Enhancing Sub Basalt Imaging Using Depth Domain Processing

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Summary

Processing of 2D long offset Seismic Reflection data for sub basalt Imaging still remains a challenge for the Processing Geophysicists. So far there is no commercial processing solution for meaningful imaging below basalt. Time domain processing has its limitations to process reflection events which are hyperbolic in nature. With careful analysis of suitably pre-conditioned long offset dataset and detailed velocity analysis, imaging could be improved to map the base of basalt, leaving scope for further improvement in the sub basalt section.

Reflection events below basalt layer are non hyperbolic in nature and hence, may improve imaging, if processed in depth domain. Further, the reflection events from the sections below basalt layer are very weak and are recorded at larger offsets in the spread. Velocity estimation for sub basalt sections and making an appropriate velocity model for carrying out pre stack depth migration (PSDM) of near and far offset wave field is the most important and difficult aspect of sub basalt imaging in depth domain.Depth domain processing was attempted on a suitably preconditioned dataset using exhaustive velocity estimation and model building from refracted and reflected events present at near and far offsets. The results brought out spectacular improvement in imaging below basalt. Far offset reflections integrated with geologic knowledge reduced the uncertainties in the estimation of suitable velocity model for carrying out depth Imaging.

Introduction

Seismic imaging of Mesozoic sediments for hydrocarbon exploration has been a difficult task. Presence of thick inhomogenous basalt layer having very high impedance contrast with the overburden, acts as acoustic barrier and restricts the energy penetration below. Strong inter beded and long period multiples, very high level of scattering, lack of reflections in the sediments below basalt, low S/N ratio in the data, further makes the sub basalt imaging difficult. In Cambay basin of Western India, long offset 2D seismic data has been acquired to explore Mesozoic sediments lying below widespread basalt body. Due to the non hyperbolic nature of sub basalt reflections associated with problems inherent to the sub basalt reflections discussed above, conventional processing fails to bring meaningful imaging below basalt.

Depth domain processing was attempted on the long offset dataset, bringing in suitable data preconditioning strategies, the geologic knowledge to limit the uncertainties, exhaustive velocity estimation and model building approach, and combination of long and short offset arrival information. This paper emphasizes that sub basalt imaging can be substantially improved using depth domain processing on long offset data with proper preconditioning of the input data, identification of sub basalt reflections on the long offset arrivals and with estimation of a most accurate and meaningful velocity model.

Data Pre Conditioning

The study has been carried out on a long offset profile (Profile-A) shot with a 9 Km long end-on spread using explosive as source. The profile is oriented NNW-SSE and passes through the well Viramgaon (fig.-1) in the NNW end of the profile. The well indicated the presence of Mesozoic sediments at a depth of 954 m after penetrating through 347 m thick column of basalt. Figure-2 shows an actual shot gather depicting various identified reflection and refraction events. Preliminary analysis from the shot gathers indicates the apparent velocity of Basalt to be around 5000 m/s. and that of Basement to be around 6000 m.sec.The data is contaminated with high frequency random noise, scattering of events and presence of multiple reflections. Sub basalt seismic signal has poor S/N ratio and thus it is difficult to identify any coherent reflection event below basalt top boundary, which is represented by the strong hyperbolic reflection event.

Having known that low frequency seismic signal can penetrate better than high frequency signal, suitable pre conditioning strategies were formulated. The data were subjected to various processes viz.. band pass filter 4-6-35-

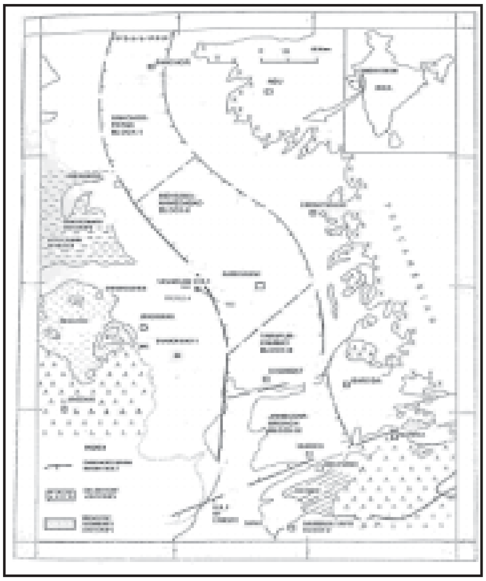

Fig.1: Location map of the study area.

Fig. 2: A raw shot gather showing various seismic refractionphases and cycle skip.

45Hz., shot domain f-k filter, large gap Deconvolution (68 m sec prediction lag, 360 m sec op. length) and Radon demultiple, which enhanced the gather quality substantially. The extent of high frequency noise reduction in the precondition gathers and the boosting of the weak sub basalt reflection events present in the far offsets traces reveled the need to focus the whole processing towards low frequencies.

Velocity Estimation and PSTM

Velocity estimation is the most important issue in processing long offset data for sub basalt imaging. With conventional velocity analysis techniques, it is only possible to estimate velocities of Tertiary sequence up to the basalt top. A conventionally processed section does not show any co-relatable event below basalt top boundary (Fig.-3).Careful velocity analysis on suitable pre conditioned gathers , having whole range of offsets, and scanning for higher velocity values shows a deviation of velocity trend which reveals the possible detection of basalt base (Fig.-4).Velocity scanning in higher velocity fan was done all along the profile, guided by geologic knowledge, to search for base basalt boundary and to estimate its velocity along the profile.

Fig.3: A conventionally processed post stack migrated section along profile-A

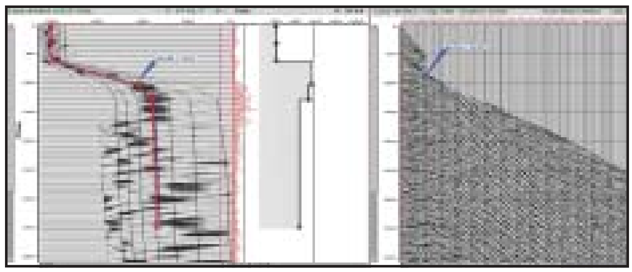

Fig. 4: Velocity analysis on long offset gathers.

NNW SSE

Having estimated the velocities, Pre Stack Time Migration (PSTM) was carried out to further refine the velocities on CRP gathers and to produce RMS velocity section along the profile to generate a PSTM stack using refined velocities(Fig.-5).

The PSTM stack section (Fig.-6) reveals the presence of a coherent and discontinuous event in the deeper section, which may possibly be attributed to base of basalt. The signature of base of basalt in the PSTM section could be mapped with the seismic signals present in the near offset traces (Fig.-7) however, suitable preconditioning of the gathers and careful velocity analysis played major role in the delineation of base basalt boundary. From the analysis of the pre conditioned gathers, it is felt that still deeper reflections are present in the far offset traces of the gathers which may be attributed to the Mesozoics and Basement

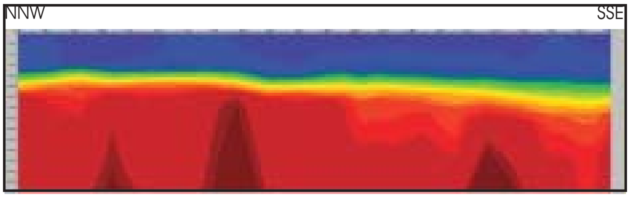

Fig.5: RMS velocity section along profile A

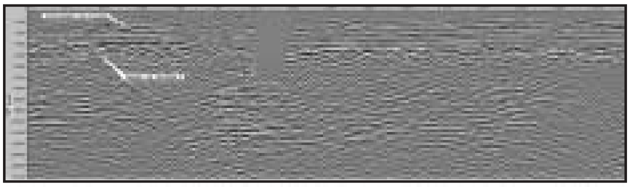

Fig.6: PSTM Section along the profile-A

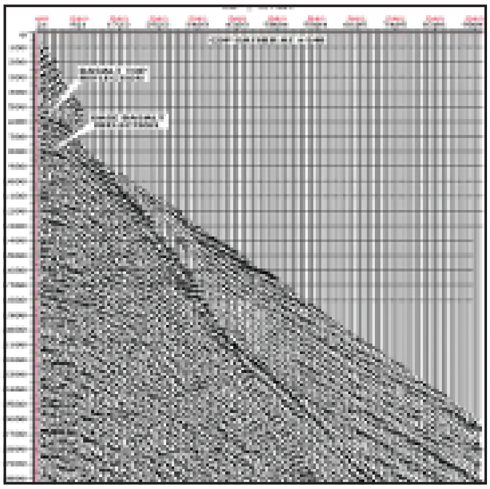

Fig.7: A CDP gather showing events corresponding to base of basalt.

(Fig.-8) but, these sub Basalt reflections are severely non-hyperbolic in nature and thus need PSDM for meaningful imaging.

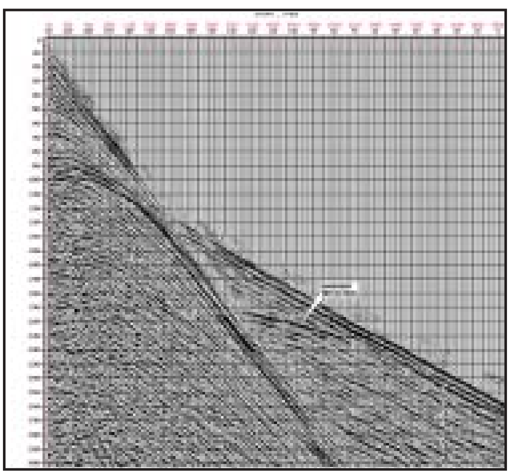

Fig.8: A gather showing event corresponding to Basement.

Velocity model building and PSDM

Success of Pre Stack Depth Imaging depends upon the accuracy of layer velocity estimation and defining the reflector geometry to build a depth velocity model. It is true that velocity-depth ambiguity can never be resolved completely in building a model however, the uncertainties can be restricted by using variety of seismic phases, geological knowledge, well information etc.

Long offset seismic gathers generally contains more information as compared to the conventional gathers. However, the issue is to identify the events and enhance them to contribute to depth imaging. Attempt has been made to fully use the information available in the near as well as the far offsets of the seismic gather in the form of refraction and reflection phases, in the model building process. The refracted arrivals contain important information corresponding to the basalt top and the basement. The presence of Mesozoic sediments below high velocity basalt layer causes velocity inversion and thus the base basalt can not be detected using refracted arrivals however, the presence of velocity inversion can be reflected in the form of "cycle skip" in the refracted arrivals (Fig.-2). The refracted arrivals of the short and long offsets were used to estimate basalt and Basement velocities and its configuration to aid in building an initial model for running PSDM. The actual model building for PSDM was done by estimating layer velocity from image gather analysis of PSDM gathers and the reflector geometry delineation from the PSDM stack section. The process was carried out in layer by layer manner iteratively. Following strategy was adopted in building the depth velocity model and running PSDM.

1. Assign vertically varying velocity functions, estimated from conventional velocity analysis to the Tertiary section up to the top of basalt layer.
2. Perform 2-D pre stack depth migration (PSDM) to verify the velocity functions with the help of image gather analysis and finalize the velocities for the Tertiary section up to the basalt top boundary.
3. Assign a range of velocities (4500-6000 m/s) to the half-space below the top basalt boundary to create a set of velocity sections and perform 2D PSDM to estimate basalt velocity and to bring out the base basalt boundary to obtain earth image up to the base of basalt. Lateral velocity variation for basalt layer if any, is also to be analyzed and accommodated at this stage.
4. Next, assign a range of velocities (3500-4500 m/s) to the half-space below the base basalt boundary and perform PSDM as described in step 3 to estimate

velocity for Mesozoic sediments lying below basalt layer and to image the basement configuration.

5. Finally assign the basement velocity (6000m/s) obtained through analysis of refracted arrivals at longer offsets in sp gathers, to the half- space below base of Mesozoic boundary
6. Use the model created at step 5 and perform PSDM on the whole line to create image gathers at discrete locations.7. Study the image gathers created in step 6 to asses the flatness of the events corresponding to various layer boundaries and update the model accordingly.
8. Run PSDM with the updated model and generate image gather for the whole line. Design a suitable mute function and generate a PSDM stack section which represents the correct image of the sub surface.

Results

Figure 9 shows the PSDM stack output from several iterations. The corresponding interval velocity section is shown in Fig.10**.** It is evident that the Tertiary section is represented by continuous seismic reflection events having desired frequency content. The Tertiary section is underlain by a massive basalt layer having very high velocity (~5000 m/s) .The top basalt layer is resolved in conventional processed section (fig.3).The base of basalt layer could be resolved in PSTM output but, only up to certain extent in the NNE part of the profile. The roughness of the basalt top is well resolved in PSDM stack output. The PSDM section is able to image the base basalt boundary quite satisfactorily indicating that the basalt layer is thinning in NNW side of the profile and thickening towards SSE .The layer below basalt is a sedimentary section corresponding to Mesozoics, represented by velocity inversion having interval velocity of the range of 3900 m/s-4300 m/s. Both intra basalt and Mesozoic section are represented by very low frequencies, discontinuous and patchy reflections. Events within the Mesozoic section are very weak .The deeper event marked red is attributed to the possible basement , having interval velocity ~6000 m/s. The PSDM image indicates the thickening of basalt layer and deepening of basement towards SSE, which is also evident from the analysis of long offset refracted arrivals of shot gathers. The well drilled at SP#506 in the NNW part of the profile indicates the presence of basalt top and base boundary at a depth of 607 m and 954 m respectively, which is very well correlated with the PSDM result .The well was terminated within the Mesozoic layer at a depth of 1183 m. The possible Basement from the PSDM image can be estimated at a depth of 1400 m.

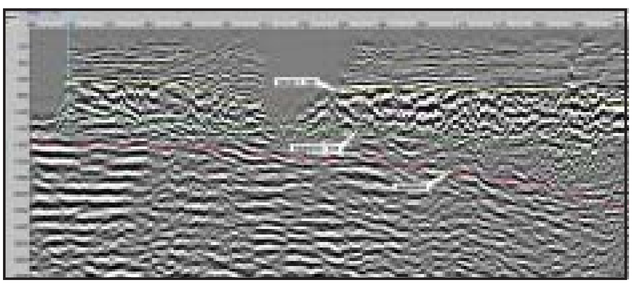

Fig. 9: PSDM Section along the profile-A

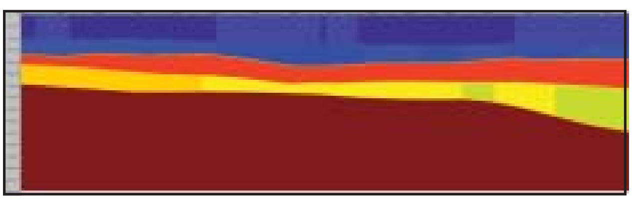

Fig. 10: Depth Interval Velocity model along profile A

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Conclusions

Processing of long offset data in depth domain generated a better image with higher amplitude and co relatable events from sub-basalt section compared to time domain. A better image of the basalt base and the probable basement has been generated using depth domain processing. However, the resolution of the processed image reduced due to large spread length used in acquisition and also the restriction made in the frequency band during processing. Estimating an accurate depth velocity model for carrying out PSDM is the challenging issue. Sub Basalt reflections being very weak, data preconditioning with a suitable work flow plays a major role in the imaging. Integrating geologic knowledge, well information, consideration of refraction phases at near and far offsets in addition to reflection phases of the gather generated greater confidence in building depth velocity model. The resolution of the processed image indicates that processing of long offset data can image only large scale features. However a detailed solution to sub basalt imaging with improved resolution is still a challenging task.

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