Delineation of Hydrocarbon bearing sands using Lithofacies classification in Olpad formation

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Summary

Interpretation of sand and shale in Olpad Formation of Padra field, Cambay Basin is quite difficult mainly due to intermixing of clastics with trapwash material. A methodology was adopted in the present study for delineating Hydrocarbon sand by thorough study of Pre-stack Stochastic inversion and its outputs like acoustic (P) impedance and Vp/Vs. Validation of the wells (producing and non-producing) were carried out meticulously. Several Cross plots were generated to study the behavior of the Olpad pay levels saturated with hydrocarbon and devoid of hydrocarbon. Behaviour of acoustic (P) impedance and Vp/Vs have been studied in hydrocarbon bearing and non-hydrocarbon bearing sands in the wells falling in the study area and it was observed that these two parameters (acoustic impedance and Vp/Vs) could discriminate between hydrocarbon and non-hydrocarbon zones.

Thus, a cross plot between Vp/Vs and P-impedance was taken into consideration and two numbers of lithofacies zones (one corresponding to hydrocarbon bearing sands and the other corresponding to non-hydrocarbon bearing sands) were identified and lithofacies volume was generated by using LithoSI module of Hampson Russel software. Hydrocarbon sand probability map was prepared after this and was validated for producing and non-producing wells in the study area.

Introduction

Identification of lithology and delineation of hydrocarbon bearing sand is a big challenge in reservoir characterization, particularly when we are dealing with a lithology comprising of mixed facies like conglomerates, shales, siltstones, ashy claystones etc. This paper attempts to show how better the outputs viz. Vp/Vs and acoustic impedance obtained from Pre stack geostatistical inversion can be used in lithofacies classification, generate the lithofacies volume and thus predict the lithology and saturation of hydrocarbon sand. The study was carried out for Olpad formation in Cambay basin.

Geology of the area

The Cambay basin, with an aerial extent of 55000 sq. kms, a rich petroleum province of India is a narrow, elongated rift graben, extending from Surat in the south to Sanchor in the north[1] (Fig. 1). It originated during Mesozoic due to rifting along N-S to NNW-SSE Dharwarian trend, but subsided more rapidly during the Tertiary[2]. It is bounded by step faults in the eastern and western margins and is divided into five tectonic blocks—Sanchore, Ahmedabad, Tarapur, Broach and Narmada. The sedimentation is controlled by pre-rift, syn-rift and post rift stages. The Early Tertiary sediments ranging from Paleocene to Early Eocene age represent syn-rift stage of deposition that was controlled by faults and basement highs in an expanding rift system[3].

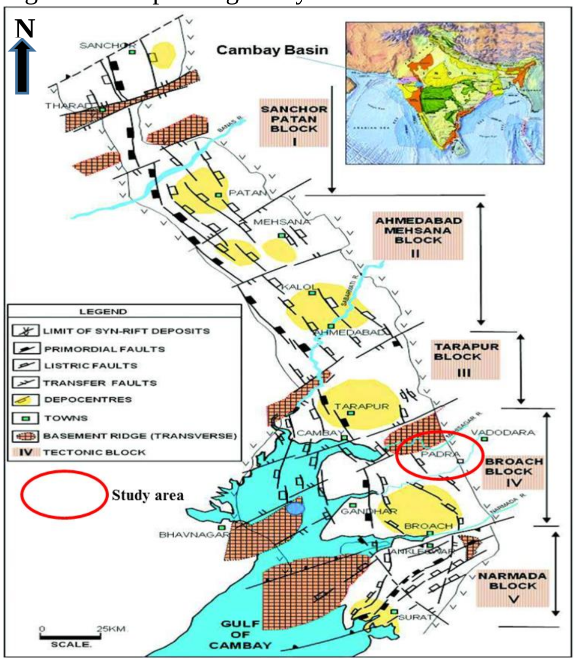

Fig.1 Tectonic Map of Cambay basin

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The Middle Eocene witnessed a regressive phase with oscillating conditions of deposition and development of deltaic sequences in the entire basin[1].

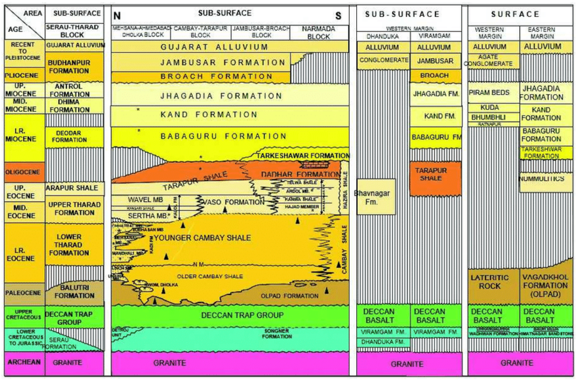

Fig.2 Generalised Stratigraphy of Cambay basin

Startigraphy of the area

The present study is mainly concentrated on Olpad pay in Padra field. Deccan trap of late Cretaceous to Paleocene age forms the basin floor or tectonic basement. Olpad Formation overlies the Deccan Trap and has a gradational relationship with the overlying Cambay Shale (Fig.2). Lithofacies within Olpad are highly variable from north to south of Cambay basin. It comprises mainly of claystones, sandstones, siltstones and volcanic conglomerates, and shales at some locations, and was deposited under fluvial to shallow marine conditions. Nawagam, Dholka, Gamij and Sanand are some of the major oil producing fields from Olpad reservoir.

Theory

Geostatistical inversion generates multiple realizations of elastic properties in fine scale stratigraphic grid, each of which honors the seismic data, the well data and the geostatistics (using Bayesian inference followed by Markov Chain Monte Carlo "MCMC" sampling) to produce a highly detailed reservoir description[4]. It has the benefit of incorporating the frequencies that are not in the seismic bandwidth by combining the above listed seismic and well data. Therefore, fine scaling details is possible in this case and the resolution of the outputs also increases to a great extent.

Pre stack Geostatistical inversion was conducted in the study area. Discrimination of sandstone and shales was achieved using a combination of Acoustic (P) impedance and Vp/Vs. QC was conducted on the mean of all realizations and the statistically identified realizations corresponding to the P10, P50 and P90. In our case we have used P50 realization.

The outputs like acoustic (P) impedance and Vp/Vs as obtained from P50 realization were used for further analysis.

Mixed lithology in Olpad pay posed a problem in reservoir characterization. To overcome this a cross plot between Vp/Vs and acoustic (P) impedance (Fig.3) was generated for DSI wells and two zones were identified – first zone corresponds to the facies which is hydrocarbon bearing (green ellipse in Fig. 3) and the second zone (representing cluster of points not falling inside green ellipse) which corresponds to the facies which are not good for accumulation of hydrocarbon (Non-hydrocarbon).

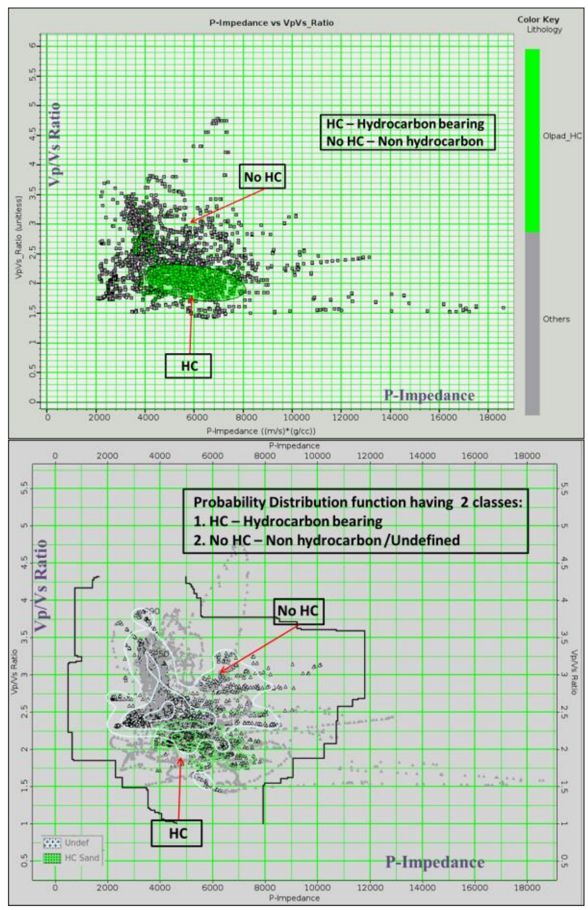

Fig.3. Cross plot between Vp/Vs and P-impedance showing two zones 1.HC bearing sands and 2. Non-HC bearing sands

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These two zones are nothing but the two litho classes which can be seen in the redrawn cross plot showing probability distribution function of each class (Fig. 3). Based on this litho classification, lithology curves were then generated in all the wells used for study.
The cross sections of Vp/Vs and acoustic (P) impedances (Fig.4) have been shown in 09 no. of producing wells and three no. of non-producing wells. The encircled green impressions on log curves are favourable zones for hydrocarbon wheras absence of them indicates non favourable zones for hydrocarbon accumulation.

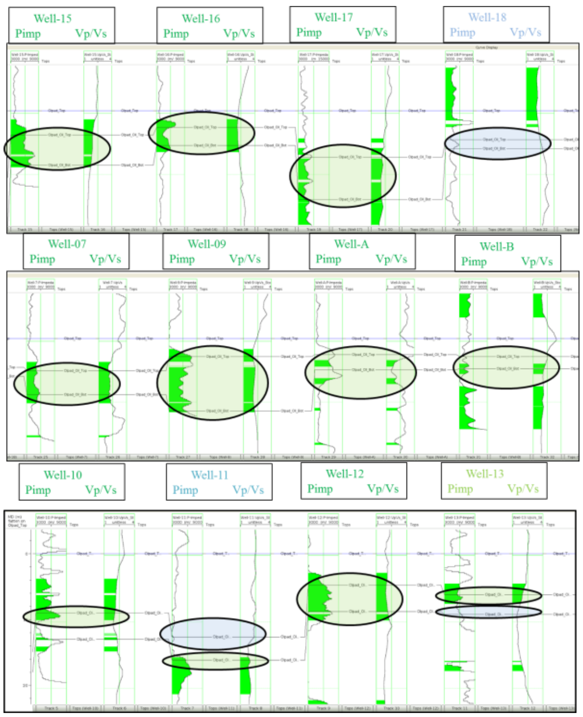

Fig.4. Cross sections of Vp/Vs and P-impedance showing the presence of Hydrocarbon and non-hydrocarbon in 12 wells

So, after deciding these two zones thus identified, a lithofacies volume was generated by taking Vp/Vs, P-impedance and litholog curves as inputs and the result was validated. A hydrocarbon sand probability map was also prepared along with lithofacies map and all the wells including blind wells were validated. In the process the wells having lithology informations were utilized to train the seismic data or simply populated by taking the seismic trend to generate lithofacies map. As already mentioned, this process was carried out using LithoSI module of Hampson Russel software. This warrants a brief discussion about the background theory[5]. It uses a Bayesian classification scheme in which we compute both the conditional probability and the a-priori probability for each class using the well logs. For say K classes, the Bayes rule for each class is written as –

$$p(c_i|X) = \frac{p(X|c_i)p(c_i)}{p(X)}, where\; p(X) = \sum_{i=1}^{k} p(X|c_i)p(c_i)$$

where p(ci|X) is the conditional probability that we are in class ci given a value of X . In our example we have two classes (hydrocarbon bearing sands and non- hydrocarbon bearing sands) and X is the two-valued vector consisting of measurements of Vp/Vs and acoustic (P) impedance at a particular integrated time on a well log. Although the most common kernel density estimate is the multivariate Gaussian distribution, LithoSI uses the Epanechnikov kernel[6] because it decays exactly to zero, unlike the Gaussian kernel.
The discussion of Bayesian classification will not be completed if we don't discuss briefly about confusion matrix. A confusion matrix is a visualization tool used in supervised learning. The instances in a predicted class are shown in the columns and the instances in an actual class are shown in the rows.
In the example of confusion matrix below we are comparing a potential stratigraphic zone say in 09 wells. The Lithology log is more or less matching with the result. As already mentioned, we have taken only two classes – 1. hydrocarbon bearing sands and 2. non-hydrocarbon bearing sands or say Undefined. The confusion matrix (Fig.5) is self-explanatory which is showing the lithology classification for HC sand and non-HC sand which is nothing but undefined class in our case. Here in the classification result unclassified is negligibly small. Also the percentage of misclassified samples is very less. We may infer fair to good match of lithology present in the wells with the predicted ones.

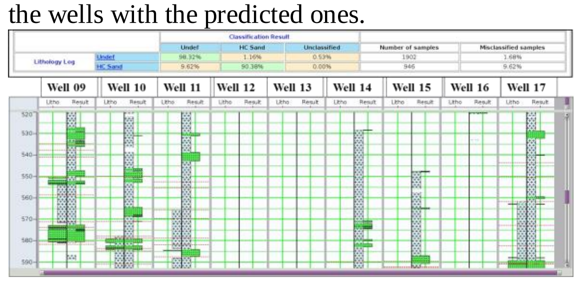

Fig.5 Confusion Matrix showing lithology classification for HC and non-HC (undefined) sands

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Methodology

Initially, a total of 7 wells having shear wave logs (Table-1) were available but since this number was insufficient for the lithofacies classification, another 11 wells covering the entire area were taken for our study. The shear wave log informations about these 11 wells were derived from the Vp/Vs output of stochastic inversion (GeoSI inversion). Since the P wave and density logs were available in all the wells, therefore original acoustic (P) impedance was used.

Sl. No.	Well Name	Type of well	Status
1.	Well-1 to 7	DSI well	Presence of Hydrocarbon
2.	Well-8 to 10	Non- DSI well	Presence of Hydrocarbon
3.	Well-11	Non- DSI well	No Hydrocarbon , only little Hydrocarbon in lower part of Olpad pay
4.	Well-12	Non- DSI well	Presence of Hydrocarbon
5.	Well-13	Non- DSI well	Presence of Hydrocarbon , no Hydrocarbon in lower part of Olpad pay
6.	Well-14 to 18	Non- DSI well	Presence of Hydrocarbon
7.	Well-18	Non- DSI well	No Hydrocarbon
8.	Well-A	DSI well	Presence of Hydrocarbon
9.	Well-B	DSI well	Presence of Hydrocarbon

Table 1: Showing well details

For carrying out feasibility study in the study area, a cross plot (Fig.3) between Vp/Vs and acoustic (P) impedance was generated to find out the discrimination between facies. In the crossplot, the cluster having maximum no. of points (green ellipse) was interpreted as the points coming from hydrocarbon bearing sands, thereby representing the favourable facies. The points away from this cluster (not falling inside green ellipse) were considered as those representing non - hydrocarbon bearing sands.

The above cluster is also reflected in the log cross sections of Vp/Vs and acoustic (P) impedance (Fig. 4) pertaining to the wells 15, 16, 17, 7, 9, 10 and 12, where the green regions or areas (as seen in Fig. 3) correspond to the hydrocarbon bearing facies in the Olpad formation. Similarly in the wells 18, 11 and 13, the regions not favourable from hydrocarbon point of view are outside the green cluster, though wells 11 and 13 have shown a little amount of hydrocarbon in the lower and upper parts of Olpad formation respectively (Table-1).

Now, by fixing these two lithofacies identified on the basis of cross plot of Vp/Vs and acoustic (P) impedance, a lithofacies volume was generated and afterwards a hydrocarbon sand probability map (Fig. 6) was prepared for the entire Olpad formation.

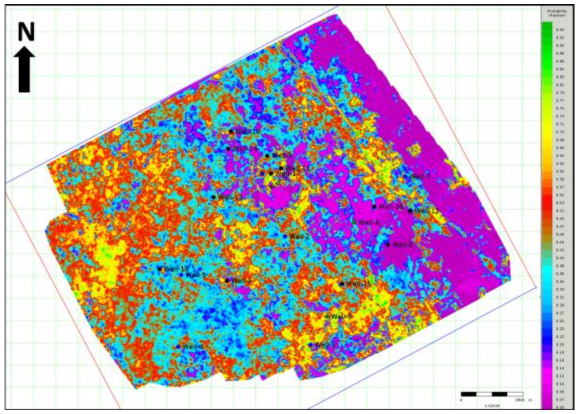

Fig.6. Hydrocarbon sand probability map showing the most probable facies.

QC of the HC sand probability map was performed for all the wells falling in the study area which was found to be satisfactory. The coloured region is prominent in the case of well no 10 which is showing more probability of HC prediction wheras low or little prominent in the case of no HC along well 5 (Fig. 7 & 8) in the sections.

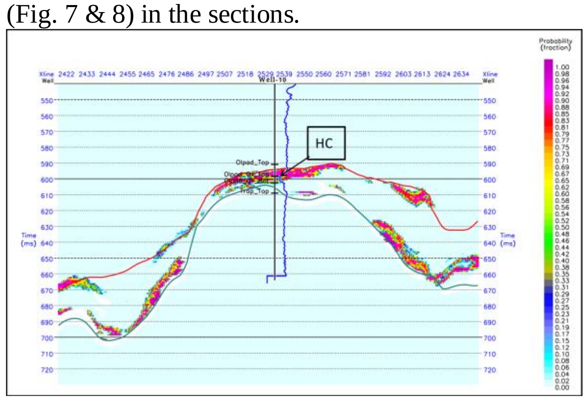

Fig.7. Cross section along well 10 predicting Hydrocarbon sand region that corresponds to high probability.

QC and validation of the probability map was also done by taking three arbitrary lines along wells 15, 16, 17 and 18; wells 7, 9, A and B; wells 10, 11, 12 and 13 (fig. 9) respectively. All these arbitrary lines were taken exactly in the same sequence as shown in the cross section map of Vp/Vs and P – impedance (Fig. 4) while doing feasibility study. The coloured regions along all the 12 wells can well be observed in the section of arbitrary lines which correspond to high, moderate and less probability for prediction of hydrocarbon.

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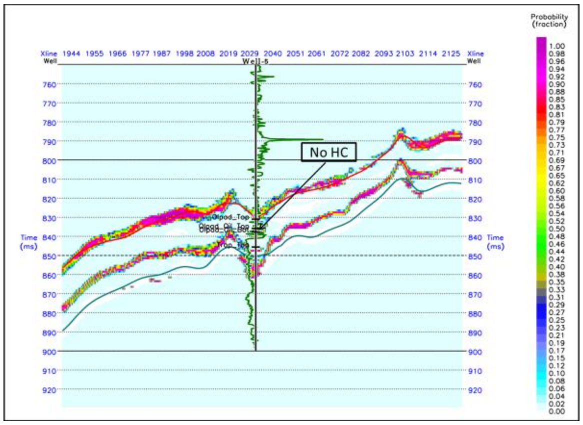

Fig.8. Cross section along well 5 predicting no Hydrocarbon sand region that corresponds to low probability.

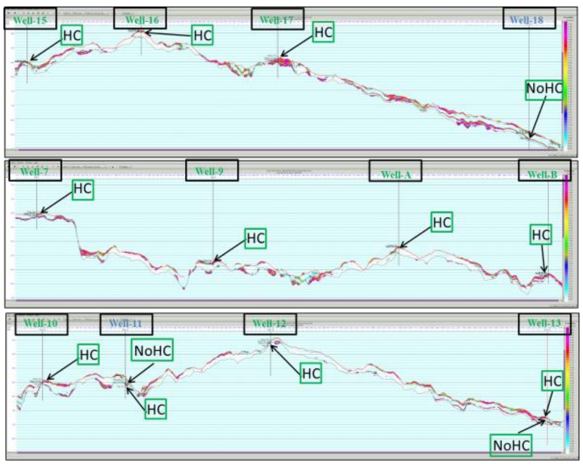

Fig.9. Arbitrary lines (3 nos.) showing the coloured impressions or regions of hydrocarbon (9) and non-hydrocarbon (3) wells.

The map was also validated by recently drilled new wells A and B. The coloured impressions in hydrocarbon sand probability sections (Figs.10a & 11a) clearly indicate better probability of hydrocarbon indication in both the wells. That means the predicted HC sand regions correspond to high probability of the order of 85 to 95%. Thus we can infer that there is high probability (>90%) within the interesting layer near the Hydrocarbon well. Also their seismic sections can be seen (Figs.10b & 11b).

Both of the recent wells A and B are producing from Olpad sands with a good rate. A validation of the hydrocarbon probability map (Fig. 6) was carried out by observing the relative probability of hydrocarbon bearing sands in and around all the 71 well locations present in the study area. Out of 71 wells 63 of the wells are satisfied, thus achieving a validation of 89%.

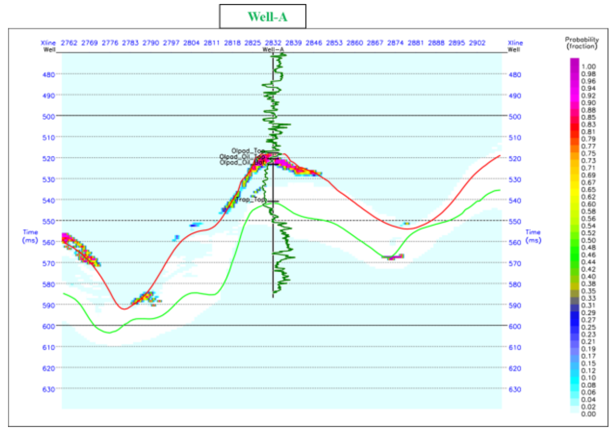

Fig.10a. Cross section along well A predicting Hydrocarbon sand region that corresponds to high probability.

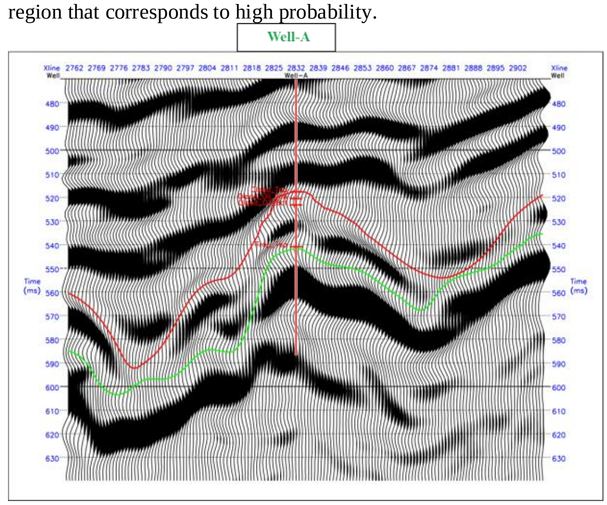

Fig.10b. Seismic section along well A

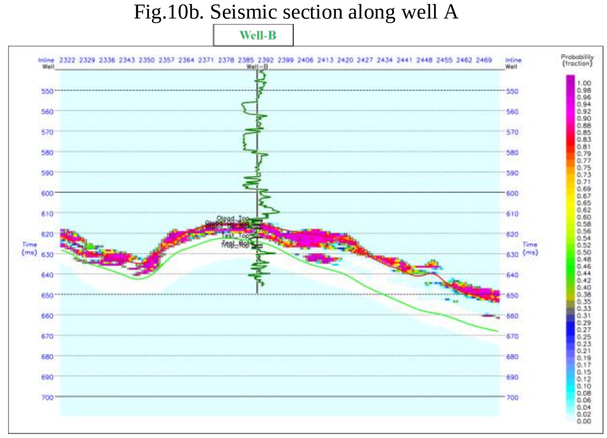

Fig.11a.Cross section along well B predicting Hydrocarbon sand region that corresponds to high probability.

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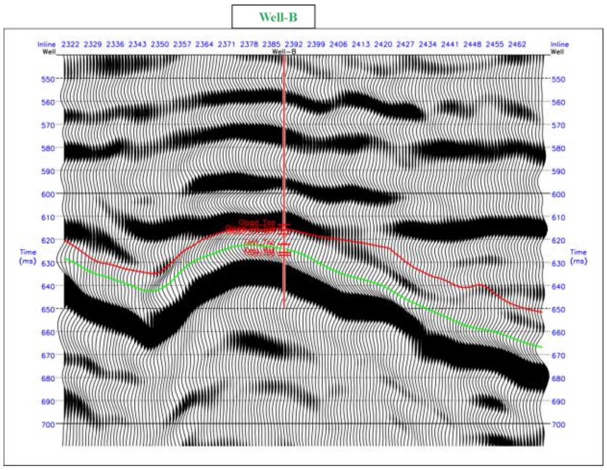

Fig.11b. Seismic section along well B

Conclusion

Delineation of hydrocarbon bearing sand can be possible if the sand probability map is prepared on the basis of lithofacies classification by using the outputs viz. acoustic (P) impedance and Vp/Vs as obtained from the Pre-stack stochastic (GeoSI) inversion. The Geostatistical inversion enables detailing of sand unit at fine scale stratigraphic grid and its outputs represent the rock properties in a better way and can be helpful in characterizing the reservoir which is below seismic resolution. The outputs like Vp/Vs and acoustic impedance in combination can be helpful in classifying the lithology grossly. The lithofacies map can be prepared by using the wells having lithologs and derived seismic attributes like Vp/Vs and P – impedance with increased resolution. Thus the wells can be utilized to train the seimic data or can be populated by taking the seismic trend to generate lithofacies map. Therefore, we may conclude that the lithofacies classification can be a useful tool in tackling the mixed lithology issues while characterizing the reservoir like Olpad formation.

N. B.: The views expressed in this paper are those of the authors only, and not necessarily the views of organization they represent.

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