Identification of spatial distribution of a discrete Barail sand integrating horizon and statistical approach - A case study from Upper Assam Basin

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Keywords

Impedance, Barail sand, lithofacies

Abstract

The Barail formation of Upper Assam Basin was deposited in fluvio-deltaic depositional environment where sand acts as potential hydrocarbon reservoir and Barail coal-shale unit act as a cap rock. Generally, it has been observed that, in case of an unconsolidated and undercompacted sand the acoustic impedance contrasts between brine sand and shale are very less. However, when the reservoir sand is saturated with hydrocarbon specially gas, a prominent impedance contrast has been observed in the sand-shale interface. The above situations are constrained by boundary conditions of fluid saturation, reservoir thickness and depth.

This study aims to delineate the extension of a hydrocarbon bearing gas sand encountered in a well within the Barail Argillaceous formation, which was absent in two nearby wells. During the study, seismic inversion was integrated to aid the resolution limit of conventional seismic section. Since, impedance can be related to layer rock properties, seismic inversion volume is helpful for mapping of the sand body, which was previously difficult to be interpreted in a seismic section. Also, inversion may attain resolution limit up to $\lambda/8$, provided seismic has good S/N ratio, where λ is the seismic wavelength.

Initial impedance log data analysis within reservoir zone of the Barail Argillaceous formation have confirmed that coal, sand & shale can be separated based on their impedance ranges. However, hydrocarbon and brine sand can't be separated because of their overlapping impedances. In the derived acoustic impedance inversion volume, sand and shale can be broadly classified. So, instead of a deterministic approach for lithology classification, a statistical approach based on Bayesian classification was adopted. Probability density function (PDF) for different lithofacies viz. sand, shale and coal has been calculated using log data and then populated in the acoustic impedance volume to derive most likely lithofacies volume.

Further, horizon interpretation was done on the acoustic impedance volume to map the top and bottom of gas sand which was exhibiting a composite low impedance response. Isochrone map was prepared using the mapped top and bottom horizons and thickness map was analyzed to delineate the possible extension of the hydrocarbon sand within the study area.

Overall, the integration of conventional mapping and statistical based approach in this study enhanced the confidence in interpretation, where conventional seismic has limitation in terms of resolution and continuity.

Introduction

Upper Assam basin is a petroliferous basin having hydrocarbon prospect from Lower Eocene to Miocene age formation. The study area is located in the North-West of OIL's main producing area having hydrocarbon potential within Barail sand of upper Eocene-Oligocene age. Barail sands are good quality reservoir rock and broadly classified into Barail Argillaceous and Barail Arenaceous units, which are further subdivided into different sand groups. However, there are some lenticular sand bodies developed within the Barail argillaceous unit that are difficult to correlate between the wells.

In the study area, initially two wells (02) viz. well D-1 and M-1 were drilled in a NNE-SSW trending anticlinal structure. This structure is a three way closure which is bounded by a major NE-SW normal fault in the west and a E-W trending normal fault in the south. The northern part of the structure is bisected by a minor N-S trending normal fault dipping towards east. The first well M-1 was drilled in the structure encountered gas within Barail formation and subsequently, well D-1 had also established the northerly extension of hydrocarbon (HC) bearing sand encountered in well M-1. In later phase, based on structural configuration and seismic interpretation two more wells viz. D-2 & D-3 were drilled to know the extent of this reservoir sand. Well D-2 & D-3 were drilled towards NE and SW direction of well D-1 respectively (refer to Figure-1).

However, in both the wells the reservoir sand was absent. It was inferred that, the development of the HC bearing Barail sand is very limited and does not continue towards NE-SW direction. So, to examine spatial distribution of the reservoir sand, as a part of post drill analysis, a model based post stack seismic inversion was carried out and interpreted deterministically and statistically to know the possible spatial extent of the reservoir sand. During the study, isochrone map from horizon and PDF based probabilistic volume were analysed to understand the facies development in the area.

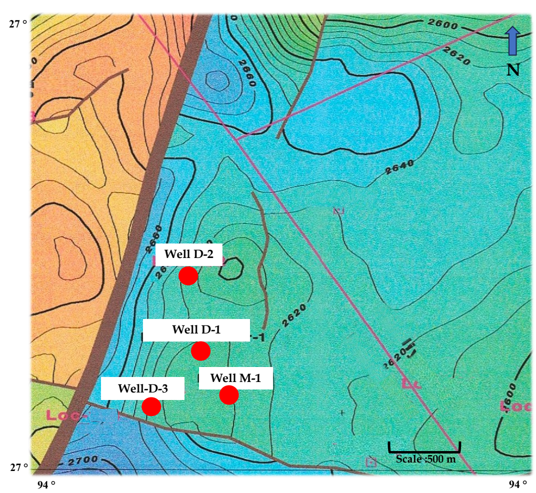

Figure 1: A TWT map of the study area with wells.

Method

The reservoir depth in the study area is around 3300 m and the well D-1 shows three sand bodies viz. S-1, S-2, S-3 within reservoir interval. The log interpretation of well D-1 is shown in Figure 2. Out of the 04 wells drilled in the study area viz. D-1,D-2, D-3 & M-1, S-2 gas sand was absent in wells D-2 & D-3. Instead, a shale break developed between the upper (S-1) and lower (S-3) sands. The sand development between well D-1 and D-2 is shown in Figure-3.

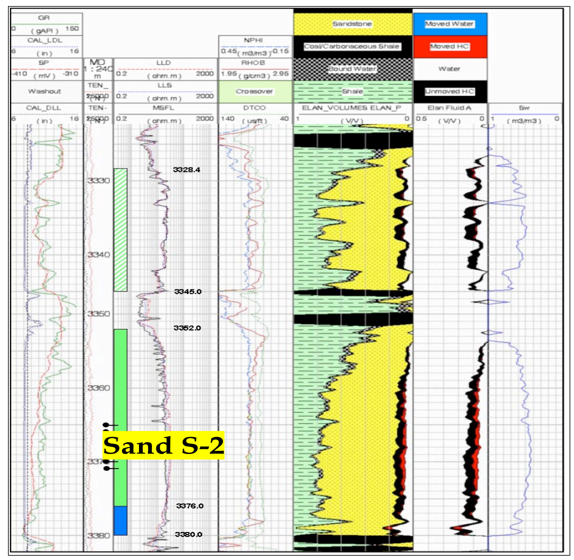

Figure 2: Log interpretation of well D-1. Sand S-2 is the gas bearing sand.

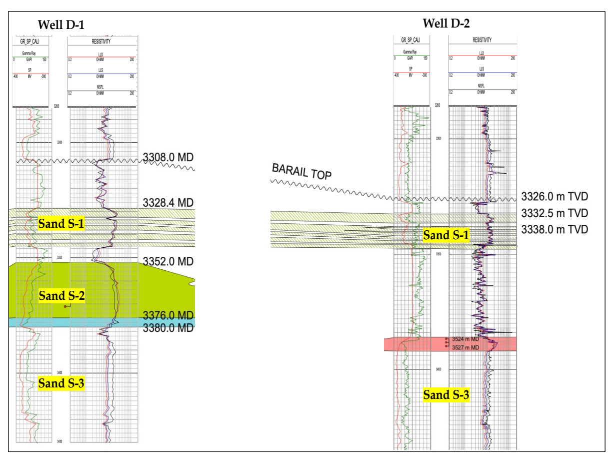

Figure 3: The sand development between well D-1 and D-2 is shown in the figure. The absent of gas bearing S-2 can be observed in the well D-2.

Feasibility analysis of well log (Impedance) data within the target interval shows that sand, shale, and coal can be differentiated based on the acoustic impedance. However, due to overlapping of the acoustic impedances gas and brine saturated sands could not be differentiated. Well log feasibility for well D-1 is shown in Figure-4.

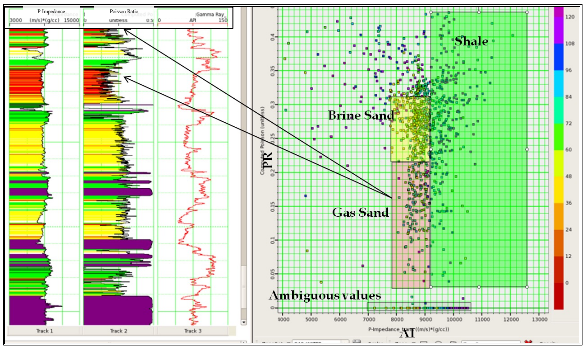

Figure 4: Log cross plot at well D-1 indicating overlapping of impedances between brine and gas sand. Shale and sand can be discriminated on the basis of P impedance.

Subsequently, a model-based post-stack inversion was carried out to delineate the possible extension of the reservoir sand. Well-to-seismic tie for well D-1 is shown in Figure 5.

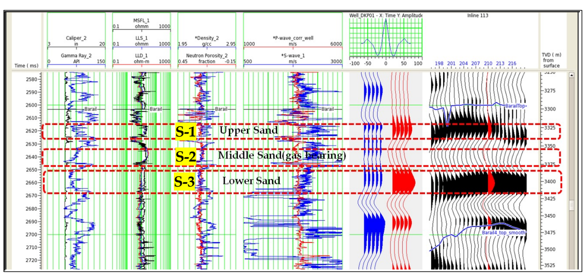

Figure 5: Well to seismic tie at well D-1 highlighting sands S-1, S-2 & S-3. Notice the small separation between S-2 & S-3 sand.

The study found that the resolution of seismic data limits the ability to distinguish individual sand bodies in the impedance volume. While there was successful resolution between sand bodies S-1 and S-3 due to their larger separation, the small separation between S-2 and S-3 at well D-1 led to a composite response in the seismic data and subsequent inverted volume. At well D-1, a composite low impedance anomaly has been observed for the gas sand S-2. The composite impedance response of gas sand S-2 is relatively lower compared to the composite response of S-1 and S-3 at wells D-2 & D-3. An impedance section passing through wells D-1, D-2 and D-3 is shown in Figure 6. Taking reference of the composite response of HC bearing S-2 sand and lower S-3 sand, top and bottom of the composite response were marked as H-1 and H-2 horizons respectively and isochrones map was prepared in the study area.

Additionally, Probability Density Function (PDF) was generated from the impedance log and three different facies viz. sand, shale and coal were classified. The PDF was then populated in the impedance volume to derive facies volumes in the study area.

Probability distribution function (PDF) is a mathematical tool that quantitatively represents the likelihood of different classes occurring based on observed characteristics. It aids in the interpretation and classification of subsurface rock units without making assumptions about data distribution. By utilizing sample data directly, this non-parametric kernel density estimation approach allows for accurate lithofacies interpretations without restrictive assumptions (Ocampo-Duqueetal.2013).

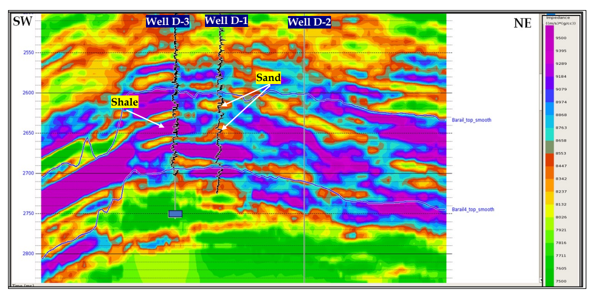

Figure 6: Sand and shale classification in acoustic impedance section. Composite response for HC bearing S-2 sand & S-3 sand can be observed.

Horizon mapping: Two horizons viz. H-1 & H-2 were marked at top and bottom of the composite response of gas sand S-2 and lower S-3 sand respectively. The interpreted horizons H-1 and H-2 overlaid on an acoustic impedance section is shown in Figure 7 .

The purpose of the horizon interpretation in this study is to map the composite low impedance anomaly for the gas sand and generate an isochrone map. The thickness of the composite low impedance anomaly may be correlated with the possible extension of the

HC bearing sand. The contour of the map (shown in Figure 8) also shows a thickness trend along NW-SE direction. It has been observed that, well D-1 and M-1 is falling in the thickening trend and well D-2 and D-3 is falling away from the trend.

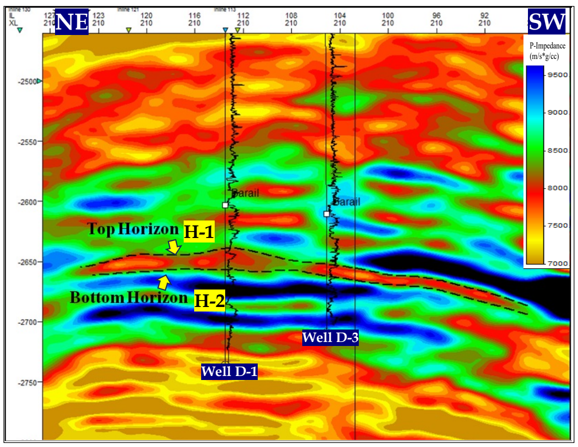

Figure 7: Interpreted horizons H-1 & H-2 overlaid on an acoustic impedance section. Top and bottom composite acoustic impedance response for gas sand S-2 and lower sand S-3 is marked as H-1 and H-2 horizon respectively.

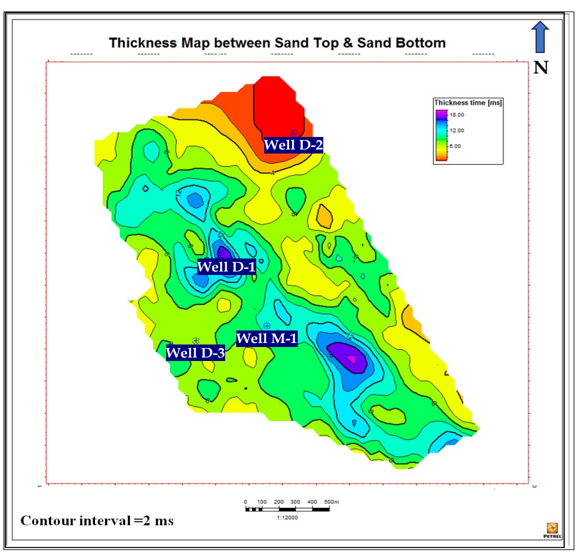

Figure 8: Isochrone map of H-1 & H-2 horizon indicating the thickness trend along NW-SW direction.

Lithofacies classification integrating PDF and seismic inversion: In the Barail formation it has been observed that, if the reservoir depth is not too great, velocity trend varies with different type of fluids & lithology for e.g., Shale, brine sand, oil/gas sand. However, at greater depth, reservoir velocity has tendency to overlap for different fluids and lithologies. Since in the study area sand, shale and coal have different acoustic impedance ranges, instead of using a deterministic approach (based on user defined cut-off values) to differentiate lithofacies a PDF based approach was adopted.

PDF has been estimated from acoustic impedance log data to quantify the most probable lithology in the zone of interest. It has been found that, based on the PDFs, sand, shale and coal lithologies can be classified in the wells (shown in Figure 9).

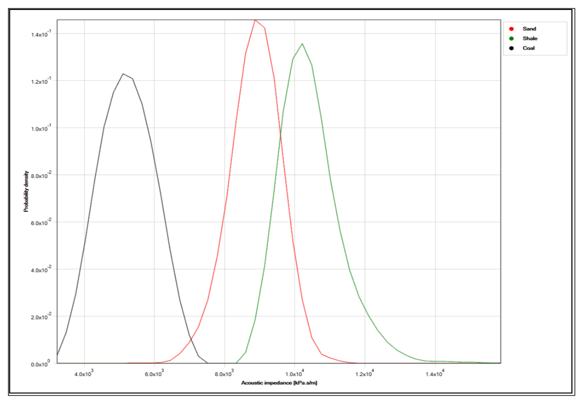

Figure 9: PDF function for sand, shale & coal lithology from P- Impedance log.

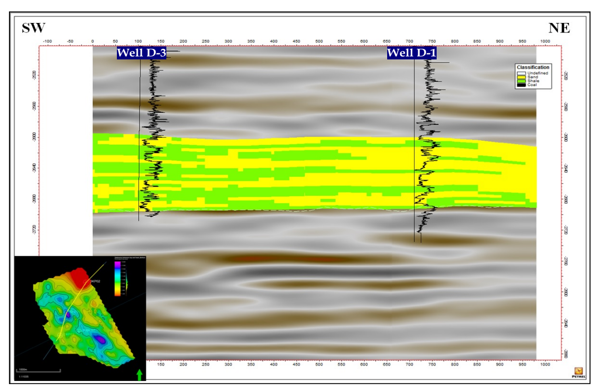

Figure 10: Lithofacies profile passing through well D-3 and D-1 showing sand (yellow) and shale (green) development across the wells.

Therefore, the PDFs was further upscaled to seismic frequency and populated over the impedance volume to derive a lithofacies volume. The resultant lithofacies volume contains all the litho-classes viz. sand, shale and coal generated using the PDFs. A lithofacies section passing through well D-3 and D-1 is shown in Figure 10. In the lithofacies volume the variation from sand to shale was very distinct between the wells. The continuation of the sand body from well D-1 to M-1 can also be seen in the Figure 11.

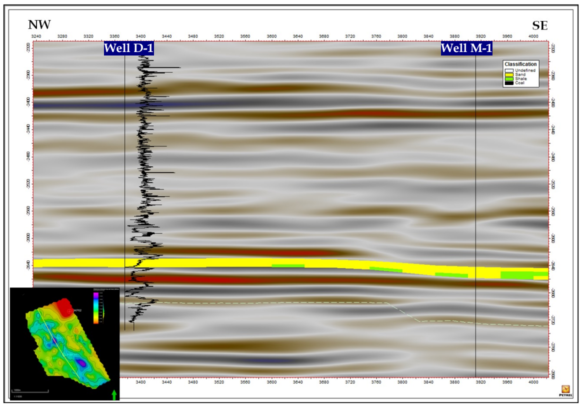

Figure 11: Lithofacies overlapped on seismic profile showing sand continuation across well D-1 and M-1.

Conclusion

Sometimes, in a seismic section it is difficult to delineate different lithologies due to certain reservoir condition like thickness, depth and fluid saturation etc. However, an integration of qualitative and quantitative attributes may be helpful to find out a plausible geological model of the subsurface. In this study, though the mapping of the lenticular sand body within Barail formation possess a challenge, the integrated analysis of the lithofacies volume and composite low impedance anomaly thickness trend helped to find out the limited extension of gas sand encountered in well M-1 & D-1.

Limitation and Way forward:

This study aims to integrate all the available data deterministically and statistically to reduce the exploration risk. However, the study has limitation with the availability of post stack inversion data only. Availability of pre-stack inversion volume may better delineate fluid and lithology in the study area.

References

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