Sub-basalt imaging and exploration: A case study from Offshore India

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Keywords
Sub-basalt, Mesozoic, very high attenuation, overlapping velocities of multiples and primaries, identification of multiples, poor S/N ratio, correct velocities.

Summary
Imaging below complexities still remains a challenge and sub-basalt imaging is no exception. In the case study presented here, disciplined and focussed approach use of processing techniques and interpretational understanding have helped achieve better sub-basalt imaging and hence better understanding of the area (which had never been seen in this basin). The ONGC data processing was carried out by TGS with very active interactive quality control and much essential interpretational support by ONGC, to identify secondary reflections among primaries.

Sub-basalt seismic signal, is typically of low frequency and is heavily masked by linear noise, scattering and secondary reflections. Synergized processing and interpretational efforts were focussed on low frequency signal recovery/enhancing to retrieve reflection signals underneath basalt, identifying and attenuating complicated secondary reflections and various multi domain noise attenuation to maximize S/N ratio. The results obtained are impressive. The new sub-basalt image has opened several possibilities in this region.

Introduction
The area under discussion has basalt overlying Mesozoic sediments. Tertiary thickness above basalt is varying up to 3km and has strong Late Oligocene/ Eocene level reflector. The existing well data suggest thickness of basalt up to 3km - thickening south-west and presence of clastic within Mesozoic. There are several drilled wells some of which have encountered Mesozoic sediments below trap where basalt is less thick.

Mesozoic sediments with two way time of 1.5s to 8s TWT form the objective for this study. The objective of the reprocessing project was to produce high resolution and reliable sub-basalt imaging.

The water depth in the area is about 30m.

The data under discussion was acquired with 12km streamer length towed at 15m, source depth 14m and recorded with Low cut of 3Hz -200Hz frequencies, giving a nominal fold of 240 at 6.25 m bin interval. An earlier attempt to process this data showed poor reflectors below basalt with very low S/N.

Challenges and solutions

The problem
Due to shallow (~ 30m) hard water bottom and shallow carbonate formation- typical in basalt setup; seismic data is dominated by strong linear noise, strong reverberations and multiples. In addition to the above shallow water problems, the thick Deccan basalt (several flow of lava, partly weathered which adds to further attenuation) prevents the penetration of reflection energy which further degraded the data quality. Multiple lava flows accompanied by erosion poses another complexity - scattering of energy.

As primary and secondary stacking velocities nearly overlap in this setup (tertiary with younger sediments includes limestone and Mesozoic which has comparatively compact clastics have similar velocities), it is essential that model (concept) based multiple removal are applied to selectively remove secondary events. This further emphasizes the need for improved S/N at gather level itself to recognize the correct velocity.

To sum up these challenges are:
1. Signal below basalt is weak and high frequencies are attenuated.
2. There is strong linear noise.
3. Strong secondary reflections contaminate sub-basalt reflections which have similar velocities as those of primaries. (It can be visualized that wherever tertiary has more of carbonate and thin basalt, primary events’ velocities within Mesozoic could well be very close to secondary reflections- a difficult situation for processor who is picking velocities)

The area is thought to have several flows of lava in the past. Hence there are likely to be several layers of basalt overlain by some eroded basalt. This complicates the setting as it tends to attenuate and lead to more scattering of seismic waves implying high frequencies are fastly lost as the wavelet propagates through basalt. With high frequencies scattered/ attenuated more than low frequencies and the low frequency component becomes more critical in distinguishing a reflection boundary, a solution to enable the identification of the reflection signal from deep
reflectors beneath the basalt is to enhance the low frequency components of the seismic signal along with the attenuation of linear noise. Therefore efforts were focussed on low frequency signal recovery/ enhancing S/N to retrieve deep reflection signals underneath basalt, complicated multiple removals and various multi domain noise attenuation to facilitate optimum velocity thus maximizing S/N ratio. Wavelet processed for low frequency boost was applied to enhance the low frequencies. (For this purpose TGS’ Clari-Fi Amplio module was used. This broadens the spectrum to a desired shape up to the first ghost notch frequency and also addresses Earth filtering effects)

Basalt is almost always overlain by limestone- this area is no exception. The biggest challenge of course is posed by the very strong inter-bed multiples (particularly related to trap and even Eocene reflector), with similar move-out as the primaries of sub-basalt. Hence we end up with nearly similar velocities for signal and secondary reflections. It is interesting to note that in this area, Eocene carbonate is easier to identify on the seismic section than trap top. Of course, it generates multiples in the target interest zone. During processing one need to separate noise from signal-only then it can be attenuated.

As primary and secondary velocity nearly overlap in this setup, model (concept) based multiple removal are applied to selectively remove secondary events. Once strong linear noise attenuation and shot domain de-multiple was done, visible strong shallow reflectors, were interpreted and corresponding secondary reflections and their velocities were identified. These can now be removed using high resolution multiple removal technique. This sets the stage for more confident velocity picking. Accurate velocity analysis in turn results in better sub-basalt stacking responses of higher S/N ratio. Availability of long offset also helped in this effort. To aid multiple attenuation, SMELT™ module of TGS, was applied in the CMP domain (It creates a multiple model for subtraction). Better images received from this processing indicates the need for improved S/N at gather level itself so as to recognize the correct velocity to boost the low frequency poor signal : that is identifying signal below basalt within a gather which is infested with strong multiples is a big challenge.

As in any processing project, at each processing step detailed investigation/tests are carried out to devise and implement the best possible processing methodology and parameters to meet the objectives. Various options- different modules of processing, to attenuate multiple removal were combined and systematically tested for better velocity picking thus enhancing poor signal. It is essential to follow this approach with precision so as to preserve the weak signal and attenuate non signal energy to maximum.

So to sum up the methodology:
1. Boost the low frequency component of the signal
2. Remove linear noise and the multiples in shot / receiver domains.
3. Model the secondaries and remove them with precision.
4. Pick the best possible velocities and follow with de-multiple.

In this case, the low frequency components are boosted (and thus seismic signal are effectively enhanced) and de-multiple was achieved using TGS’s modules (Clari-Fi® Amplio® modules for low freq. enhancement and HMT and SMELT for demultiple processing).

Imaging results
Significant improvement to the intra and sub-basalt image has been achieved. A comparison between the new processed and vintage processing is shown to demonstrate low frequency enhanced signal and better S/N ratio below basalt. The trap bottom and reflections arising from sills/dykes within Mesozoic could be imaged. The E-W lines images syn-rift sequences nicely. The NNW-SSE trending Dharwarian fault system associated with rifting of Kutch basin is clearly imaged in this effort, thus bringing out rift graben geometry in the area. Tertiary highs formed due to reactivation of these fault system causing late-inversion structures.

Conclusion
Adjusting processing workflows based on the complexities of the area in term of geology and data guide is the key to solving challenging problems. Significant improvements have been achieved with this work-flow for sub-basalt imaging through:
1. Low frequency enhancement.
2. Identification and removal of secondary reflections using precision demultiple techniques and inferring their times and velocities.
3. Careful design and implementation of multi domain noise attenuation techniques.

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Declaration
Views expressed in the paper are strictly those of the authors only.

References


Figure 1a: Major Primary reflection simplified model.

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Figure 1b Major secondary events.

Figure 1c: Major primary and secondary events. It is difficult to distinguish primary and secondary events from velocity. The secondary events follow the geometries of primary events from which these can be identified and even their velocities inferred, after that only these can be removed with precision de-multiple techniques.

Table below: Typical reflection co-eff.
Fig 2a: Spectra and Wavelet before (green) and after (orange) low freq. (upto 3Hz) boost

Fig 2b: Wavelet before (red box) and after (blue box) low freq. (upto 3Hz) boost
After low frequency enhancement, suppressed side-lobes/weaker reverberation.

Processing Flow:

To improve S/N to the maximum so as to boost the weak signal, processing flow attempted to attenuate linear noise and multiples through
- LNA in both shot and receiver domain,
- Multiple removals both in shot and CMP domain using model and velocity based approach (both before and after velocity refinement).
Post migration, gathers and stack were also further processed for noise removal.

Fig 3. Summarized work flow

Fig 4a. Stack after Deswell

Fig 4b. Stack after demultiple: The background indicates poor S/N
Fig 4c. Migrated raw stack.

Fig 5a earlier image.

Fig 5b Final image

Fig 5c Earlier image spectra

Fig 5c present image spectra dominantly low freq