Revealing Deep Geological Structures and Pay Zones through Advanced Broadband PSDM Processing on an Offshore India Field

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Summary

In this paper, we describe a comprehensive de-multiple flow and TTI velocity model building technique that brought out the true value for broadband data in the Mumbai offshore basin. The processed broadband gathers were then used for reservoir characterization.

Introduction

The Mumbai offshore basin is a divergent passive continental margin basin located on the broad continental shelf of the west coast of India. The basin is composed of three broad lithological units: 1) basal sand, lignite, clay of Paleocene age, 2) a middle unit of limestone of Eocene age, and 3) limestone-shale alternations of Late Oligocene to Middle Miocene age. Overlaying these units is a sequence of limestone and shale alternations. Both the limestone and sandstone are reservoirs besides the fractured basement, making the sedimentation pattern and reservoir distribution complex. Moreover, there are thin clastic wedge outs, which require broadband data to provide a high-resolution image.

The water depth in the area varies from 50m to 100m. The extreme shallow seabed, thick sediment and strong carbonate layers result in strong multiples, high frequency signal attenuation and geological image distortion. Various technologies in acquisition and processing were applied to overcome these challenges.

Broadband acquisition with multi-depth synchronized sources and variable-depth streamers was used to mitigate strong source and receiver ghost notches. Ghost Wavefield Elimination (GWE) (Wang, et. al., 2013) processing technique separates primary and ghost energy to give a broad amplitude spectrum. The broadband methods improve the resolution of the shallow structures and enhance the clarity of the deep structures due to enhanced penetration of low frequency energy. PSDM velocity modelling also benefits from broader bandwidth and deeper penetration of source energy.

With the help of more than 30 wells, the new broadband acquisition and processing result led to high quality inversion results, which made it possible to delineate pay zones within the survey.

Survey Location and Acquisition Parameters

The new 3D marine broadband acquisition was acquired in 2018. A dual-layer synchronizing source located at 7m and 10m depth from the sea surface was used to reduce source ghost notch. 12 streamers with 100m cable separation and 6km length were towed at a varying depth of 12-30m from near to far offset. The nearest offset at the outermost streamer is more than 550m, which has a reflection angle beyond the critical angle of the seabed.

De-multiple Package

A comprehensive de-multiple package was the key to the success of the project. Typical 3D wide-towed marine acquisition is not ideal for shallow water due to the lack of the near offset data. However, the latest de-multiple flow makes it possible to re-image the seabed and results in a more accurate multiple model for outer cable and shallow structures. The de-multiple flow comprised:

1. One-way Wavefield Extrapolation Modelling and Migration (WEMM) (Zhang, et. al., 2002) was utilized to obtain accurate depth of seabed using multiple energy;
2. Joint Sail line model-based water-layer demultiple (SLMWD) (Wang, et. al., 2011) and Shallow water demultiple (SWD) (Yang, et. al.,

2012) took the accurate water depth generated from WEMM to generate a shallow water multiple model;

3. 3D SRME predicted long-period multiples generated by various layers in the shallow sediment zone and in the deep section (Figure 1);
4. Internal multiples were attenuated using the inverse scattered series (ISS) method (Wang, et. al., 2014). In this survey, a set of nearly parallel strong reflectors in sediment are the generators of inter-bed multiples that interfere the deep structures (Figure 2).
5. Curvelet domain subtraction (Wu, et. al., 2015) method was used to avoid damaging the primary energy to provide a better multiple separation.

TTI Velocity Model Building

A TTI model was built for PSDM. Non-linear tomography (Guillaume et. al., 2001) was used in this survey to obtain a geologically conformable model from shallow sediment to deeper layers. For the fast carbonate velocity layers in most places of this survey, reflectivity inversion (Ji, et. al. 2010) together with dip-constrained tomography (Carotti, et. al., 2015) were able to capture local anomalies and high velocity contrast in the model.

With a large number of wells, target layers with high velocity contrast were iteratively identified and corrected using well calibration for both velocity and anisotropy factors. Finally, a velocity scanning method was used to find the optimized model with strong velocity contrast for fault imaging below the basement (Figure 3).

With advanced de-multiple package and various technologies used for velocity model building, the subsurface imaging of the survey was significantly improved, compared to PSTM of legacy surveys in the same area as shown in Figure 4. It yielded much sharper imaging with wider bandwidth and more accurate positioning. The complex deeper structures, which were masked by strong multiples, were also clearly imagined.

Reservoir Characterization

These newly processed high quality broadband gathers together with more than 30 wells were

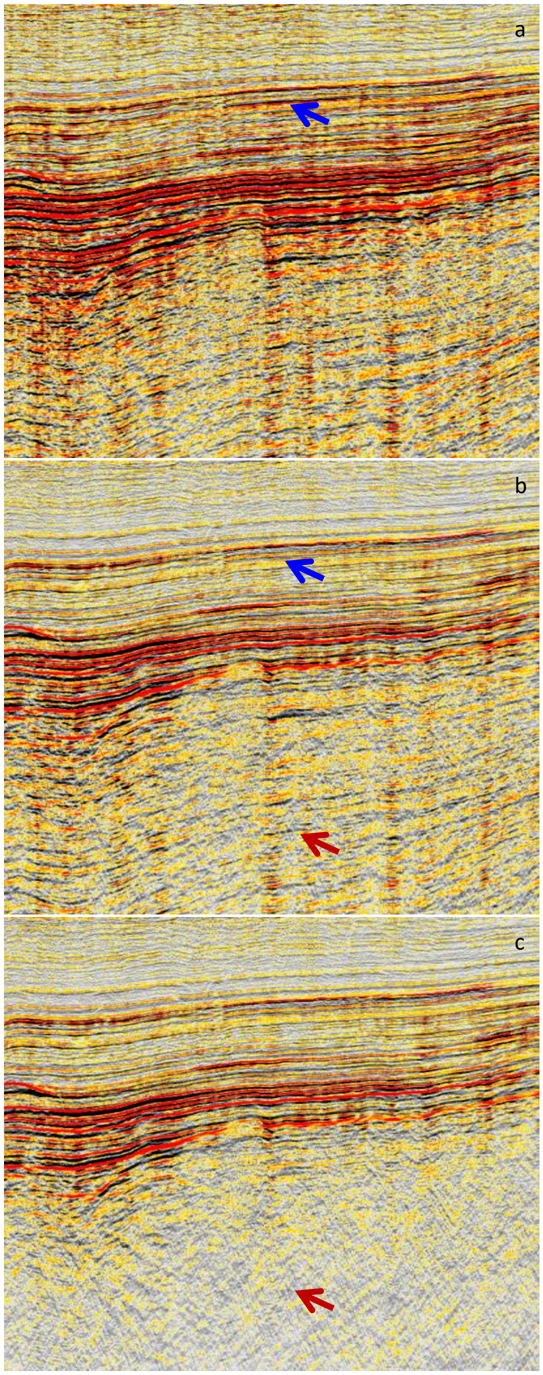

Figure 1 Example of a stack section of surface multiple attenuation progress with input data (a), joint SLMWD and SWD (b) and 3D SRME (c). Joint SLMWD attenuates the short period multiples (blue arrow), while 3D SRME tackles long period multiples (red arrow)

subsequently used for reservoir characterization. All wells were QC-ed and edited as needed and relevant wells (with both p and s sonic logs and good quality seismic / well tie) were integrated into the angle stack generation process. AVO synthetics from well data consistently suggested a critical angle of 45 degrees at target level and the AVO analyses of the seismic gathers showed good quality seismic signal up to 45 degrees. These analyses helped to define the angle ranges and 5 angle stacks were generated to be used for the seismic inversion. In this project, the inversion was parameterized in term of P impedance and v_p/v_s ratio as these properties seemed to be good reservoir discriminators. Inverted elastic properties were compared with the elastic logs at well location

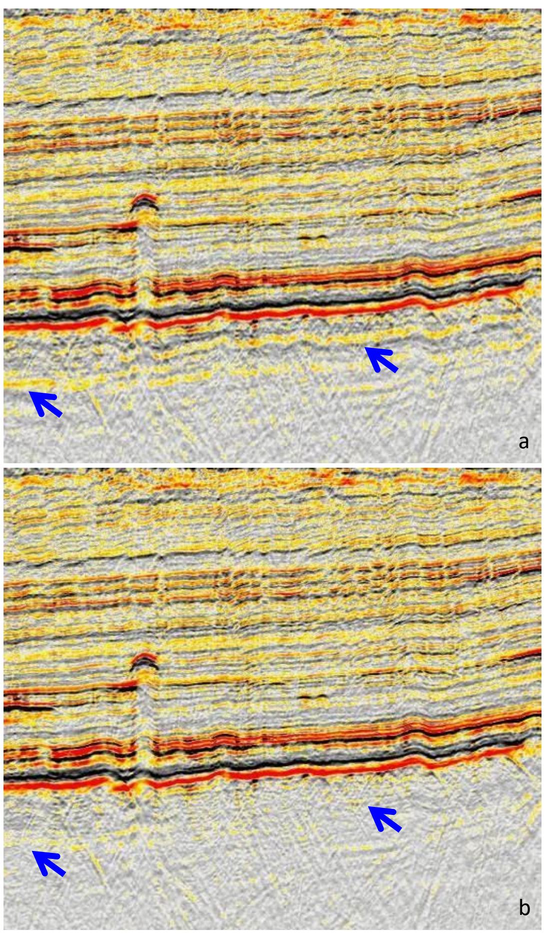

Figure 2 Imaging of faulty deep structures is clearer after inter-bed multiple attenuation (b), compared to the input that is masked by inter-bed multiple (a).

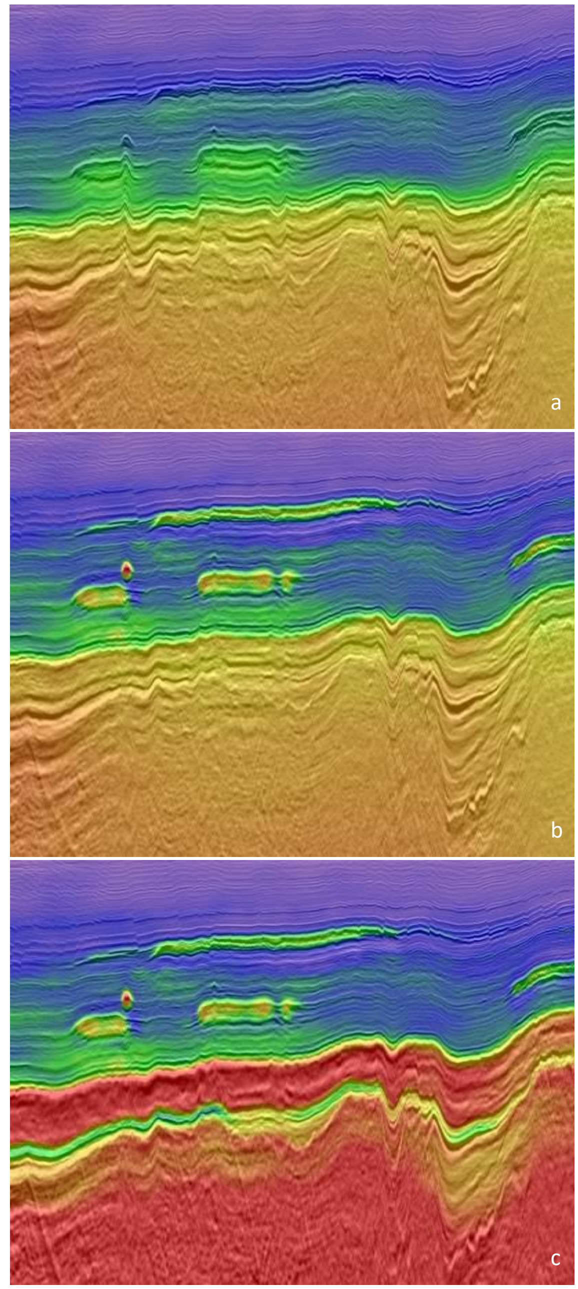

Figure 3 Depth migration velocity modelling involves several iterations of non-linear tomography. To obtain fast carbonate layers within sediment, reflectivity inversion together with dip-constrained tomography were applied (b) to identify local velocity anomalies over the smooth initial model (a). Well information and velocity scan were used to build a model with strong velocity contrast (c) and improve the deep structure imaging.

and good results were observed. An example of P impedance and v_p/v_s sections is presented in Figure 5a and 5b respectively where the low impedance and v_p/v_s can be tracked from the well data. These sections suggest limited extension of the reservoir to the West from the well, better prospect is depicted toward to the East (in green corresponding to the low impedance for example).

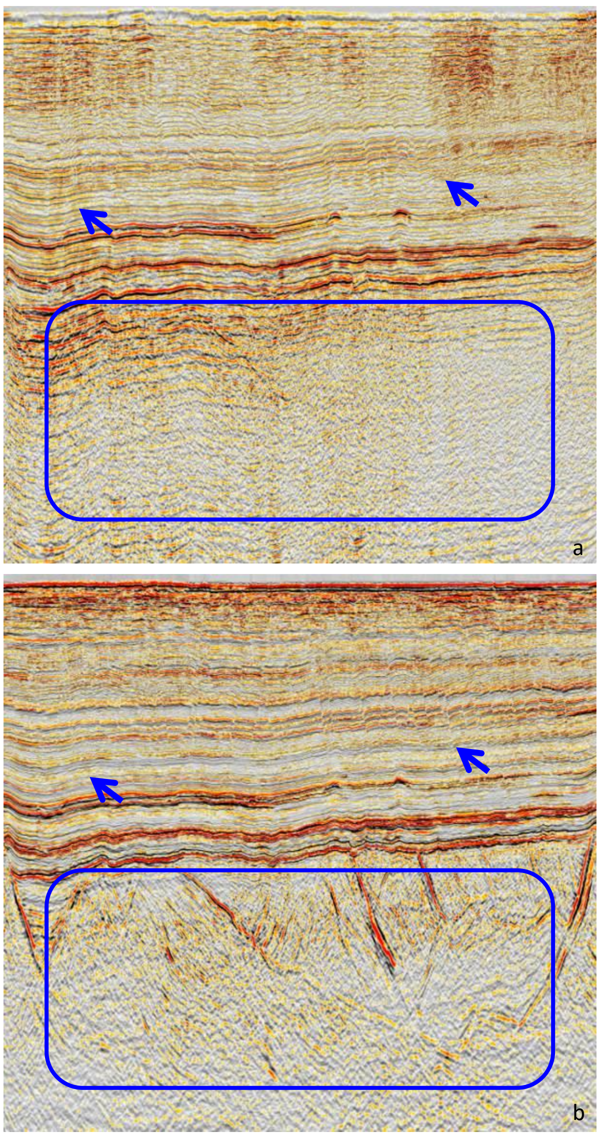

Figure 4 Compared to legacy PSTM (a), the final PSDM stack (converted to time domain) (b) shows improved contrast between reflectors due to wider bandwidth. The clarity of the deep structures is significantly enhanced with a full series of de-multiple process and depth velocity modelling.

The newly-processed seismic data and the use of more than 30 wells resulted in high quality inversion results able to delineate pay zones within the survey. The presence of these pay zones is confirmed by the existing wells giving confidence in prediction where no wells are drilled.

Conclusion

With broadband acquisition, comprehensive de-multiple workflow and detailed velocity model building process, we have shown that it is able to unlock the potential of the deep structure beneath the thick sediment layers with higher confidence. Elastic attributes from inversion helped in the delimitation of the prospective locations in the pay zone.

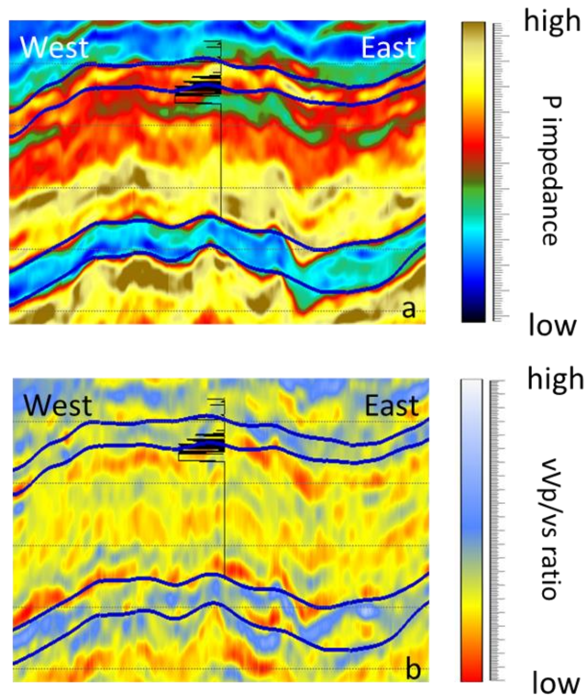

Figure 5 Results of pre-stack inversion. P-Impedance section (a), V_p/V_s ratio section (b) shows good response in hydrocarbon pay zone.

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