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Imaging Improvements in Thrust-Belt using Travel Time Tomography: A case study from NE Part of India

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Summary

The discovery of Digboi oil field in 1889 & series of oil seepages brought Nagafoot hills region into focus for its hydrocarbon potential in the past. Yet, a vast prognosticated resource of hydrocarbon remains unexplored due to complex geological set up and poor seismic response in thrust zones/ below thrusts. The characteristic rugged topography and complex subsurface geology poses significant physical and technical challenges in acquiring, processing and interpreting the datasets in the quest of hydrocarbon resources. Estimation of precise statics correction and velocity from the acquired dataset are key elements that dictate the quality of images that can be faithfully reconstructed. In areas compounded by such challenges, utility of travel time tomography for estimation of the near surface velocity model can be used as a supplementary aid to conventional processing approaches. The estimated velocity-depth model from travel time inversion of first beak arrival picks can be further converted in to rms velocity in time and used for deriving more accurate stacking velocity for further processing.

In this paper we demonstrate how the use of potent tools such as travel time tomography can aid in reconstruction of geologically conformable images of the subsurface along with the selection and application of appropriate noise attenuation schemes, proper accounting for long & short wavelength statics, extraction and use of hybrid stacking velocity for improved imaging of the subsurface.

Keywords: *Thrust Belt, First Break, Velocity-depth Model, tomography, inversion*

Introduction

Thrust belt areas have always excited explorationsist for search of hydrocarbon resources despite the challenging nature of surface topography and sub-surface geological complexity it offers. Assam-Arakan Basin, one of the oldest & most prolific onshore basin of India is also not an exception. Since the discovery of first Oil well in thrust region of this basin, constant endeavors have taken place for exploration of hydrocarbon potential. Quality of Seismic data and limited understanding of the complex thrust-belt geology are major concern for better Imaging of the areas in and around Naga thrust. In the study area, 2-D seismic data were acquired along a line approximately perpendicular to the trend of the thrust belt. The data comprises of moderate signal-to-noise ratio and suffer from ground roll and other acquisition generated noise. Furthermore, lack of adequate understanding of the thrust- belt geology limits the ability of conventional processing to yield a reliable velocity model which in turn leads to a poor subsurface image.

Geotectonic Framework

The Upper Assam Basin is situated in the far northeast of India, within the bend of the Assam Syntaxis. The basin experienced sedimentation from the Paleocene through to the Pliocene. It has thrusted margins on three sides; to the south the Naga Hills thrust belt; and to the east and north the Main Frontal

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Thrust of the Himalayas. The regional structural map of upper Assam basin is illustrated in Figure 1. The thrust belt lies on the southern side of the Upper Assam Basin and depicted in the Figure 2. It consists of a series of NE-SW trending thrusts affecting sedimentary section which is equivalent to the less structured sections of the basin.

The geological structures under investigation in this study are part of a young fold and thrust belt. The geological cross-section map is shown in Figure 3. The foreland of this thrust belt is the alluvium plain of the river Brahmaputra and it is characterized by well stratified fluvial sediments, the Namsang formation, up to a depth of ~ 2 km. Naga thrust sheet comprises of three distinct geological units. On top is a flood plain clay rich unit of upper Miocene age known as the Girujan formation overlying a massive sand rich deltaic unit of mid-Miocene age known as the Tipam formation. The Tipam formation in turn overlies an upper Eocene - lower Oligocene Barail Group deposited in a marginal-marine to fluvial setting.

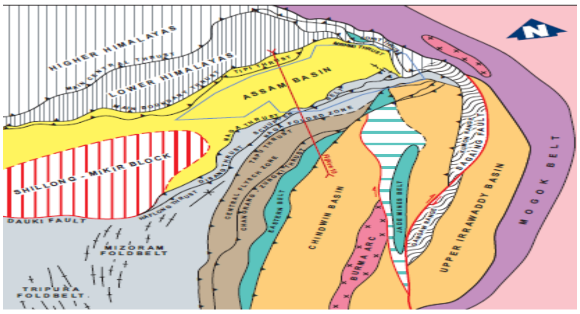

Figure 1: Regional Structural Map

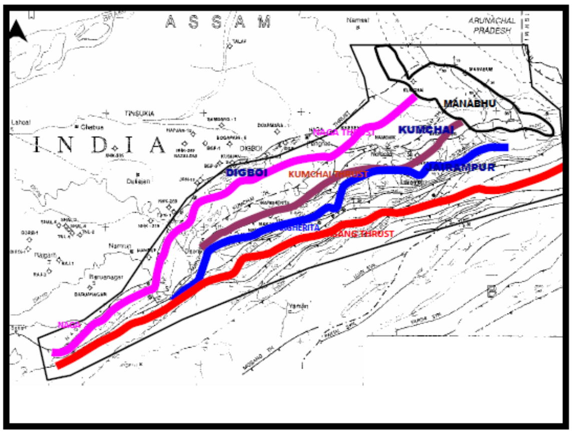

Figure 2: Thrust Belt Region of Upper Assam Basin

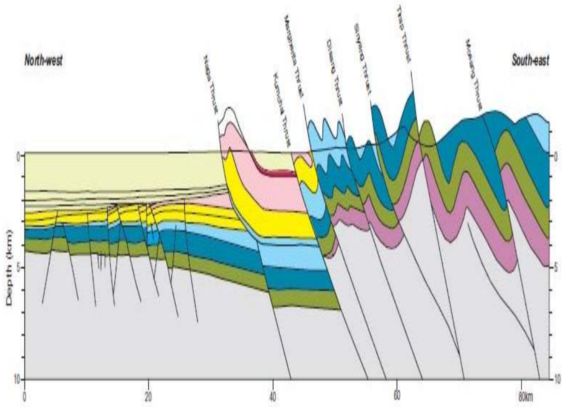

Figure3: Geological Cross-section

Challenges in Imaging

The thrust belts areas are characterized by complex near and subsurface geology exhibiting strong lateral and vertical velocity variations over and above the difficult near surface logistics in effectively carrying out exploration campaigns. The spatially varying noise characteristics, energy scattering / backscattering, poor energy penetration along several patches of the profile, near surface boulder beds etc. further compound the challenge of mapping the subsurface with fidelity. Good mappability on the recorded shot gathers is observed towards the north of the profile while the area in and around the thrust region suffers from lack of discernible reflection events due to several aspects as indicated above. Further one constant fear that haunts the processing geophysicist in such areas during velocity analysis is where to pick as the velocity analysis panels are devoid of adequate coherence. Therefore, a processing geophysicist requires a more rigorous insight of the area in terms of geology as well as be ready to experiment with novel techniques available to handle such datasets. In this context a well thought out processing strategy was chalked out to address the imaging challenges in the area under discussion.

Processing Strategy & Methodology

An attempt has been made to derive a near surface velocity- depth model by travel time topography utilizing the geological & other previous geophysical information/ knowledge of the study area. The modeled velocity is further used as a guide function to generate the semblance values and for picking vertical velocity function on semblance panels. We generated a hybrid stacking velocity function with the help of velocity-depth model generated by travel time topography and stacking velocity analysis. The methodology enabled in resolving the near subsurface and patches of stack where the conventional velocity control was almost absent. The procedures followed are as follow:

- The data is scanned thoroughly on the basis of source surface location and grouped in different subgroups depending on their noise pattern, surface location & geology.

- Mild preconditioning was carried out on raw shot gathers which helped in better visualization/ picking of first breaks. First breaks were picked on every 5th shot gather. The first break picks were quality controlled and any outliers were dropped aiming to reduce errors and glitches during further analysis.

- The second step involved in generation of an initial velocity depth model employing turning ray tomography with the picked first breaks as the primary input. Turning ray tomography involves in averaging the picks across shots and and application of some smoothing between offsets. The resultant travel time versus offset readings are converted to refractor velocity/depth under the assumption that velocity is monotonically increasing in depth. A initial interval velocity model is created from the first break picks in depth using flat layer theory of refracted arrivals. Caution must be exercised in construction of initial velocity depth model so that it is closer to the subsurface under investigation.

- Further, the travel times were predicted from the derived initial velocity depth model which are then compared with the picked travel times. Initial velocity models are also used to produce the ray paths which are used in the Tomographic inversion. The approach uses a Langan & Lerche style ray tracer, which is a shooting method that traces rays through a gridded velocity field using triangles.

- The predicted travel time are subtracted from the picked travel time values as residual travel times and stored in the database. The residual travel times thereafter serve as the input for Tomographic inversion.

- Further Tomographic inversion was carried out using the residual travel time as input through adjustment of velocity along ray paths. The prime objective is to reduce the travel time deviations and arrive at velocity depth model which tries to honor the subsurface geology. This process is iteratively repeated with perturbation of key parameters till the model is found to consistent with the subsurface geology.

- Further, the obtained velocity-depth function is converted in to rms velocity function and used as a guide function for calculating semblance values and precise picking of velocities particularly at near subsurface and near/below the thrust region. The velocity was picked at small intervals of 250m.

- Moreover, a minimal process approach was the first premise implemented to retain the useful & basic inherent characteristic of the dataset. The raw shot gathers were subjected to mild noise attenuation scheme to eliminate the more visible noise on the shot gathers along with appropriate use of long & short wavelength statics correction. The overall methodology employed during the course of seismic data processing helped in enhancing the Signal to Noise ratio and yielded an improved image of the subsurface.

Case Study

The approach was experienced on 2D seismic data set from thrust belt of Upper Assam basin as shown in Figure 4. Raw shot gathers were edited and mild pre-conditioning is applied for better picking of first breaks. First breaks were picked on preconditioned shot gathers at every 5th gather as shown in Figure 5. The comparison of raw shot gather & preconditioned gather is shown in Figure 6 and Figure 7.

Figure 4: Base Map of Study Area

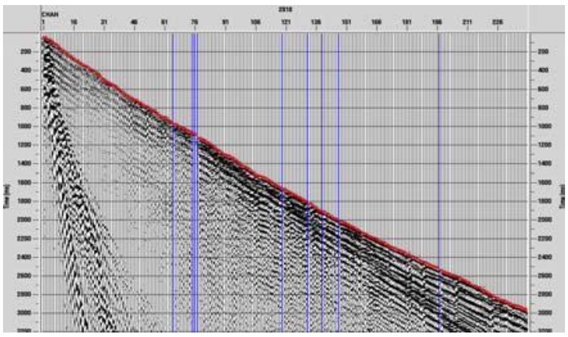

Figure 5: Geometry Merged shotgather with First Break Picks

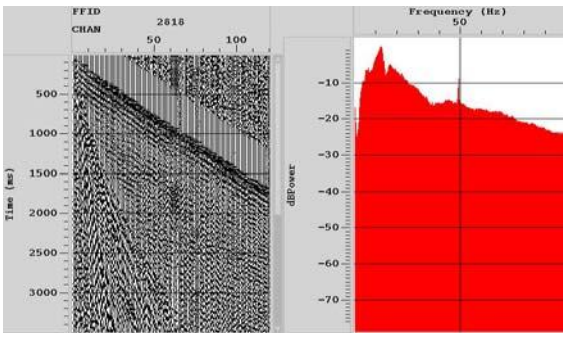

Figure 6: Raw shot gather and Spectral analysis.

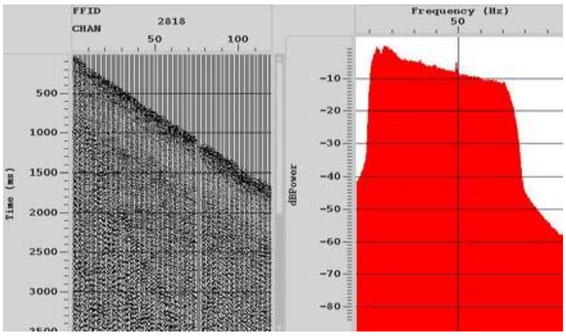

Figure 7: Preconditioned gather and Spectral analysis

The first break picks, geological information and other ancillary information were used to create an initial velocity depth model. The generated initial velocity model was modified till it resembles our geological knowledge of the area. The final velocity-depth model is depicted in Figure 8. The maximum information of velocity obtained in depth is only up to 1700 m. The accuracy of model & depth information is constrained due to farthest offset, bad picks, skipped shots etc. Further this velocity depth model is converted in to rms velocity function and used as a guide function for computing semblance values and precise picking of stacking velocity function.

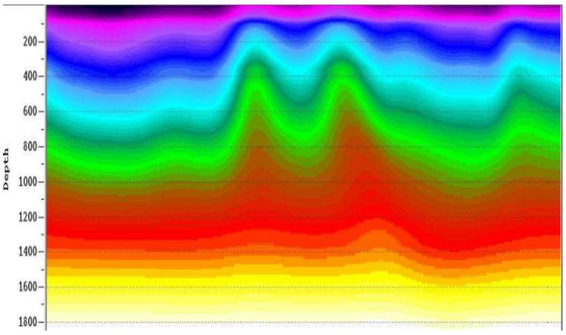

Figure 8: Velocity-depth Model.

Initial processing was done with standard practice of processing which includes preconditioning of data, statics correction using refraction method, surface consistent deconvoultion, nmo correction followed by residual statics correction. The resultant stack section is depicted in Figure 9. The velocity semblance panel obtained at two different locations along the profile is shown in Figure 10 & 11 illustrating the representative semblance panel in foreland and thrust region respectively.

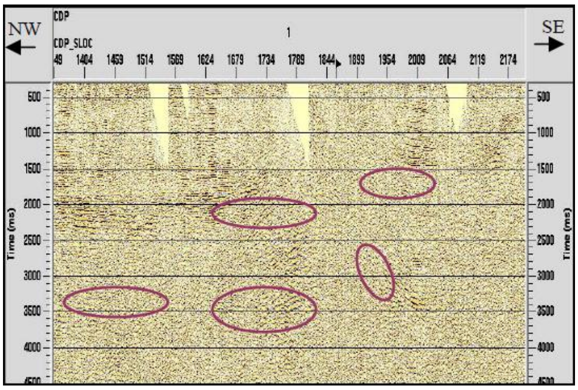

Figure 9: Stack with Conventional Processing

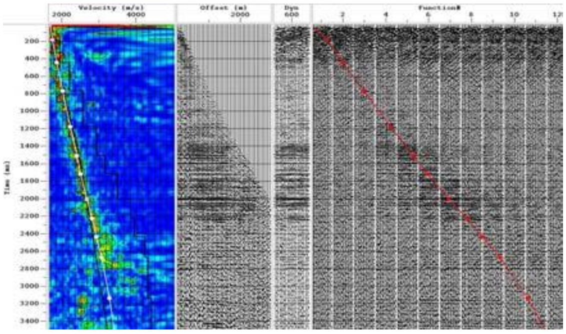

Figure 10. Velocity Sembalance Panel from Foreland region.

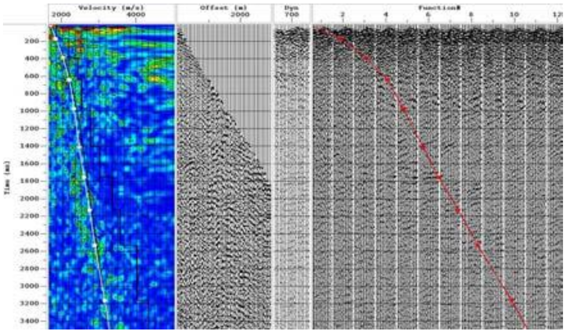

Figure 11: Velocity Sembalance Panel from Thrust belt-region.

The dataset were again processed using the above explained approach and additional hybrid stacking velocity function derived with the help of velocity-depth model obtained from travel time inversion of first break picks were used in processing. The stacked and migrated section with improvements particuraly in near or below the thrust belt is shown in Figure 12 and 13.

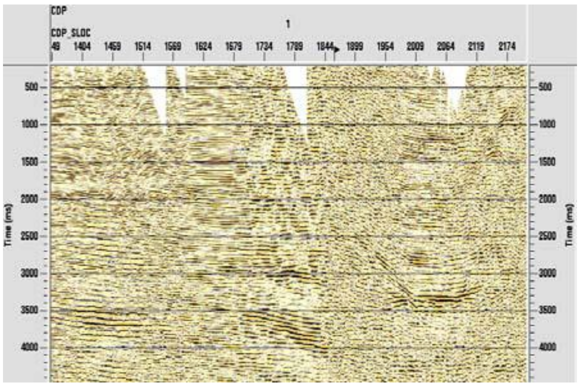

Figure 12: Stack Section

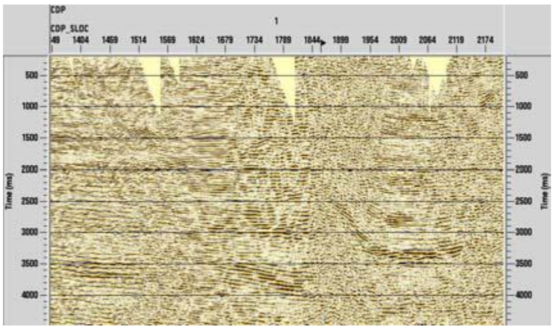

Figure 13: Migrated Section

Conclusion

Reliable Velocity-depth model can be constructed by proper use of Travel Time Tomography using good quality of First break picks, appropriate initial velocity model & selection of optimal inversion parameters among other. Further, this velocity-depth model can be efficiently used for generating more precise stacking velocity in complex geological subsurface. Moreover, this velocity can also be used for better statics solutions using tomostatics solution schemes, wave equation datuming etc.

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