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Sub-basalt imaging in the Gulf of Kutch

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Summary

We present a case study which describes a sub-basalt imaging project in the Gulf of Kutch. The objective of the project was to improve the seismic imaging of Mesozoic sediments lying beneath the Deccan Trap basalts. As the earlier processing attempts were unable to bring out sufficient resolution of the structure so to improve confidence in the interpretation ahead of a further phase of exploration drilling a detailed study was commissioned which included seismic modelling, re-processing of the two available surveys from field tapes, velocity modelling and pre-stack depth migration using the very latest algorithms including Beam and Reverse Time Migration.

Introduction

The area of the study falls in the shallow waters of Kutch basin and is characterized by 800m to 1000m thick Deccan trap basaltic lava flows sandwiched between Tertiary and Mesozoic sediments. The Cretaceous Bhuj reservoirs lying below the basalt layer are considered potential hydrocarbon targets but imaging these sub basalt events is challenging due to attenuation of energy, strong presence of multiples and mode conversions, and guided waves within the heterogeneous layers of basalt. The objectives of the project have been

- Accurate focusing and positioning of sub basalt structural play.
- Imaging the geometry of Deccan trap basalts.
- Determination of major litho-facies boundaries (clastics /carbonate).

To address these issues the project comprised the following steps:-

- Analysis and modelling of shot records close to existing exploration wells to try and understand the nature of the arrivals and tailor the noise suppression techniques to suit.
- Derive a robust scheme for attenuation of surface, water layer and interbed multiples.
- Build a velocity model which honours the overburden and accurately delineates the high velocity basalt unit.

- Selection of the most appropriate depth migration algorithm.

The existing datasets in the area had very poor sub-basalt imaging and the experienced eye of the interpreter was critical in taking decisions during the interpretive processing sequence. There was close cooperation between ONGC and GXT staff thorough the project particularly during the velocity model building phase and in choosing the appropriate migration algorithm.

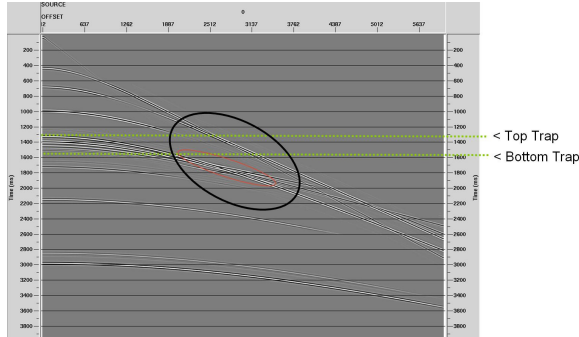
Method

The strong velocity contrast between basalt and the overlying sediments results in a strong refracted basalt arrival together with a number of mode converted arrivals and noise trains (Fruehn et al, 2001). It is important therefore to understand where we might expect this energy on the shot record.

The first step was to perform analysis of the available well logs and shot record modelling to determine the expected position and dip of primary top and base basalt reflections at far offsets on the shot records (Figure 1). This information then allowed optimum parameters for mode converted linear noise suppression to be selected without harming potentially useful reflection data.



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Synthetic shot record modelled using well logs, note the top, base and intra basalt reflections (within the red ellipse) which must be preserved during any linear noise suppression.

A proprietary radial trace filtering tool combined with carefully designed muting in the linear Tau-p domain was applied to attenuate the linear noise.

Next the multiples were addressed using a cascade of Tau-p domain deconvolution and de-aliased high resolution radon demultiple. The strong dominant short period water-layer multiple arising from the very shallow sea-bed (10m to 39m), was successfully attenuated along with other short period inter-bed multiples using a combination of both shot and receiver domain Tau-p predictive deconvolution. High resolution radon demultiple, using a de-aliased implementation provided good multiple attenuation of the longer period multiple on the mid to far offsets. Figure 2a and 2b below show how the radon demultiple and a near trace mute attenuated the persistent multiples beneath the Top Trap.

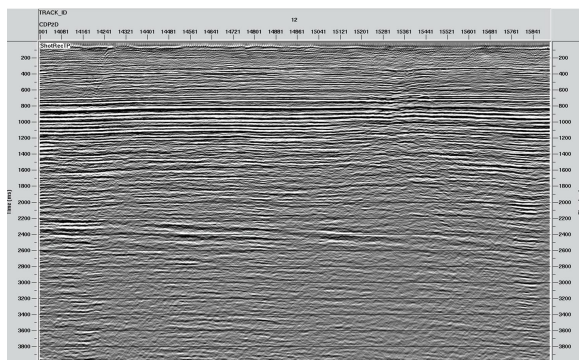


Figure 2a: Intermediate stack with shot and receiver Tau-p Deconvolution.

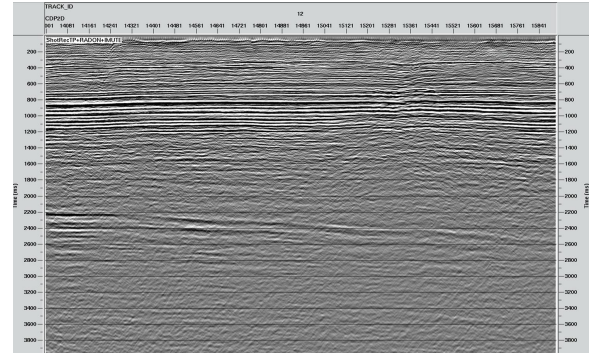


Figure 2b: Intermediate stack with Tau-p deconvolution, HR de-aliased radon and inner trace mute – note the reduction in multiple energy beneath 1.2 seconds.

For input to velocity model building the near offset high amplitude, high frequencies were reduced using a modelling and threshold technique.

Velocity model building for pre-stack depth migration ultimately involved 6 iterations of hybrid gridded tomography working down from the shallow to deep section with picked and frozen surfaces at Top and Base Basalt.

The technique used for velocity model building is well documented by Valler et al, 2008 and Jones et al, 2007 however there were a number of issues worth highlighting.

The previous processing velocities supplied were used to generate the initial model however these velocities exhibited a lot of lateral variation and to begin the model building process without bias, these velocities were very heavily smoothed laterally and vertically.

Velocity functions at the well locations were superimposed over the sonic logs but not all of the logs were found to be a reliable so only a subset could be used.

Relatively early in the model building procedure possible channel based velocity anomalies were noticed in the shallow section overlying regional faults. These appeared to correlate with sags in the horizons beneath. Tests were conducted to try and remove the sags by picking the top and base of the channels and introducing a low velocity infill. Unfortunately, due to the complexity of the channel features none of the channel velocity updates tested



completely removed the channel imprint and a decision had to be taken whether to continue re-picking the channel geometries or in the interest of staying on schedule accept the sags. Since the integrity of the exploration structures were unlikely to be compromised by the shallow velocity anomalies a decision was taken to proceed without the shallow channel model.

Modelling the Trap unit required significant input from the project interpreters. For Top Trap a volume of data was output and due to the continuous, unambiguous nature of the reflection it was straightforward to pick this horizon. Using the available sonic log as a guide the background model derived by tomographic inversion was scaled by between 110 and 120% within the Top Trap to better match the well and provide improved focussing and event flattening at Base Trap. Figure 3 below shows the velocity profile at the well. A Base Trap horizon was then picked after re-migrating a volume with the velocity field scaled by 110% in the Trap unit.

The final iteration of velocity updating was performed after freezing the Trap layer in the model, allowing only updates in the deep section.

Migration algorithm tests were conducted to output a fully migrated inline through one of the exploration wells. The motivation for testing the various algorithms is that we might expect the high velocity contrasts and rugose nature of the Trap to compromise a ray theory algorithm such as Kirchhoff migration. In such an environment we might expect a wavefield extrapolation technique such as Wave Equation Migration (WEM) or Reverse Time Migration (RTM) to perform better (Farmer et al, 2006). Additionally Beam migration which although a ray theory algorithm has excellent noise handling characteristics might prove beneficial on these data.

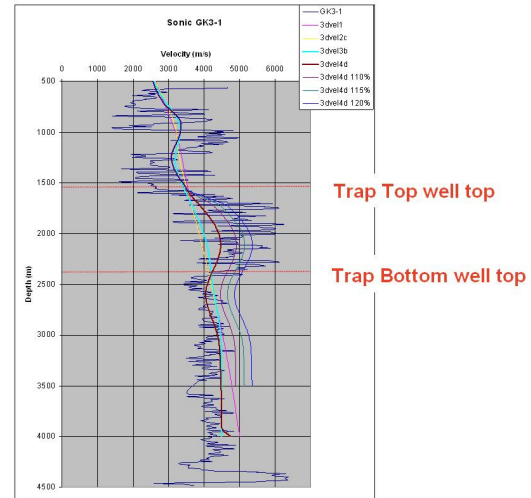


Figure 3: Well log profile with each of four velocity model iterations plotted together with the 110,115 and 120% speed up for the Trap unit.

The migration algorithms tested were Kirchhoff, Beam, WEM and RTM and after a detailed review by ONGC it was determined that the Beam migration product gave the most significant improvement in signal-noise ratio at depth and together with the RTM offered the best imaging. The four migration algorithms are compared in Figures 4a to 4d.

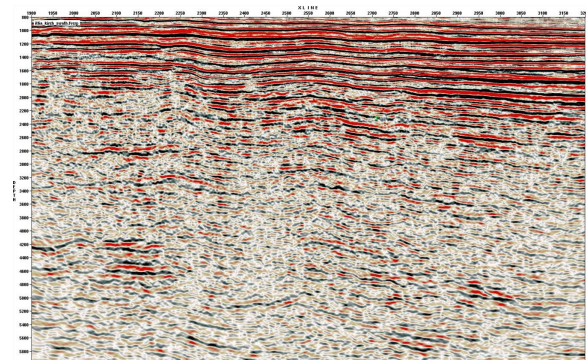


Figure 4a Kirchhoff PSDM



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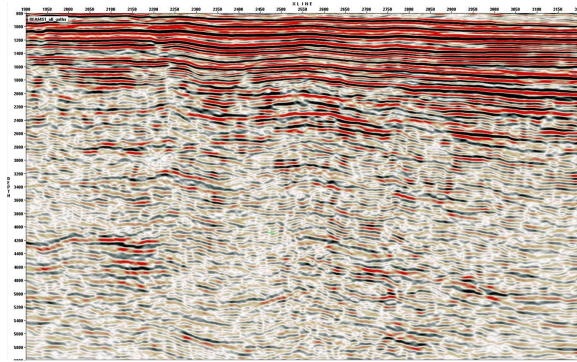


Figure 4b Beam PSDM

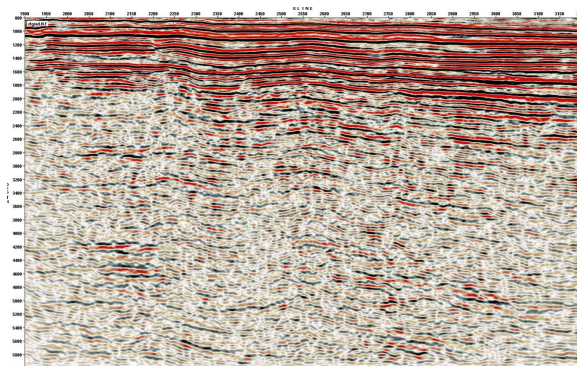


Figure 4c Reverse Time Migration

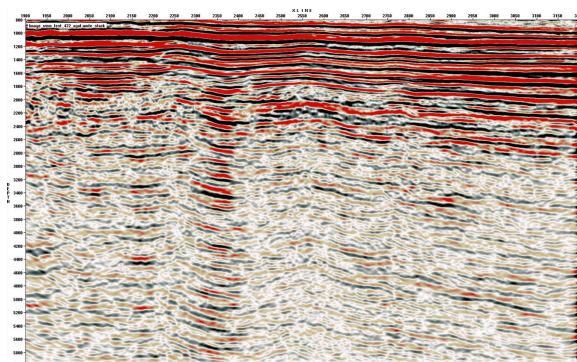


Figure 4d Wave Equation Migration

Conclusions

Success of a complex commercial imaging project such as this depends much more upon than the quality of the final image, specifically:

- Did the data arrive in time to impact the drilling plan?
- Is the data more interpretable leading to more confidence when planning the next well?

The data were processed and delivered within the original time plan. This required extra effort to accommodate additional early processing steps however timely project completion enabled the interpreter to stay on track with the well planning

Careful quality control, parameter selection and implementation at each step in the processing route led to the generation of a very high quality input to imaging. Particular attention paid to de-noise and the demultiple combination of both shot and receiver domain Tau-p deconvolution plus Hi-Resolution De-aliased Radon produced significant confidence in the final input to migration.

The image quality, event coherency and structural positioning were significantly improved over previous 2007 PreSTM processing, particularly beneath the Top Trap horizon. Through the careful use of six iterations of velocity model building involving densely spaced tomographic velocity updates an optimum data driven velocity model was derived. However, it was difficult to converge the tomography beneath the basalt due to multiple and weak reflectors.

The final Beam Pre Stack Depth Migration image of the full area has significant improvements in terms of event focusing, resolution, structural positioning and noise reduction when compared with the vintage 2007 PreSTM processing as shown in Figure 5a and 5b.

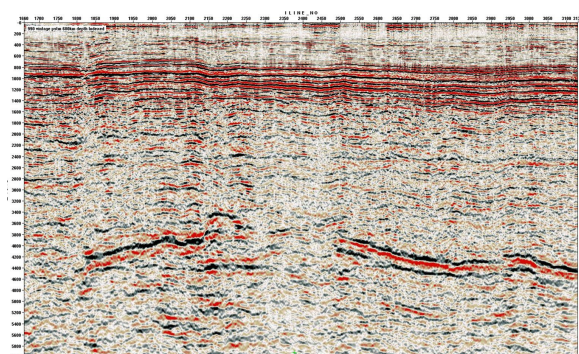


Figure 5a – Previous Pre-STM Processing converted to depth with Pre-SDM velocity field.

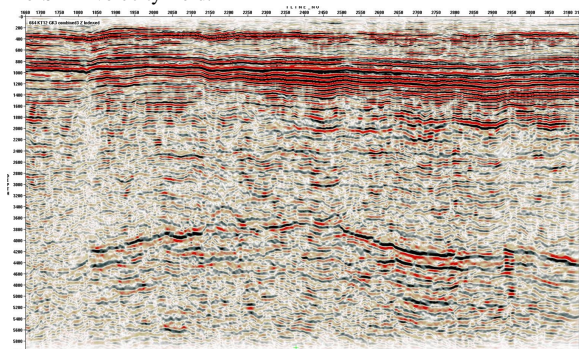


Figure 5b – Final Beam Pre-SDM, note the improved continuity of the sub-basalt reflections between 2 and 6 km.

Acknowledgements

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