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An integrated approach to delineate the reservoir facies under complex data uncertainties through multi attributes analysis: a case study from Cambay Basin, India

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Abstract:

Reservoir properties, through petrophysical analysis, when merged with seismic can bring out reservoir geometry far away from well location. Multi attributes studies applied to seismic volume helps not only in identification of reservoir distribution pattern but also gives a fair indication of the quality of reservoir which can be expected in yet to be explored/developed areas. In the study area, low impedance contrast between sand-shale which is inter-bedded with coal, hinders proper imaging of reservoir geometry. The present study pertains to Jhalora field of Cambay basin, India where Post stack seismic inversion was carried out to remove coal seam effect. Various cross plots between P-Impedance & Vp/Vs and other log attributes have been taken to identify the different lithologies with fluid type. Since the reservoir geometry is complex in nature and has variations in lithology & mineralogy, histogram of various log response along with facies and fluid have also been taken to demarcate the coal, sand & shale distribution. The cross plot between P-impedance & Vp/Vs and P-impedance & NPHI shows a clear demarcation of reservoir facies. The data was subjected to Multi-attribute analysis through application of probabilistic neural network for reservoir characterization and property prediction. This methodology with the help of log property & seismic attribute has given a lead for exploration & exploitation strategy in this heterogeneous reservoir.

Introduction:

Jhalora field, located 50 km NW of Ahmedabad is on production since 1977 from Kalol pays. The field has an areal extent of 30 sq. km (Fig.1A).The structure is an asymmetrical anticline trending NW-SE and plunges towards northwest. The field consists of three main pay zones, namely, K-III, K-IV & K-IX+X, and the other pay is Chhatral. Jhalora field has been producing from K-IX and K-IV pay sands, and so far more than 155 wells have been drilled (Fig.1B). A major fault trend has a hade towards east. Development of K-IX and K-IV sands on the western side of the fault was not clearly understood due to less well control. The main challenge of the study was to see the extension of these pay sands which is obstruct by thick coal pack present just below these sand, and is not resolved by seismic amplitudes domain in normal seismic sections.

The Jhalora field falls in the prolific Cambay Shale - Kalol Petroleum System that prevails in the north of the Cambay Basin. The principal source rocks of this system are the shales of the Cambay Group, whilst the principal reservoirs are deltaic sandstones of the Kalol Formation. This petroleum system is restricted to the Patan-Tharad, Mehsana-Ahmedabad and Cambay-Tarapur blocks in the northern half of the Cambay basin. Over 70 fields / discoveries are located within this area (May 2007), the bulk of which are located in the Mehsana-Ahmedabad Block and the southernmost part of the Cambay-Tarapur Block.

A G&G study was carried out with an objective to predict the extension of pay sand units (K-IV and K-IX), especially, in the west and southwest side of a major fault trending NNW-SSE. Post stack seismic inversion and Multi-attribute analysis based on probabilistic neural network (PNN) approach was carried out to characterize the lithology pattern of the reservoir and discriminate the fluid type present in the area of study.
The findings of the study facilitated better understanding of the likely distribution of K-IV and K-IX sands across the western flank of the NNW-SSE trending fault in the producing field. The presented

workflow focused on the methodologies for better reservoir characterization which leads to delineation of facies under complex uncertainties.

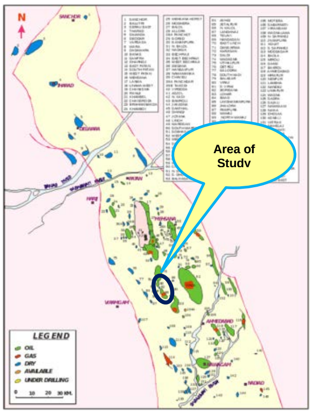


Fig.1: Index Map of study area

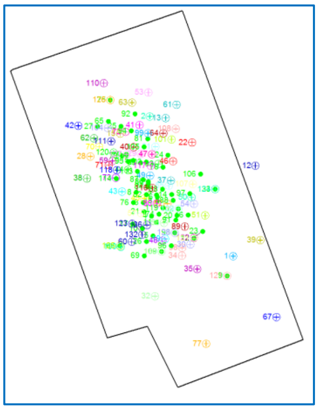


Fig.1A: Base map with wells in area of study

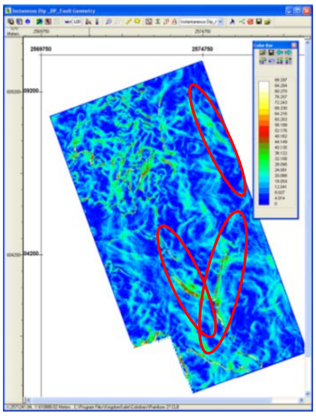


Fig.2A: Instantaneous dip attribute for fault pattern recognition

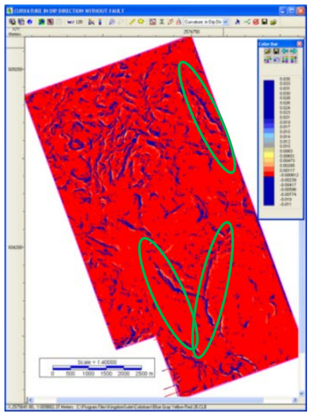


Fig.2B: Curvature in dip direction attribute for fault pattern recognition

Methodology:

Initially the efforts have been made to identify the existing fault pattern in the study area with the help of PSTM seismic data, well data and seismic derived attributes like instantaneous dip, dip of maximum similarity and curvature in dip direction (Fig.2A& 2B).The patterns revealed by these attributes are very well matched with the correlated faults on the seismic section (Fig.8B). Subsequently horizon correlation, log correlation and velocity modelling is performed to carry out reservoir characterization of the study area. Details of reservoir characterization mythologies are as follows:

1. Rock physics Analysis:

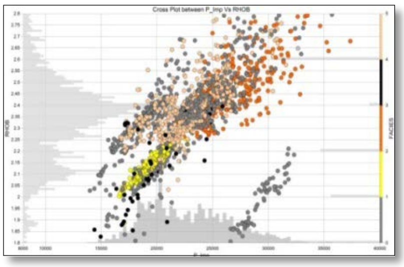


Fig.3A: Crossplot between P-imp and RHOB colored with facies

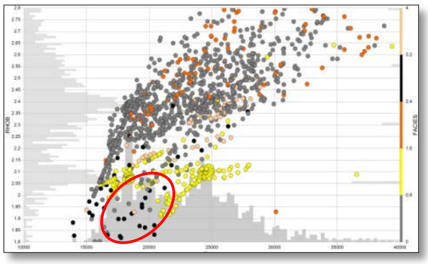


Fig.3B: Crossplot between P-imp and RHOB colored with facies

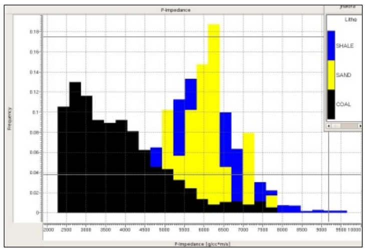


Fig.3C: Histogram of P-imp logs colored with litho-logs

From the crossplot between P-impedance and RHOB (Fig.3A) it is evident that sand, shale, silt are not discriminable in acoustic domain. Therefore the inverted volume of RHOB and impedance are not suitable for identification of lithologies but coal may be identified in the lower density range less than 1.8, which is shown in Fig. 3B. It is also confirmed by generating histogram of p-impedance logs coloured with lithofacies (Fig.3C) that the clear separation of coal from shale/sand is seen. To delineate the effect of coal on the entire 3D volume, a low frequency P-impedance model was built and model based inversion process was carried out after selecting most suited inversion parameters to generate P-impedance volume. The analysis was done in two zones namely Kalol top to K-IX Top and K-IX Top to Cambay Shale Top to discriminate the P-impedance in better way. Quality check of inversion result was performed by comparing inverted P-impedance and well P-impedance. Reasonable match between both have been observed. P-impedance section along arbitrary line passing through wells is shown in Fig.4.Further K-IV coal bottom and K-IX coal bottom is mapped in seismic for better control for deciding the windows for attribute analysis.

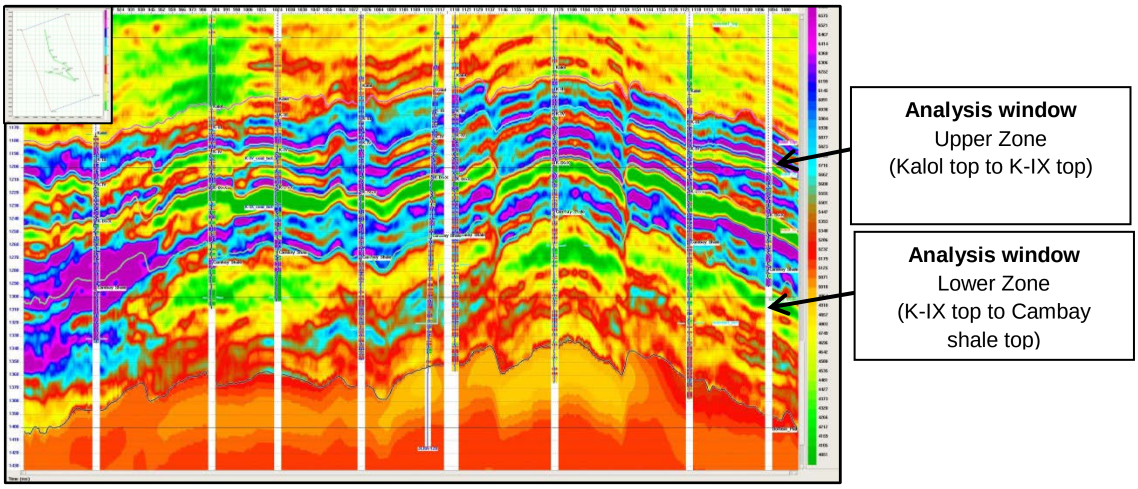


Fig.4: Inversion results along an arbitrary line overlaid with P-impedance logs

2. Prediction of Reservoir parameters:

A cross plot has been taken between P-impedance and NPHI which clearly demarcate the sands and shales. The sands are below the range of 0.35 of NPHI (Fig.5A), while impedance is ranging from 15000-20000. There are few well in which DSI log was recorded and a cross plot between P impedance and Vp/Vs has been attempted (Fig.5B).

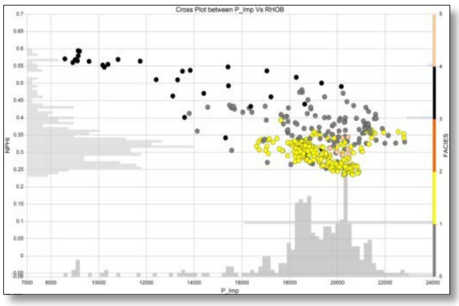


Fig.5A: Crossplot between P-imp and NPHI

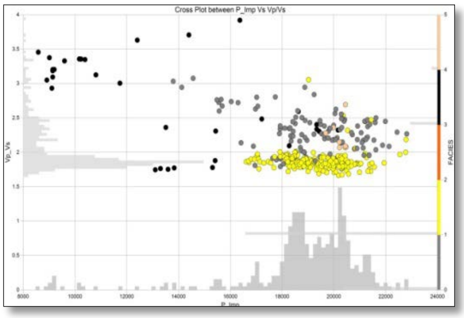


Fig.5B: Crossplot between P-imp and Vp/Vs

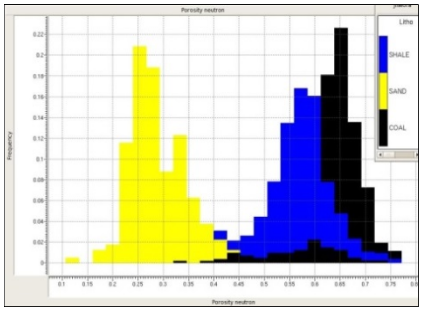


Fig.5C: Histogram of NPHI logs colored with litho-logs

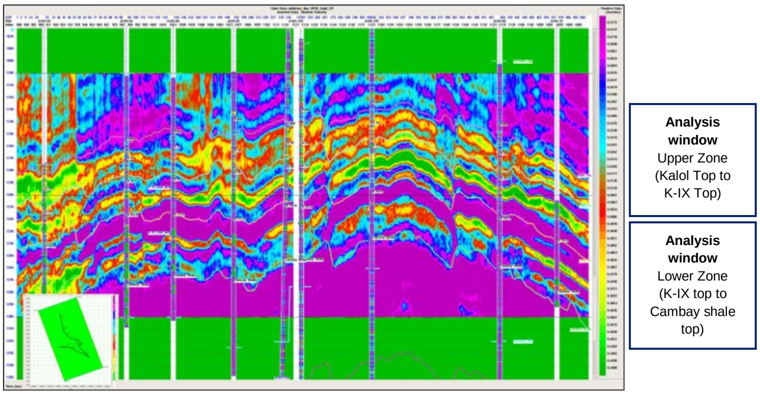


Fig.6A: Computed NPHI values using PNN along an arbitrary well line with Neutron porosity log overlay (Zone: K-IX top to Cambay shale top)

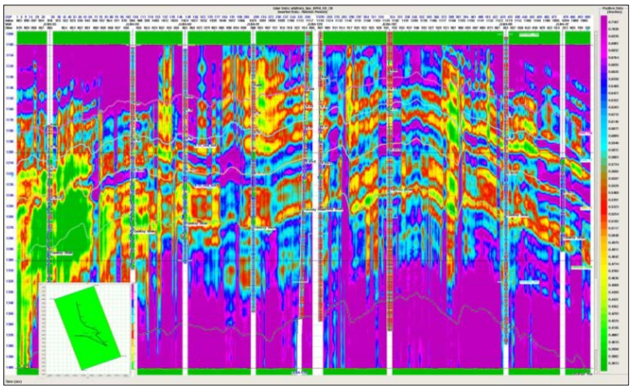


Fig.6B: Computed NPHI values using PNN along an arbitrary well line with Neutron porosity log overlay (Zone: K-IX top to Cambay shale top)

This crossplot also able to discriminate sand facies in the range 1.5-2.0 of Vp/Vs values in the same impedance range. Therefore both NPHI and Vp/Vs are good indicator for shale/sand discrimination in acoustic domain. On the basis of these crossplot results a 3D volume of NPHI has been generated using 11 seismic attributes (integrated absolute amplitude, average frequency, dominant frequency, quadrature trace, integrate, cosine instantaneous phase, second derivative instantaneous amplitude, filter 35/40-45/50, instantaneous frequency, integrated absolute amplitude and amplitude weighted cosine phase) including inversion output (P-impedance volume) in both the zones through Probabilistic Neural Network technique (EMERGE). This analysis is also performed in two zones namely Kalol Top to K-IX Top and K-IX Top to Cambay Shale Top.

Arbitrary lines in NPHI volume through wells has been extracted in upper and lower zone and is overlaid by NPHI logs reveals match between actual and predicted reservoir properties shown in Fig.6A and 6B.It is also observed from these figures that the characterization of K-IV sand is better than the K-IX sand, which is mainly due to the average seismic data quality at lower levels and less numbers of wells having NPHI logs.

Reservoir Characterization:

Neutron porosity attribute maps were generated from neutron porosity volume by picking the minimum value within the defined window. These attribute maps were generated for K-IV and K-IX sands to understand their distribution pattern. Since relatively lower neutron porosity values are indicative of better sand facies and higher neutron porosity values are relatively shaly sand or coal, the likely sand distribution pattern can be inferred from the lower values concentrations in the attribute maps.

For K-IV the sand window was identified by superimposing logs over seismic inverted sections (Fig7A). Neutron porosity distribution map in the window 12 ms below K-IV Coal bottom (K-IV_CB) shows the likely sand distribution pattern at this level, represented by low porosity value range, which is present almost everywhere and is quite wide spread in the study area except in the north western part (Fig. 7B).

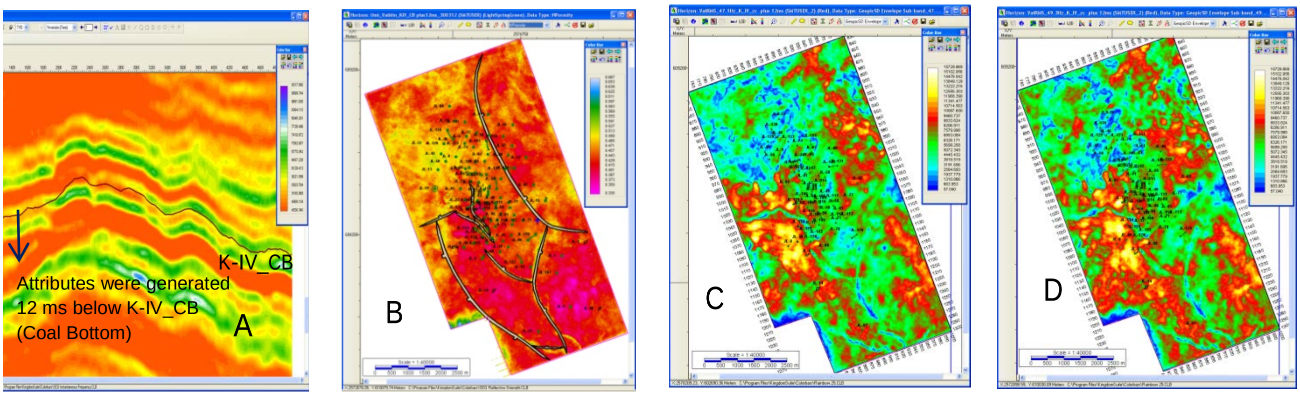


Fig.7A: Correlated horizon Kalol-IV-Coal Bottom in Impedance volume
Fig.7B: Window based Neutron porosity map from Neutron porosity volume (window: 12 ms below K-IV Coal bottom)

Fig.7C: Windowed RMS amplitude attribute (window: 12 ms below K-IV_ZC) from spectral decomposed data at 47 Hz
Fig.7D: Windowed RMS amplitude attribute (window: 12 ms below K-IV_ZC) from spectral decomposed data at 49 Hz

The aforementioned fact is also supported by the sand isopachs and high amplitudes area in the spectral decomposition maps prepared from 45 to 51 Hz indicating sand thickness of around 13 m shown in Fig. 7C & 7D.

For K-IX sand, window was identified by superimposing logs over seismic inverted sections between K-IX_Coal bottom (K-IX_CB) and Cambay Shale. This window was further divided into two units by mid horizon such that the upper unit is corresponding to the K-IX sands “A” and the lower unit corresponding to sand “B” shown in Fig.8A. The mid horizon was proportionately computed between K-IX_CB and Cambay Shale Top. Neutron porosity distribution generated within the window between K-IX_CB and mid horizon reflects the response mainly of sands A of the K-IX unit. Unlike K-IV, the sand distribution at this level, represented by low neutron porosity values appears not to be wide spread in the study area, with a northeast to southwest trend Fig.8B.

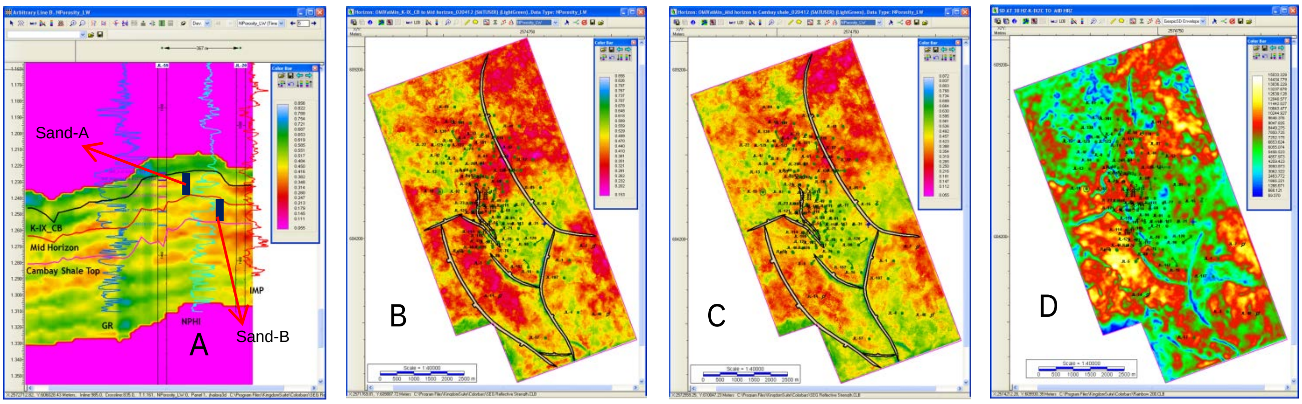


Fig.8A: A representative neutron porosity section showing K-IX_CB, mid horizon and Cambay Shale top

Fig.8B: Window based Neutron porosity map from Neutron porosity volume (window: K-IX_CB to Mid horizon)

Fig.8C: Window based Neutron porosity map from Neutron porosity volume (window: Mid horizon to Cambay shale top)

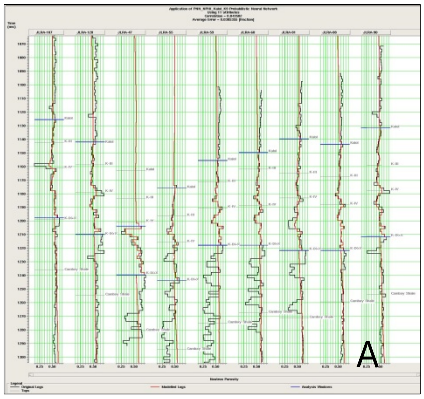
Fig.8D: Windowed RMS amplitude attribute (window K-IX_ZC and mid horizon) from spectral decomposed data at 38 Hz

Neutron porosity distribution generated within the lower unit of the window, that is between mid horizon and Top of Cambay Shale, where response could be mainly attributed to sand B, shows a similar distribution pattern as that of the upper window comprising of sands A (Fig.8C). Neutron porosity distribution in the total pack (window between K-IX_CB and Top of Cambay Shale) also shows a similar trend as shown in Fig.8C.

Spectral decomposition studies at various frequencies indicate high amplitude response at 38 Hz to 42 Hz in the area of interest implying sediment thickness of around 16 to 18 m, which corroborates with the well data (Fig8D).

Result and discussion:

From the Fig. 9 A & B it is evident that the predicted NPHI through PNN (multi attribute analysis) in upper zone i.e. Kalol top to K-IX top reveals the average correlation of 85% and validation of around 55% at well location with NPHI logs. In lower zone i.e. K-IX top to cambay shale top 90% correlation was achieved while validation was around 64% (Fig.9 C&D). This reveals a good match between predicated and actual NPHI logs at well location in the zone of interest. Therefore the NHPI volume generated from application of PNN with assimilation of P-impedance and seismic derived attributes can predict the reservoir property other than well location in better way and gives locales for further development and exploitation. The validation percentage is bit lower due to limited wells having NPHI logs, which were utilized for property prediction in EMERGE technique.



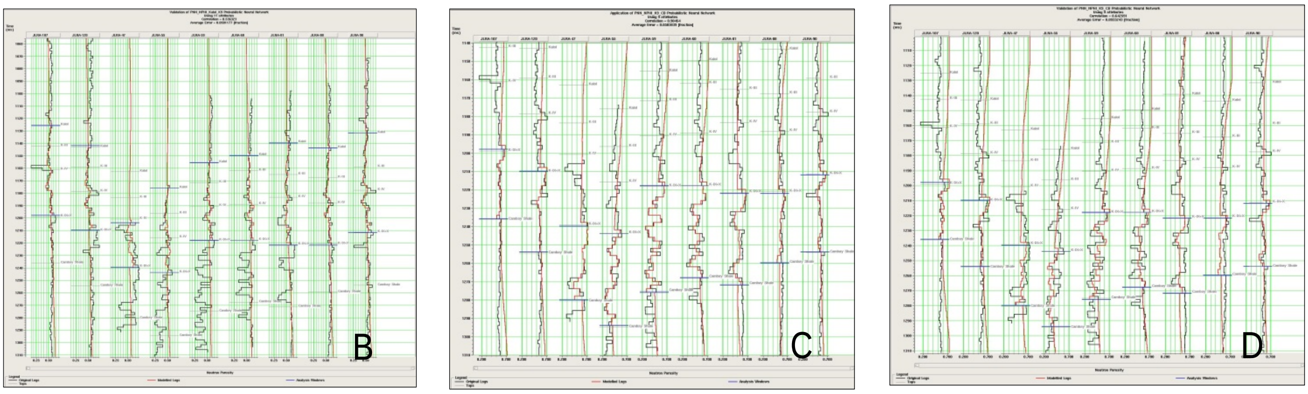
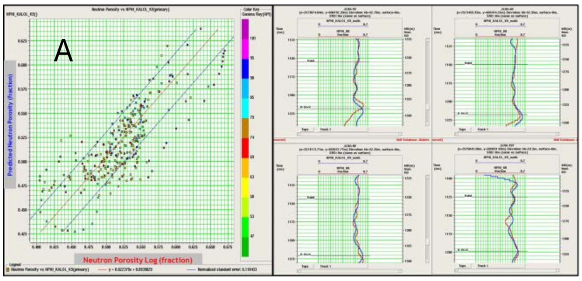


Fig.9A: Application of Probabilistic Neural Networking (PNN) for Neutron Porosity (Kalol top to K-IX+X top)
Correlation around 85%

Fig.9B: Validation of Probabilistic Neural Networking (PNN) for Neutron Porosity (Kalol top to K-IX+X top)
Correlation around 54%

Fig.9A: Application of Probabilistic Neural Networking (PNN) for Neutron Porosity (K-IX+X top to Cambay Shale top)
Correlation around 90%

Fig.9B: Validation of Probabilistic Neural Networking (PNN) for Neutron Porosity (K-IX+X top to Cambay Shale top)
Correlation around 64%



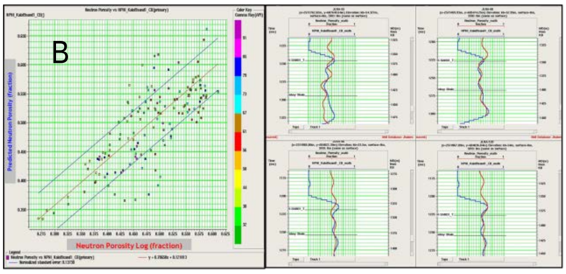


Fig.10A: Comparison between Neutron porosity log and Predicted Neutron porosity (Kalol top to K-IX+X top) Correlation is 75%
Fig.10B: Comparison between Neutron porosity log and Predicted Neutron porosity (K-IX+X to Cambay shale top) Correlation is 55%

Further validation of predicated NPHI was carried out by extracting a trace from NPHI volume at well locations and comparing it with actual NPHI logs in all the wells taken for study. The predication was validated for K-IV pay sands are of 75% (upper zone: Kalol top to K-IX Top) where the validation percentage was 55% (lower zone: K-IX top to cambay shale top) in case of K-IX sands shown in Fig 10A & 10B respectively. Thus the neutron porosity computation attempted from seismic indicates that the level of confidence in prediction of porosity distribution pattern of K-IV is better compared to K-IX sands.

Conclusions:

From above mentioned technique, present study has brought out two areas to the west and southwest of the major fault trending NNE-SSW, with good sand development as is brought out by the neutron porosity attribute maps generated within the sand windows at Kalol-IV and Kalol-IX levels, bounded by major fault to the east and OWC to the west (Fig. 7 & 8). QC cross plot between inverted impedance and well impedance shows reasonably good results indicating the possibility of deducing the lithological inferences from known to unknown. Expression of sand signatures of Kalol-IV and Kalol-IX sand units are characterized with lower order computed neutron porosity values within neutron porosity volume generated using PNN. The validation percentage of computed porosities with that of log porosities is about 54% and 64% at both Kalol-IV and Kalol-IX levels (Fig.9 & 10). Present study presented a way of unique combination of reservoir properties and seismic derived attributes through multi attribute analysis that can be utilized where the heterogeneity of fluid content is present. When there is limited number of wells in the area concern this methodology is very useful for generation of locales/leads for exploration & exploitation strategy in development stages.

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The views expressed in this paper are solely of the authors and do not reflect the view of ONGC.

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