Reservoir Characterization in Coal Dominated Deltaic Environment- Case Study

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Abstract
The present study deals with two different fields of Cambay basin. The complex geological environment in the fields, has resulted in abrupt facies variations. Presence of thick coal above reservoir facies also reduces the ability to quantify reservoir properties and its extension. Simpistic reservoir models may not be able to capture the finer details in such environments. To address these challenges, detailed reservoir characterization has been performed. To identify geo-bodies, facies boundaries and geomorphological features, targeted seismic attribute analysis, waveform classification and inversion was carried out. In the first case study, a channel system at K-X/XI pay level has been identified. Moreover, qualitative assessment of K-XI reservoir facies was carried out by using inverted p-impedance volume. The second case study, which is post drill analysis, was carried out to examine the cause of missing of Kalol pays in a well. The study successfully identifies the termination/pinch-out of the Kalol pays.

Introduction
The Cambay basin in western onshore of India, is a composite basin characterized by two stage structure; an Upper Cretaceous-Tertiary basin superimposed upon Upper Jurassic-Lower Cretaceous platform basin\(^1\). These two stages are separated by thick basaltic (Deccan) Traps. The upper structural stage is i.e. Upper Cretaceous-Tertiary basin is classified as Marginal Aulacogen Rift Basin\(^2\). Based on the regional basement fault trends, the basin has been divided into several blocks, namely Sanchor-Patan, Mehsana- Ahmedabad, Tarapur, Broach-Jambusar and Narmada. The generalised stratigraphy of Cambay basin is shown in figure-1. The depositional environment of Cambay basin varies from marine to deltaic to fluvial. Two case studies have been carried out in two different fields of Cambay basin.

Figure-1. General Stratigraphy of Cambay Basin.

The first case study is carried out for Sertha member pays (K-X/XI) of Kalol Formation where the environment is predominantly deltaic. The targeted reservoir is overlain by thick coal (K-IX), causing difficulty in reservoir delineation. Presence of multiple layers of coal, which, exists above the target reservoir reduces characterization ability of seismic data. Well log data, on the other hand provide most accurate lithology and fluid properties near the wellbore. Populating well data based on interpolation methods such kriging/variograms may give reasonable distribution of simple reservoirs, but when the reservoir geometry is guided by deltaic/Pro-deltaic environment, these interpolations may not capture the detailed variations in geometry and properties of reservoir facies.

In the second case study, the field lies in basinal margin and the depositional environment is pro-deltaic. Due to steep slope, the reservoir facies
terminates abruptly, making placement of new wells challenging.

**Methodology**

3-D seismic data may provide useful insights in identification and delineation of reservoir facies in coal dominated environments, which always poses a great challenge. Techniques such as seismic post/pre-stack inversion, multi-attribute analysis and, waveform classification have emerged as great tools not only for reservoir delineation but also for the integration of well and seismic data. These techniques have been applied in both case studies, to delineate reservoir geometry/channel system and for the reservoir characterization.

**Case study-1**

The study was carried out in fields of Cambay basin where the target reservoir (K-X/XI) was lying below thick coal seam (K-IX coal). As the coals have strong reflectivity contrast vis-a-vis other sedimentary rocks, they absorb/reflect most of energy of the seismic. To overcome these challenges unsupervised waveform classification was carried out from horizon near K-X top to 30ms window. The classifier uses neural network to identify similar wave shapes in the given window and then assigns it to one class. Four classes were generated in the process and one of the class (in cyan color) shows channel like feature (figure-2a & b).

Using the seismic data, a 3D volume of dominant frequency was generated and for the same time window (K-X top to 30ms window) mean of dominant frequency was extracted (figure-3a & b).
Both, the waveform classification and slice of mean amplitude of dominant frequency shows a channel like feature. The channel orientation is broadly from north to south, with meandering like feature in-between. The direction of the channel is similar to regional dip direction. A smaller NE-SW trending portion of channel could be a Chute channel. The facies observed in the chute channel is dominated by coal while the primary channel has silty-sand to shaly facies at k-XI pay level.

The southernmost part of channel appears like beginning of river mouth. The width of the observed channel is about 1.5 km in the north and about 3.5 km in the southern most part. To delineate reservoir facies variations of K-XI pay, post stack inversion was carried out. To understand the property distribution, well correlation for K-XI pay was carried out. Correlation of four wells is shown in figure-4, flattened at K-IX Coal Top. As seen in the well correlation, the well A, B and D have poor reservoir facies. While Well C has good reservoir facies. An arbitrary line of p-impedance passing through well-A, B, C, and D is shown in figure-5.

Due to poor resolution, the impedance response is combined effect of K-X and K-XI pay. Therefore K-X and K-XI pay could not be delineated separately. Areas where K-X pay is not present (or shale out), the variations in the impedance can be attributed to changes in properties of K-XI pay. In the field, the impedance of shale is higher than that of sand.

In the p-impedance section (figure-5), it is observed that well-A, B, and D has much higher impedance value than Well C. The highlighted area in the impedance color bar shows the probable range for better reservoir facies (6700 to 7300 KPa.s/m). It should be noted that the impedance may provide only qualitative assessment of K-X/XI pays and it can not be utilized for quantitative interpretation due to poor resolution.

**Case study-2**

The field of study lies in the basin margin of Cambay basin (figure-6). Sedimentary structures and the
distribution pattern suggest deposition of Chhatral in prodelta / distal delta front environment, whereas K-III+IV unit is inferred to have been deposited as distal delta front facies. The study was carried out in field to analyze the missing Kalol pays in one of the drilled wells. Well-X was drilled to target Kalol pays, but it was observed that only high density oolitic layer which lies just below Kalol top, was present. All other Kalol formations were missing in the well. The next well-Y was drilled 254 m. west of well-X, which has encountered various Kalol formations and K-VI/VII pay.

The well correlation (figure-7) shows that kalol top and oolitic layers are present in both of the wells but other Kalol formations are missing in well-X. Also, K-VI/VII pay is present in well-Y. It is not possible to narrow down the boundary of Kalol formations based on well correlation only. To demarcate the lateral extension and facies distribution of Kalol pays, pre-stack inversion was carried out. The Vp/Vs ratio which is closely related to Poisson’s ratio may capture the lithological variations, which only p-impedance (Ip) may not.

**Pre-Stack Inversion**

Model based deterministic pre-stack inversion was carried out to obtain Vp/Vs and Ip volumes. Ten wells, seismic velocity and PSTM gather data were utilized for the study. Gather data as conditioned and angle gather was generated with mute applied at 45 degree.

The conditioned angle gathers were then converted into partial angle stacks and were utilized for pre-stack inversion. The inversion analysis for well-A is shown in figure-8.

Figure-6. Location map of field of study.

Figure-7. Well correlation of Well-Y & X (West to east).

Figure-8 Inversion analysis for well-A.
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The cross plot between inverted and well log derived Ip & Vp/Vs are shown in figure-9. Both, the inverted Ip and Vp/Vs have shown very good correlation with wells derived data.

![Figure-9](image1.png)

Figure-9. Cross plot between inverted and well log Ip and Vp/Vs

Vp/Vs and Ip volumes were obtained by Pre-stack inversion. Un-interpreted sections of Ip and Vp/Vs passing through well-X and Y shown in figure-10a & b.

![Figure-10a](image2.png)

Figure-10a Un-interpreted p-impedance section passing through well X & Y.

The faults F-1 defines the eastern boundary for Kalol formation where pay zones are developed.

![Figure-10b](image3.png)

Figure-10b Un-interpreted Vp/Vs section passing through well X & Y.

The fault F-2 is prominent at K-IX/X level and it diminishes as it moves upwards (F-1, F-2 are normal faults). At Oolitic layer the impression of the F-2 fault is completely diminished.

![Figure-11a](image4.png)

Figure-11a Interpreted p-impedance section passing through well X&Y.

It can be seen in the figure-11a, that, while the Oolitic layer is present in both of the wells, most of the Kalol formations are terminating before well-X. It is also observed (figure-11a & b) that eastward
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Transgression of facies (of Kalol formation) has occurred (older to younger). From these two sections it can be establish that the well-X has narrowly missed the Kalol formations. The encircled area (figure-11a&b) is K-VI/VII pay zone which shows low Vp/Vs and high p-impedance. The dashed line FcB may be considered as the eastern boundary K-VI/VII pay. It can be seen in Vp/Vs section that the pay terminates just before well-X.

These observations suggest that the environment of deposition of Kalol formation is syn-depositional, i.e. the deposition was occurring with continuous fault regime. As we move westward, the accommodation space increases because of successive faulting. And due to syn-deposition, the thickness of sediments increases from east to west. In other words, abrupt reduction/termination in sediment thickness is observed across the faults in the west to east direction. The stated phenomenon can be observed as we move from the well-Y to well-X. And by utilizing this study, such terminations and pinch out zones can be avoided.

Conclusions

The seismic tools can provide the valuable information about the reservoirs even in most difficult geological environments. As seen in both the case studies that well based simple reservoir models may not be able to delineate the reservoirs. In the first case study, the channel geometry was captured by waveform classification as well as by dominant frequency slice. In the second case study, the seismic analysis not only identifies the cause of missing Kalol formations in well-X, but it has also demarcated the extent of pay reservoir observed in well-Y. Furthermore, the study also establishes the dominant role of seismic analysis for reservoir characterization in such complex depositional environments. Pre-stack inversion can play very important to avoid dry wells and to demarcate the lateral extension of reservoir. The approach adapted in the study should be applied in all the complex environment fields of Cambay basin.

References


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