Understanding Himalaya's Thrust Fold Belt

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Abstract

It being complex geology in thrust fold belt areas world over, requires special efforts in exploration right from seismic data acquisition, processing, interpretation (API) to exploratory drilling. Imaging issues are complicated further because of overriding high velocity layers over low velocity layers coupled with erosion and sedimentation of reworked old sediments. Age determination issues of reworked sediments having old rocks' grains adds to complexity in absence of fossils. In analogy with other thrust fold belts, earlier authors have mapped the Himalayan geology on surface with the help of out crops and with limitation of limited sub-surface seismic data and well data. Whatever seismic data is available today represents sub-surface image of Himalaya in limited span and depth. The posterior sub-surface image is to be taken back to the time of subduction of Indian Shield below Eurasian Plate with the help of structural balancing. This requires seismic imaging down to basement and in the entire span of Himalayas. This paper explores some of the fundamental issues of understanding Himalaya, bottom to top as its kinematics evolved with time.

Introduction

Among the five East-West trending geographic belts from South to North (Sub-Himalaya, Lesser Himalaya, Higher Himalaya, Tethyan Himalaya and Trans Himalaya) 2D seismic data acquisition has taken place mainly in the southern most Sub-Himalayan sector with a few lines beyond Main Boundary Thrust (MBT) since the inception of ONGC. Reprocessing efforts of these 2D seismic data sets (though inadequate with respect to total foothills area of ~30,000 sq.km) have significantly improved geological and structural understanding. Latest reprocessing software have considerably facilitated improved imaging and brought out interpretable seismic sections from poor, noisy un-interpretable seismic sections.

Acquisition

In Himalayan Foothills area the first 2D seismic data (24 fold and above) acquisition started in 1981-82 in Himachal Pradesh (H.P.) and in Jammu & Kashmir (J&K). After that in 1986-87 acquisition started in Uttarakhand (Doon valley) and in adjacent Ganga Plains (Part of Uttar Pradesh). In 1988-89 acquisition started in the Punjab Plains (Haryana). Thus as of now ~6525 GLK 2D seismic data is available in Himalayan Foothills area.

Processing/ Reprocessing

After initial processing of ~6525 GLK 2D seismic data, time to time the re-processing works were undertaken with the arrival of latest softwares in ONGC. In 2011, 895 GLK seismic data was outsourced for reprocessing with advanced processing steps like tomographic refraction statics, Extended Generalized Reciprocal Method (EGRM) statics etc. The improvements after the re-processing are shown below (Figures 1a-c, 2a-c).

Understanding NW Himalayas

To comprehend the structural set-up and evolution of Himalayan thrust fold belt, geological cross-section balancing

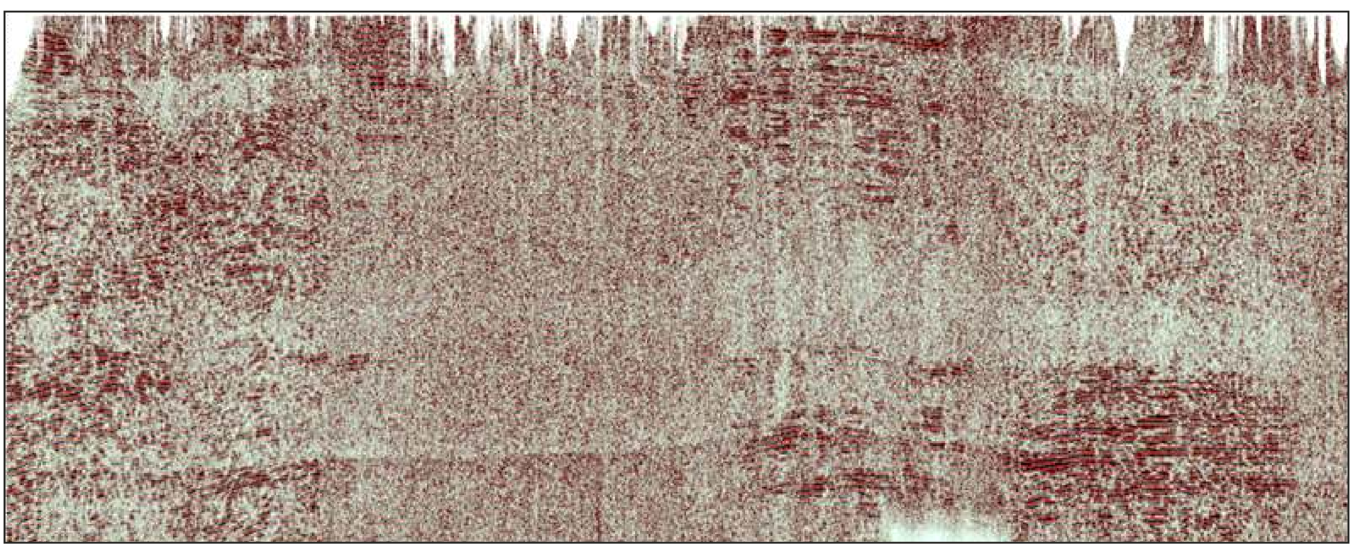

Fig. 1a: Old reprocessed line HP-AA-02

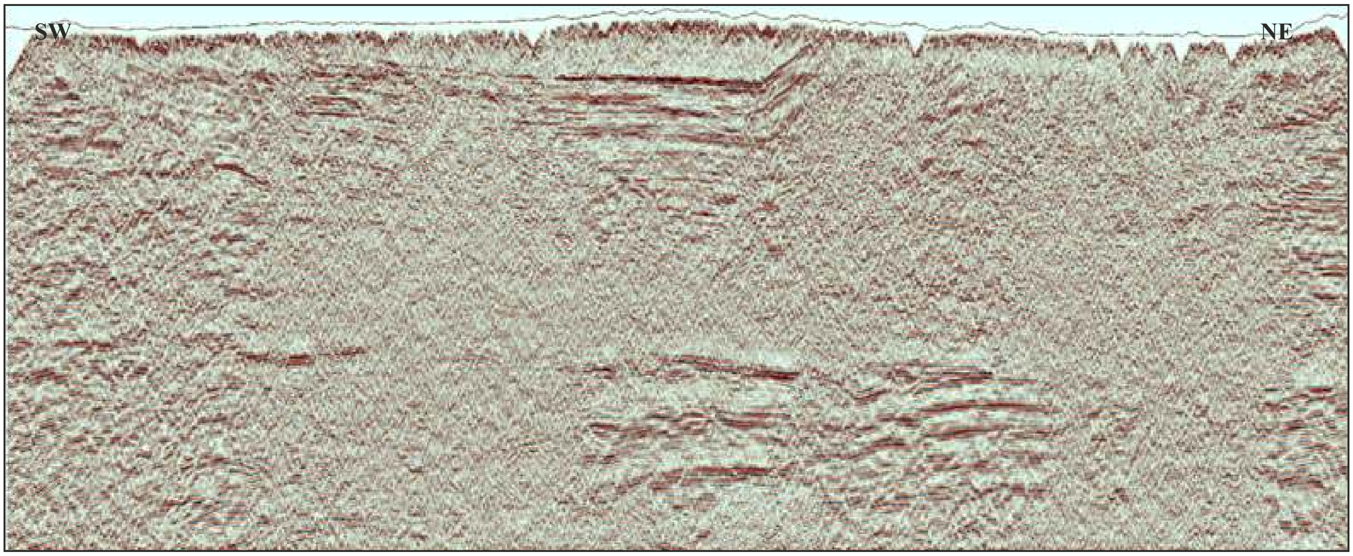

Fig. 1b: Outsourced reprocessed line HP-AA-02

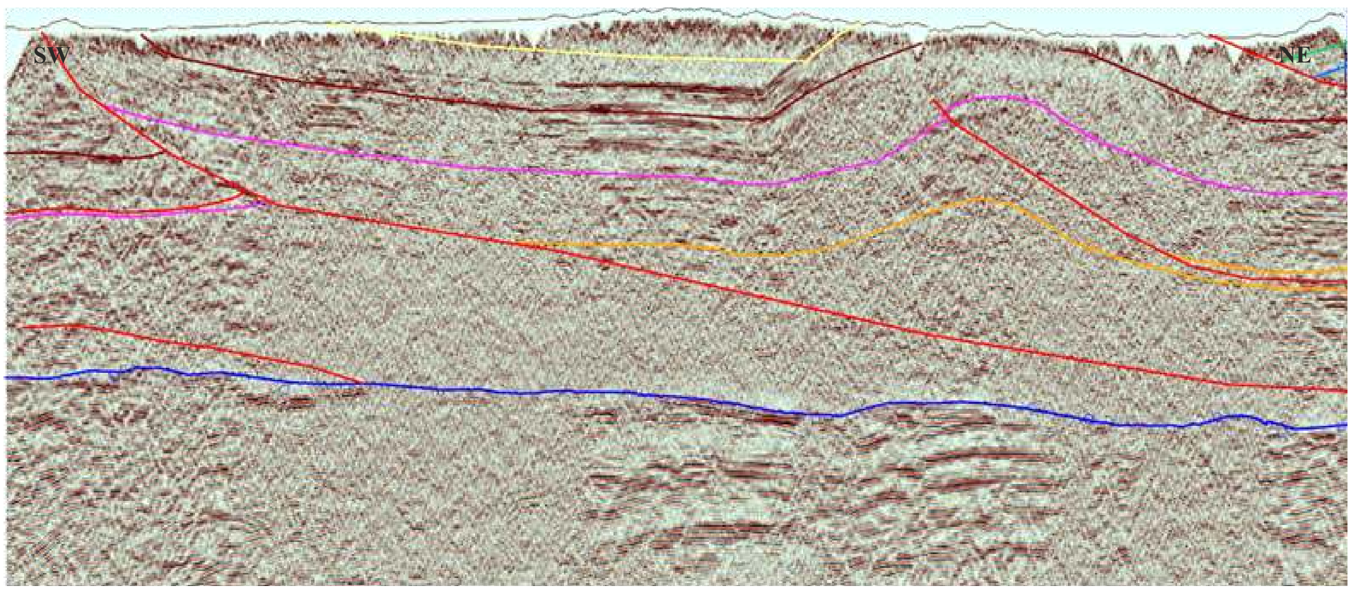

Fig. 1c: Interpretation in reprocessed line HP-AA-02

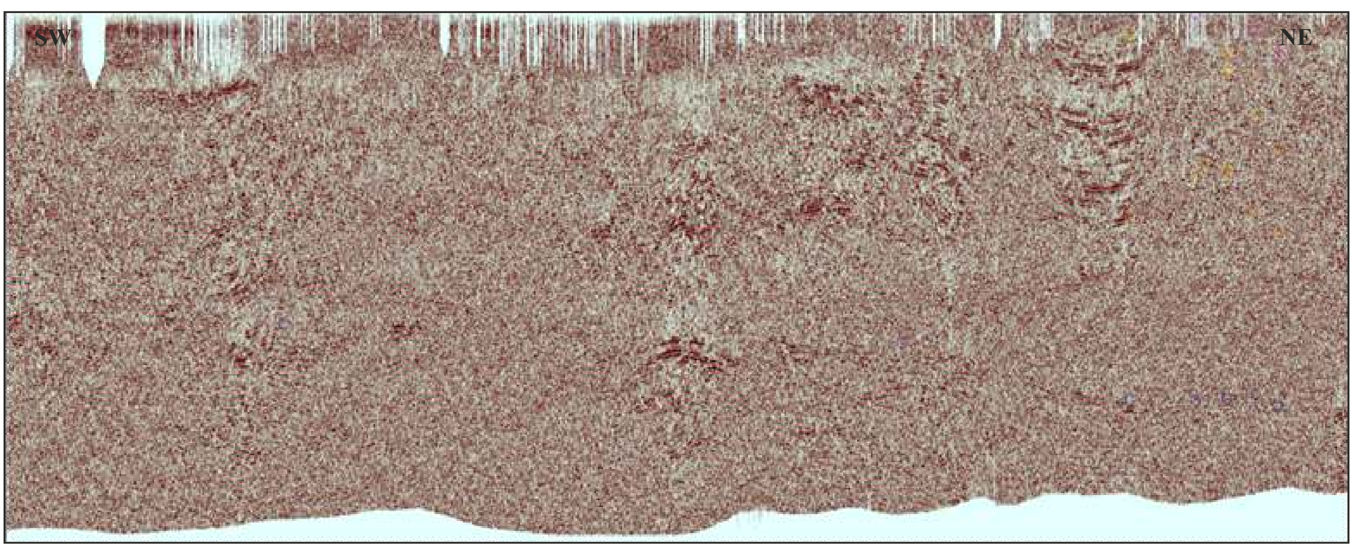

Fig. 2a: Old reprocessed line HP-BB-01

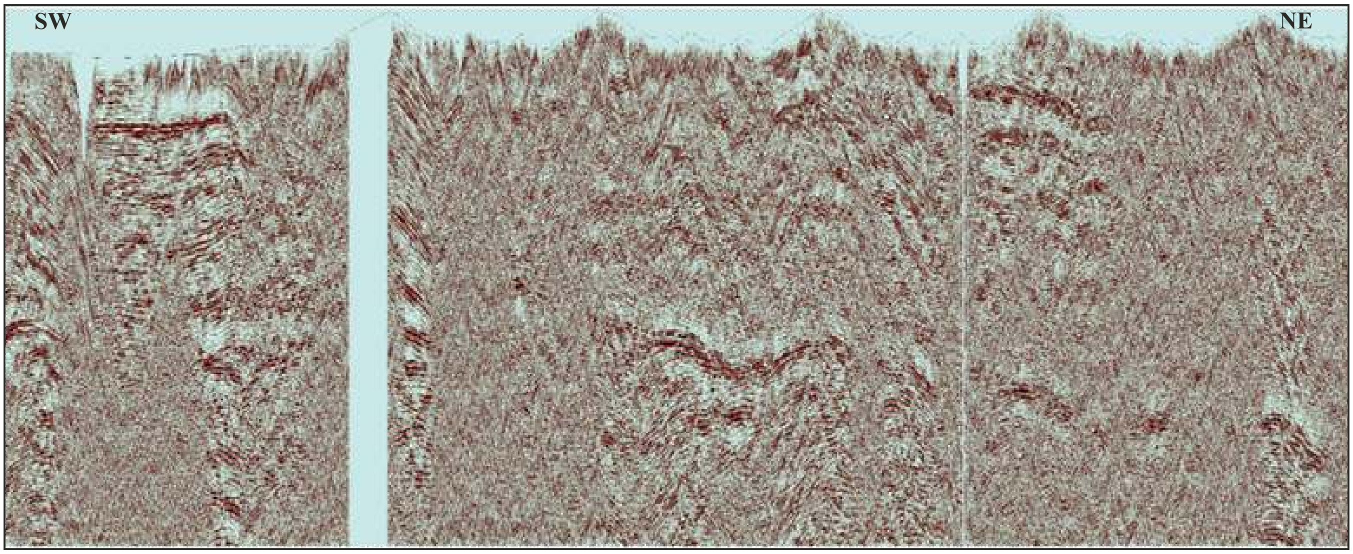

Fig. 2b: Outsourced reprocessed line HP-BB-01

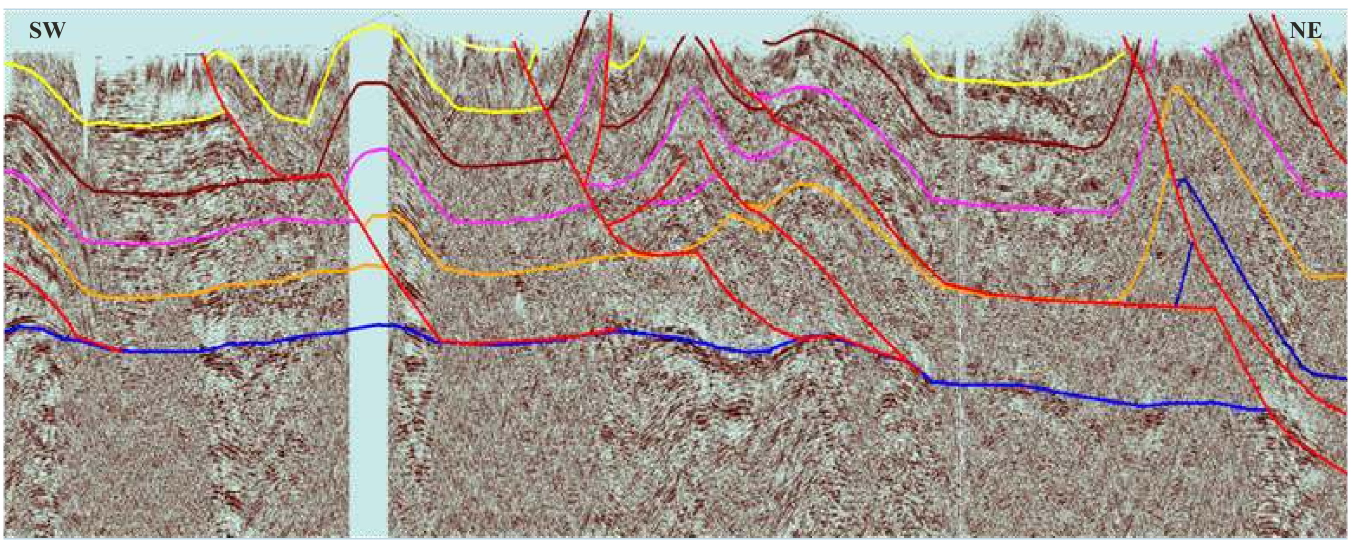

Fig. 2c: Interpretation in reprocessed line HP-BB-01

method has been adopted in this study. Two balanced geological cross-sections and their sequential restoration across Kangra Recess were prepared with the help of re-processed datasets. Earlier, geoscientists like Powers, Lillie and Yeats (1998) (Figure 3a) and *Bally* (*1997*) (Figure 3b) attempted to balance the cross sections near Jawalamukhi and Changartalai area, Himachal Pradesh but the data sets that were used for earlier models (models of *Bally* 1997 and *Powers et. al., 1998*) were surface geological maps, available well data and seismic sections marred by imaging issues. Whereas in the present study (Figure 3c), additionally outsourced reprocessed 2D seismic data sets (HP-AA-02 and HP-BB-01 as mentioned above) with available geological sections in the area by previous workers are used. The earlier processed 2D seismic lines are almost uninterpretable but reprocessing of these lines improve image significantly and are used for structural modeling. On the basis of geometry and structural style in the model, few observations are made and described below.

In case of Jawalamukhi section by *Powers et. al., (1998)* a back thrust was modelled for Janauri anticline (i) but no such back thrust is reported in this area and not been modelled by *Bally (1997)* and in the present study. In Case of Soan anticline (ii) which is a major anticline formed due to deformation caused by Soan Thrust as shown in the present study appears bit steep in comparison with flat and gentle in the models of *Powers et. al., (1998) and Bally (1997)*. Multiple back thrusts have been modelled in *Powers et. al., (1998)* and *Bally (1997)* models in West of Jawalamukhi area (iii) whereas a single Barsar Back Thrust is modelled in the present study as seen in the seismic section. Two thrusts were used to form Paror anticline (iv) (by the deformation of Drang Thrust and its splay) in the model of *Powers et. al.,* (1998). Whereas the anticline can be modelled through a single thrust (Drang Thrust) as shown by *Bally (1997)* and in the present study.

In case of Changartalai area model, in between

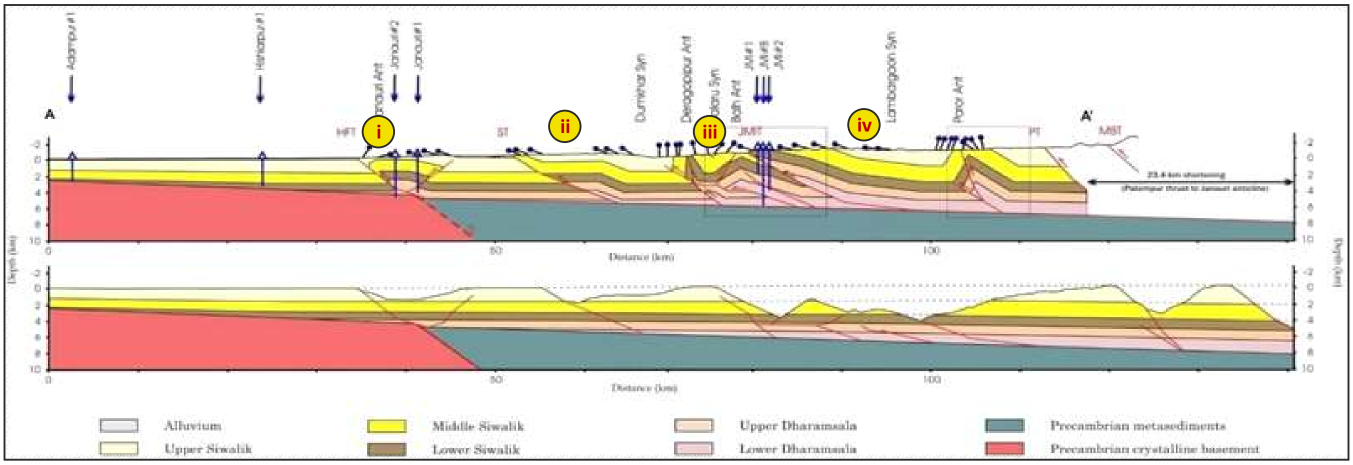

Fig. 3a: Preparation of Balanced cross section in Jawalamukhi area by Powers, Lillie and Yeats (1998)

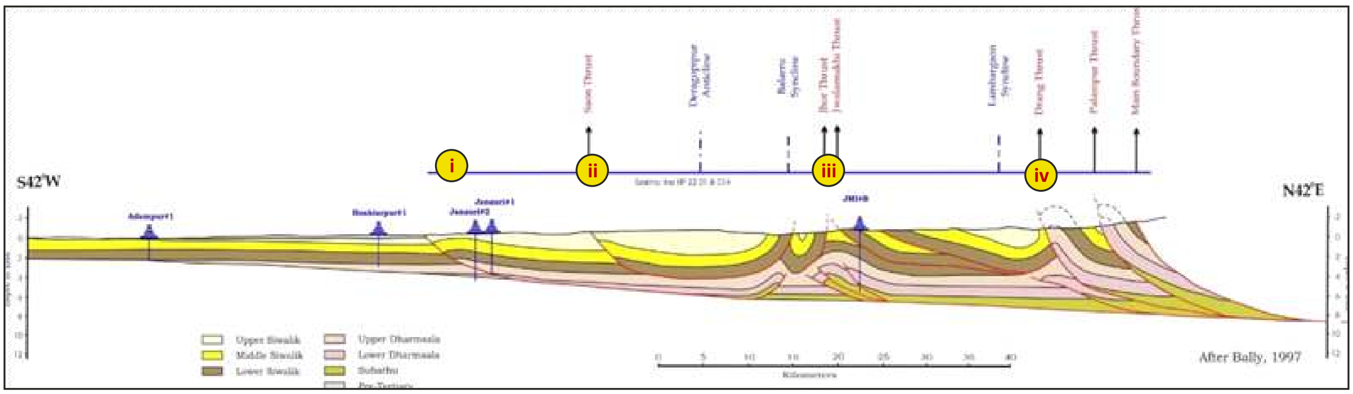

Fig. 3b: Preparation of Balanced cross section in Jawalamukhi area by Bally (1997)

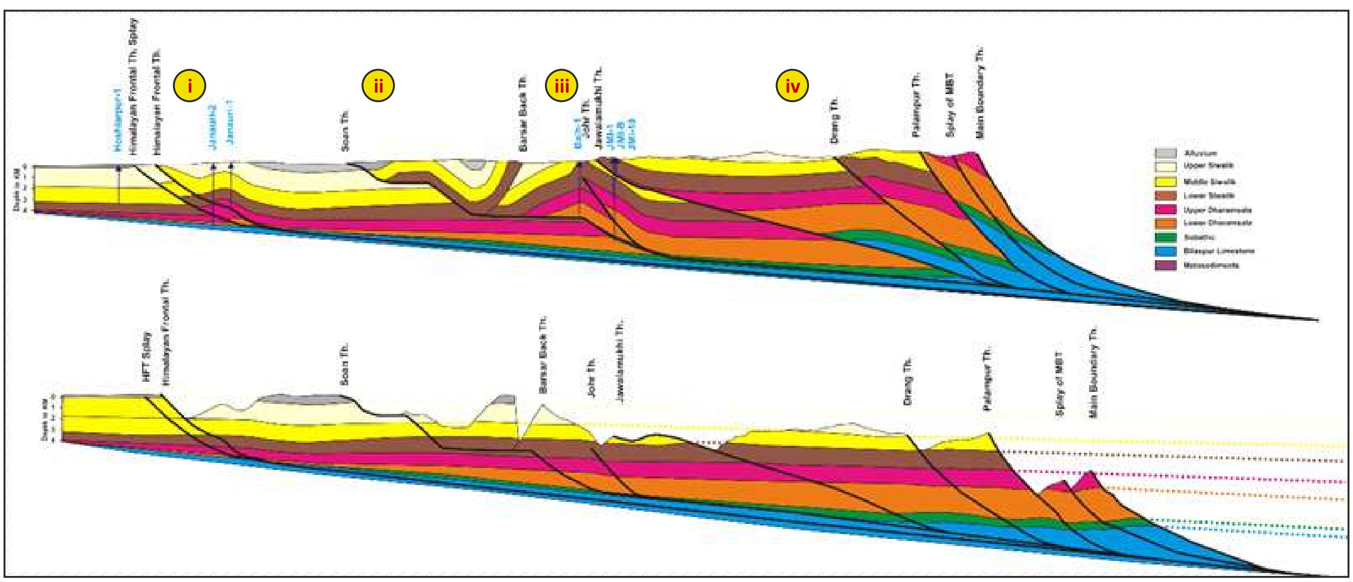

Fig. 3c: Preparation of balanced cross section near Jawalamukhi area in the present study

Jogindernagar Thrust and Sonli Khad Thrust (i) many back thrusts were shown in model by *Bally (1997)* (Figure 4b) whereas the model prepared in the present study (Figure 4a) had shown only fore thrusts. Moreover, maps prepared by various workers in this area did not show any back thrusts.

Scope for further improvements

There is an obvious requirement of modification of acquisition, processing parameters and data interpretation approach for better understanding about Himalaya.

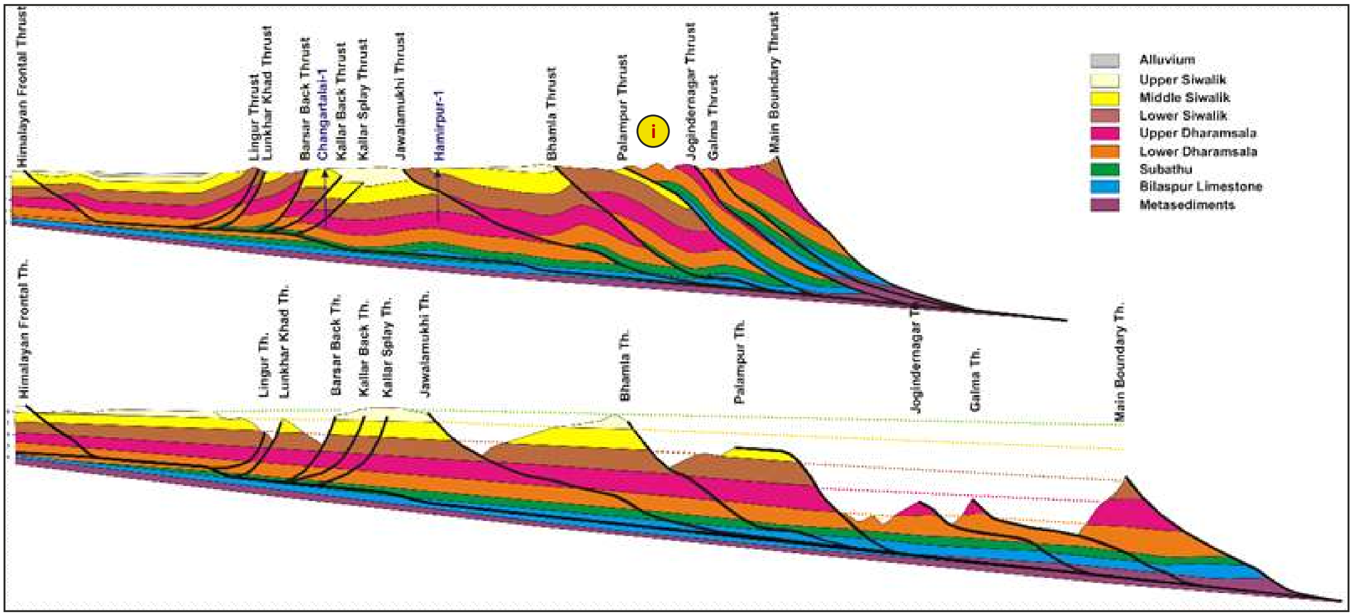

Fig. 4a: Preparation of balanced cross section near Changartalai area in the present study

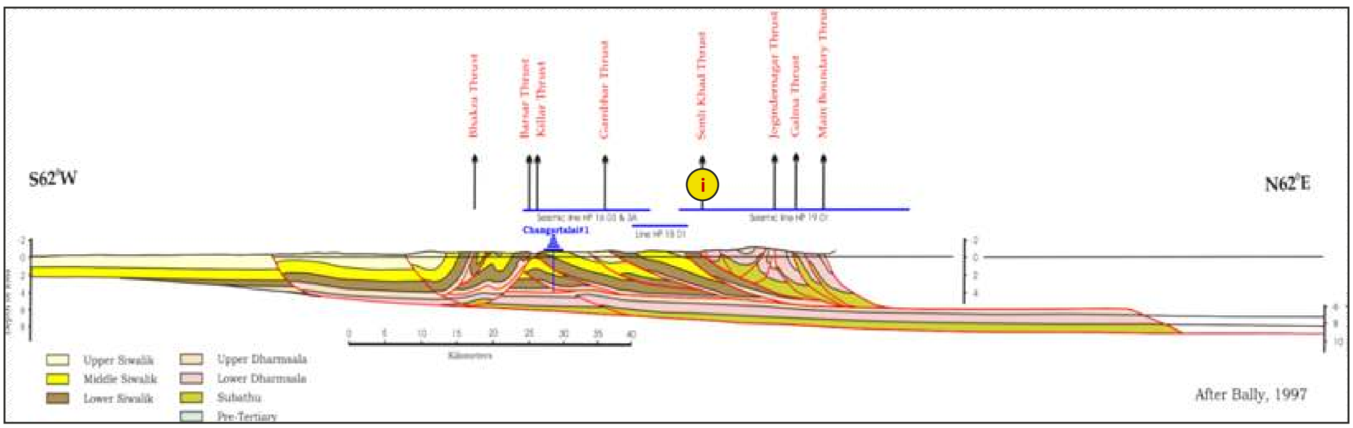

Fig. 4b: Preparation of balanced cross section in Changartalai area by Bally (1997)

Acquisition approach

Latest improvements in the seismic instrumentation can deal with acquiring closely sampled long offset seismic data which has been proposed in the below table 1. This long offset densely sampled data can considerably enhance the imaging of thrust belt area. Model based and target oriented survey designs and acquisition approach can improve the seismic data significantly. In the following table the acquisition parameter used for earlier data and new parameters required for future datasets are summarized (Table 1).

Processing approach

In a fold-thrust belt complex surface, near-surface,

Table1: Earlier acquisition parameters and proposed acquisition parameters

Parameters	**Parameter earlier used (1993-2000)**	**Required parameters**
Geometry	Symmetric Split Spread, Asymmetric Split Spread (ASS) and End on	Asymmetric Split Spread (ASS)
Group interval	15-30 m	10 m
Shot interval	20-40 m	20 m
No. of Channels	96-200	2200 +200= 2400
Near offset	20 m	110 m
Far offset	4200 m	110+21990= 22100 m and 110+1990= 2100 m
Record length	6 sec	15 sec
Sampling interval	2 ms	2 ms
Energy Source	Explosives	Explosives

subsurface structures, steeply dipping layers, lateral and vertical velocity variations are essential elements which require special attention during seismic data processing. Structures having dipping strata show in-built anisotropy with tilted axis of symmetry. Therefore, conventional methodology for seismic data acquisition and processing considering isotropic strata can't bring out close to true imaging for thrust-fold belt.

For precisely imaging the deeper structures, proper velocity model is essential. The discrepancies in velocity computation distort the subsurface image and reduce the reliability of the deeper events. Also the conventional methodology for static correction which adopt the vertical near surface ray-paths is not effective for uneven topography and complex near surface structures. Wave equation datuming *(Berryhill, 1979)* for accurate imaging of the near surface events must be considered. This will enhance the imaging of deeper subsurface structures. High resolution near surface velocity model which is important for accurate static computations, can be derived by first arrival tomography *(Stefani, 1995)*. This first arrival waves (both direct & refracted waves) are picked along the seismic profiles and seismic waveform inversion of those picked first arrival yield a high resolution velocity model.

Most of the vintage seismic data in this area have poor signal to noise ratio, short energy penetration and poor multiplicity. As a result, conventional velocity analysis by the semblance method could impose serious error and imaging issues. Waveform inversion of the reflection travel times *(Murphy and Gray, 1999)* and obtaining anisotropic velocity field are some of the promising approaches to develop improved velocity model. Additionally most of the vintage seismic data have poor offsets and thus precise anisotropic velocity model building is a tough task. Sometimes travel time inversion using non-hyperbolic move-out equations *(Thomsen and Tsvankin, 1994; Kumar et. al., 2004) can* provide better anisotropic velocity fields which is essentially required for depth domain migration.

Non-availability of multi-component data and information of anisotropic parameters are major constraints for proper imaging of the subsurface in this region. For computing proper anisotropic parameters, sufficient well data is required *(Bakulin et al., 2010)*and it could possibly do the exact decomposition of anisotropic parameters during inversion. The walk-away VSP and cross-hole tomography, focusing analysis *(He,et.al. 2009)*, the smear differences between near and far offset data *(Issac and Lawton, 2004)* are some of the alternative approach that can be used to get proper anisotropic parameters.

Interpretation approach

Integrated interpretation approach with all available G&G data (geological, geophysical (seismic, gravity, magnetics, magneto-telluric), geochemical, remote sensing, GIS etc. may constraint the model and reduce the uncertainty. Clues obtained from the Foothills area can be the guiding factors for the remaining part of the fold belt. Till date hardly a few seismic lines are available beyond MBT, though many authors have prepared cross sections of entire Himalaya based on the surface geological data. Besides sub-Himalaya a part of Lesser Himalaya and Tethyan Himalaya can be prospective which lack prioritization due to paucity of seismic data. Unless we acquire more seismic data beyond MBT our understanding about Himalaya's thrust fold belt will be incomplete. Improved imaging with structural balancing has brought out gentle structures in sub-thrust which could be future exploration targets in North-West Himalaya.

Challenges

Elevation differences have always been a problem for acquisition in Himalayan Foothills area. Topography varies from 200m to 3000m in sub-Himalaya and possess extreme difficulties in seismic data acquisition. Poor seismic imaging is another major concern in this area due to thrusting, folding, amalgamation of fore thrusts and back thrusts in triangle zone, vertical nature of thrusts in the inner belt near the MBT and over riding high velocity older layers over low velocity younger layers. Time to Depth conversion and proper velocity modeling is also an overwhelming challenge in fold thrust belt. Velocity model building requires representative well control points in every tectonic unit covering map area for Time-Depth conversion. Issues as 'velocity pull ups in sub-thrust remain unresolved in the absence of proper velocity model. Map of Eocene unconformity is brought out by some authors *(Arya et. al., 2015)*, but basement configuration is farfetched dream in the absence of deep seismic data. Moreover Logistics issues in hills, availability of flat lands due to steep slopes and forest cover enhance further difficulties in drilling of wells in hilly terrain.

Conclusions and Way forward

Acquisition, Processing & Interpretation (API) of sediments and basement is required with deep imaging as suggested in Table 1.

Seismic profile covering Himalayan Frontal Thrust to Indus Tsangpo Suture Zone, thereafter structural balancing may reveal complex processes of kinematics involved during Himalayan Orogeny.

State of the art Node Based seismic data acquisition (reducing cable laying and connection time) may facilitate swift survey.

In order to address logistics and climatic issues in highly elevated terrain, deployment of man with high altitude gear, hardware, portable shot hole drilling rigs and other machinery may be carried out with the help of helicopter operations.

Pre-Stack Depth Migration processing is required to prepare proper velocity model and address sub-thrust velocity pull up issues.

References

Arya, A.K., Verma, N.K., Baruah, M.K., Dutta, T., and Ram, J. (2015): Temple Flame Mystery Unfolds, ONGC Bulletin.

Bally, A.W., Liu, C.J., Singh, A.K., Das, S.K. and Hareendran, A. (1997): Hydrocarbon potential of the ganga basin and Himalayan Foothills (In India's Folded Belts and Foreland Basins, Summary Report), ONGC (unpub).

Powers, P.M., Lillie, R.J., Yeats, R.S. (1998): Structure and shortening of the Kangra and Dehradun reentrants, Sub-Himalaya, India, Geological Society of America, Bulletin, 110, 1010-1027.

Bakulin, A., Woodward, M., Nichols, D., Osypov, K., and Zdraveva, O., 2010, Building tilted transversely isotropic depth models using localized anisotropic tomography with well information: Geophysics, 75, D27-D36.

Berryhill, R. T., 1979, Wave equation damming: Geophysics, 44, 1329-1344.

He, Y., Cai,J., Whiteside,W., Li,Z., Guo,M., Wang, B., Xie,J., Yoon,K. and Nessler, E., 2009, TTI/VTI anisotropy estimation by focusing analysis, Part II: SEG 79th Ann. Mtg., Expanded Abstracts.

Isaac, J.H., and Lawton, D.C., 2004, A practical method for estimating effective parameters of anisotropy from reflection seismic data: Geophysics, 69,681-689.

Kumar, D., Sen, M.K., Ferguson, R.J., 2004, Travel-time calculation and prestack depth migration in tilted transversely isotropic media: Geophysics, 69, 37-44.

Murphy, G.E. and Gray, S. H., 1999, Manual seismic reflection tomography: Geophysics, 64, 1546-1552.

Stefani, J.P., 1995, Turning-ray tomography: Geophysics, 60, 1917-1929.

Thomsen, L., Tsvankin, I., 1994, Non hyperbolic reflection moveout in anisotropic media: Geophysics, 59, 1290–130.