Effective demultiple and depth migration enhances basalt and sub-basalt features: A case study from Kutch Offshore, India

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Abstract

Thick Mesozoic sediments under the basalt cover, the Deccan traps, along the northwest coast of India are considered to be potential targets for hydrocarbon exploration. The basalt is composed of multi-layered extrusive flows that suggest at least 40 periodic pulses of lava forming inter-trap deposits (Kumar et. al., 2004). This generates heterogeneous basalt layers, which makes sub-basalt imaging more difficult. Sub-basalt seismic imaging is very challenging in these areas due to Deccan trap morphology. The trap comprises of multi-layered lava flows with high surface rugosity and considerable thickness about 1500 m. Seismic imaging issues associated with high velocity basalt include:

1. Multiples generated in interbedded units of basalt and the top of basalt and water bottom.
2. Energy scattering from and absorption by basalt heterogeneities.
3. Wave mode conversion at the top of the basalt.

The present study is about enhancing the sub-basalt as well as basaltic sequences with pre-migration demultiple and depth migration. The data used for demultiple processing are both source and receiver deghosted so as to retrieve the low frequency part of the signal. The low frequency signal can propagate down the thick basalt and is the main component for gathering sub-basalt information. The depth migration like beam migration can effectively consider the lateral velocity variations and ray bending at velocity boundaries. Moreover, the multi-pathing and steep dips are also well taken care by beam algorithm. The beam methods are themselves very accurate, flexible and efficient.

Introduction

Mesozoic sediments below thick basalt are considered to be potential targets for hydrocarbon exploration in NW part of India. The difficulty in imaging of sub-basalt features arises due to the presence of multi-layered and highly heterogeneous basalt. The imaging issue is greatly affected by the generation of short as well as long period multiples. In offshore Kutch area, there are three strong seismic reflection interfaces: (1) the sea floor, (2) the top of the basalt and (3) the base of the basalt. These surfaces are the major sources of multiples among which the top basalt is strongest reflector. The multiple between top basalt and water bottom is very strong in nature and masks the reflection from the sub-basalt sedimentary layers. In addition, the interference with various types of multiples and their high orders further cover the Mesozoic reflections. The multiples from various sources, single-to-higher orders and interference badly contaminate the useful signals in the data from top-to-bottom.

The water bottom multiple and the higher order multiples between surface and water bottom have been effectively handled before migration. The attenuation of water bottom related multiple boosts the intra-basaltic sequences whereas the higher order multiple attenuation technique boost the sub-basaltic sequences. Then, the deconvolution in tau-p domain is also applied to the data which attenuates small period ringing. The multiples are generated from various sources such as water bottom, top basalt and bottom of the basalt. Again, the interference of multiples with the primary below basalt diminishes the S/N ratio. In addition, the multiples cause rapid broadening of the primary reflections which reduces the resolution of the sub-basaltic sequences (Figure 1).

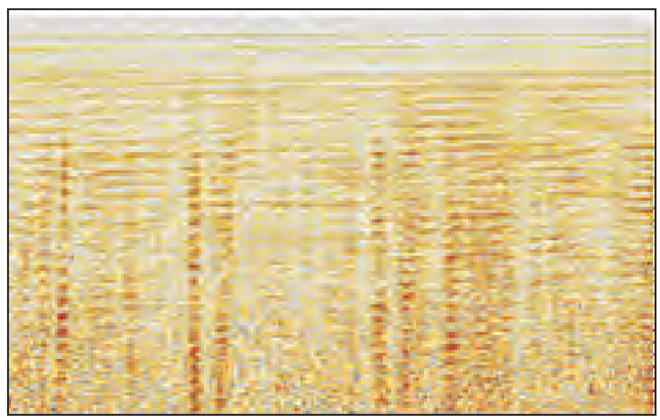

Figure 1: Common channel raw data of the near cable showing the presence of strong reverberations that mimic the presence of false layers of the subsurface.

In first hand, the demultiple data was migrated with aperture 11km in Kirchhoff time migration scheme. The time migration is able to image the sub-basaltic sequences. Therefore, demultiple schemes are key to pre-migration processing for enhancing sub-basalt formations. But, it suffers from the incorrect depth matching of sub-basaltic layers at well location which is inherent in complex overburden scenario.

The complex overburden like high velocity basalt imposes strong lateral velocity variation as well as abrupt vertical velocity variation. The time migration scheme assumes a very smooth velocity field which could not incorporate the velocity issues imposed by basaltic overburden.

The study area is situated in the north-west part of western offshore India (marked in Figure 2).

Figure 2: Location map showing the study area (red circle)

The broadband (BB) data used here was acquired in broadband (BB) sense with slant streamer and multi-level source. The broadband (BB) acquisition effectively reduces both source and receiver ghosts during acquisition stage by employing multilevel sources and slant streamers. The data was processed to further improve the spectrum by effective deghosting and demultiple. The principal aim of the pre-migration processing scheme is to attenuate all types of multiples that badly contaminate the primaries. The attenuation of multiple was attempted in multiple domains; shot as well as CMP domain during pre-migration processing. Then, Kirchhoff time migration and beam depth migration were carried out on the demultiple broadband data for comparison. In addition, the vintage beam migration on conventional streamer data was also analyzed in terms of improvement against the broadband beam migration.

Methodology and results

The processing flow followed for the study is shown below.

1. SEG-D input
2. Remove recording delay.
3. Navigation merge.
4. Low cut filter.
5. Trace edits
6. T^2 spherical divergence
7. Section sensitivity correction
8. Random noise attenuation
9. Linear noise attenuation
10. Prep deghost – residual noise removal
11. Designature and Source Deghost stage
12. Demultiple-1 (Water Bottom Demultiple)
13. Residual Denoise
14. Offset domain Interpolation
15. 2D SRME (CMP Domain), Demultiple-2
16. High Resolution RADON Demultiple, Demultiple-3
17. Tau-P Deconvolution, Demultiple-4
18. Prestack Migration (KPSTM and Beam)
19. Residual demultiple
20. Raw stack
21. Post-stack processing

Figure 3: Processing flow

The processing flow as mentioned above is mainly designed to attenuate the multiples that dominate the raw data (Figure 3). Prior to demultiple the deghosting technique amplifies the amplitude at the ghost notches and retrieve the low frequency part of the signal. The water bottom demultiple (demultiple -1) was attempted in shot domain by method of modelling and subtraction principle to eliminate the water bottom related multiples in Figure 4, which are common in marine data and are quite strong in basalt flow regime. After regularization of data in CMP domain, the surface related multiples (demultiple-2) are attenuated by method of modelling and subtraction shown in Figure 5. The residual multiples are also seen in the data even if after application of two pass demultiple schemes.

The shot period multiples seen after three pass demultiple schemes are removed (Demultiple-4) by deconvolution in tau-p domain (Figure 7) with appropriate prediction distance without harming the wavelet; the central lobe of the autocorrelation functions.

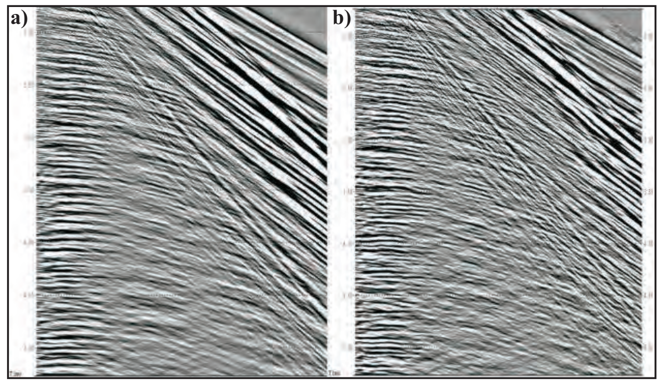

Figure 4: a) A segement of a shot record (left) before, and b) after demultiple process 1. Notice the significantly reduced multiple activity in (b).

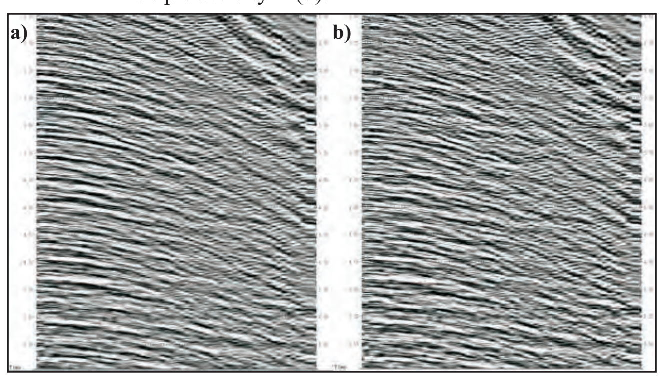

Figure 5: a) A segment of a CMP gather (left) before, and b) after demultiple process 2. Notice the significantly reduced multiple activity in (b).

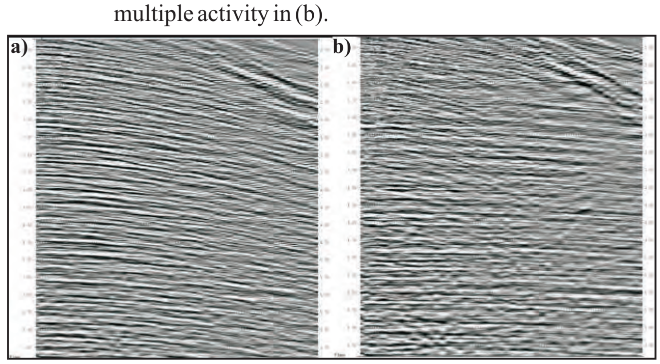

Figure 6: a) A segment of a CMP gather (left) before, and b) after demultiple process 3. Notice the significantly reduced multiple activity in (b).

Those multiples are attenuated by moveout filtering in radon domain (demultiple-3) as shown in Figure 6.

The undulations; the ups and downs in amplitude spectra gradually decreased after various demultiple methods and finally the spectrum looks more balanced (Figure 8).

The cascaded demultiple processes in multi domains and varied prediction and removal effectively weaken the multiples in the data shown in Figure 9. This is evident from the autocorrelation functions of the stacks shown in Figure 10 where the reverberation side lobes away from the central lobes diminished after each demultiple methods.

The demultiple techniques discussed above are applied to the broadband data acquired with multi-level sources and slant streamer. The demultiple output gathers are migrated with Kirchhoff time, beam depth migration scheme. The outputs of beam depth migration are compared with the earlier beam depth migration with same velocity carried out with limited demultiple processes on the conventional data. The demultiple KPSTM stack shows good detailing below trap (Figure 11).

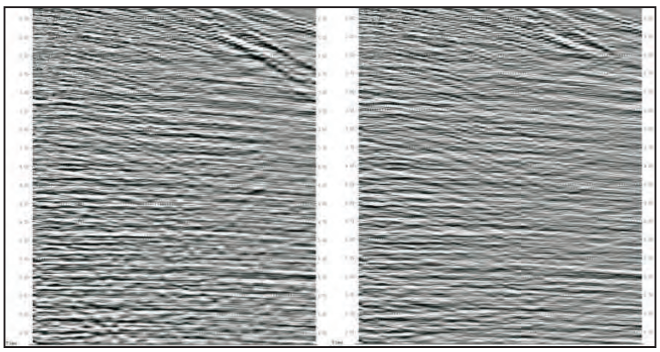

Figure 7: a) A segment of a CMP gather (left) before, and b) after demultiple process 4. Notice the significantly reduced multiple activity in (b).

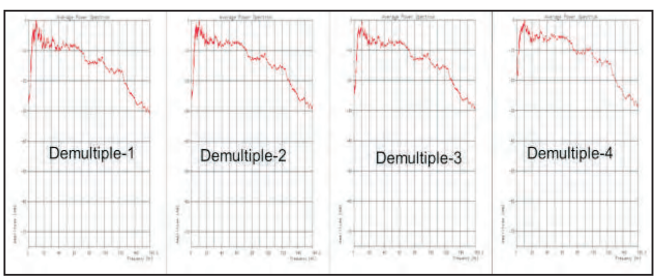

Figure 8: Spectra comparison of the gathers after application of various demultiple processes.

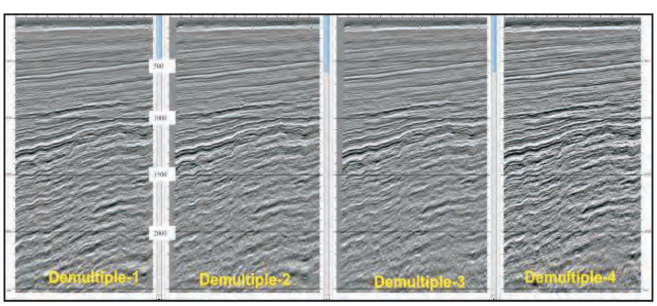

Figure 9: Stack comparison after various demultiples

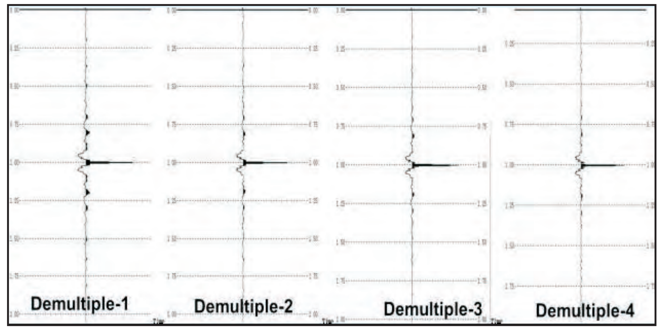

Figure 10: Autocorrelation function comparison after various demultiple techniques

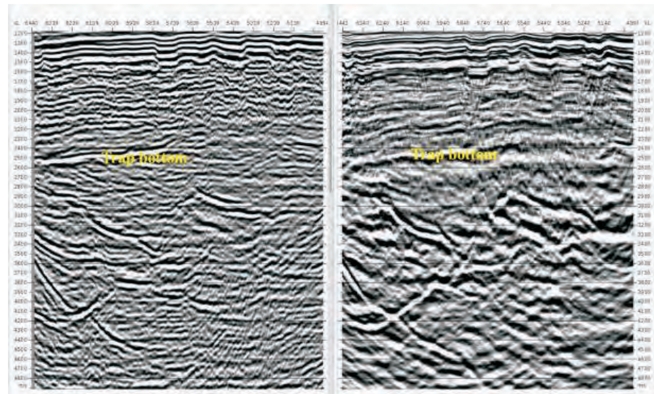

Figure 11: Pre-stack migrated comparison; vintage beam migration scaled to time (left), KPSTM of broadband (right)

The Gaussian beam migration (Hill, 1990) is an elegant, accurate, and efficient depth migration method. It has the ability to image complicated geologic structures with fidelity exceeding that of single-arrival Kirchhoff migration and approaching that of wave-equation migration (Gray, 2004). In fact, its accuracy can exceed that of most wave-equation migrations in imaging very steep dips, especially in three dimensions and especially in the presence of anisotropy.

The outputs of beam depth stack and earlier beam depth stack scale to time are shown in Figures 12 and 13 for comparison. Imaging in depth domain using beam migration has improved the continuity of trap bottom in demultiple data discussed above in comparison to the vintage data. The

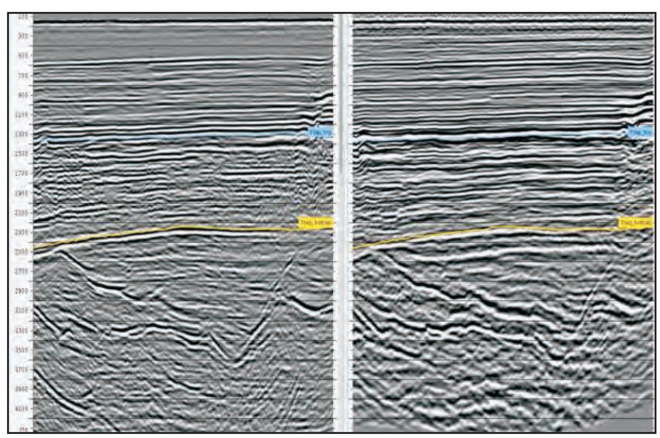

Figure 12: Pre-stack beam migrated scaled to time comparison; vintage (left), broadband (right)

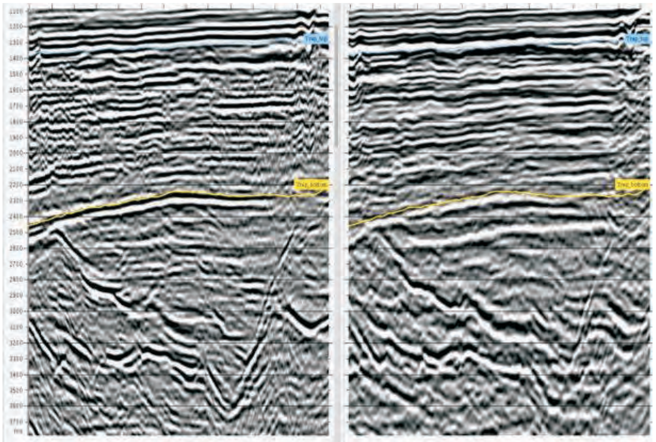

Figure 13: Pre-stack beam migrated scaled to time comparison; vintage (left), broadband (right)

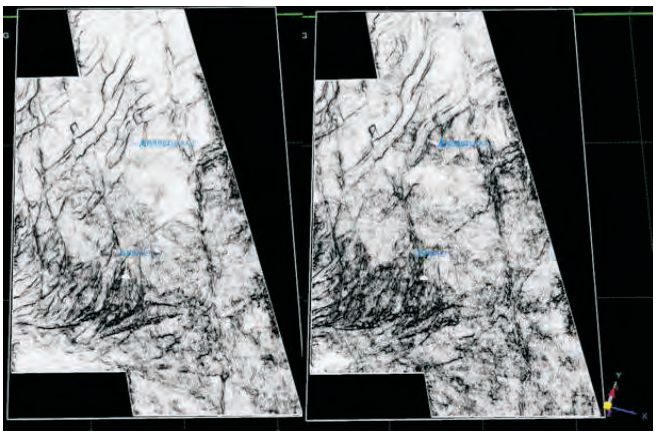

Figure 14: Time slices left (1500 ms) and right (1600 ms) from coherence volume showing fracture and fault pattern within the basaltic sequences in KPSTM broadband data.

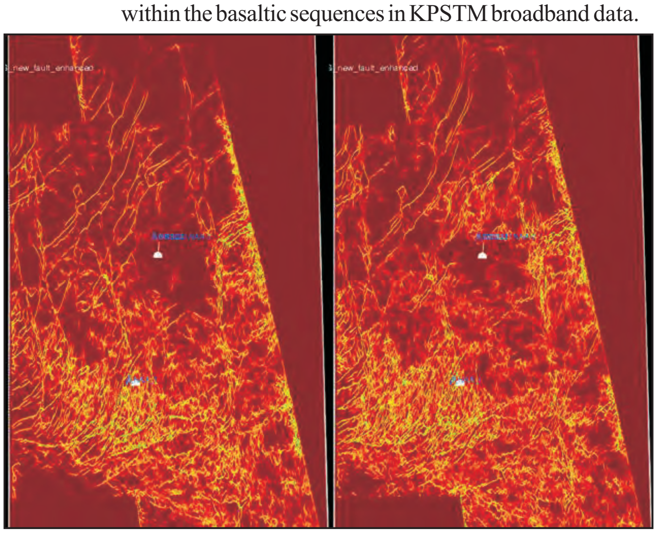

Figure 15: Time slices left (1500 ms) and right (1600 ms) of fault enhanced volume showing fracture and fault pattern within the basaltic sequences in KPSTM broadband data

additional low frequency event just below trap (black arrow) has come up very nicely. In addition, the clarity steep dip events within Mesozoic are clearly brought out in recent demultiple depth migrated output.

Fault and fracture pattern analysis

The additional benefits of broadband data with cascaded demultiple methods clearly image the fault and fracture pattern in time slices of coherence cube (Figure 14) and fault enhance slice (Figure 15) within the basalt sequences. The extension of the network above the basalt as well as in Mesozoic sequences can also be observed in the section (Figure 11).

Conclusions

The demultiple algorithms in multiple domains such as shot and CDP domain effectively attenuate multiples. The reflections below basalt stand out after the cascaded multiple attenuation schemes. Therefore, it is very much essential part of pre-migration processing that the demultiple schemes are applied to the datasets in multiple domains through modelling and subtraction, through moveout based subtraction so as to improve the subtle reflections from subbasalt sequences.

The beam migration of broadband data is able to image the base basalt along with the dipping events below basalts very much clearly. In addition, the sediment sequences below basalt are coming better in comparison to the conventional beam migration and KPSTM of broadband data. The KPSTM of broadband data has better definition below basalt, although the base basalt is better tracked in both beam migrated datasets.

However, the fault pattern and fracture network within and below basalt sequences are only tracked in broadband (BB) KPSTM data. Hence, this further broadens the exploration scenario within the basalt sequences and the existence of hydrocarbon in the fracture can be thought of as in case of fracture basement set-up.

The broadband data has got potential to retain low frequency which in turn focusses the sub-trapeans as well as intra-trapeans sequences.

The broadband acquisition and broadband processing in combination of cascaded demultiple schemes in multiple domains can be one of the best input for migration.

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