



Technological Innovations Lead to Improved Imaging Below Deccan Trap: Studies From Western Offshore India

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Basalt, Broadband, Deghosting, Demultiple, FWI, RTM

Summary

The present paper outlines the various technological innovations in both seismic acquisition and processing that have been adopted to overcome the challenges in sub-basalt imaging of western offshore India, particularly the Mesozoic exploration. The study summarizes the hierarchical approaches to meet the exploration objectives in this complex volcanic realm where the expectation of hydrocarbon prospects has been a massive discussion over the desk of geoscientists. The technical approach and technological innovation for sub-basalt (Mesozoic) exploration in this type of complex regime may be outlined as below.

1. Conventional streamer (old) data with conventional processing technology (old)
2. Conventional streamer (old) data with new processing technology
3. Broadband acquisition (new) data with new processing technology

A decade back the exploration objectives were restricted to the tertiary part of the volcanic basins. A Then the conventional streamer (source depth of ~5m and flat streamer depth of ~7 m) data was processed with the available processing technology able to bring the tertiary features leading to multiple discoveries. However, the processing technology adopted was inadequate to image the Mesozoic below basalt. The gradual technological innovations and advancements in acquisition and pre-migration processing techniques such as deghosting, demultiple velocity model building such as full waveform inversion (FWI) and imaging method like reverse time migration have resolved the issues to large extent. The present study indicating the implementation of new innovative technology for the improvement in sub-basalt imaging and opens up further Mesozoic exploration in Kutch-Saurashtra basin of Western Offshore part of India.

Introduction

The exploration strategy in the volcanic regime in the worldwide basins is gradually challenging due to some criticality of the sub-surface geology. The challenge takes more critical mode in Kutch and Kutch Saurashtra basin of western offshore India. The reasons being the origin of the basalt, its thickness and morphology that not only puzzle the geoscientists but also limits the seismic methods to receive echoes from below. The exploration of hydrocarbon is always probabilistic in nature due to the translation of exact property of earth to average property on the surface except at well locations. The drilling of well in offshore has been a costly affair and the economics gets many fold when drilling the thick basalt. Hence, seeing below basalt needs approaches that considers all critical issues associated with the sub-surface under consideration.

The evolution of Deccan basalt in the western offshore India has great impact on the morphology, the texture, the mineralogy. The complexity associated with Deccan basalt are outlined as;

- a) Presence of varied lithological columns with different properties
- b) Huge thickness & variations of the basalt layer
- c) Presence of multiple lava flows giving rise to multiple depositions within basalt
- d) Highly rugged surface which scatters the incident energy
- e) The multiple lava flows resulting in intratrapeans that cause the attenuation of the transmitted wavefield.
- f) Physical and mineralogical heterogeneity
- g) Varied lithology below basalt
- h) Existence of intrusive bodies within the Mesozoic sediments
- i) Unconformity related issues

The above geological complexity results in the following geophysical effects;

- I. **Intense multiples**- generated from three strong reflectors; water bottom, trap top and

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trap bottom. In addition, intratrapeans and carbonates also create short period reverberations (Figure 1).

- II. Chaotic reflections
- III. Poor energy penetration- Scattering and attenuation
- IV. Poor S/N Ratio
- V. Difficult velocity analysis
- VI. Diffractions
- VII. Mode conversions from trap top and bottom

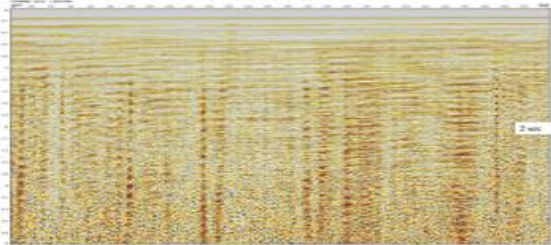


Figure 1: The raw data (common channel)

Methods

Case 1 - Conventional data and conventional processing:

The conventional acquisition technique where the streamer/ (sensor) and source kept at fixed depth below sea surface generates both source and receiver ghosts which narrow down the bandwidth of the data and lessen valuable information at low frequency. The conventional processing technology does not involve the appropriate methodology to reduce the effect ghost and gain the amplitude level. In addition, the demultiple technologies have not been evolved to attenuate the multiples created from various multiple generators. Again, some of techniques need high computing power to solve the algorithm which was not available in earlier days. Therefore, the processed data in the complex volcanic regime have limitations in seeing below basalt.

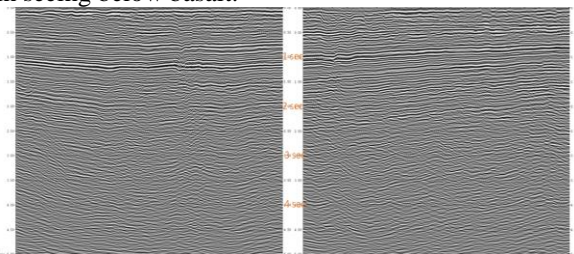


Figure 2: Final KPSTM stack: conventional data with conventional technology

Case 2 - Conventional data and new processing:

The innovations in pre-processing technologies; considered as new technologies such as deghosting, 3D demultiple including interbed, 5D interpolation have enhanced the data quality in the volcanic basins. The thick basalt layer has extreme effect in attenuating higher frequency due to scattering and intrinsic attenuation. Hence, the signals from below basalt have very low frequency of the order of 20-30 Hz. Deghosting faithfully reduce the ghosting effects and retrieve the low frequency events thereby adding more octaves to the data which has impact on resolution and its interpretability. These frequencies, which was subdued due to ghost notch, have amplitude level much above the noise level after deghosting. The raw data in volcanic basin are composed of multiples that have intense signature (Figure 1). The demultiple techniques is one of the key processing techniques in the processing steps of the basaltic regime. The technique is applied in multiple domains, from model based to moveout based, from extrapolation methods to high resolution, in time domain to frequency domain. The various demultiple techniques are;

- A. Model based water bottom demultiple in shot domain
- B. Model based surface related demultiple in shot domain
- C. Long period moveout based demultiple in high resolution radon domain of CMP gather
- D. Long period demultiple in tau-p domain
- E. Residual moveout based demultiple in migrated gather

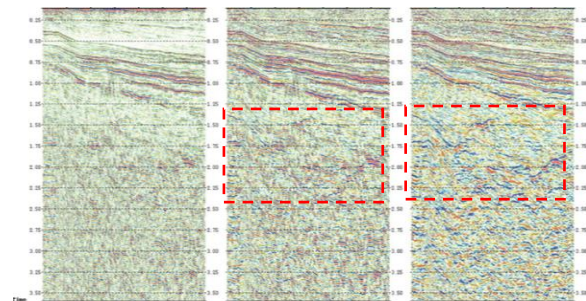


Figure 3: Stack sections; before (left), after deghosting (middle) and after water bottom demultiple (right)

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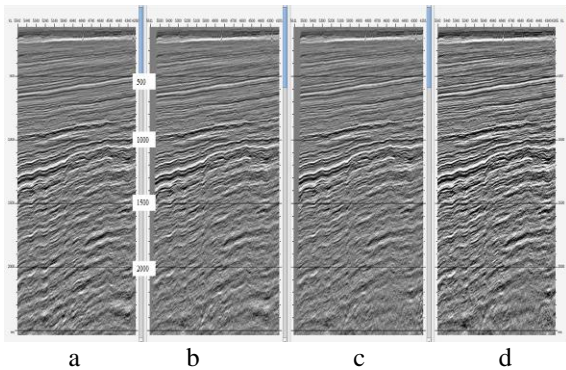


Figure 4: Stack sections after demultiple from left to right: after model based shot domain (a & b), after moveout based (c) and after tau-p domain demultiple (d)

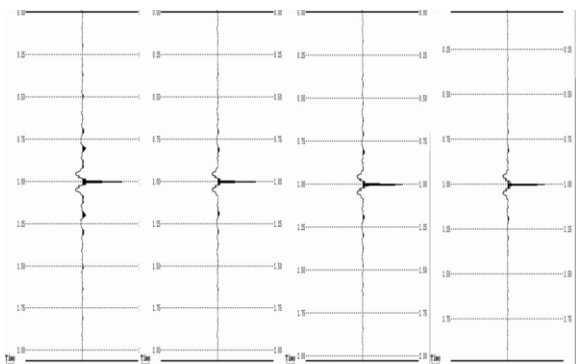


Figure 5: Normalized autocorrelation functions of the stack sections in the Figure 3

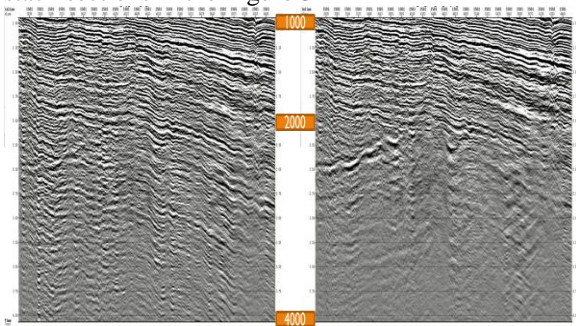


Figure 6: Stack sections before (left) and after (right) model based surface related demultiple in CMP domain

The various demultiple schemes as described above are unable to attenuate all types of multiple particularly generated from intratrapeans and some residuals of surface related as shown as blue arrow in Figure 7.

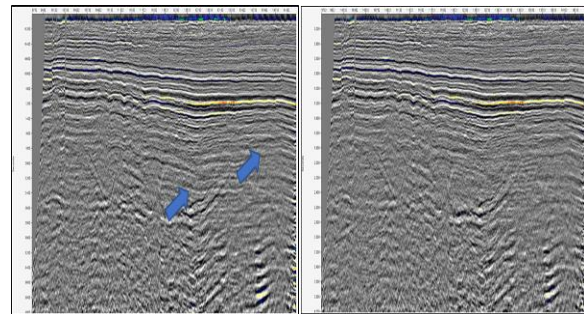


Figure 7: Stack sections before (left) and after (right) interbed demultiple in CMP domain

The interbed demultiple step further reduce the effect of trap related reverberations and brought out the Mesozoic reflections.

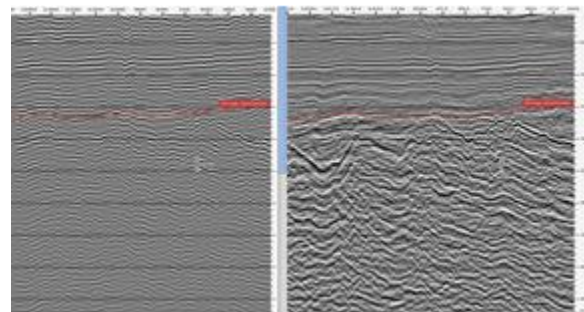


Figure 8: Final KPSTM stack: conventional technology (left) and with new technology (right)

The appropriate image in time and depth domain of the sub-basalt from demultiple gather needs to adopt the advance imaging technique. Every imaging method requires an accurate velocity model to produce the precise picture of the sub-surface. Hence, in this highly complex velocity regime the recent methods such as full waveform inversion, non-linear tomography were considered. The maximum offset restriction of the old as well as new data limits the FWI velocity update to upper part of the trap. But, the near accurate velocity model of shallow part give rise to better travel time computation for deeper part and helps in tomographic velocity updates. The blending of tomographic method of velocity model building of deeper part with FWI provides better earth model for better depth imaging using advanced compute intensive algorithm like RTM.

Technological Innovations Lead to Improved Imaging Below Deccan Trap: Studies From Western Offshore India

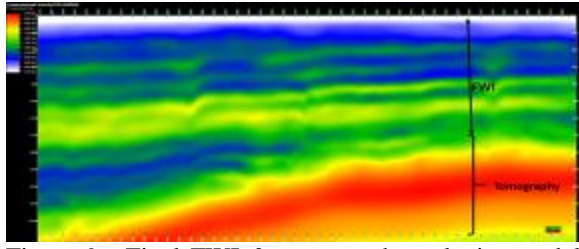


Figure 9: Final FWI & tomography velocity model from old dataset

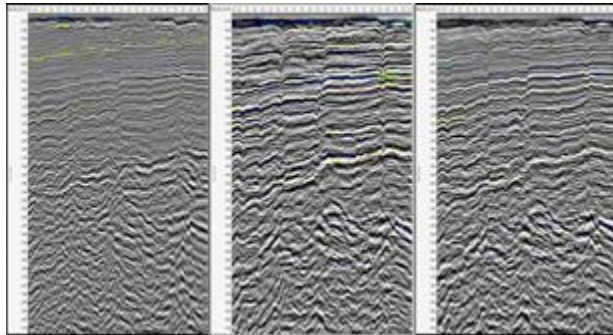


Figure 10: Final stack: old data with conventional technology -KPSTM (left), old data with FWI & RTM (middle) and old data with new technology-KPSTM (right)

Case 3 - Broadband data and new processing:

The value addition in the current broadband data acquisition has been tested in many complex regimes. The new acquisition techniques such as multi-level sources (Figure 11) and slanted streamer (Figure 12) reduced the ghost effect in the acquisition stage only. In slanted streamer receiver depth changes along the cable by means of slanting the cable, thus, changes the receiver ghost-notch frequency. As a result, when traces with different source-receiver offsets are combined, as they are in processes such as stacking and migration, frequencies attenuated at one offset are complemented by other traces with different offsets where these frequencies are not so attenuated. Then, further deghosting methods during processing shift the frequency spectra to lower side thereby increasing the imaging capability below highly attentive media such as basalt and deeper information. The broadband acquisition technique partially reduces the effect of source ghost and decreases diversity of the receiver side ghosts during recording itself. The effect can be thought of as data driven which is quite deterministic, in contrast, by

application of algorithm to reduce the ghosts' effect in old dataset which is quite stochastic statistical.

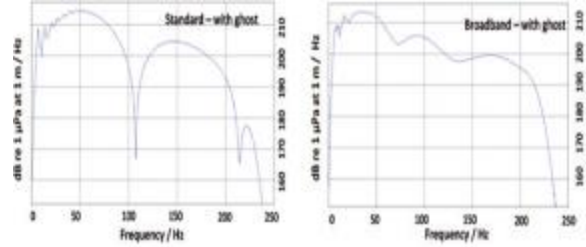


Figure 11: The modelled source spectrum of the conventional source (left) and broadband source (right)

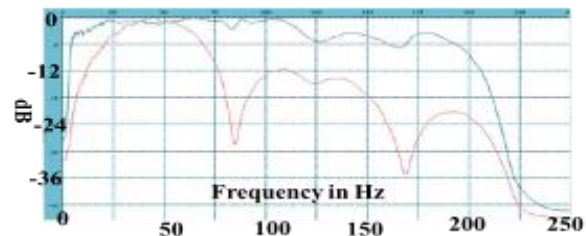


Figure 12: The spectra before designation & deghosting (red color) and after designation & deghosting (blue color)

The remaining ghosts' effect can be effectively handled during processing to stabilize the low frequency more accurately. This new data with new processing technologies further add to the better imaging in sub-basalt sequences. The presence of low frequency in the data itself is very helpful for FWI model building. The improved low frequency below trap results in the standout of the sub-basalt events that can be better picked up as primary events and hence helps in velocity model building more precisely.

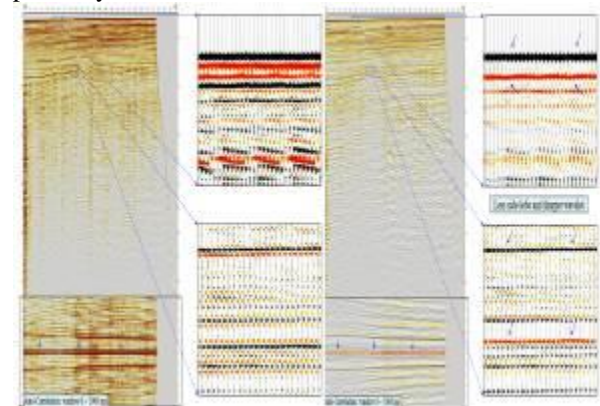


Figure 13: Before and after deghosting

Technological Innovations Lead to Improved Imaging Below Deccan Trap: Studies From Western Offshore India

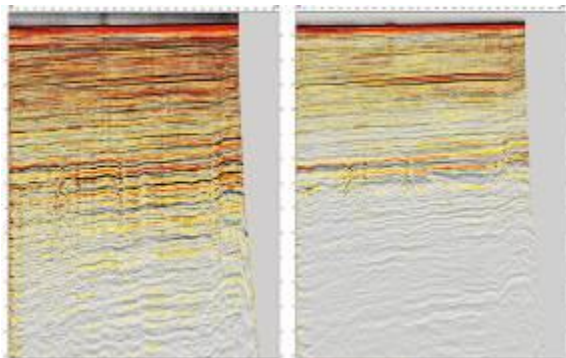


Figure 14a: Before and after demultiple (Shallow Water Demultiple)

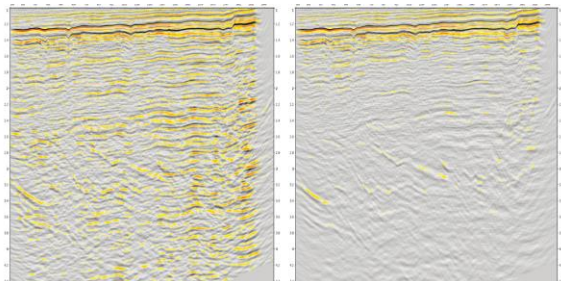


Figure 14b: Before and after demultiple (3D SRME)

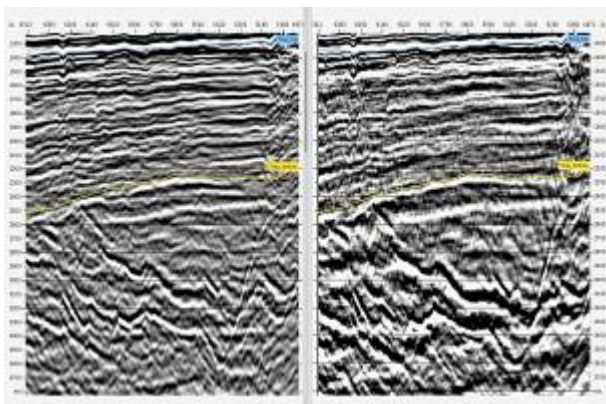


Figure 15: Beam migrated stack-old data with conventional technology (left) and KPSTM stack-with new technology (right)

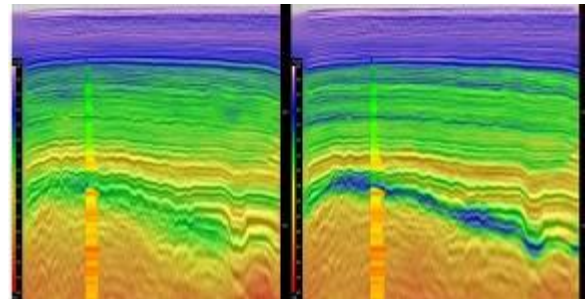


Figure 16: Final FWI & tomography velocity model from new data

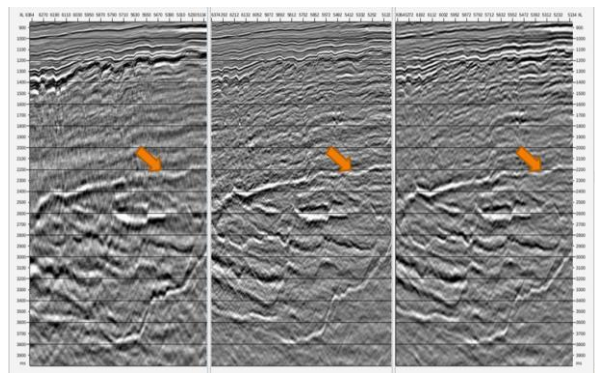


Figure 17: Final stack of new data with new technology -KPSTM (left), KPSDM (middle) and FWI & RTM (right)

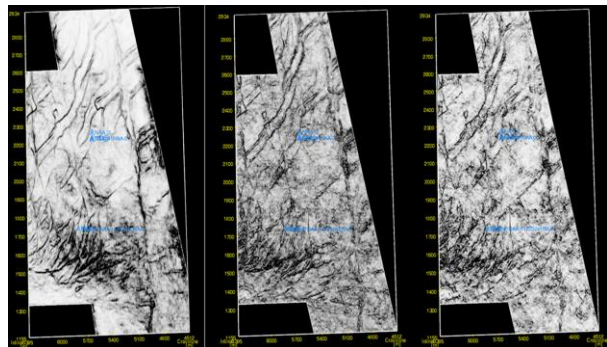


Figure 18: Fault extraction in coherence cube on final stacks (slice at 1600ms): new data with new technology -KPSTM (left), new data with new technology-KPSDM (middle) and new data with FWI & RTM (right)

Discussions

The technological innovations in processing and imaging have accelerated the sub-basalt exploration

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in strategic manner. The presence of ghosts & multiples creates strong fictitious layers that are very much ambiguous in demarcation of the major velocity contrast boundaries as shown in Figure 1. The conventional processing on conventional data is unable to handle the complex nature of ghosting and demultiple that results in poor imaging below basalt (Figure 2).

The deghosting and various demultiple steps in multiple domains with model based and moveout based subtraction in the conventional dataset have brought out the sub-basalt events (Figure 3 through 6). In addition, recently developed modelling and subtraction of interbed multiple partly attenuate the multiples below basalt that increases the visibility of sub-basalt structures (Figure 7). The final stack after new processing technologies on old dataset capable of delineating the base basalt as well as structural framework below basalt (Figure 8). The old dataset have proven the capability of exploring beneath the basalt with the advanced velocity model building & imaging techniques (Figure 9 & 10). The FWI for model update in the shallow able to incorporate the high frequency information and also stabilizes the model for depth migration. The RTM output better preserves the steep dipping events, images faults in better way, enhances the signal strength thereby providing an improved picture of the structural part below basalt.

The event standout, the dipping events below trap bottom are better in PSTM image of new data with new technology than the earlier processed old data PSDM image in time domain (Figure 15). The FWI, tomography, HRHD velocity analysis on new data set have shown improved velocity field around anomalous velocity zones that suggest the presence of gas in the wells (Figure 16). In addition to that, the areal extent of the low velocity anomaly is better demarcated in the velocity volume. The RTM method efficiently image the steeping dipping events and preserves the fault planes in better way than the PSDM & PSTM image (Figure 17). The strength of the fault pattern and the continuity in coherence cube slice within the trap are quite comparable in all the outputs (Figure 18). However, the detailed of the fault pattern is better revealed in RTM image.

Conclusions

The conventional processing technology might be obsolete in applications to the complex sub-surface regime of volcanic basins where the objectives are focused within and below trap. In contrast, the new processing technologies with old data are able to explore the sub-basalt feature to an extent. But, the new broadband data with new technology has more potential to image the low frequency events below basalt. In addition, the images in the tertiary sequences (above basalt) have gained good interpretability in terms of S/N and resolution. However, the limited offset and the narrow azimuth nature of the broadband streamer data itself limit the application of processing technologies like FWI, AVAZ analyses of the deeper zones of sub-basalt which are the prime exploration targets. Again, the narrow azimuth data is unable to delineate the detailing of structural complexity and their variable dipping nature, the abrupt lithological contrast, the presence of extrusive like dykes, sills below basalt.

The views expressed in this paper are exclusively of the authors and need not necessarily match with official views of ONGC.

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