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Predicting Depositional model and extent of Reservoir facies within Panna and Devgarh Formations , Play Prospectivity analysis using high frequency sequence stratigraphic framework and post stack acoustic inversion studies in D-33 & B-41 areas of DCS sector, Mumbai Offshore Basin- A case study

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Keywords

TST & HST Sequence, Barrier Bar complex, Distributary Mouth Bar, SOF, cross plots, Post stack Acoustic Impedance.

Summary

The present study pertains to delineation of thin sandy reservoir fairways of Panna and Devgarh Formations of Paleocene to Early Eocene discovered in D-33 and B-41 fields located in deep continental shelf of Mumbai offshore Basin. The study was aimed at bringing out the distribution of sporadic occurrences of HCs established so far, so that an effective field development scheme for exploitation could be implemented.

To achieve this, a comprehensive workflow using high frequency cycles on logs based on sequence stratigraphy was adopted. The topmost sequence within Panna was subdivided into TST and HST based on logs and subsequently calibrated with seismic data.

The area (740 SKM) is covered by 3D Q-Marine PSTM seismic data. An innovative and comprehensive processing work flow was adopted for significant enhancement of band width, dominant frequency, signal to noise ratio and considerable reduction of high frequency noise associated with initial seismic volume. Time migrated stack volume generated after applying different post stack conditioning processes like Coherency filtering, Structure Oriented Filtering (SOF) and Spectral Balancing (SB) showed considerable improvement in seismic data quality. The SOF data was used for structural mapping as it enhanced the continuity of seismic event and Spectral Balanced output data for attributes generation as well as post stack impedance inversion studies.

Six seismic horizons corresponding to Basement, Trapwash, Sequence Boundary SB1 within Panna, Maximum Flooding Surface (S2-MFS) within Panna, Panna clastic top & Devgarh MFS (close to Devgarh top) levels were mapped. Detailed fault interpretation based on attributes like structure cube, inline dip and crossline dip brought out three major tectonic trends in the study area. The initial synrift basin forming E-W trend responsible for major subsidence accommodating thick rift fill sequences has been cut by the second generation basin modifying NE-SW fault trends. The third generation of NNE-SSW faults are a result of post Mid. Miocene inversion tectonics which created the late formed structures.

This conceptualized sequence stratigraphic model has been further corroborated by the Post-stack impedance inversion carried out for Paleocene to Early Eocene. As the interpreted Panna clastic top horizon did not show a very good match with the impedance volume due to the mix phase nature of the seismic data used for horizon picking, it was re-correlated/repicked at the carbonate-clastic interface in impedance volume for extracting impedance slices.

Window based impedance slices corresponding to different pay sands were generated and analysed. Based on this study, the extent of pay sands in D-33 and B-41 area has been delineated.

Analysis of impedance slice has brought out the prograding distributary system with mouth bar at the terminal end representing the high stand system at the top and a barrier bar complex geometry during TST sequences at the bottom. The sand bars are oriented almost east-west thereby indicating possible back barrier system towards the northern part of study area.

Analysis of B-41-A pay sands corresponding to Devgarh Formations reveals three distinctive areas corresponding to i) dominantly clastic system, ii) a mixed siliciclastic-carbonate and iii) a distal dominant carbonate system. Hence, the extension of B-41-A clastic pays within carbonate may be probed in the mixed siliciclastic-carbonate system.

The structural model and facies distribution mapping integrated with various seismic attributes especially post stack P-Impedance inversion have helped in identifying exploratory prospects within Panna and Devgarh that will add to the reserve-base in D-33 and B-41 area.

Introduction

D-33, a broad terrace feature and B-41 structure are situated to the SSW of giant Mumbai High Field, NW of D-18 field and south of WO-5 prospect. (Fig.-1). D-33 Field was discovered in 2005 and B-41 in 2014. Hydrocarbon accumulations are established within the Early Eocene clastics of Panna Formations in D-33-A and D-33-B wells and sand layers within Early Eocene Devgarh carbonates in B-41-A well in this area of study (Fig.-2).

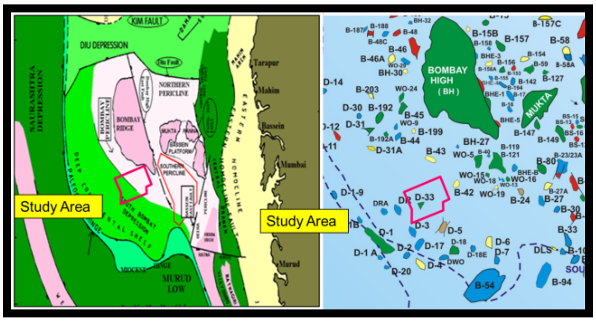

Fig.- 1: Study area on regional tectonic elements and Prospect map of Western Offshore Basin.

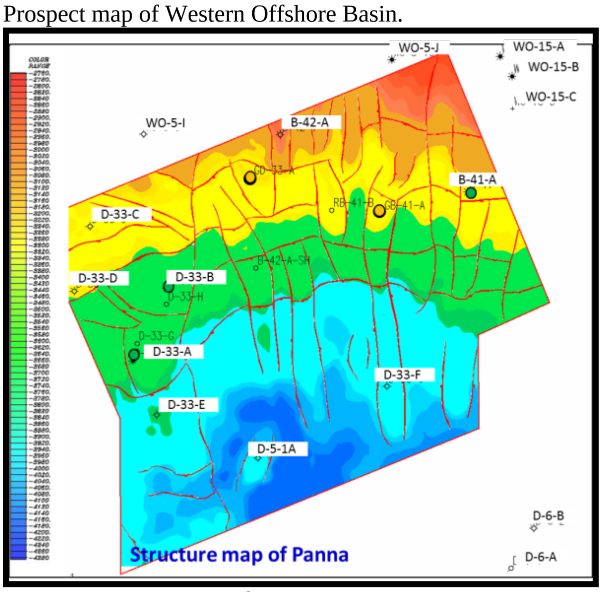

Fig. - 2: Structure Map of Panna showing key wells

Data Quality Enhancement:

The area (740 SKM) is covered by 3D Q-Marine PSTM seismic data. A comprehensive processing work flow was taken up aimed at significant enhancement of band width, dominant frequency, signal to noise ratio and considerable reduction of high frequency noise associated with initial seismic volume. Time migrated stack volume generated after applying different post stack conditioning processes like Coherency filtering, Structure Oriented Filtering (SOF) and Spectral Balancing (SB), showed considerable improvement in seismic data quality in terms of marker continuity and event definitions. The Spectral Balanced output data has been used for attributes generation as well as post stack impedance inversion studies. The comparison of data quality from initial volume to final output is shown in Fig.-3.

G& G Interpretation workflows:

Initially correlation of stratigraphic markers from bottom to top was done on the basis of log response and bio-stratigraphic age boundaries and correlated across the area. These markers are Basement top (H5), Panna clastic top, Devgarh MFS, Early Eocene top (H4), Lower Bassein top, H3B (Upper Bassein top) and H3A. In general the pack thickness is increasing towards basin ward south Mumbai low in the southern part of study area. (Fig.-4)

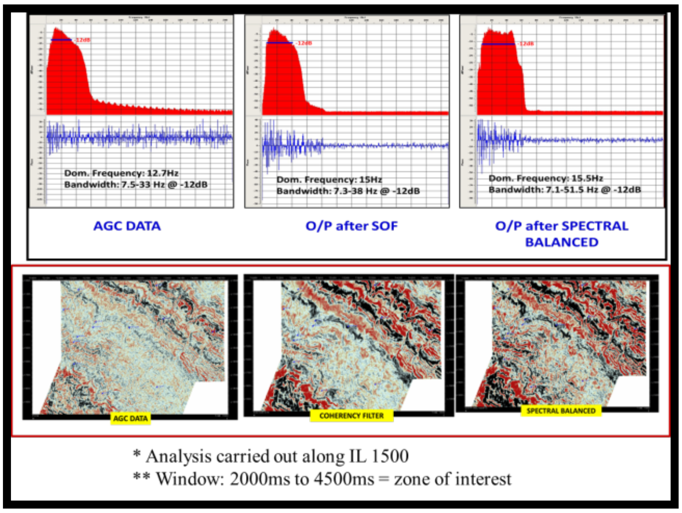

Fig.-3: Spectral analysis of seismic data with pre and post conditioning processes.

Sequence stratigraphy is the fundamental approach for understanding and predicting the distribution of reservoir facies. The stratal stacking pattern evolves in response to the interplay of accommodation available for sediments to fill, shoreline trajectories, base level changes and sediment load. The dominant facies observed from well log correlations are siltstone, shale, coals and sands. Since lot of sporadic coals are seen in Panna sections, a sequence stratigraphic framework was adopted to understand why the coals are formed where they are within a succession and predict the geometry and thickness of coals vis-à-vis system tracts. Coals are formed in all the three system tracts namely- low stand system tract (LST), transgressive system tract (TST) and High stand system tract (HST). During TST, the nature of coals formed is mostly thin and discontinuous. Taking this analogy, the topmost sequence within Panna was subdivided into TST and HST based on logs and subsequently calibrated with seismic data.

An electrologs correlation profile (Fig.-4) connecting five wells in D-33 area has been constructed to observe over all facies variation in time and space within Panna for high frequency cycle identification. Based on bio-stratigraphy, the topmost sequence begins with a Late Paleocene

Sequence Boundary(SB1) above which various transgressive back stepping onlapping high frequency cycles are observed both on logs and seismic as a result of relative rise of sea-level. Based on log responses of mainly gamma, sonic and computed impedance logs in wells, four Flooding Surfaces (FS) and one Maximum Flooding Surface (MFS) which constitute the entire Transgressive system tract (TST) have been picked. Above the MFS, a typical coarsening upward sequence with gradual shifting of sandy facies towards basin has established the occurrences of

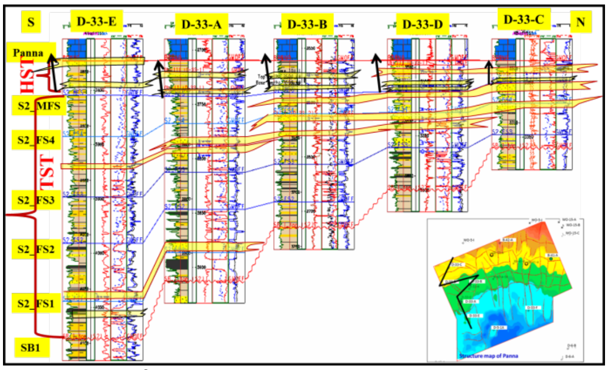

Fig.-4: High frequency cycle correlation within Panna clastic.

High stand prograding system. Sedimentological analysis, petrography of cores, logs, paleo-bathymetry, bio-stratigraphic evidences and available G & G data are analysed to decipher the depositional environment prevailing during Early Eocene geological past which explains the distribution of hydrocarbons/pay sands in D-33 field.

Seismic data interpretation

For matching seismic markers and well picks, T/D functions generated by synthetic to seismic matching and VSP were considered. Synthetic Seismogram of well D-33-B is shown in (Fig.-5).

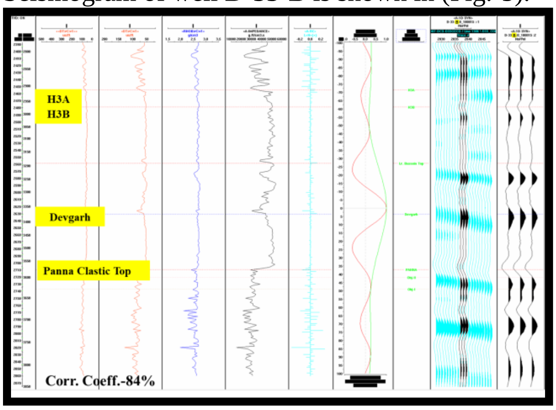

Fig.-5: Synthetic to seismic correlation of well D-33-B, Well tie 84%, time 2390 to 2870 ms .

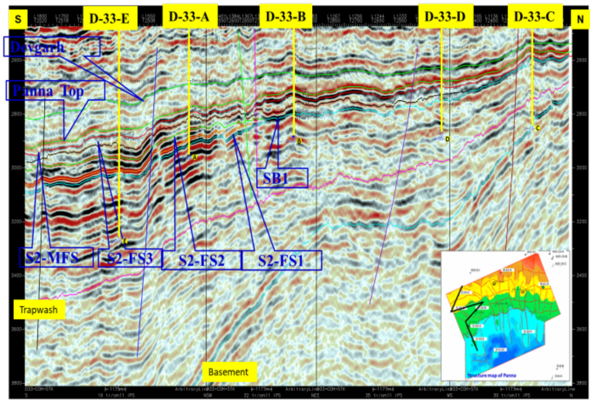

Fig.-6: Arbitrary Line Passing through wells D-33-E, A, B, D & C Showing Horizon Correlation.

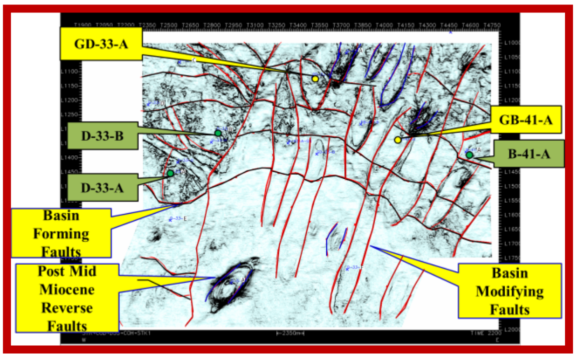

Fig. -8a: Structure Cube time slice at 2200 ms with faults.

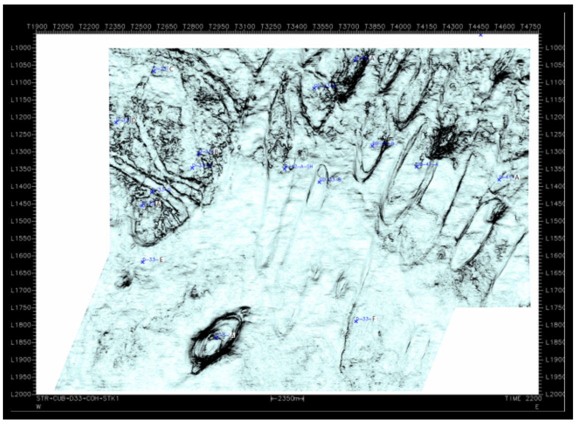
Fig. -8b: Structure Cube time slice at 2200 ms without faults

Statistically there is good match of 84% between synthetic and surface seismic. The high frequency cycles correlated on logs were calibrated on seismic dip profile along an arbitrary line connecting same wells (Fig.6 &7).

In the present study, Six seismic horizons corresponding to Basement, Trapwash, Sequence Boundary SB1 within Panna, Maximum Flooding Surface (S2-MFS) within Panna, Panna clastic top & Devgarh MFS (close to Devgarh top) levels were mapped.

Detailed fault interpretation based on attributes like structure cube, inline dip and crossline dip brought out three major tectonic trends in the study area

(Fig.-8). The initial synrift basin forming E-W trend responsible for major subsidence/thick rift fill sediments accommodating thickness has been cut by the second generation basin modifying NE-SW fault trends. The third generations of NNE-SSW faults are a result of post Mid. Miocene inversion tectonics which created the late formed structures.

Cross-Plot Analysis:

A cross plot between P-Impedance and NPHI taking gamma log in the Z-axis for 50m section covering both the objects that were oil and gas bearing in well D-33-A was generated. Three separate clusters representing shaly, sandy and silty/tight were observed based on gamma log (Fig.-9). The lowest P-impedance points correspond to shales/carb.shales, the moderate impedance cluster corresponds to sands and higher impedance more than 11500 (g/cc)*(m/s) corresponds to tighter facies like siltstones. A similar trend is also observed for well D-33-B.

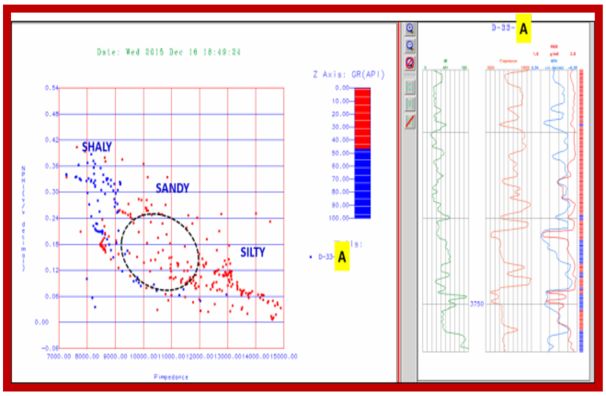

Fig. -9: Cross Plot of P-Impedance vs NPHI log in well D-33-A

Post Stack Acoustic Inversion: Spectral balanced seismic data along with 7 well log data used for inversion process and impedance volume generation. Conditioned well logs of 7 wells were used for seismic to well tie correlation. Average correlation coefficient ranges from 0.7 to 0.92. Impedance volume generated using D-33-B well wavelet.

The conceptualized sequence stratigraphic model has been further corroborated by the Post-stack impedance inversion carried out for Paleocene to Early Eocene.

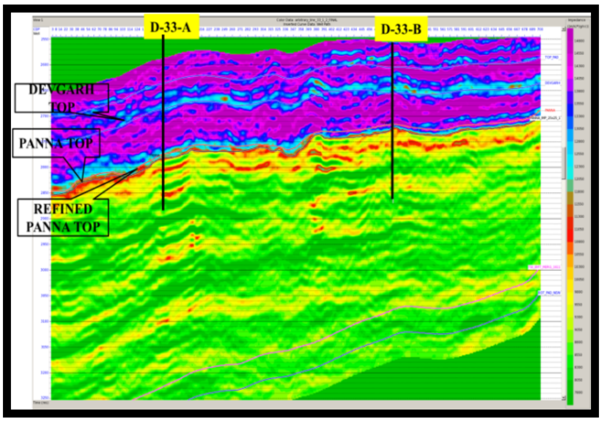

Fig. -10: Impedance section through D-33-A & D-33-B showing Panna correlation refinement **.**

As the interpreted Panna clastic top horizon did not show a very good match with the impedance volume due to the mix phase nature of the seismic data used for horizon picking, it was re-picked/recorrelated (Fig.-10) at the carbonate-clastic interface in impedance volume for extracting impedance slices of two different pay sand zones established in D-33 area.

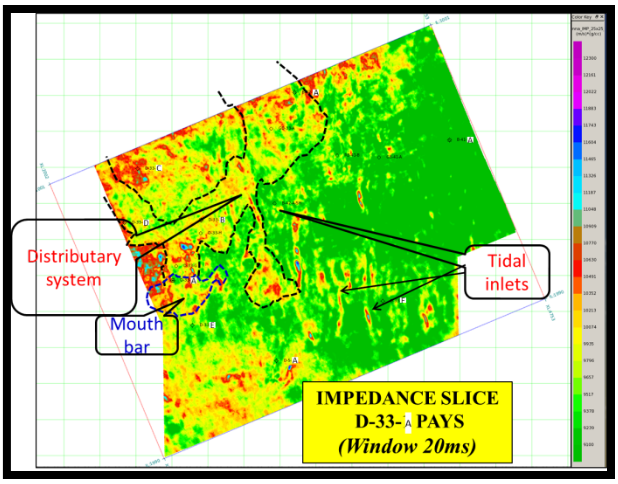

Fig. -11: Impedance slice 20 ms below Panna top depicting highstand prograding distributary system with Mouth bar

Impedance slices generated for 20ms window below Panna clastic top (Fig.11) is representing average response of the 35m sand-shale-coal response constituting the HST pack. This 20ms window is the combined response of both the pay sand layers corresponding to Object-II and III in well D-33-A.

Similarly, impedance slice generated for 18ms window giving an offset of 18ms below Panna clastic top (Fig.12) represents the combined response of sand-shale-coal. This is equivalent of D-33-B Panna pay which is a part of TST sequences.

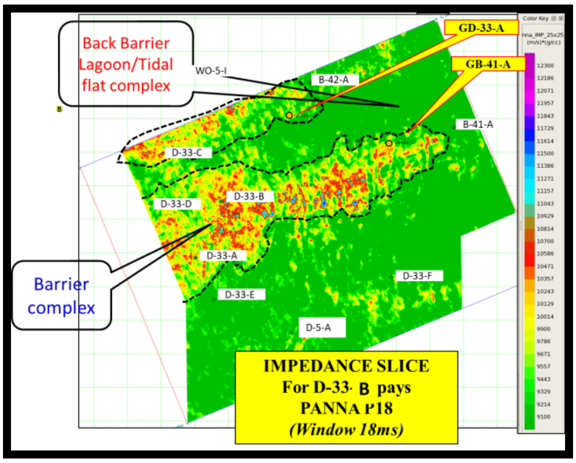

Fig.-12: Impedance slice for 18ms window corresponds to TST pack using Panna surface (offset 18ms from Panna top) showing a transgressive barrier complex geometry.

Depositional Model of pay sands within Panna:

Both these impedance slices give rise to two distinctive trends of facies distribution .The impedance slice which corresponds to the pay sands of well D-33-A shows high stand prograding distributary system with mouth bar at the terminal end. In the eastern part, impressions of tidal inlets are also observed through which marine influences might have been exchanged.

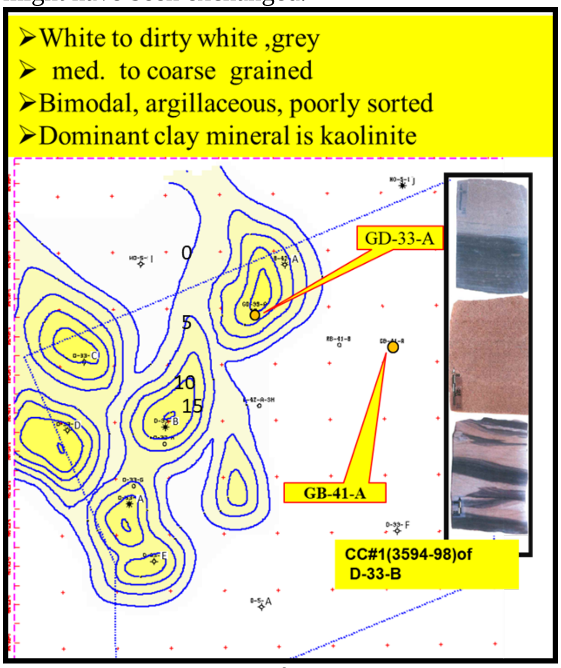

Fig.-13: Sand Isolith Map of HST pack representing the pay sand package of D-33-A (S2-MFS to Panna top)

Integrating with distinctive impedance trend along with core data and sedimentological analysis, the sand isolith map for the HST pack is drawn (Fig.-13)

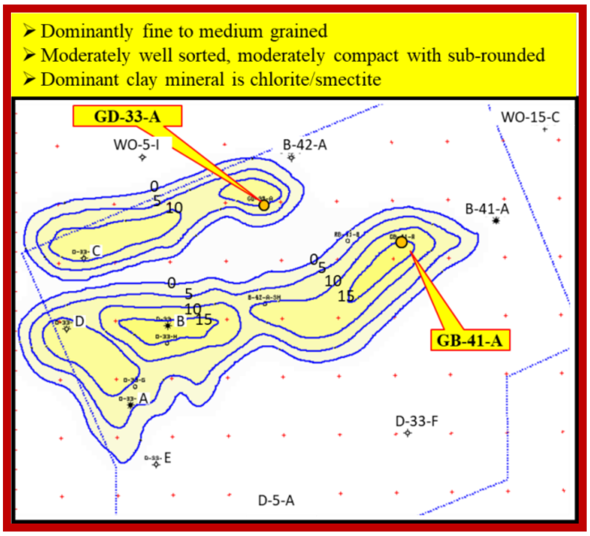

Fig.-14: Sand Isolith Map of TST pack representing the pay sand package of D-33-B (S2-FS3 to S2-MFS).

The impedance slice equivalent to the older D-33-B well pay pack reveals the existence of a barrier complex in the study area (Fig.-14). The sand bars are oriented almost east-west thereby indicating possible back barrier system towards the northern part of study area. In the slice, the areas representing impedance range 9500 to 10500 are falling in the barrier complex. Areas with impedance less than 8500 may represent the poorer facies as these are dominated by shales or carbonaceous matters.

The disposition of pay sand layers in well B-41-A is in between Devgarh MFS and Early Eocene unconformity H4. For understanding the mixed siliciclastic carbonate system as observed in discovery well B-41-A, an impedance slice was generated 18ms above the correlated Devgarh MFS

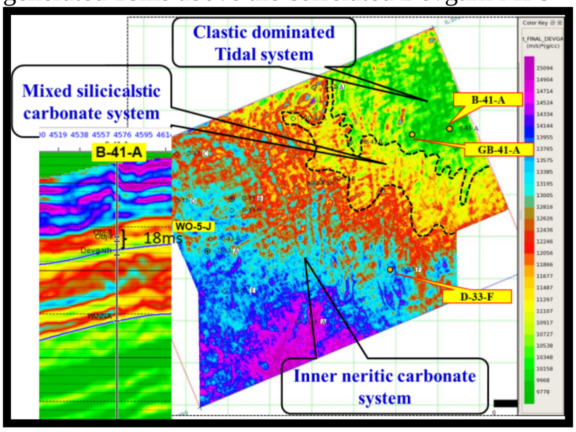

Fig.-15: Impedance Slice B-41-1 Pay–Devgarh (Window -18ms)

horizon. The generated slice reveals three distinctive areas in the map (Fig.-15).The prevalence of clastic system in the northeast of well B-41-A, a mixed siliciclastic-carbonate system further south including B-41-A well area and further down below towards the west a dominant carbonate system are inferred. Hence, the delineation of B-41-A clastic pays within carbonate needs to be probed in the mixed siliciclastic-carbonate system.

Play Prospectivity analysis:

Based on this study, the extent of pay sands in D-33-A and B have been delineated and the upside potential in equivalent sands towards north and north-east brought out. The equivalent of B-41-A Devgarh sands have limited extent towards south and west as they grade from mixed siliciclastic carbonate to more carbonate dominated environment in this direction. The structural model and facies distribution mapping integrated with various seismic attributes especially post stack P-Impedance inversion have helped in identifying exploratory prospects. One location as a fourway closure for delineating exclusively the three pays of D-33 Panna Formation and another as a fourway/fault closure for delineating both sands of B-41-A pays within Devgarh as well as Panna pay sand of D-33-B have been firmed up for probing the HC prospectivity in the study area.

Conclusion:

- An innovative processing workflow aimed at seismic data quality enhancement in terms of bandwidth, dominant frequency, signal to noise ratio, event continuity and considerable reduction of high frequency noise has helped immensely for high frequency cycles correlation in reprocessed seismic data.
- The major challenge was to map thin sand fairways within Panna and Devgarh of Paleocene to Early Eocene in D-33 and B-41 area and to bring out the extent of occurrences of HCs using high frequency cycles correlation and P-impedance attribute trends.
- Two 3rd order sequences S1 and S2 from bottom to top are mapped within Panna Formation. The topmost sequence S2 is the most significant from reservoir point of view. Both TST & HST packs have been identified based on logs as well as seismic correlation.
- The pay sands of well D-33-A belong to HST pack and pay sands of D-33-B well belong to TST pack.
- Various seismic attributes are generated out of which the window based slice derived from recorrelated/repicked Panna clastic top in impedance volume has revealed two distinctive sand facies trends.
- The pay sands of D-33-A correspond to high stand prograding distributary system with mouth bar at the terminal end. Tidal inlets are also observed through which marine influences might have been exchanged in the eastern part.
- The pay sands of D-33-A correspond to high stand prograding distributary system with mouth bar at the terminal end. Tidal inlets are also observed through which marine influences might have been exchanged in the eastern part.
- The impedance slice equivalent to the older D-33-B well pay pack reveals the existence of a barrier complex in the study area. The sand bars are oriented almost east-west thereby indicating possible back barrier system towards the northern part of study area.
- Impedance slice equivalent to Early Eocene pay sands of B-41-A reveals prevalence of clastic system, a mixed siliciclastic-carbonate system and a dominant carbonate system with respect to well B-41-A.
- As an upside potential, exploratory prospects are identified to further delineate the pay sands of D-33 and B-41 area which are likely to add considerable reserve base.

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