Summary

The importance of statics corrections in seismic data processing especially in land data is well known. However, in folded and thrust belt areas the field statics corrections is quite inadequate for proper imaging of these geologically complex areas. The rugged topography, huge elevation variations, weathered layer velocity and thickness variations in both vertical and horizontal direction, severely hampers field statics computation resulting in poor imaging of the sub-surface. A case study of a thrust-belt area 3D seismic data processing from NE-India is presented here, where the problems arising due to complex surface and sub-surface have been addressed through nonlinear tomography and step wise refraction statics corrections to obtain optimum results. The results are inspiring and may potentially open up a new vista in seismic data processing of the entire NE region of India and adjoining Bangladesh, both of which are prolific hydrocarbon producing provinces.

Keywords: Tomo-Statics, Thrust Belt Area

Introduction

The NE-India region is a prolific hydrocarbon producer for over a century with oil being first discovered in the upper Assam shelf. The study area is in Tripura located south-west to Assam shelf and is known as Assam- Arakan fold belt area. To the west of the area lie the oil and gas fields of Bangladesh. So, proximity to known hydrocarbon provinces has accelerated the exploration of the Assam- Arakan region which includes mainly Tripura (east and west), Cachar (Assam), Mizoram and Manipur. The efforts for discovering substantial Miocene gas reserves has finally succeeded with the discovery of the Khubal gas field of eastern Tripura- area of the study and suspected to be the largest gas reserve of the region. Efforts are still continuing for the exploration of yet to be found reserves as the Assam- Arakan region has got a huge potential for future discovery.

The Tripura area has almost the same tectono sedimentary environment and petroleum system as that of adjoining Bangladesh. The discovery of huge gas fields in Bangladesh close to Tripura suggests that source depocenters are highly active in the entire region. Natural gas occurs in lower and middle Miocene sands of the Bokabil and Bhuban formations upto a depth of 4500m. The structural trends of Tripura and Bangladesh are almost the same along east to west except that deformation decreases towards west (Fig: 1). The Khubal structure is a well-defined doubly plunging anticline structure trending in the NNE-SSW direction. This anticline is 30 km long and 15 km wide with the northern plunge gently broader and well defined while the southern plunge is steeply abrupted by the kanchanchara fault. The eastern and western limbs are affected by major faults running in N-S direction. Exploratory well drilling has testified that Miocene sands of Middle and lower Bhuban are proven reservoirs of gas deposits.

Fig 1: The location map of the area showing the ANN- ONN2001/1 block (top) and structure map showing the various syncline and anticline structures tending in N-S and NNE-SSW direction (bottom).
The 3D data set used for the study comprised of 8220 shots of split-spread shooting at an interval of 90m with 7 active receiver lines in a template. A total of 21520 receivers were laid out at an interval of 60m and the maximum offset recorded for each shot is 6400m. The elevation variation is approximately 250m across the entire survey area.

Mostly a hilly terrain area it has steep hills along the eastern and western margin. Towards the north the area assumes a smooth valley whereas one can find hillocks along the southern margin thus creating a complex geological setting for seismic API.

The complex geology of the area and poor seismic imageability is a challenge for every explorationist. This area has sudden hills and gorges, rivers, streams and other physiological landforms common to fold belt areas making acquisition a challenging task. The problems in data acquisition due to rugged topography and associated logistics translate into statics calculation problem for seismic data processing and in general low S/N data. Moreover, the sudden change in near surface geology due to thrusting makes the estimation of near surface velocity model from uphole surveys un-reliable. Correct Statics application in such cases make a huge difference to the entire imaging especially because most processing algorithms developed in recent times assumes a flat datum for processing as a precondition. The statics computation in our case is done stage wise in three steps following mostly the Feng Zeyuan et al, (2003) method.

**Methodology**

The method for statics calculation starts with estimation of the near surface velocity model using non-linear refraction tomography (Jie Zhang et al. 1998) followed by wave-equation datuming technique for statics computation to the floating datum and finally an elevation correction from floating datum to final flat datum. Residual statics were calculated subsequently in the CMP’s at a later stage in processing. A detail description of the process is described below.

**First break picking:** After merging the raw seismic data with geometry information, the first break picks for all the shots are picked and manual correction for incorrect picks are done. Fig 2 shows the first break picks for a shot. The reciprocal error of each shot is checked. Theoretically the reciprocal error i.e. the error in travel times if shots and receivers are interchanged should be zero. But errors in geometry, mispicks, charge depth and heterogeneities near shot and receiver can cause differences in reciprocal times. We had a reciprocal error of 15ms which suggested no problems in geometry or wrong picks.

**1-D Velocity model generation:** The computation of refractor velocity and depth is based on the delay time technique of Gardner, 1967. The first break traveltimes trajectories are bundled and plotted against shot-receiver offset and any change in the slope and intercept of the traveltimes (at the crossover point, Sheriff, 1984) is used to calculate the refractor velocity and depth. All possible first breaks of multi shots are used and reciprocal records are not a necessity for this algorithm, thus making it more robust for both split spread and end-on surveys. A simple 3-layer model is shown in Fig 3, where segment (I) corresponds to the direct arrivals in the first layer and segment (II) and (III) corresponds to two deeper refractors. The actual identification of slopes is difficult and subjective. The slope determination is shown in Fig 4, where 5 different slopes were identified and a 5layer initial 1-D velocity model (Fig 5) without any lateral heterogeneity was created.

**Non-linear tomography:** The 1D velocity model is input to non-linear first arrival tomography and the final near surface velocity model is derived by perturbing the input model inorder to minimise the RMS-error of calculated synthetic traveltimes and first break pick traveltimes.

Fig 2 : The first break picks of the shot is shown in red , active receivers of the shot in yellow of the 3D data.
Fig 3: The difference in traveltimes corresponds to different refractors. A 3-layer model example

Fig 4: Generation of initial 1D velocity model by the slope intercept method using the traveltimes of all shots together.

The non-linear tomography (Zhang et al, 1998) addresses the limitations of conventional delay time, GLI and linear inversion methods where the refractor is assumed to be locally flat within a spread length. These methods are robust for simple geology and topography where linearity of velocity structures are common. However, they fail in complex geology and topography situations where vertical velocity variations and non-linearity are common such as in thrust belt areas. The non-linear tomography assigns all types of first-arrival gradients to velocity changes in the near surface rather than considering them as belonging to a single refractor. The algorithm used by us is a new version of tomography consisting of shortest path ray-tracing approach (SPR), regularized inversion method using the Tikhonov method to avoid solving an ill-posed inverse problem and a Monte carlo method for non-linear uncertainty analysis of the final solution. The grids used for our tomography is 40X40X20 m. The final RMS-error after 20 iterations of grided non-linear tomography was 18ms, which we thought to be good enough for this type of noisy data.

Fig 5: Initial 1D velocity model

Fig 6: Near surface velocity model after tomography with surface topography displayed.

Fig 7: depth slices of the near surface velocity model at A) -10 m B) 100m C) 200m D) 400m depth. (vertical scale is from 1200 m/s to 4000 m/s)

The slices of the near surface velocity model from tomography shows an interesting trend. (Fig 7). The near surface is compartmentalized into a low velocity zone towards the north i.e the valley portion, medium velocity towards the south i.e. hillocks region and high velocity along the eastern and western margins which lie below the
steep hills. We feel that this velocity trend is quite consistent with the thrusting seen on the surface. Moreover, the ray diagram (Fig 8) shows ray penetration up to 700m depth and thus we were confident of the velocity model up to this depth.

**Refraction statics computation:** The shot and receiver statics is calculated in 3 stages. First, the floating datum which is a smoothened version of the topography and intermediate datum which is the interface between heterogenous low velocities and high sub-surface velocity is picked (Fig 9). Then using wave equation datuming method we moved the shots and receivers to the intermediate datum from the floating datum using the low heterogenous velocities. Then they were again moved to the floating datum using the replacement velocity which is an average velocity of the intermediate datum. This effectively means removing the near surface low heterogenous velocities. The 3rd stage is elevation statics correction to MSL from the floating datum using an elevation velocity which is the average velocity of the high velocity target formations. Both long wavelength and short wavelength statics corresponding to features larger than and shorter than the spread length were calculated. Finally, residual statics were calculated on CMP gathers at a later stage of processing. The results of the 3 stages of statics computation are shown in Fig 10.

**Results:** The statics applied shots are shown in Fig 11 and corresponding stacks in Fig 12. As is evident the final images have more meaningful information in terms of continuity of events and imaging below the hilly portion of the area. Some reflectors which were completely missing in earlier images have been mapped to a large degree making interpretation much more meaningful. This type of improvements in processing were not seen even after repeated noise attenuation and various migrations in earlier attempts. Finally, proper statics correction was helpful in delineating the never seen structures.

Moreover, the near surface velocity model provides a wonderful guide for stacking or RMS velocity picking. This velocity model may also be used for Depth imaging where the top part of the interval velocity model is replaced by this near surface velocity model. However, our practical experience of PSDM using interval velocity with this type of near surface velocity model at the topmost part is that the low velocity weathered layer between floating and intermediate datum must be replaced by the replacement velocity. Another approach that we have used to good effect is velocity analysis on reflector positions instead of reflection positions. The rugged topography with significant elevation variations and near surface velocity heterogenities invalidates the CMP concept and hence the approach which we use regularly is RMS velocity picking.
on reflector positions on image panels of constant velocity shot migrated from topography. (Oz Yilmaz et. al., 2007)

**Conclusion**

Our case study has shown that the statics corrections so commonly done using field statics doesn't produce interpretable images in fold belt areas like Tripura. Refraction statics computation using non-linear tomography is definitely a way forward and the effects on overall image may be immense. Mostly refraction statics computation is done on small 2D dataset but the results of our study inspire us to calculate refraction statics even on bulk 3D data, inspite of the time and labour requirement because the benefits are potentially huge.

**Acknowledgements**

The authors are grateful to Oil and Natural Gas Corporation Limited, India for providing the necessary facilities to carry out this work and for granting permission to publish this paper. We thank Mr. A. Sood, HOI, GEOPIC, Mr. T.R.Murali Mohan, Head Processing Div., Dr Sankar Sen, DGM(s) and Mr. C.B Yadav, DGM(s) for encouraging and guiding us at various stages during the course of our work.

**References**


Zeyuan, F., Li Peiming., Li Zhenhua., Zu Yunfei., Hou Xichang., 2003, Static correction techniques and application in complex areas of Western China: BGP Technical seminar.


![Fig 11a: Shot with field statics applied (above) and same shots with refraction statics applied. (below)]

![Fig 11b: Shot with field statics applied (above) and same shots with refraction statics applied. (below)]
Fig 12a: Stack with field statics applied (A) and refraction statics (B) applied. Inline along the northern margin.

Fig 12b: Stack with field statics applied (C) and refraction statics (D) applied. Inline along the southern margin.