Exploring beyond basalt, Kutch offshore basin: A success story of sub-basalt imaging

S. K. Biswal (ONGC Ltd, India), S. Basu (ONGC Ltd, India), S. Sengupta (WesternGeco, India), S. K. Goswami (WesternGeco, India), G. Menzel-Jones (WesternGeco, Malaysia), B. Chowdhury (WesternGeco, India), Artem Sazykin (WesternGeco, Malaysia)*

SSengupta@slb.com

Keywords

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Summary

A potentially prolific petroleum system remains hidden under Deccan flood basalt off the west coast of India. The sedimentary sequence below the flood basalt is mainly characterized by Mesozoic strata with a varying thickness of 1000 m to 2500 m. It is considered that requisite heat generation due to Deccan Trap volcanism soon after the Cretaceous sedimentation may have acted as a catalyst in hydrocarbon potential in this area (Vardhan et al. 2008). Imaging hydrocarbon-bearing Mesozoic sediments hidden below the Deccan flood basalt is considered as a serious problem for hydrocarbon exploration because of poor penetration and significant loss of seismic energy due to scattering, attenuation, absorption, and mode conversion when the seismic energy encounters the strongly attenuating flood basalt with high and variable acoustic impedance.

This case study demonstrates that, even with legacy marine streamer surveys, an appropriate workflow of combining suitable advanced technologies can help to overcome the long-standing challenges of sub-basalt imaging. The reprocessed data show clear uplift in the sub-basalt imaging and the inversion results validate the quality of the new data in relation to the well logs.

Introduction

The present study area is in the Kutch basin, off the west coast of India. The Kutch offshore basin forms the northern part of the western Offshore basin of India and is characterized by the presence of the Deccan Traps, a large igneous province up to 2000 m thick basalt lava flows. These lava flows have hindered successfully imaging sub-basalt Mesozoic sediments for hydrocarbon exploration. So far, no single technique has been found to produce large improvements in deeper image quality, and the solution lies in an appropriate combination of advanced technologies.

This case study shows applying advanced technologies to legacy ultra-shallow-water (water bottom from 25 m to 50 m) marine streamer surveys. Three legacy data sets were conventionally acquired with flat and shallow streamer depths. A tailored processing workflow was able to significantly improve on the existing data quality and provide new insights into the sub-basalt geology, thereby opening a new play to exploration and production.

Challenges and workflow

Sub-basalt imaging challenges include transmission losses, scattering, complex wave kinematics, prevalent multiples, interference effects, and variable illumination due to high and variable acoustic impedance of thick heterogeneous basalt layers. The tertiary sedimentary sequences overlying the Deccan Trap volcanic consist predominantly of carbonates, shale, and fine-grained clastics, with the presence of channels and nearly vertical faulting. The geological complexities from the water bottom to the base of the basalt present a substantial geophysical challenge to successful deeper imaging and require an appropriate workflow to mitigate them. Broadband processing including deghosting increases the signal-to-noise ratio across the broad range of frequencies in the seismic bandwidth, thus enhancing the lower frequencies that are required to achieve enhanced imaging at sub-basalt targets. Demultiple methods can reduce the presence of surface-related and interbed multiples that prohibits reliable interpretation of Mesozoic sediment; imaging methods can focus the recorded data when used in conjunction with an accurate earth model that captures the velocity complexities of carbonates, shale, basalt channel, and faults.

Source- and receiver-side deghosting (Rickett et al. 2014) were applied to remove the ghost effects, thereby broadening the signal bandwidth.

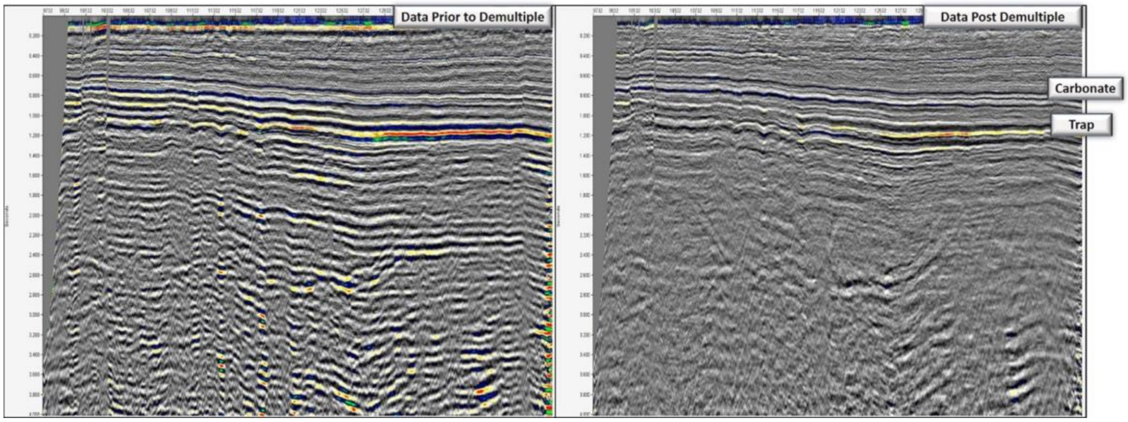


Figure 1: Before (left) and after (right) demultiple on a pre-migration stack section. Carbonate and Deccan Trap geologies are indicated.

The first step in the demultiple workflow was to address the surface-related multiples through a cascaded approach of generalized shallow-water demultiple (Kostov et al. 2015) and conventional 3D surface-related multiple elimination (Dragoset et al. 2010). Interpreted horizons were used as multiple generators for interbed multiple modelling and subtraction (El-Emam et al. 2011). Figure 1 shows an example of before and after demultiple on a pre-migration stack section.

The earth model building workflow consisted of initial model building, full-waveform inversion (FWI), velocity scanning, and common image point (CIP) tomography. A geologically plausible initial model was built based on the wells and using early Palaeocene, Eocene, Top Basalt and Base Basalt

This model was then updated by adjustive FWI, a method that uses an objective function based on the local traveltime differences (Jiao et al. 2015; Vigh et al. 2016) to overcome the limitations of conventional least-squares FWI with a simple initial model. After the smooth adjustive FWI update, least-squares FWI using both refraction and reflection energy was used to derive a high-resolution, geologically consistent velocity model. With an acquisition geometry cable length of 6 km, the diving-wave penetration was

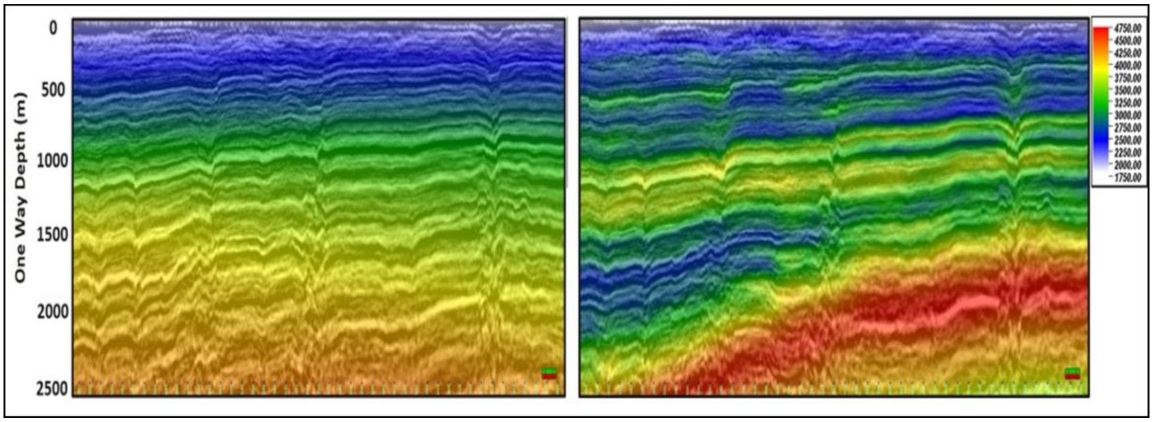


Figure 2: Comparison of velocity models from legacy processing (left) and after reprocessing (right).

limited up to a maximum depth of approximately 1.8 km. To update the deeper sections, a velocity scanning approach and followed by multiple passes of CIP tomography (Woodward et al. 2008) were used, with a focus on updating the velocities within the basalt trap and at the sub-basalt Mesozoic sediment. Figure 2 shows a comparison of the legacy velocity model with the final velocity model from reprocessing. The high resolution of the final velocity model is apparent, with the velocities being geologically conformable and capturing the significant lateral and vertical velocity variations required by the complex post-basalt and basalt geologies.

Imaging and Inversion

For final imaging, Kirchhoff prestack depth migration and reverse time migration (RTM) were used. The final imaged data show consistent improvement throughout the section, significantly improving event continuity and structural definition both in Tertiary and Mesozoic sections.

This is apparent in Figure 4, where we see a comparison of the legacy image and final RTM image.

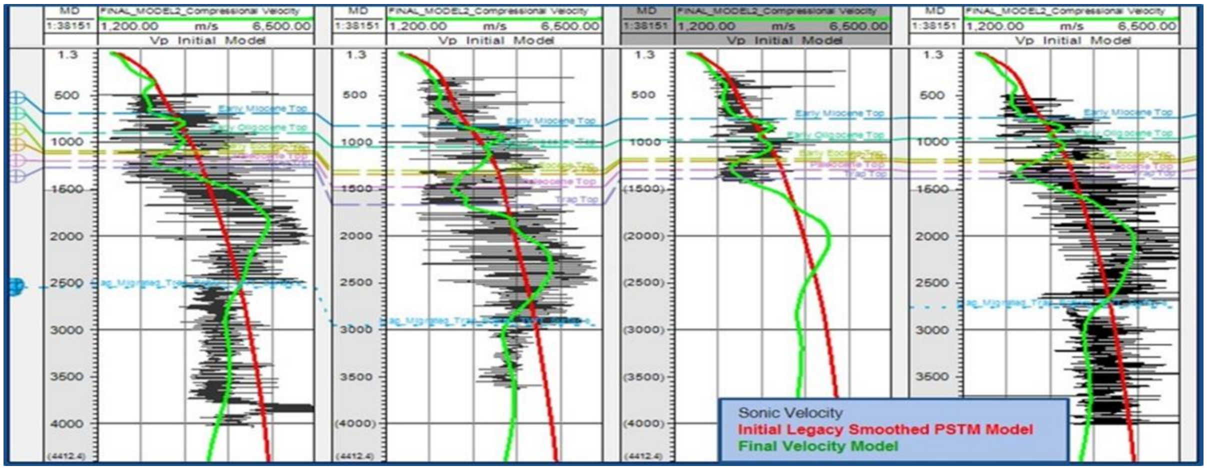


Figure 3: QC of final velocity at shallow and deep well sections shows close resemblance. PSTM refers to prestack time migration.

A further QC of the final velocity model is shown in Figure 3, where the reprocessing model is compared to the well logs from four well locations. Overall, a close match is seen between the well velocity and the reprocessed model. The fast carbonate and basalt velocities were captured, as well as the slow post- and pre-basalt clastic velocities.

The reprocessed image and reliable earth model allowed improved structural and stratigraphic interpretation, providing a more complete understanding of the field geology.

After imaging, a prestack simultaneous amplitude variation with offset inversion workflow was applied to the migrated data.

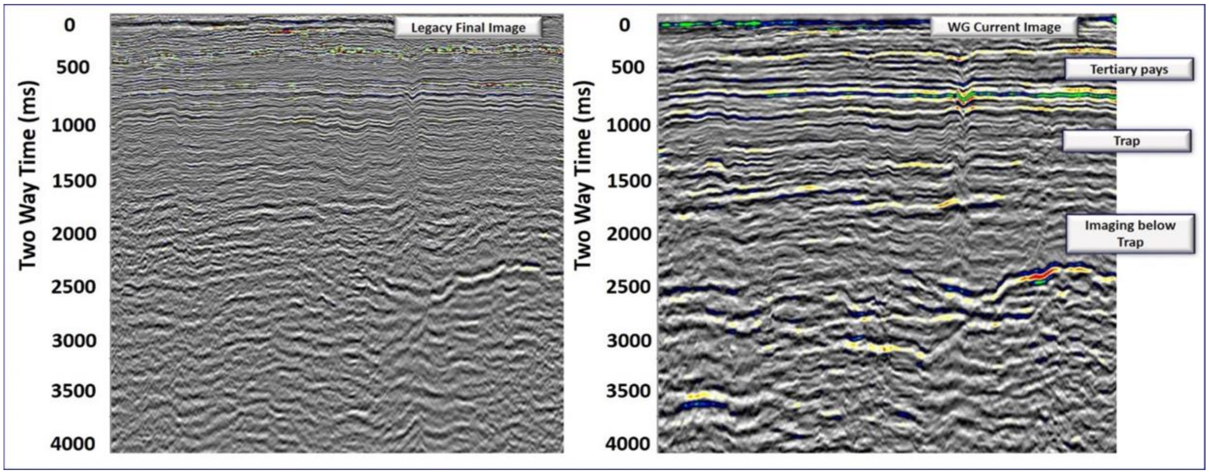


Figure 4: Comparison of legacy image (left) and final RTM image (right).

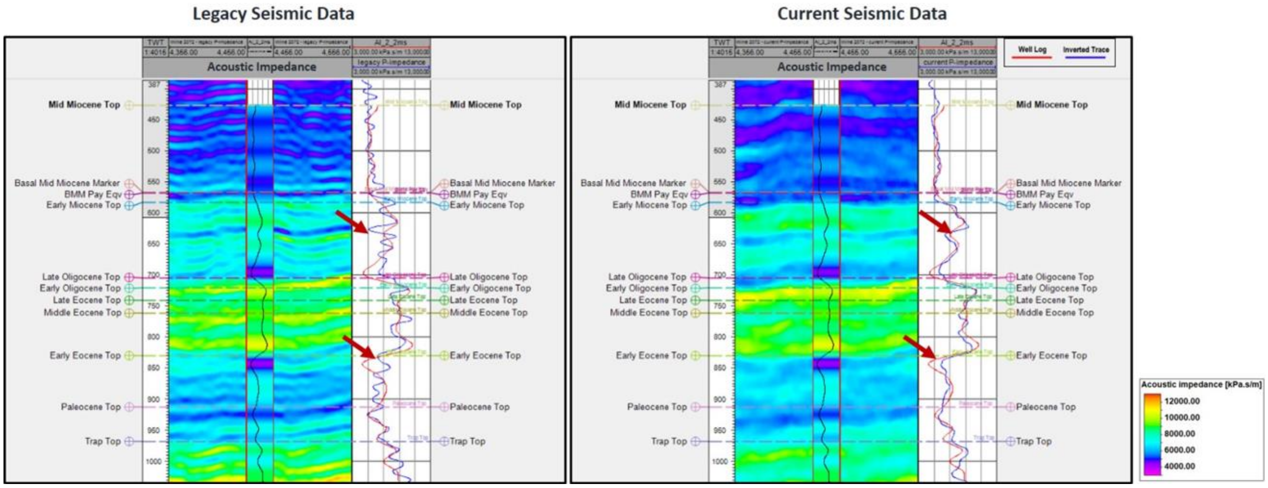
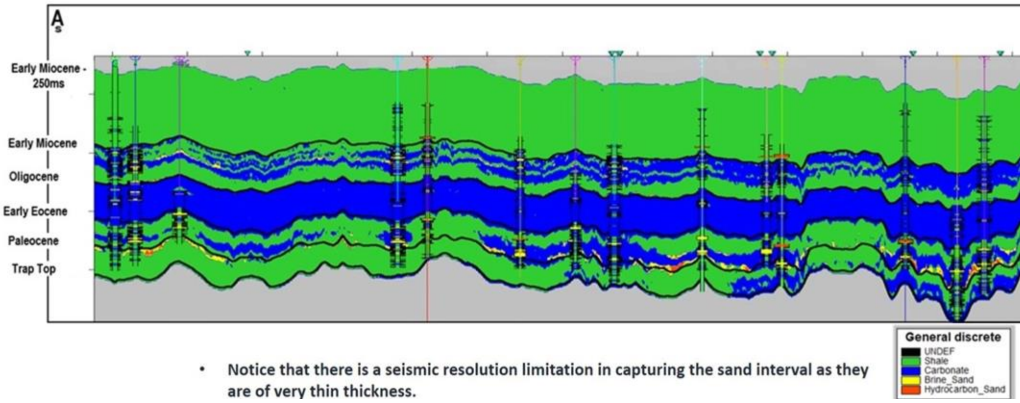


Figure 5: Comparison of inverted AI between legacy (left) and reprocessed data (right). The red trace on the well QC shows the well log; the blue trace shows the inversion result. The red arrows indicate areas of clear improvement in the reprocessed data.



- Notice that there is a seismic resolution limitation in capturing the sand interval as they are of very thin thickness.

Figure 6: Litho-class predicted for the shallow section above the trap top, highlighting areas of good reservoir presence.

The inverted acoustic impedance (AI) attributes using the new data show a better match to the well AI log compared to the legacy data, as highlighted in Figure 5. Bayesian classification using the inverted attributes successfully predicted areas of good reservoir presence in the shallow and the deep sections. Figure 6 presents the result along an arbitrary line for a shallow interval above the trap top.

Conclusions

This work demonstrates that, with previously acquired seismic data, an appropriate workflow of combining advanced technologies can help to overcome the long-standing challenges of sub-basalt imaging. The reprocessed data show clear uplift in the sub-basalt imaging and the inversion results validate the quality of the new data in relation to the well logs.

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