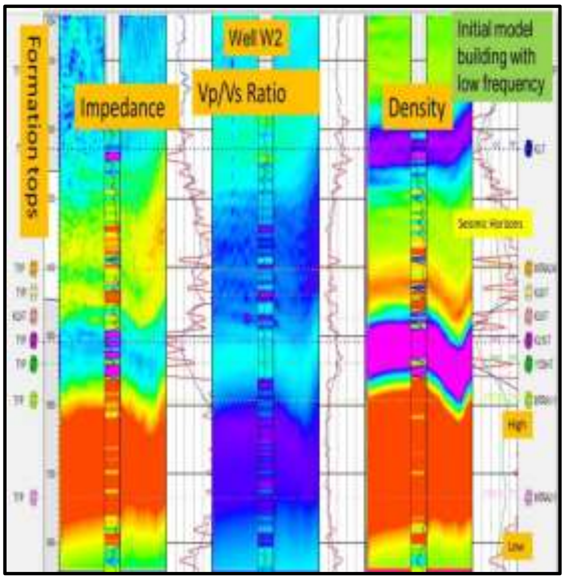

Figure 5: P wave impedance, Vp/Vs ratio and density inversion model result showing good match between log derived values and inversion results

Time structure maps of K-VIII, K-IX and K-X reflectors were initially generated in addition to structural maps for tops of Babaguru , Tarapur , Kadi /Younger Cambay shale and Older Cambay shale after tie up with formation tops established after log correlation. The sand/siltstone and coal depositional model were finally derived by a thorough analysis of logs, geologic knowledge, seismic attribute. One of map showing structural configuration within Kalol sands reservoirs is shown in **figure 6** with confidence map (left and upper corner) showing more than 90% confidence.

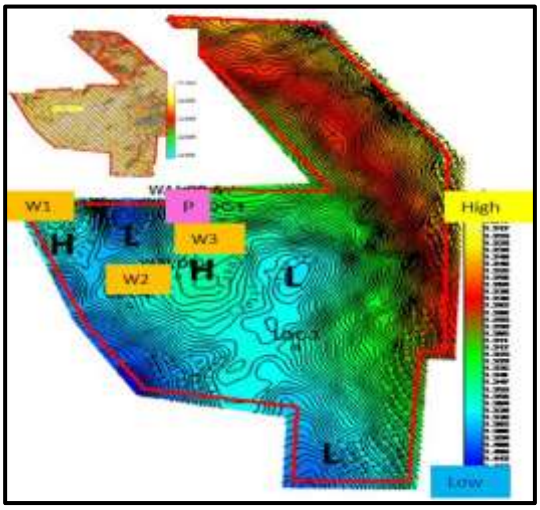

Figure 6: Structure map with confidence factor map (Upper left corner) at reservoir layer within Kalol formation

(iii) Post stack Inversion workflow

The steps needed to perform model based inversion of seismic data are well known: log preparation, wavelet estimation, seismic to well ties, initial model construction, inversion and QC. The work flow is performed in the time domain.

Three wells were used in this study , none of which have a shear velocity log, which is important not only for rock physics analysis but also for pre stack seismic inversion .To solve this problem S-velocity logs were estimated with relationship of Castagna et al.(1985) , using linear equation. Vertical section (arbitrary line) passing through wells and extracted from poststack seismic inversion volume **(figure 7)** and one of acoustic impedance map at Kalol reservoir is shown in **figure** 8 and **figure** 9 with color bar indicating low and high values.

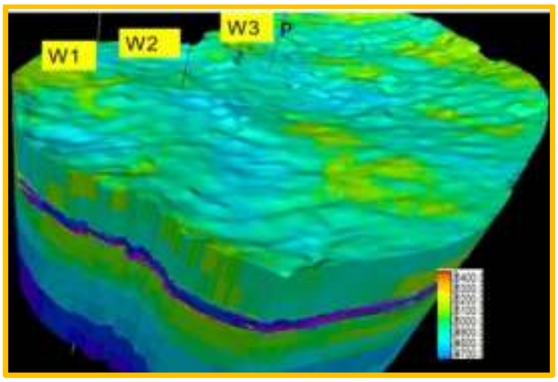

Figure 7: Acoustic impedance volume computed from 3 D seismic volume

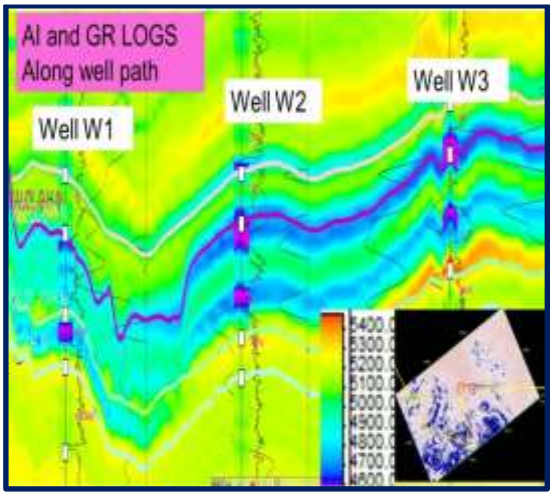

Figure 8: Vertical section (arbitrary line) extracted from acoustic impedance volume and passing through wells.

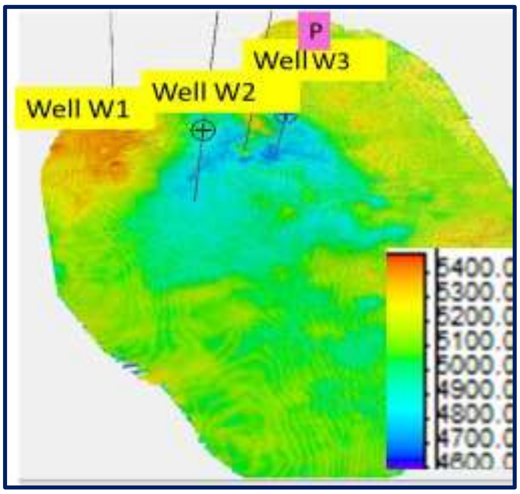

Figure 9: Acoustic impedance map at reservoir layer within Kalol formation

Not only the internal property and heterogeneity of rocks is identified with acoustic impedance section as shown in **figure 8** (composite line passing through wells) but also the structural interpretation becomes easier in impedance section than normal seismic section. Notice that this much detail and lateral discontinuity of sands is not possible to detect in the normal seismic. Superimposed acoustic impedance log and Gamma Ray log were used for calibration , integration and validation of acoustic impedance output results.

(iv) Simultaneous impedance Inversion and rock physics analysis

Traditional inversion methods demonstrate a number of difficulties such as non-uniqueness, noise sensitive and stability issues resulting from independent inversion of compressional and shear (P and S) impedance. Simultaneous inversion, on the other hand , overcome or minimise these difficulties by incorporation of multi offset or multi-angle seismic data into single solution by computing Vp, Vs and density. A robust simultaneous inversion incorporates the geological information and constrain the model to improve the resolution and lateral variability. Low frequency information below 10Hz was taken again from well logs to build model. During the model building, all surfaces mapped during structural interpretation, wells and its acoustic impedance logs were given as inputs. The procedure is same as post stack inversion.

(v) Rock physics and Lithoclassification

In the present case inverted volume of P wave impedance , Vp/ Vs ratio, and density volume was used for rock physics analysis using petrophysical properties processed though ELAN log processing. The cross plot of Acoustic impedance versus Vp/Vs ratio is sensitive to Vcl, porosity (PHI) and Sw as tested one by one and shown in **figure 10.** Once the relationship is established and separation of reservoir sands observed away from dry rock or mud rock line , the combined volume of P impedance and Vp/Vs was converted to rock/ litho classification and for their litho probability one by one.

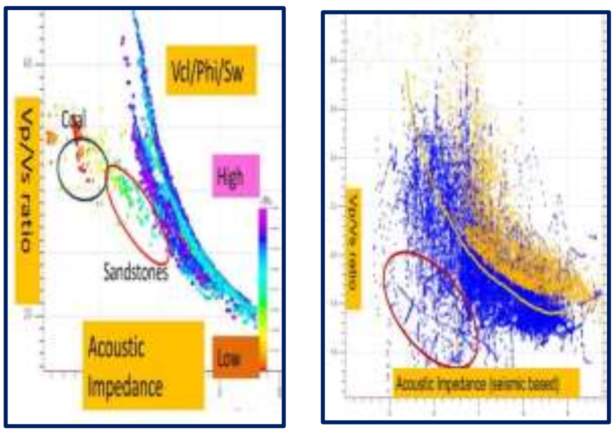

Figure 10 : Cross plots of Acoustic impedance and Vp/Vs ratio to establish relationship between rock physics and elastic properties as elastic properties are common with logs (left side) and seismic (right)

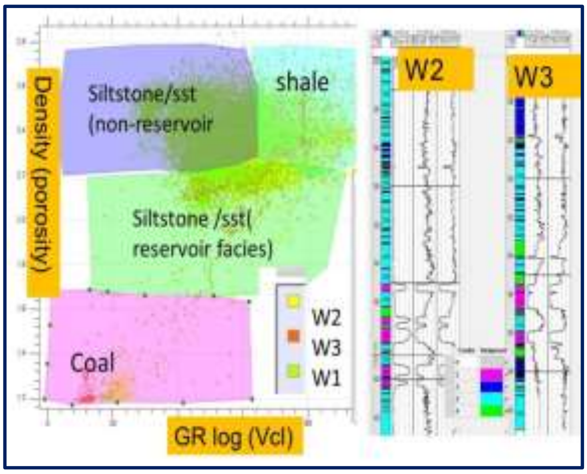

Figure 11: Crossplot of Gamma Ray log (Vcl) and Density (porosity) for rock physics classification and creation of litholog

Now the cross plot of density (related to porosity) and Gamma Ray log (related to shale volume) indicating the different cluster of shale and siltstone /sand stone was taken as shown in **figure** 11. The coal is very clearly isolated from silty sandstone and shale by low density /velocity and Gamma ray values. On the basis of this cross plot , seismic volume was found suitable for litho-classified volume. One of vertical section extracted from lithoclassified volume is is shown in **figure** 12 depicting four classes of facies.

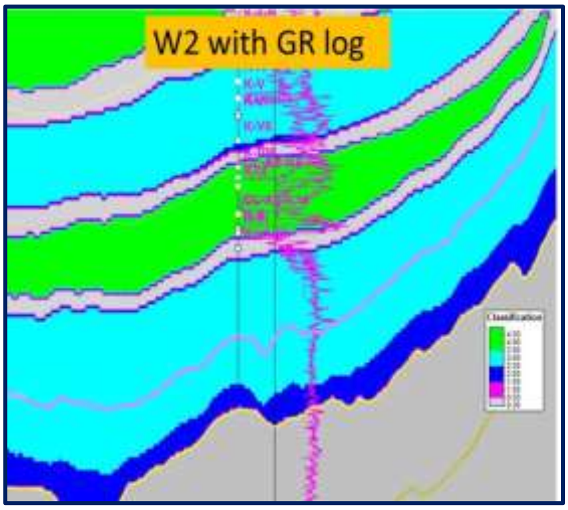

Figure 12: Rock facies classification based on xplot. Four classes as reservoir siltstone/ sandstone (green), shale (light blue), coal (light pink) and non-reservoir sandstone/siltstone (dark blue)

The litho probability volumes for each class were computed simultaneously during classification of rock physics. The litho probability section for reservoir rock within Kalol formation is shown **in figure** 13. The color bar indicates the high probability for occurance of reservoir with red and yellow color.

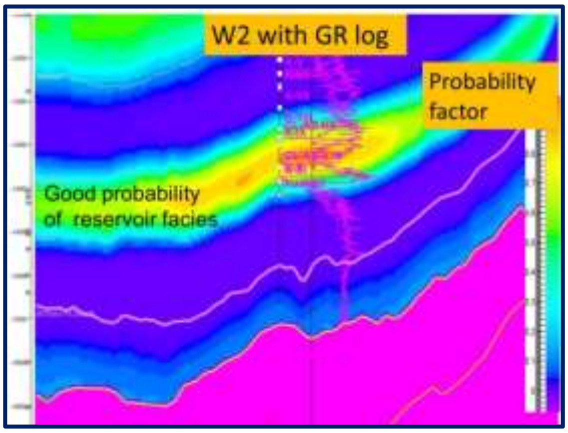

Figure 13: Probability factor analysis for reservoir facies and vertical section of litho-probability extracted from volume

Computation of AVO attribute and Interpretation

The support of other investigation techniques like AVO analysis increases the confidence in the inversion results. Even a negative correlation between AVO attributes and acoustic impedance is important as it result in an increase of risk attached to the prospect. The ranking can be done and priority can be fixed for the drilling of locations.

After all limitation, AVO cross plot were generated between intercept and gradient derived from gather data and AVO model based on well as shown in **figure 14.** The well based model indicate class 2p either due to presence of heavy oil or presence of silty sandstone whereas seismic gather analysis does not show a clear-cut AVO class due noisy data at near offset due to shot generated noise and far offset due to very low energy.

Prospect identification carried out with seismic inversion were validated with AVO analysis by computation of Intercept (P), gradient (G) and product of P*G for fluid analysis as AVO attributes are more sensitive to fluid. Anomalies maps **(figure 15)** for P*G of Kalol sands were prepared at expected reservoir levels keeping in mind about pitfalls of AVO and background effects of coal beds.

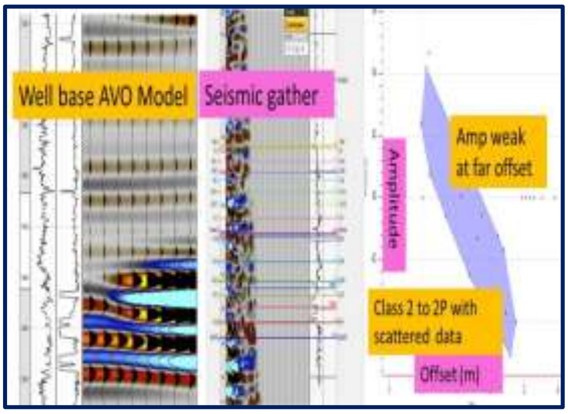

Figure 14: AVO Modelling: well based (left) and seismic gather based (right)

Coals are an integral part of Kalol formations and dominant from sands of Kalol-VIII to Kalol-X. They are very much part of the interpretation scenario. Apart from being the source of some hydrocarbons, they produce continuous and strong reflections and are commonly used by interpreter as marker horizons. On one hand coal markers affects the Inversion and AVO analysis having the similar

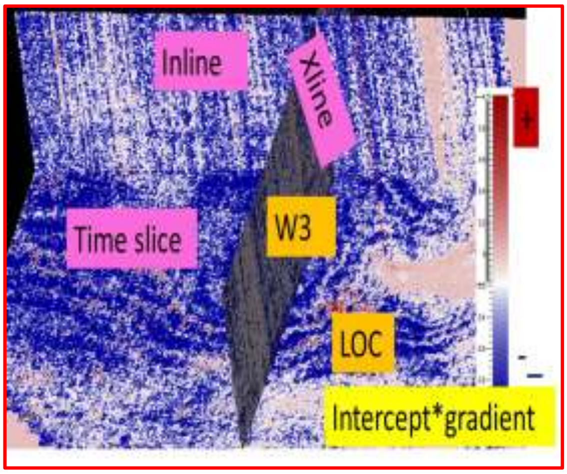

Figure 15: Inline, crossline and time slice extracted from AVO Attribute volume showing class 2p effect near new location

properties but on other hand they act as reference in tracking of Kalol prospective sands. Unfortunately, coals produce strong negative amplitude/ very low acoustic impedance responses which are often confused with a possible hydrocarbon response. Geological and geophysical analysis of coal beds with logs and AVO class reveals that they have low gamma ray response as sands, very low density and resistivity (spikes) low acoustic impedance as gas but different AVO class (generally class 4) is able to isolate from gas/oil sands. By that way, coal has been isolated from reservoir rock. Vp/Vs ratio done during prestack inversion is also able to differentiate coal from reservoir rocks.

Results and Discussion

The new well drilled on the basis of study was used as blind well test and inversion result was refined further.

The decrease in acoustic impedance values at target level indicates the presence of sweet spots by integrating the rock physics. Simultaneous inversion was used as further tool to support the post stack inversion and detailing. Also, the volumes of P wave impedance , Vp/ Vs ratio was used to classify the rock physics by analysing the cross-plots using the elastic property based on well/seismic and petrophysical properties as Shaliness, porosity and saturation processed from ELAN Logs.

The analysis has been very helpful for predicting lithology and distinguishing reservoir, non-reservoir facies and coal and establishing the relationship of reservoir property and acoustic property.

Conclusion

-It was a rare opportunity for author to be associated throughout A (acquisition),P (processing), I (Interpretation) and prospect evaluation to witness the oil discovery in the field within a year from commencement of data acquisition.

-Seismic inversion have significantly improved the ability of seismic data to resolve thin beds beyond theoretical limits as high frequency and low frequency has been added in conventional seismic during model building for seismic inversion.

-Acoustic impedance provided the detailed reservoir characterisation compared to reflection amplitudes and amplitude based attributes. Higher vertical resolution and layer by layer extrapolation of acoustic impedance improved the stratigraphic interpretation and lithology prediction which were used subsequently to refine the drilling plan of new exploratory wells.

-Litho-classification and litho probability analysis helps in visualisation of rock /reservoir facies with integration of ELAN processed logs and pre stack inversion.

AVO analysis is able to analyse the fluid contents in reservoir and hence increases the confidence in ranking of prospects and reservoir management.

-The case history presented here shows the simultaneous application of AVO and seismic inversion to predict the presence of reservoir in massive shale and coal bed alternation where 3-D seismic image is not able to discriminate individual reservoir layers.

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