J. Ind. Geophys. Union (October 2014)
v.18, no.4, pp:455-460

Multi-litho Attribute based Inversion for Reservoir Classification in Kalol Reservoir, Cambay Basin, India

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ABSTRACT

Kalol Field, Cambay Basin India, was discovered in June 1961 and put on production in 1964. But the production history reveals that oil recovery remained hardly around 10% (Jena, 2008). Most often, the contributing factor for this low recovery is poor reservoir facies (tight silts) within the major producing sequences like Kalol IX and Kalol X. Identifying areas of better reservoir facies remained a challenging task before the geo-scientists.

To tackle the above challenge, geo-scientists evolved seismic inversion. Inversion through sonic log has been a trend for many years as a litho-prediction tool. But it is often observed that sonic log alone is not fully effective in resolving the subtle differences between clastic facies like Silty Sand and Silty Shale.

Conventional seismic inversion approach has been modified and a "Multi-litho Attribute based Inversion" has been developed to overcome this challenge of reservoir classification in which 3D attribute volume of petrophysical properties are calculated through Genetic Inversion algorithm using a correlation between seismic property and log property. Calculated 3D attribute volume of petrophysical properties are utilized for reservoir classification.

It is known that Gamma Ray log is very effective in differentiating subtle vertical variations in clastic litho-facies in wells, whereas resistivity gives the idea of porosity. Keeping this in view, an attempt is made to develop a correlation between log property (Gamma Ray, Resistivity) and seismic property (seismic envelope) against the reservoir section in Kalol Pay and developed a "Multi-litho Attribute based Inversion" method to identify the areas of better reservoir facies within the productive sequences in the field. This approach is operative even if the reservoir is very thin beyond seismic resolution and can provide a probability distribution map of reservoir. This approach is also effective in determining the reservoir geometry and quality of reservoir, which may help in planning future drilling locations.

INTRODUCTION

Kalol Field is situated in Ahmedabad-Mehsana tectonic block of Cambay Basin (Fig.1) (Biswas, 1987). The silty-sand layers within Kalol Formation,namely K-IX and K-X (Middle to Upper Eocene age) (Fig. 2) are the main hydrocarbon bearing reservoirs (Gupta et al. 2006).

Kalol Formation consists of a combination of thinly inter-bedded sandstone, siltstone, shale and coal. Reservoir intervals can be categorized regionally and locally into numerous correlatable units. The lithology of the Kalol pay sands varies widely from silty sands to shaly silts to silty shale with coal and shale intercalations at places as well as clean porous and permeable siltstones (particularly in K-IX, the main producing horizon) (Gupta et al. 2006). Kalol pays generally show strati-structural entrapment as the formation represents an Upper Delta Plain depositional system. Hence, the reservoir quality shows dependency on facies distribution. The main reservoir lies within the Kalol formation

In Kalol reservoir, a series of thin clastic reservoirs are sandwiched between K-IX and K-X exhibiting several lateral lithological variation. Seismically, it is difficult to resolve the reservoir as they are beyond seismic resolution and over and underlying coal layers mask the seismic wave, creating resolution problem.(Gupta et al., 2006). Due to the above limitations, conventional seismic inversion has been modified through an integrated approach and a "Multi-litho Attribute based Inversion" method has been developed to identify the areas of better reservoir facies within the productive sequences.

ANALYSIS AND DESCRIPTION

The specific details and the effectiveness of "Multi-litho Attribute based Inversion" is illustrated with a case study. The study area (Fig.1) is a marginal field of Kalol Field situated in Ahmadabad-Mehsana tectonic block of Cambay Basin. Like the other parts of the Kalol Field, the main reservoir lies within Kalol Formation, namely K-IX and K-X (Middle to Upper Eocene age) (Fig.2) and suffers from considerable facies variation. The study area(4.5sq-km) is fully covered by 3D PSTM seismic data. 5 wells (A, B, C, D and E) are drilled in this region. Gamma Ray (GR) and Resistivity Logs (RT) are available for all five wells ,while Sonic (DT) and Density logs are available only for wells

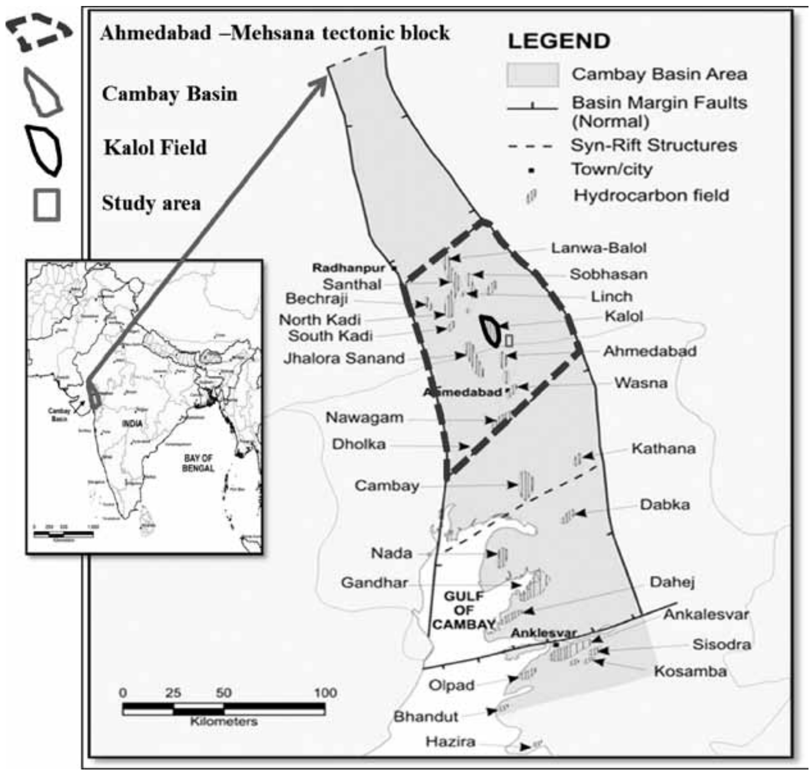

Figure 1. Location map of the study area (Modified from Dhar & Bhattacharya 1993) showing major hydrocarbon field in Ahmedabad-Meshana tectonic block .The study area is a part of Kalol field, Cambay Basin, India

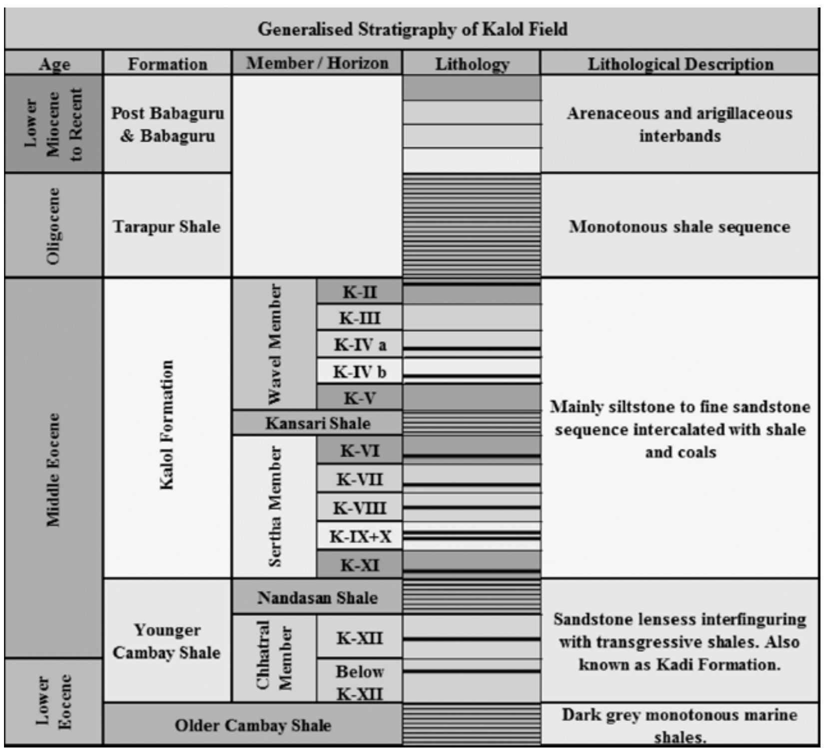

Figure 2. Generalized Stratigraphy of Kalol field (Modified from A.K. Jena et al., 2008).

A, B and C. Out of these five wells, only 'Well-A' gives oil production of the order of 10-15 M^3 /d ,whereas other wells produce at very low rates (1-1.5 M^3/d).

MULTI-LITHO ATTRIBUTE BASED INVERSION

This is an approach to derive petro-physical attribute from seismic attribute (amplitude based) and well logs. Multi layer neural networks as well as genetic algorithm are combined in order to provide a robust and straight forward seismic inversion. The estimation of rock properties using seismic data and derived attributes has always been a very important but challenging task. There are number of different methods for achieving this goal. All of them are based on strong and constraining a priori information. The required knowledge of an initial model (for the stochastic inversions), or source wavelet (colored, Sparse Spike inversion), is in several cases hard to acquire,if not impossible. Moreover, the results of this kind of inversion is often biased by the initial model itself.

In the case of Genetic Inversion, the required inputs are limited to the seismic attribute (amplitude based) and well logs used as training data. Indeed no single unique wavelet, initial property modeling, is needed as input prior to run this inversion. A genetic algorithm back -propagates the error in order to update the weights for the neural networks. The advantage of this method of generating a property estimation, is that the genetic algorithm constrains the convergence of the inversion in a way that the chance of achieving a minimum error is much greater than in other neural network based inversions.

In the present case, seismic envelope cube is generated from the seimic volume through volume attribute analysis. The calculated envelope cube is trained with GR, RT and DT logs to establish a correlation between seismic envelope and petrophysical logs. Using the corelation between seismic envelope and petrophysical logs (GR, RT & DT), genetic inversion has been performed to calculate 3D attribute volume of the petrophisical property (in this case GR,RT and DT). The above process is repeated until a good match is observed between the actual and the synthetic logs. Fig.3 shows the comparison between the actual/ synthetic curves generated from "Multi-litho Attribute based Inversion". Finally the calculated 3D attribute volume is resampled(upscaled) in the structural grid.

SEGMENTATION

It is observed that GR and RT value ranges from 65 to 85 API and 10 to 15 ohm-m in Well-A, Well-B and Well-C, while in Well-D and Well- E it ranges between 45 and 55 API unit and 4 to 8 ohm-m (Fig.3). GR indicates some characteristics of the provenance from which the sediment is derived. It is apparent that there is a possibility of two different streams bringing the sediments from two proximal but distinct provenances.

Thus, the litho-facies mapping has been carried out by considering two separate segments. Segment I comprises Wells A, B and C ,whereas Segment II comprises Wells D and E. It is to be noted that this segmentation has no tectonic significance and it is only for the purpose of litho-facies mapping.

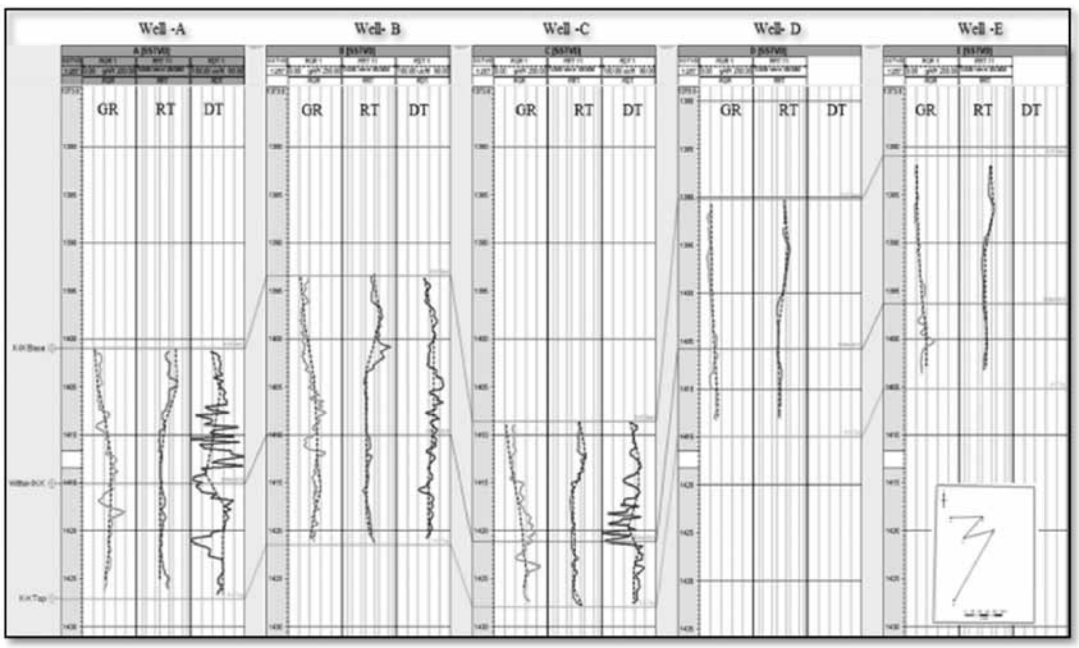

Figure 3. Comparison with the actual/synthetic curves generated from Multi-litho Attribute based Inversion approach. The black dotted curves are the synthetic curves generated from the Multi-litho Attribute based Inversion

SEISMO-FACIES CLASSIFICATION

Reservoir and non-reservoir facies(seismo facies) volume is seperated out based on a mathematical relation(logical operation) of the calculated 3D attribute volume of petrophysical properties. In the present study following empirical relation is used for reservoir classification:

Reservoir in the Segment I

RE SegI=if ((GR<=85 and RT>=10), Reservoir, otherwise Non Reservoir)................(I)

Similarly,

Reservoir in the Segment II

RE SegII=if ((GR<=60 and RT>=4), Reservoir, otherwise Non Reservoir)................(II)

Fig.4 shows the reservoir and non reservoir distribution within the field calculated from the above mathematical relations. It indicates the existance of two different clusters of reservoir within the area.

Fig.5 shows the reservoir distribution at top reservoir level with degree of certainty. The yellow to pink color represents good reservoir to non reservoir. It is apparent that only Well A is located in a region of 100% certainity. This proves the fact that the production in Well A is maximum among all the wells. However,one must note here that the cutoff values GR and RT vary from field to field.

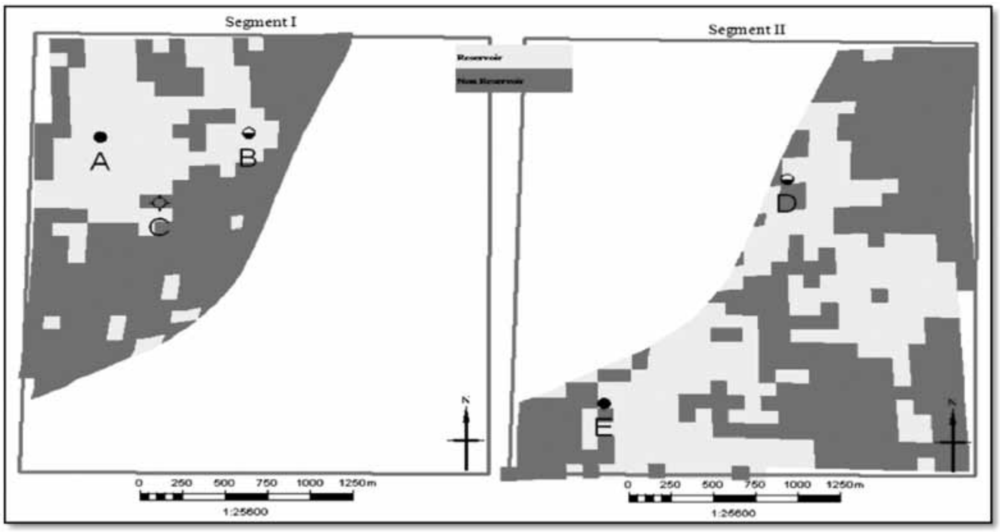

Figure 4. Reservoir classification at top reservoir level for Segment I and II.

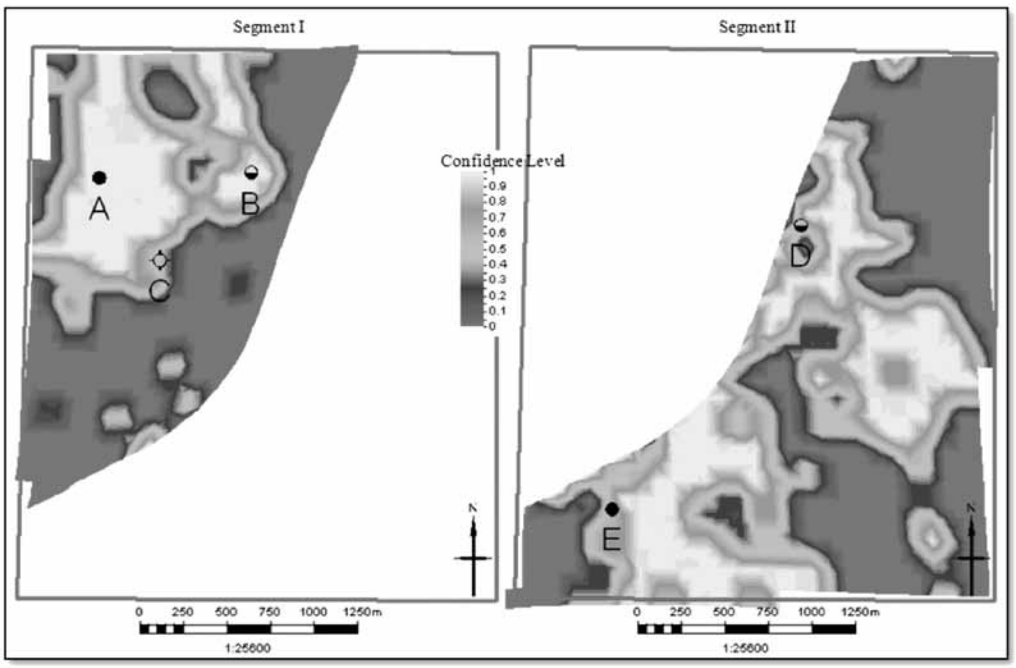

Figure 5. Probability distribution map of top reservoir level.

RESERVOIR CLASSIFICATION

The reservoirs are classified broadly into four categories viz., Good Reservoir, Moderate Reservoir, Non-Reservoir and Coal. The well correlation and facies distribution at well location is shown in Fig.6. This indicates that the reservoirs show maximum depth at Well C and minimum at Well E. In addition, the reservoirs suffer considerable lateral facies variation within the wells.

Facies Modeling is processed by Sequential Indicator Simulation (Geo-statistical-Algorithm) taking seismo facies as calculated by the "Multi-litho Attribute based Inversion" as the base model. The seismo facies volume (attribute volume calculated from Multi-litho Attribute based Inversion) is used as a secondary input to provide the trend to the facies modeling away from the well location.This approach effectively uses the seismic property (Seismic envelope) for facies classification over well based facies modeling.The intersectional & 3D view of facies distribution within the field is shown in Fig.7.It shows that out of the five wells, only Well-A was drilled at good reservoir facies (Sand) and the other wells B,C, D and E are drilled in moderate reservoir facies (Mainly Silty). Fig.8 shows the facies variation through the wells. Here, the facies model is superimposed on depth domain seismic section to show the facies distribution within the reservoir sequence.

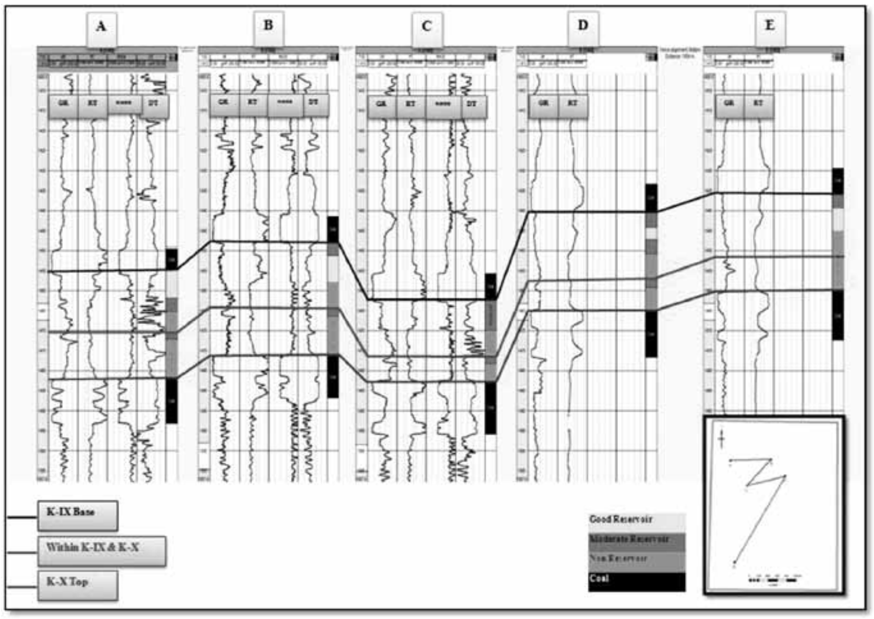

Figure 6. Well correlation map and identified litho-facies log. Litho-facies logs show lateral variation of facies and the reservoirs are very thin.

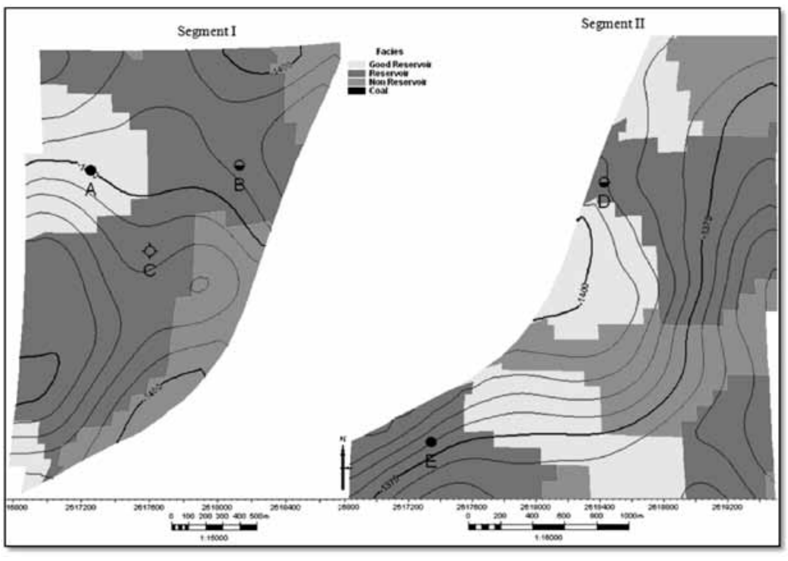

Figure 7. Facies distribution map at top reservoir level for Segment I and II

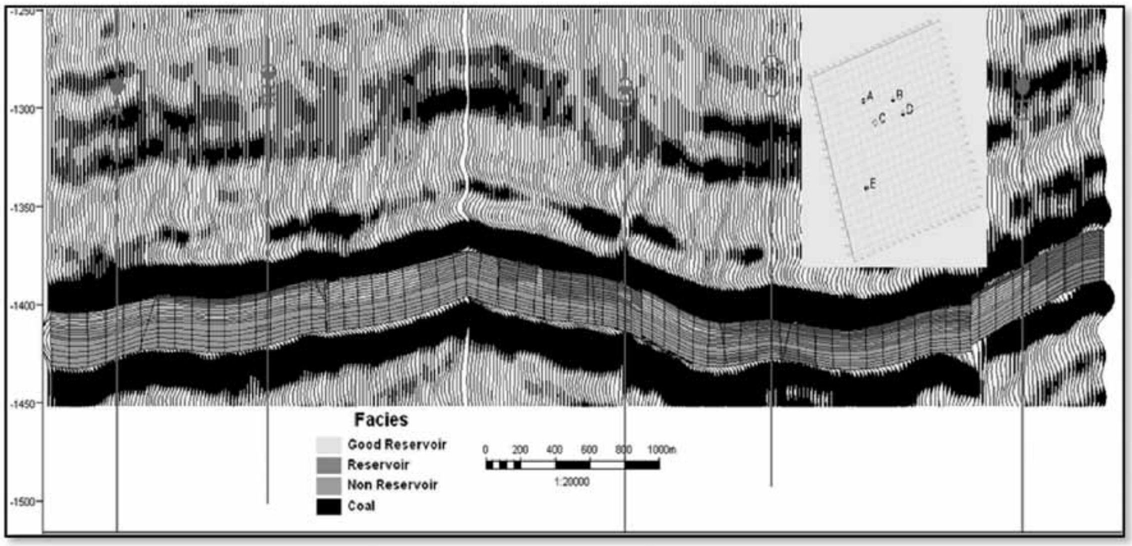

Figure 8. Intersectional view of facies distribution within the reservoir sequence (Arbitrary line passes through the wells)

CONCLUSIONS

"Multi-litho Attribute based Inversion" provides a way to generate 3D attribute volume of log property(GR, RT, DT and other conventional well logs) from seismic and well log data.

Reservoir/Non reservoir can be easily separated out using this approach.

This approach is operative even if the reservoir is very thin beyond seismic resolution and can provide a probability distribution map of reservoir.

"Multi-litho Attribute based Inversion" approach is very effective in determining the reservoir geometry and quality of reservoir ,which may help in planning future drilling locations.

This innovative and integrated approach greatly helps in improving the success rate, fluid recovery from the field and finally the economics of the investment.

ACKNOWLEDGEMENTS

Author is grateful to Prize Petroleum Company Limited (a wholly owned company of HPCL) and ONGC for providing the necessary information to carry out this work. Author acknowledges his sincere thanks to Mr. M K Surana, CEO Prize Petroleum for giving permission to publish this work. Author also acknowledges his sincere thanks to Dr Prabhakar Thakur, Head Technical, Prize Petroleum and Mrs Kavita Bhardwaj,Manager, Prize Petroleum for their valuable advise. Author is greatful to Mr. Syam Sundar Yalamarty and Dr Udayan Dasgupta advisor Prize Petroleum for their valuable guidance.

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