PSDM from topography: Using refractions to model subsurface and reflections to image

S. P. Das[1], Shankar Thakur[2], K. Pal[1] and Arjeesh Gupta[1]*
**Email: das_sp25@ongc.co.in [1] GEOPIC, ONGC Dehradun, [2] OVL, Delhi*

Keywords
Near surface, Refraction based non-linear tomography, half space velocity analysis, PSDM.

Summary

One of the main challenges in foothills exploration is deriving a subsurface image which is geologically consistent. The common issues often encountered during imaging are related to fluctuating terrain, near surface heterogeneities, ambiguity in subsurface velocity modeling and an imaging solution addressing the spatial velocity variations. The present study is an illustration of depth imaging in the thrust fold belts, wherein the refraction data is used to obtain good near surface velocity model.

Introduction

Seismic imaging remains the main challenge for petroleum exploration in the foothills and thrust fold belts. Several factors reduce the effectiveness of seismic methods in the thrust-belts. These exploration frontiers are usually characterized by steeply dipping beds, large scale structural features and rapid spatial velocity variations. This large scale subsurface feature makes velocity estimation extremely sensitive and hence increases the imaging challenges. The complexities in the near surface compound the problem. The topography in such frontiers is usually rugged and is associated with complex near-surface velocity variations which degrade the quality of the seismic image. These characteristics lead to inadequate penetration of energy through overburden leading to poor signal-to-noise ratio. The raw records are also contaminated with ground roll and guided wave. Therefore a comprehensive methodology needs be adopted which will take care of both near surface as well as subsurface complexities. Depth migration addresses the complex ray bending arising due to strong spatial variations in the velocity distribution..

In this study, a comprehensive workflow for imaging in thrust fold belt is presented for a 2D seismic line pertaining to a thrust fold belt area. Large scale structural features like faulted anticlines, drag synclines and deep seated *decollment* planes characterize the subsurface. The relevant aspects of near surface modeling, noise attenuation and time migration is addressed in this work. The need for a comprehensive velocity model building from the near surface for depth imaging is being highlighted.

Methodology

The thrust belt regimes are associated with data sets which are poor in signal-to-noise ratio. Due to dominance of ground roll and other noise, the reflection events are hardly visible in the raw records. Such data set necessitates an appropriate noise attenuation scheme to preserve as much signal energy as possible. The generalized workflow undertaken for imaging should address the following considerations.

i. Comprehensive near surface solution
ii. Optimal signal conditioning
iii. Reliable residual statics solution
iv. Honoring strong spatial velocity changes in subsurface model building and imaging

Input Data

The input raw data is vintage data, pertaining to thrust foldbelts, acquired in the early nineties. The recording and the acquisition parameters are given below:

Record Length	10 s
Sample Rate	2 ms
# Channels	240
Group Interval	25 m
Shot Interval	25 m
Shot Type	Dynamite (Pattern Holes)
Receiver Type	12 Geophones at 2.08 m

Initially all the survey details, the coordinates and elevation were checked to rectify typographical errors. The geometry merging is checked through LMO application and incorrectly positioned shots were suitably relocated.

Near Surface solution and statics computation

Refracted energies implicitly contain the near surface information and manifest as first arrivals in the seismic data. Inversion of first breaks for near surface velocity modeling has been practiced in the industry. First break picking is carried out by automated picker based on energy ratio. The auto-picker fails or registers false picks, where the ambient noise level is quite large. For those instants, the pickers are usually guided with synthetic traveltimes generated from tomography. Figure 1 shows a refinement of picks obtained using the above method.

The diving (non-linear) ray tomography is used to model the near surface. The observed data is inverted through non-linear tomography (Zhiang and Toksov, 1998) and estimate the near-surface. The iterations are stopped after a desired convergence of the residual errors is achieved; in this case around 10 ms. Near surface model so obtained has to be geologically consistent, so appropriate smoothing criterion is chosen, and *a priori* constraints are applied during the runs. The residual misfits of individual shots are plotted across the profile. Uniform convergence of residual errors is desired across the entire profile. The near surface velocity model derived from tomography is shown in Figure 3.

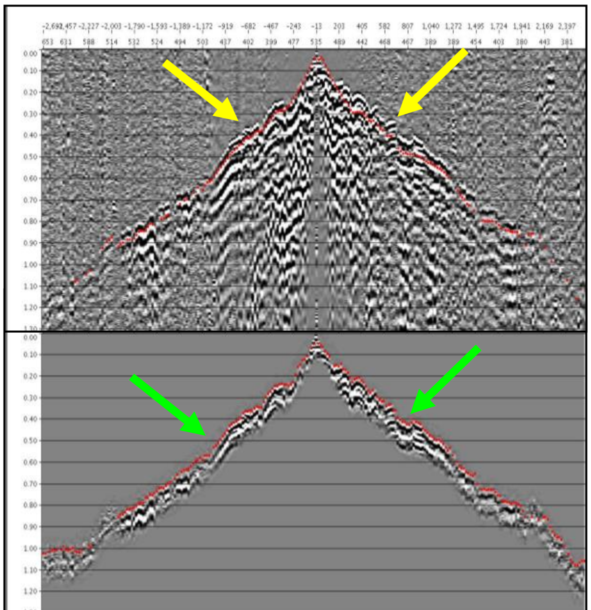

Figure 1: Registering false picks at noisy traces (top) and Rectification of false picks (bottom) by using synthetic picks as guides and to zero in on the actual first breaks.

The statics solution is divided into long wavelength and short wavelength contributions (Jones, 2012). The long wavelength statics solution addresses the large scale changes (heterogeneities) in the near surface. The long wavelength statics requires a model (near-surface model), and hence is a model based solution. This is calculated from the obtained near surface model after choosing proper floating and intermediate datum from the model and appropriate replacement velocity for layer replacement.

Short wavelength statics would compensate for more rapid variations in the first breaks. The short wavelength statics are calculated through a data-driven approach and hence require good quality of first break picks. This method is refraction based residual statics solution which tries to achieve perfect alignment of the first breaks. The first-breaks over a portion of the refractor are taken as input and LMO is applied with a suitable refractor velocity. The first-breaks are usually smoothed over a user-defined radius. The actual first break time is compared with its smoothed counterpart, the time difference between them is taken as time-shift. These time-shifts are redistributed in a surface consistent manner over the shots and the receivers as surface consistent statics. The choice of the smoothing radius is the crucial parameter, which has to be chosen optimally looking at the alignment of first breaks on the gathers. Figure 2 shows the impact of statics on the shot records.

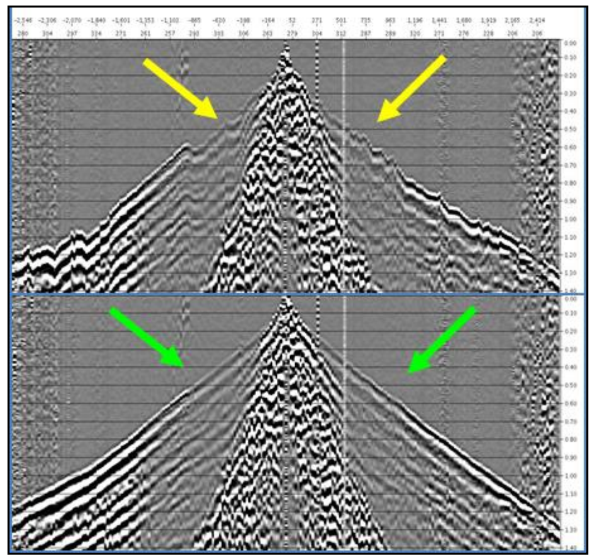

Figure 2: Shot gather without statics (top) and with statics (bottom) shows perfect alignment of the first breaks.

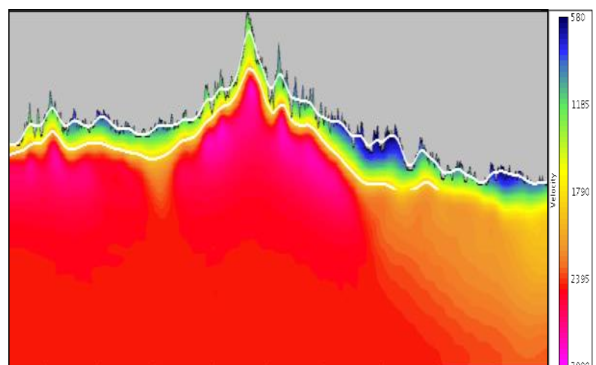

Figure 3: The near surface model derived from non-linear refraction tomography

Signal Conditioning

The thrustbelt dataset are known for weak energy penetration and hence the shot records are having poor signal content. It is also obvious (Figure 2) that even the coherent noise are not perfectly aligned before application of statics, hence any multi-channel processing at early stages can be detrimental to the data. This also demands that noise attenuation be carried out in several stages. In the initial stage, the single trace based processes such as band pass, de-spike, anomalous noise attenuation, etc. are applied. After application of statics, multi-channel based processes are attempted for attenuating the ground roll and guided waves. The radial trace median filtering (Henley, 1999, and Pal, 2006) is a good option since it effectively attenuates the linear noise while preserving the reflections and also generates minimum artifacts.

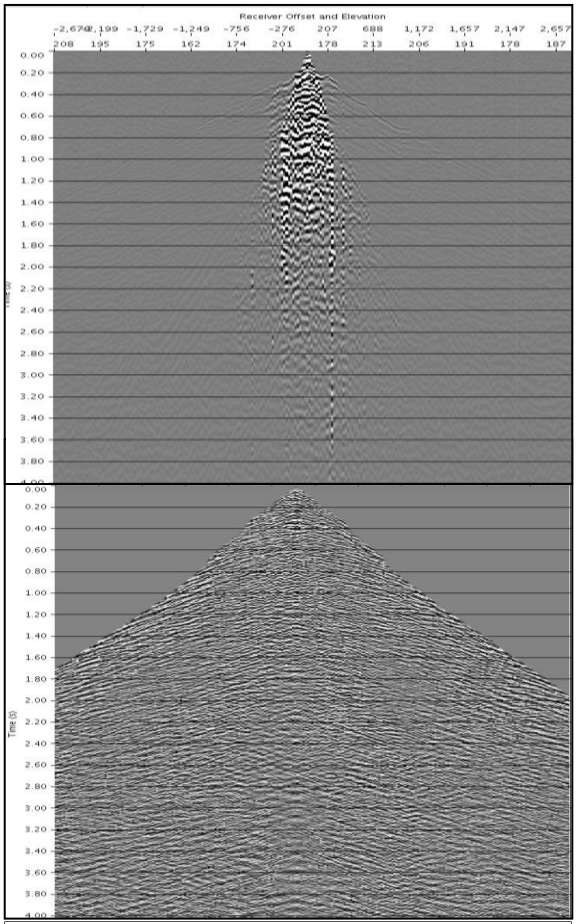

Figure 4: Raw shot gather before (top) and after (bottom) signal conditioning

After the general noise removal from the traces, deconvolution was applied to boost the frequency content in the data. A pass of anomalous amplitude attenuation is used after deconvolution to attenuate any high energy burst. Even after applying the long wavelength statics and refraction residuals, the statics were not fully compensated. The subtle high frequency jitters within the gather has to be compensated. Since this data set is of low signal to noise ratio, the stack-power maximization method (Ronen & Claerbout, 1985) of reflection residual statics is chosen. Multiple passes of residual statics were tried to achieve the intended results. After every pass of statics a further pass of stacking velocity was required so as to make the residual statics work more efficiently. Figure 5 shows the comparison of the stack without residual statics and stack after the final pass of residual statics.

After the final pass of statics application, the reflections were fairly aligned and the random noise attenuation is attempted. Another multi-channel processing in the form of F-X Cadzow (Trickett, 2003) is applied. The FX Cadzow filter is an eigenimage based filter. The coherent energies are mapped into the first few eigenvalues (singular values). The image reconstructed with a limited number of singular values, retaining only the coherent energies, and random noise is discarded in this process. The filter can be used to target a particular noise by suitably limiting the frequency range. It is often practised to suitably flatten the gathers with the stacking velocity before application of the filter.

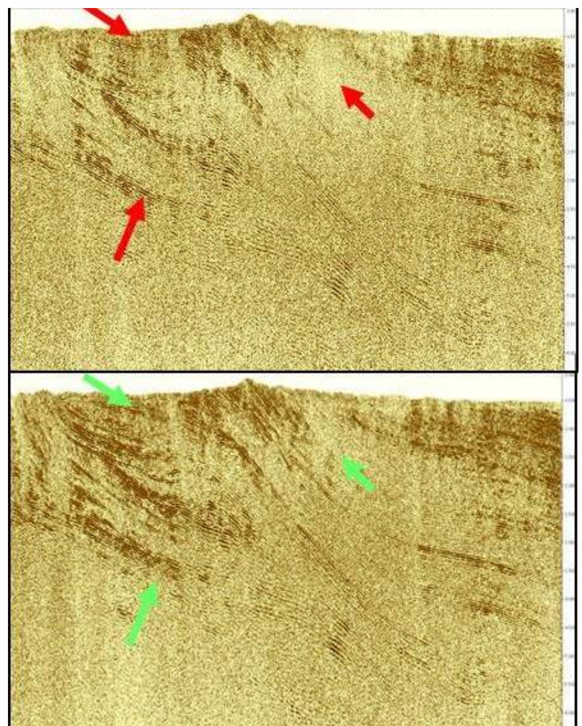

Figure 5: Stack without (top) and with (bottom) residual statics application

Velocity Model Building and Imaging in time

Velocity analysis of cmp gathers in the un-migrated domain may not yield velocities of the intended location. Also, methods based on vertical semblance panels and gather flatness only might not help with datasets with poor signal to noise ratio. It is necessary to reposition the energies through some migration for correctly estimating the velocity. Pre stack time migration (PSTM) from floating datum, which is a smoothed version of topography, for a range of constant velocities was implemented. All these constant velocity panels were interpreted for the time horizons which were focused with a particular velocity. Semblances were picked along each of the horizon strands to ascertain the correct velocity along the strand. This will accommodate lateral velocity variations along horizons. Finally a composite PSTM stack was created for the entire data and the velocity model was derived. The figure below shows one such velocity panel on which the velocity is assigned along horizon strands.

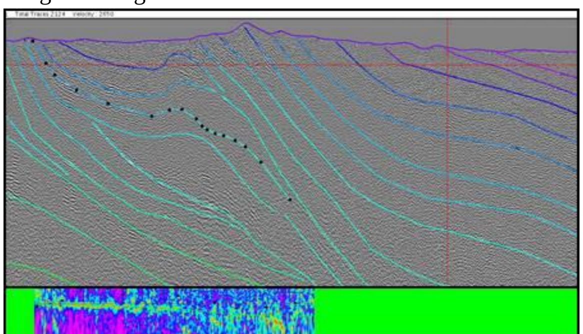

Figure 6: A constant velocity panel (2650 m/s). Velocity assigned along the horizon strands on the basis of semblances.

The velocity model so obtained is the RMS velocity field. In a similar way, eta (fourth order) analysis was also performed in the time migrated domain. The velocity obtained from the above step is used and data is time migrated again from the floating datum using a range of eta values. The horizons which were interpreted on the velocity panels were reloaded. The semblances computed along the strand were the eta values (which will ensure gather flatness for offset/depth ratio greater than one). The eta field is obtained by a composite stack of the entire data at different eta values. Finally a velocity field and an eta field were obtained which were used for re-migrating the conditioned pre-stack data from the floating datum and derive a time migrated image (Figure 7).

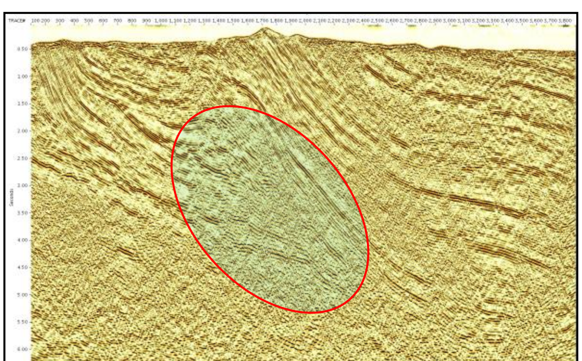

Figure 7: PSTM section

For interval velocity modeling in depth, layer stripping (top to down) half space velocity analysis approach is chosen instead of Dix based RMS to Interval velocity conversion (Yilmaz *et.al.*, 2010). The near surface velocity model obtained from picking the first breaks is the starting model. This is a reliable estimate of the shallowest layer velocity. The model is suitably extended to a desired depth and a Pre Stack Depth Migration (PSDM) is carried out. A horizon (H1) is picked in depth demarcating the boundary above which the interval velocity is known and below which the interval velocity needs to be estimated. This is ascertained by the flatness of the gathers of the initial PSDM. So PSDM with a set of constant velocities are performed, giving a velocity depth cube for a range of velocities. Through this velocity depth cube a velocity is picked which flattens the gathers below horizon (H1). It is to be noted that only significant velocity contrasts are picked, therefore each layer is divided into numerous thin layers, by creating phantom horizons, to preserve the lateral and vertical velocity within each layers. Appropriate lateral and vertical smoothing is applied each of those layers to render a velocity model with gradational changes.

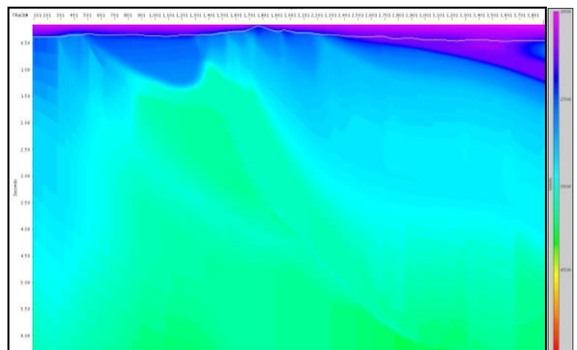

Figure 8: Interval Velocity Model

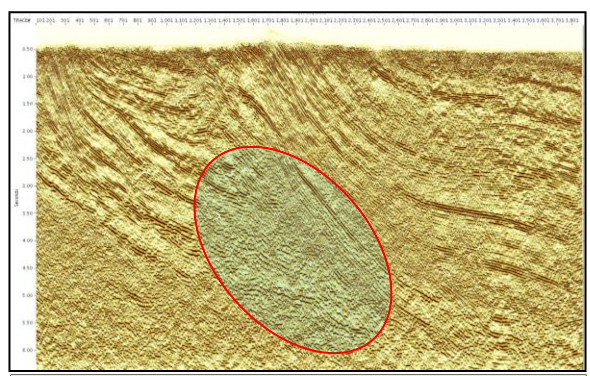

Figure 9: PSDM section scaled to time

Once the velocity model is fixed PSDM is performed to check the gather flatness. A second horizon (H2) is interpreted in depth up to which, the reliability of the model is justified on the basis of gather flatness. So further the same procedure of scanning velocities in depth is repeated and the velocity model is ascertained. And thereafter another PSDM is performed to fix the depth on the basis of the gather flatness.

The procedure is repeated for as many layers necessary, till a reliable velocity model conformal to the subsurface structures shown in the seismic and ascertained by the gather flatness is obtained. Implementing PSDM for as many iterations may be time consuming and costly. But this can be mitigated by suitably resampling the data and using limited range for half-space velocity analysis. The final interval velocity derived is shown in Figure 8. Finally a Kirchoff's PSDM is performed from the floating datum. The PSDM gathers were stacked with suitable conditioning to render a final depth migrated image (Figure 9). The depth image is scaled to time and assessed for value addition. The depth image shows improvements in the sub-thrust regime.

Conclusions

Undulated topography, low signal to noise ratio and complex subsurface velocity structures make the thrust belts an intriguing imaging experience. Using both refracted and reflected arrivals efficiently can mitigate some of these challenges. Refractions provide a very efficient method to image the near surface heterogeneities. Good quality first break picks with iterative refinement is necessary to obtain a reliable near surface model.

Correction of near surface model leads to alignment of both signal and coherent noise thus making it easier to remove the noise through multi-channel processing. A parsimonious workflow for signal processing would retain as much signal as possible. Structure consistent subsurface velocity modeling is essential for the time or depth imaging. In the thrust fold belts regimes, velocity modeling based on constant velocity stack and constant velocity migration proves to be better than other approaches. In the current study, this strategy resulted in improved image compared to the earlier sections.

References

Henley, D. C., (1999), Coherent noise attenuation in radial trace domain: introduction and demonstration, CREWES Research Report – Volume 11

Ian F. Jones (2012). "Tutorial: Incorporating near-surface velocity anomalies in pre-stack depth migration models", First Break, Volume 30 (March), 47-58

Pal, A., and Niyogi, K., (2006) "Removal of Coherent Linear Noise without "Side Effects" and its Application to Pre-stack and Post-stack Seismic Data"; 6th Exploration Conference & Exposition on Petroleum Geophysics

Trickett, S. R., (2003), "F-xy Eigenimage Noise Suppression", Geophysics, 68, 751-759

Yilmaz, O., Uygun, S. Cali, E., (2010) Mapping Imbricate Structures in the Thrust Belt of Southeast Turkey by Large-Offset Seismic Survey; SEG Expanded Abstracts, 80th Ann. Internat. Mtg., Soc. Expl. Geophys.

Zhang, J. and Toksoz Nafi, M., (1998), Nonlinear refraction traveltime tomography; Geophysics, 63, 1726-1737

Acknowledgements

The authors are thankful to Dir. (E), ONGC, for permitting the publication of this work. The authors are deeply thankful to MD, OVL for permitting to use the data set. The authors deeply acknowledge the support received from Sh. A. K. Deshwal, ED-OVL, while carrying out this assignment. The authors acknowledge Sh. Anil Sood, ex-ED-HOI, GEOPIC and Sh. Ashutosh Bhardwaj, ED-HOI, GEOPIC, ONGC for providing the infra-structural facilities to carry out the work. The authors also express the heart-felt thanks to Sh. T R Murali Mohan, GGM-Head Processing, for his constant suggestions and motivations to carry out this work. The authors also acknowledge the support and advice received from colleagues throughout this project.

The views expressed in the above article are entirely of the authors and not the organization.