Modeling with Restoration Key to Resolve Complexity of Himalayas

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ABSTRACT

Himalayas comprise of four major tectonic divisions namely Sub-Himalaya, Lesser Himalaya, Higher Himalaya and Tethyan Himalaya (Figure 1). From South to North these divisions are marked by Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and Indus Tsangpo Suture Zone (ITSZ). A number of faults/thrusts which are not mentioned here also subdivide these major tectonic divisions. Modeling in the study is carried out by integrating all available geoscientific data. Parametric calibration is adopted by taking into account robust algorithms while preparing model. Geological sections of previous authors have been used in the model where seismic data is not available. A few available well data have been used to constrain the priori model. Restoration of geological model is carried out along two profiles in sub-Himalayas in this study. During the study it is realized that similar study is required up to ITSZ to resolve complexity of Himalayas.

INTRODUCTION

A series of cross sections have been prepared by Steck (2003) for entire NW Himalaya which suggest the frontal part is less geologically complex and has moderate to high topographic elevation (~200-2200m). As of now ~6525 GLK 2D seismic data is available in Sub-Himalayan part only and a few extend beyond MBT. Reprocessing efforts to these 2D seismic data sets have significantly improved geological and structural understanding through structural modeling. Various in-house reprocessing facilities at ONGC like GEOPIC, RCC Jorhat and out sourced like M/s. Thrust Belt Imaging (TBI), Canada have considerably facilitated to improving seismic dataset from poor, noisy un-interpretable seismic sections. During structural modeling due care has been taken where re-processed 2D seismic data is absent and geological cross sectionshave been used. Moreover field geological maps have been used for surface dips and linear features like anticline, syncline axes and lithological contacts etc.

Present work

Various geoscientists like Bally (1997) and Powers, Lillie and Yeats (1998) attempted balanced cross sections near Jawalamukhi and Changartalai area, Himachal Pradesh due to availability of well data in this area. In the present study two balanced cross sections were prepared for the same area. The data sets that were used for earlier models by Bally (1997) and Powers et al., (1998) were surface geological maps, well data and seismic sections marred by imaging issues. Whereas in case of present model additionally reprocessed 2D seismic data set by M/s. TBI with available geological sections in the area by previous workers were used. Two balanced geological cross-sections and their sequential restoration across Kangra Recess were prepared with the help of re-processed datasets (Profile-1 and Profile-2). The earlier processed 2D seismic lines were almost uninterpretable and after the improvement through reprocessing these lines were used for structural modeling. The TBI reprocessed seismic lines and its improvements have been shown in Figures 2 and 3. Present day geological map, legacy geological maps, dip data in the area, dip data along the profile, geological cross sections in the area where seismic is not available and available TBI-re-processed seismic data used for modelling in the area are shown in Figures 4 to 11.

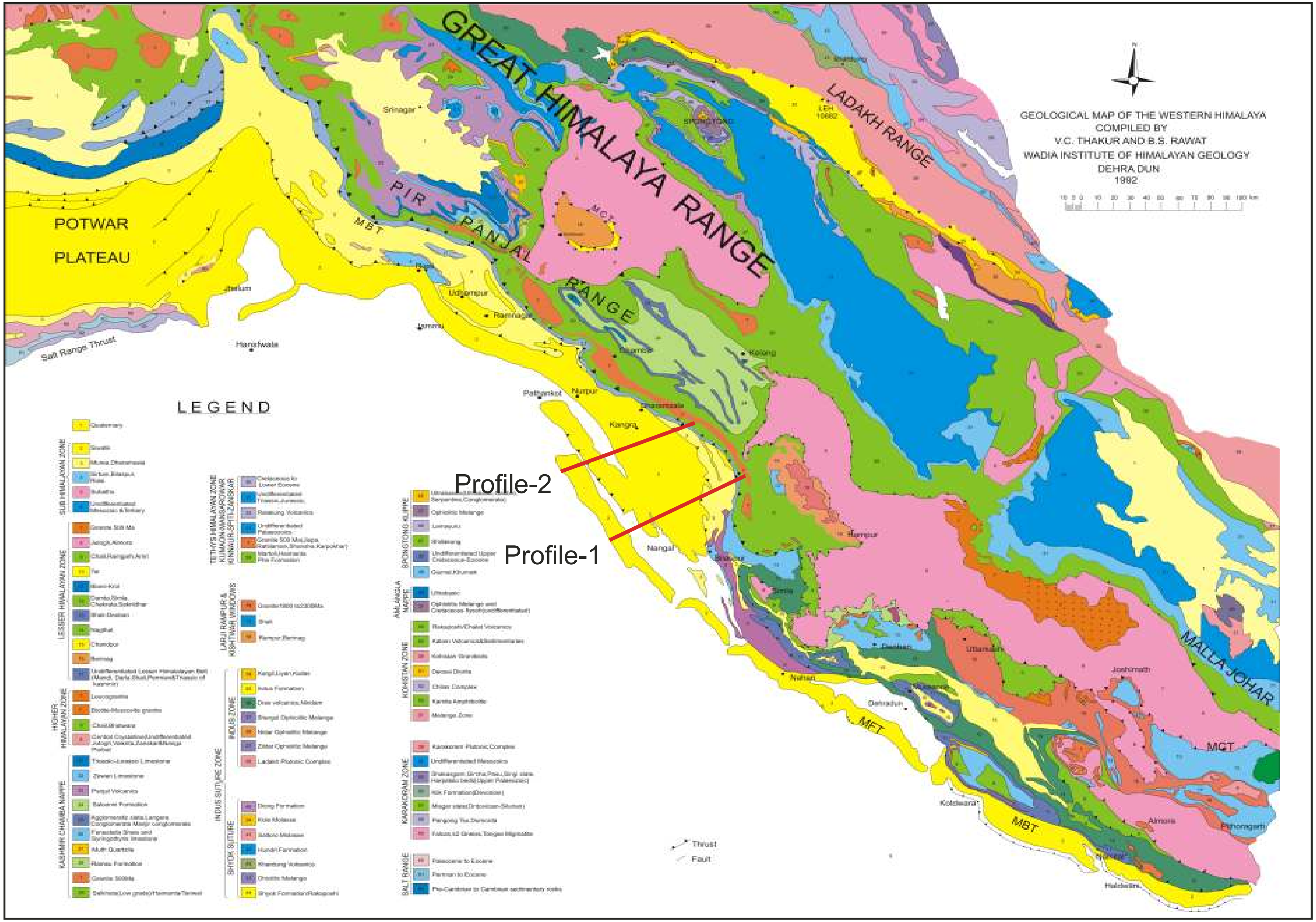


Fig. 1: Geological map of NW Himalaya showing Showing Sub-Himalaya, Lesser Himalaya, Higher Himalaya, Tethyan Himalaya and Trans Himalaya (V.C Thakur and B. S Rawat, 1992)

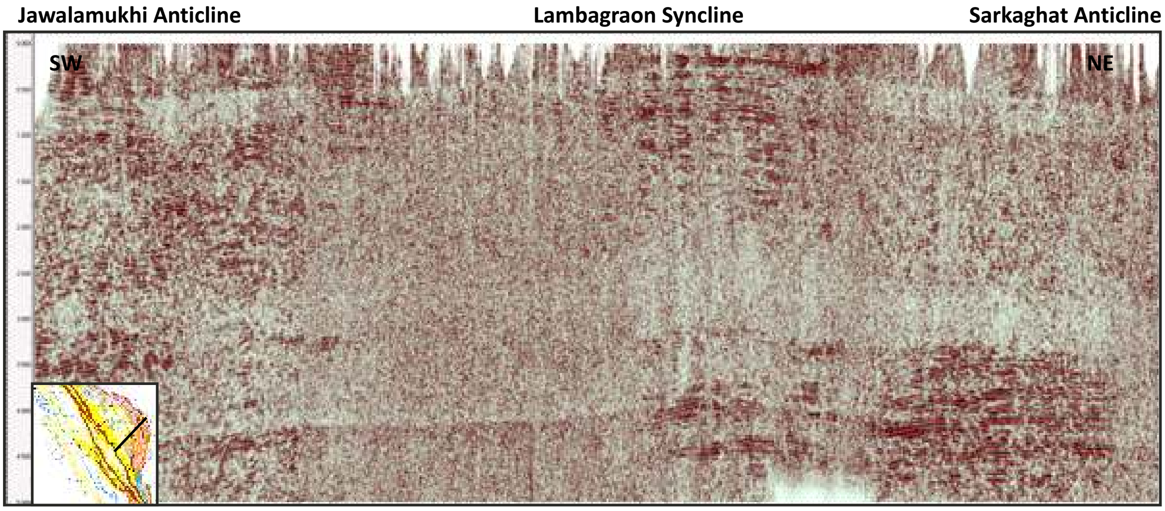


Fig. 2a: Old reprocessed line HP-AA-02

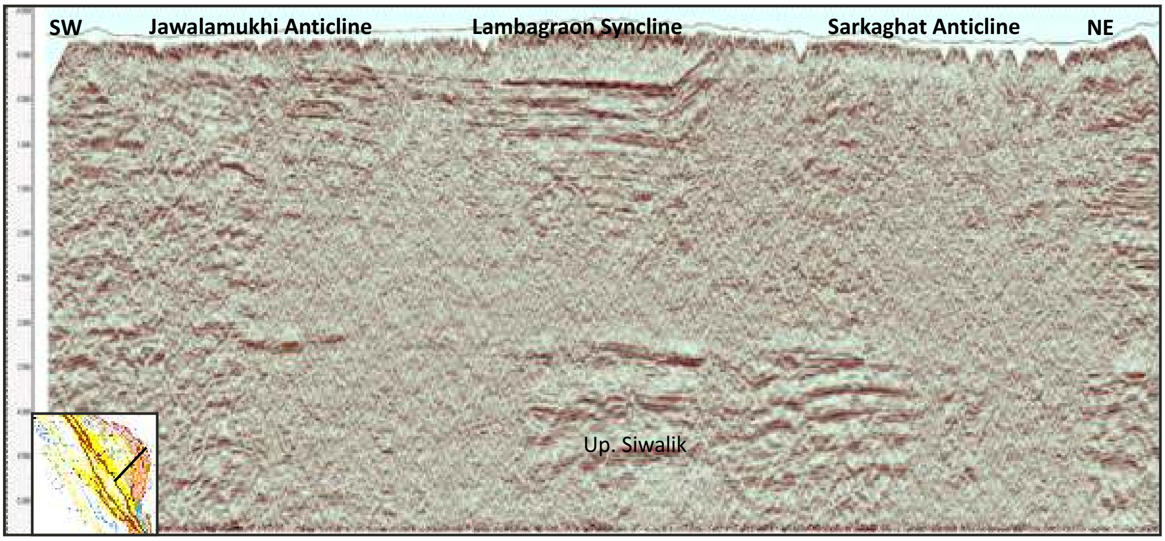


Fig. 2b: TBI reprocessed line HP-AA-02

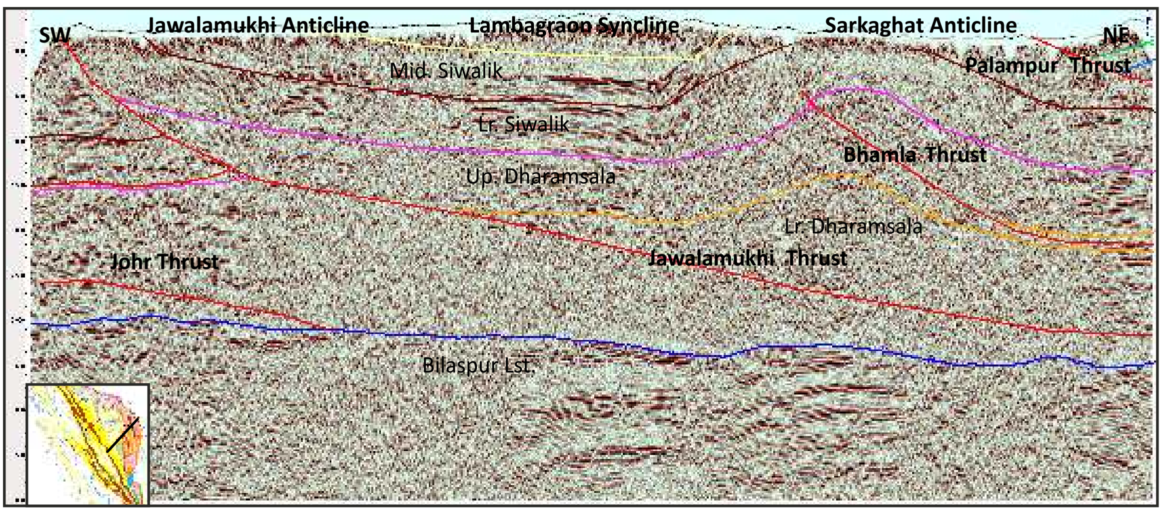


Fig. 2c: Interpretation in reprocessed TBI line HP-AA-02 (used to construct profile 1)

Index

Bilaspur Limestone
Subathu
Lower Dharamsala
Upper Dharamsala
Lower Siwalik
Middle Siwalik
Upper Siwalik

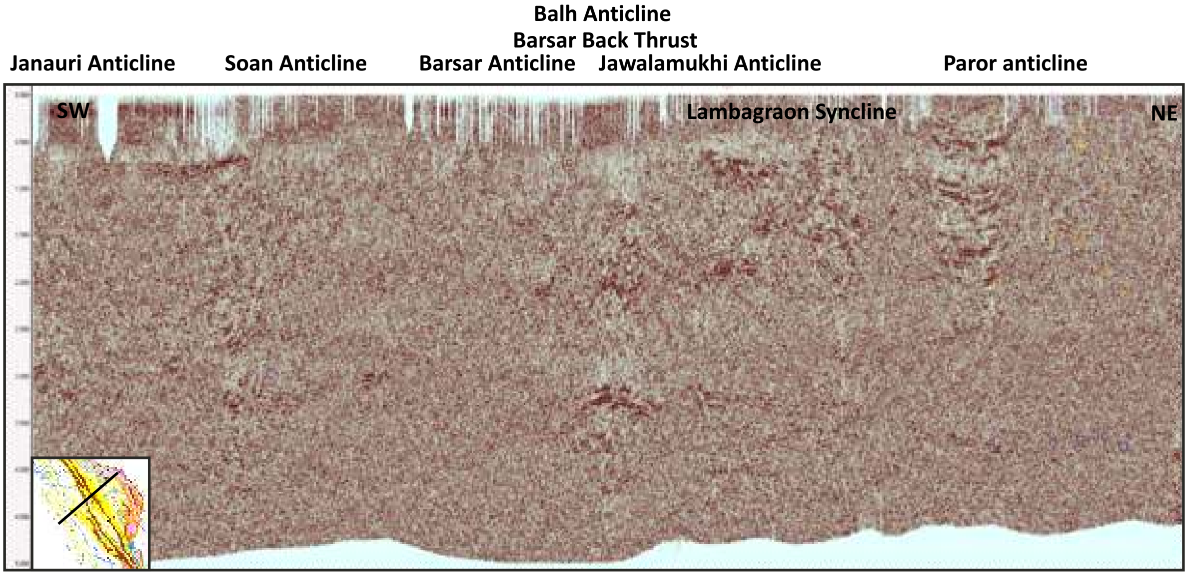


Fig. 3a: Old reprocessed line HP-BB-01

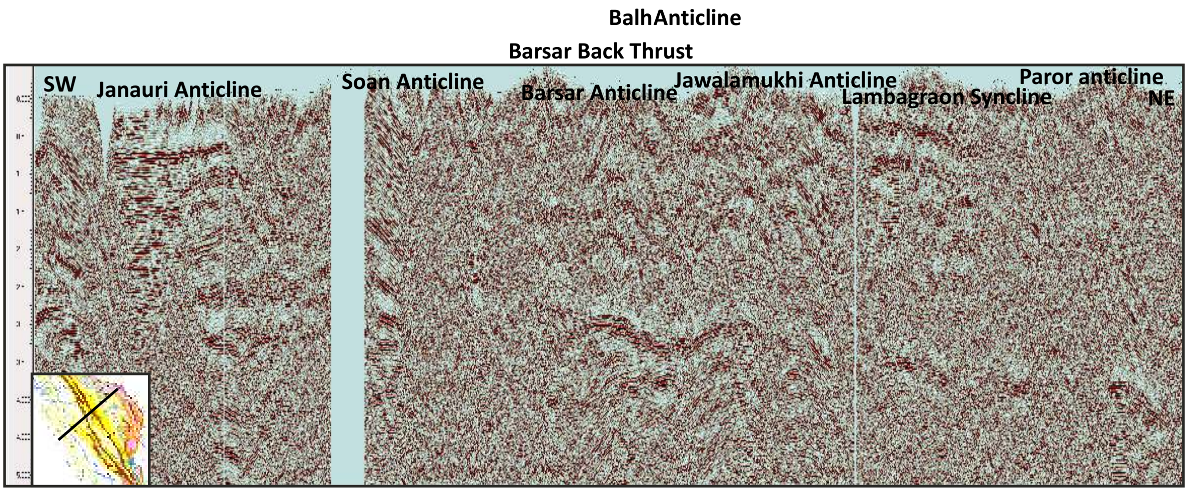


Fig. 3b: TBI reprocessed line HP-BB-01

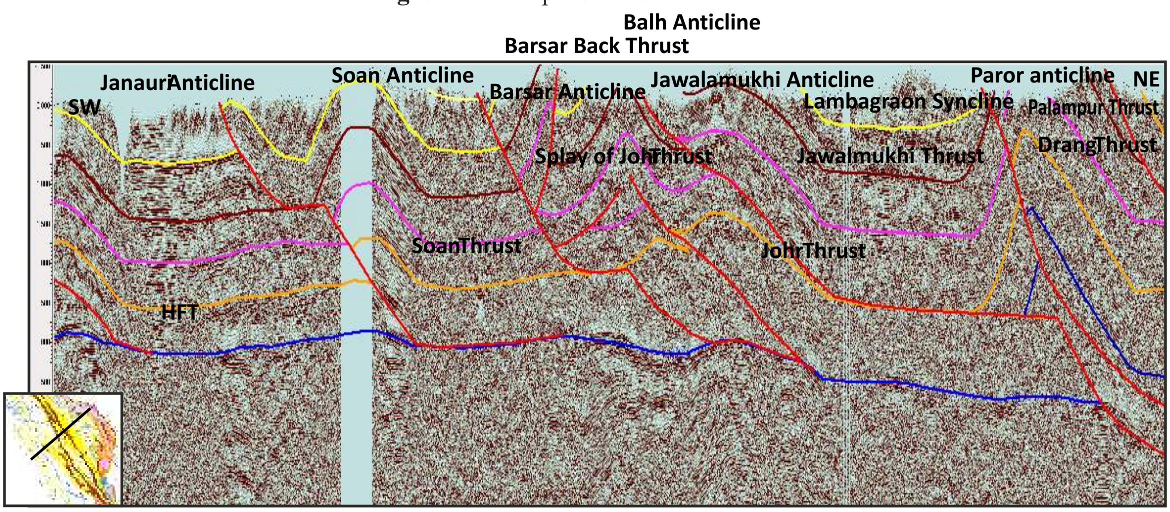


Fig. 3c: Interpretation in reprocessed TBI line HP-BB-01 (used to construct profile-2)

Index

Bilaspur Limestone, Subathu, Lower Dharamsala, Upper Dharamsala, Lower Siwalik, Middle Siwalik, Upper Siwalik

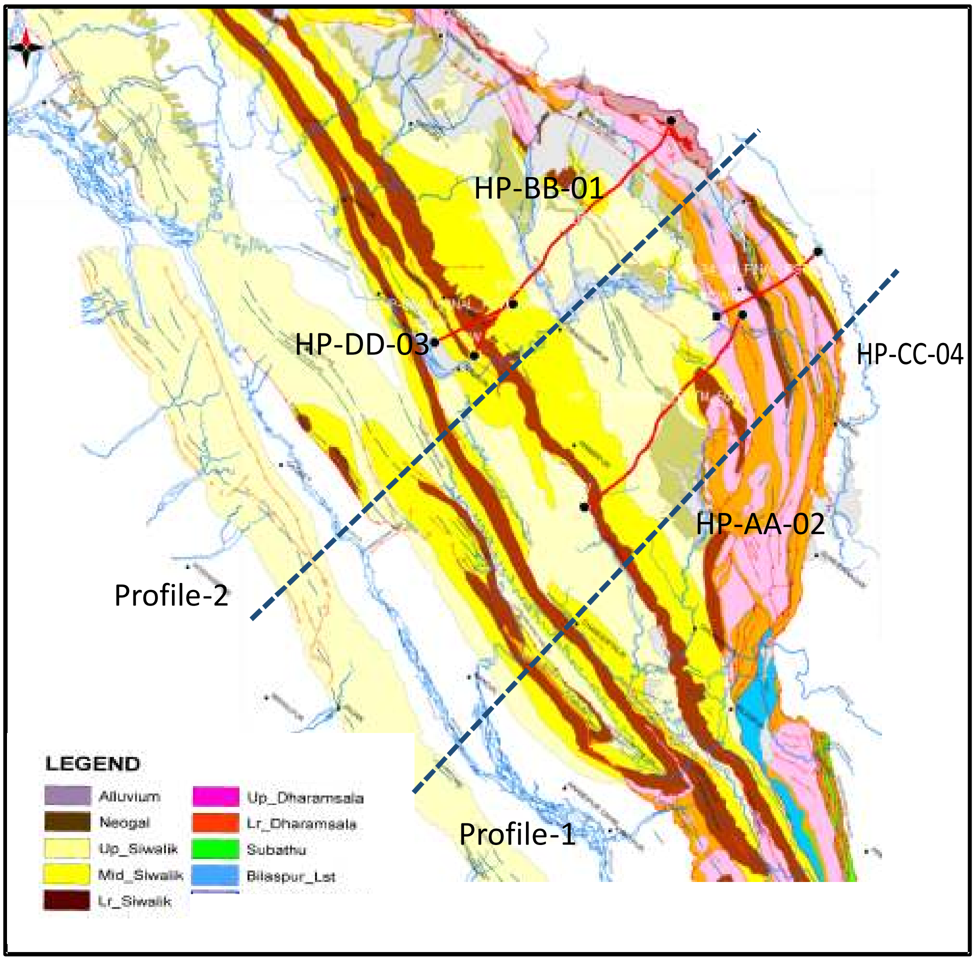


Fig. 4: Seismic lines HP-AA-02 and HP-CC-04 are used to construct the profile-1 and HP-DD-03 and HP-BB-01 are used to construct profile-2

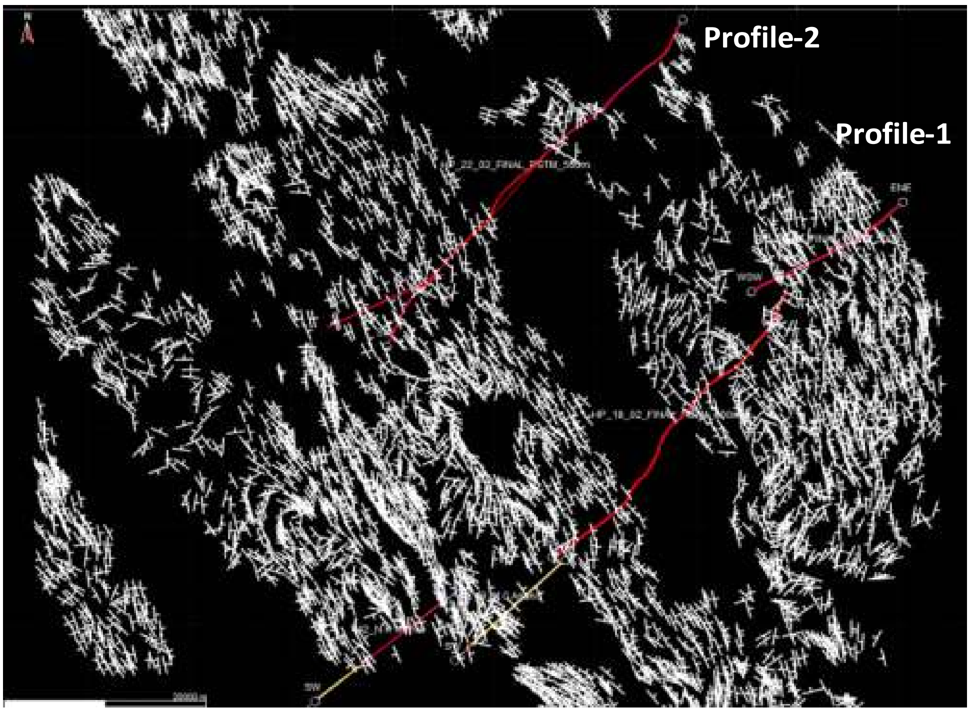


Fig. 5: Dip and strike data of the area with the surface traces of seismic lines used to model two profiles

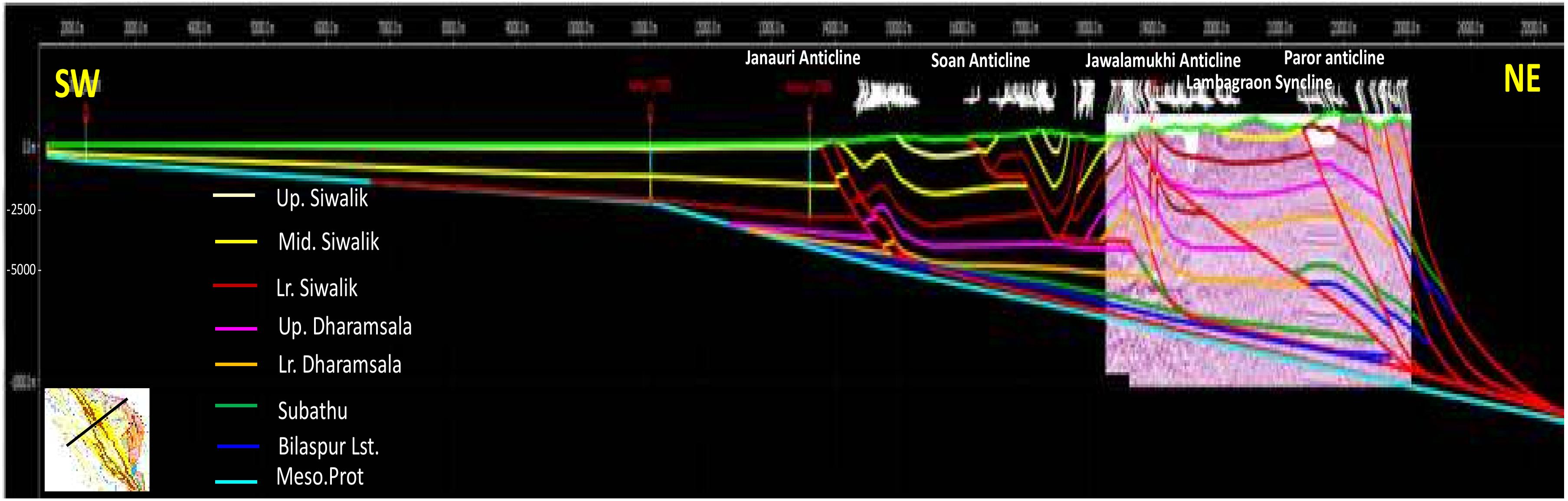


Fig. 6: Dip data has been used to model profiles (Example: profile-2).

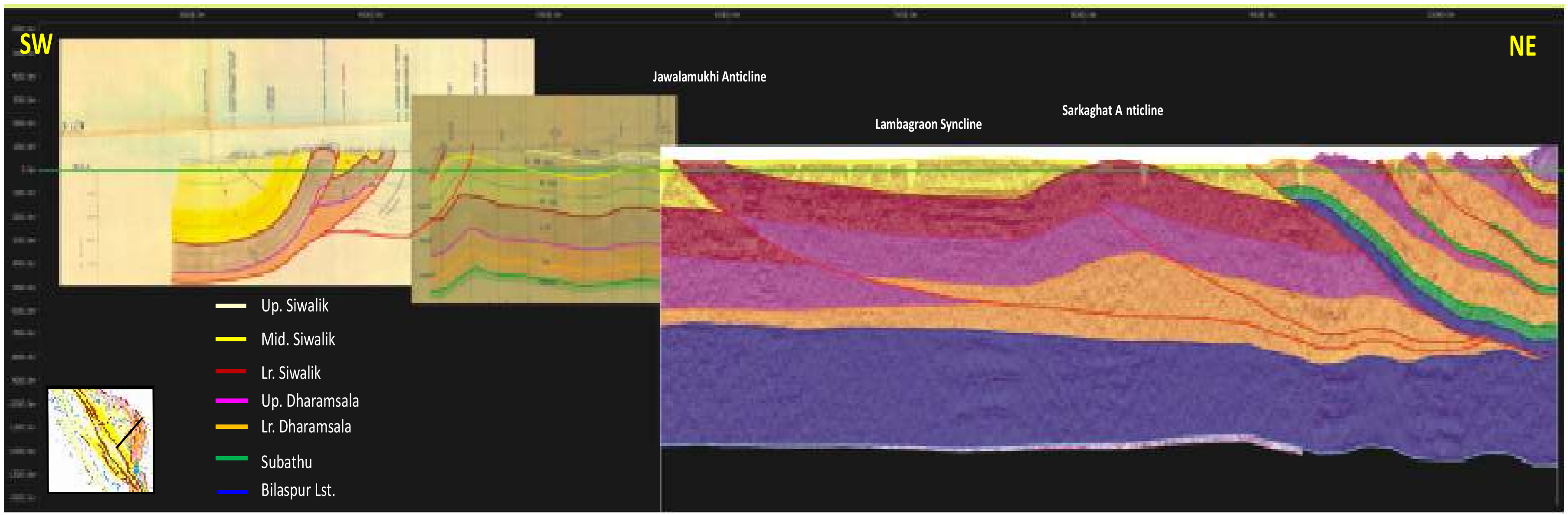


Fig. 7: Geological cross sections and depth converted seismic sections together in profile 1. Interpretation carried out in TBI reprocessed seismic lines.

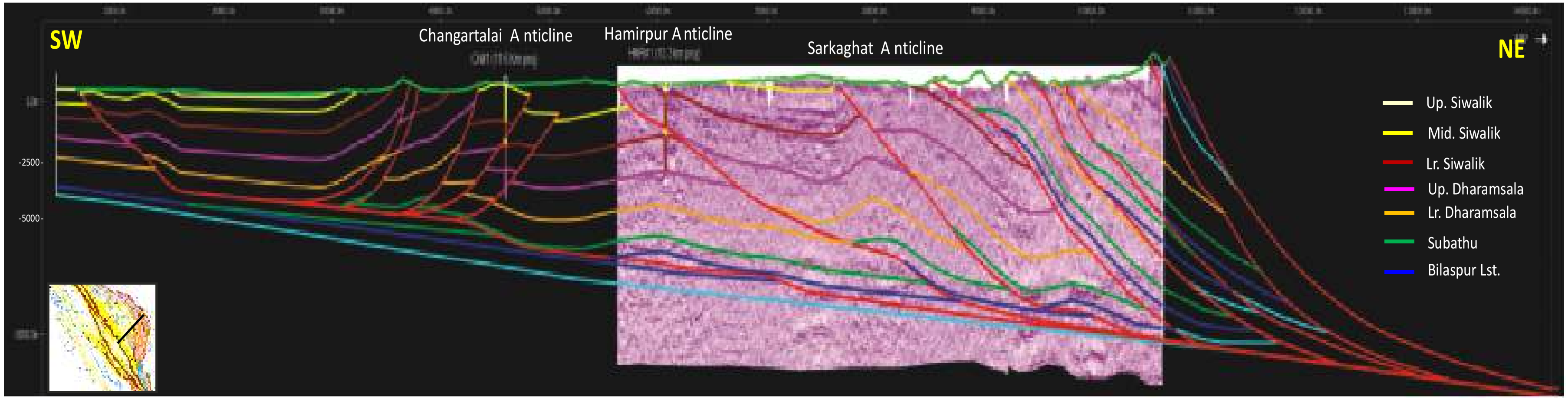


Fig. 8: Profile-1with well tie of CNGT-A and HMR-A and complete profile.

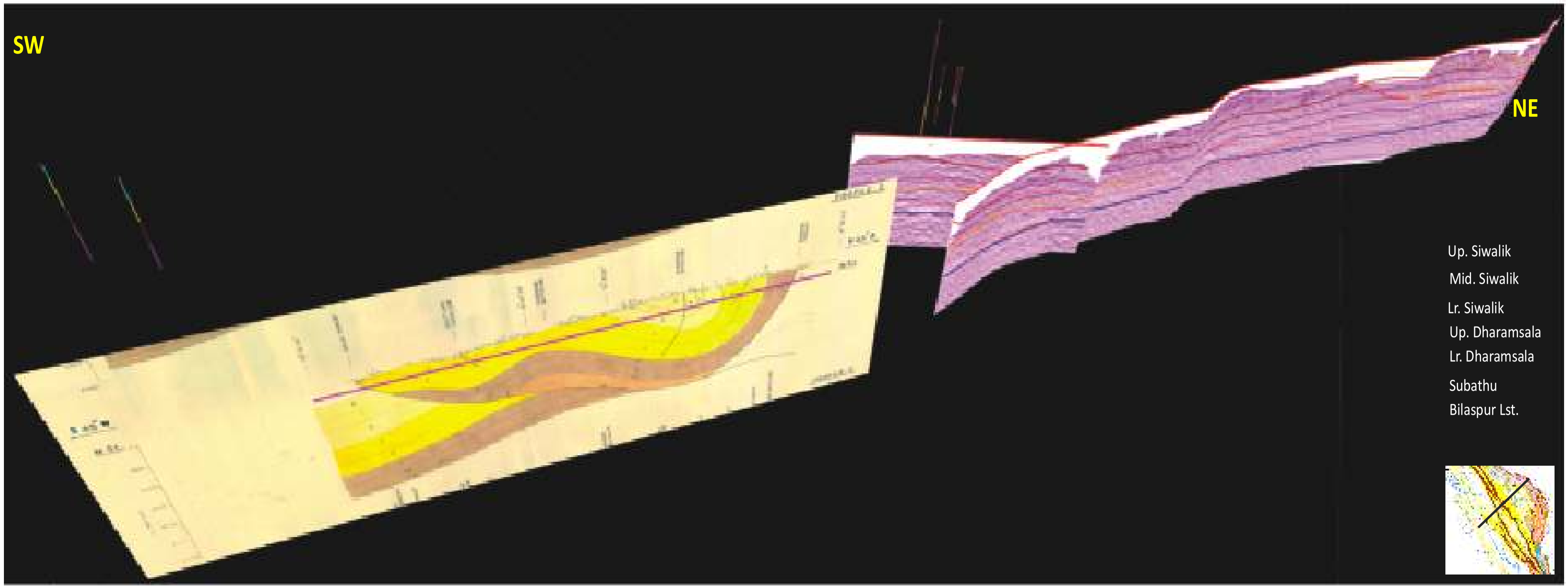


Fig. 9: Area of data gap was covered by the available geological cross section (Cross section of the area around Amb-Bhakra-Naina Devi, N.K. Verma et al., 1986-87) in profile 2

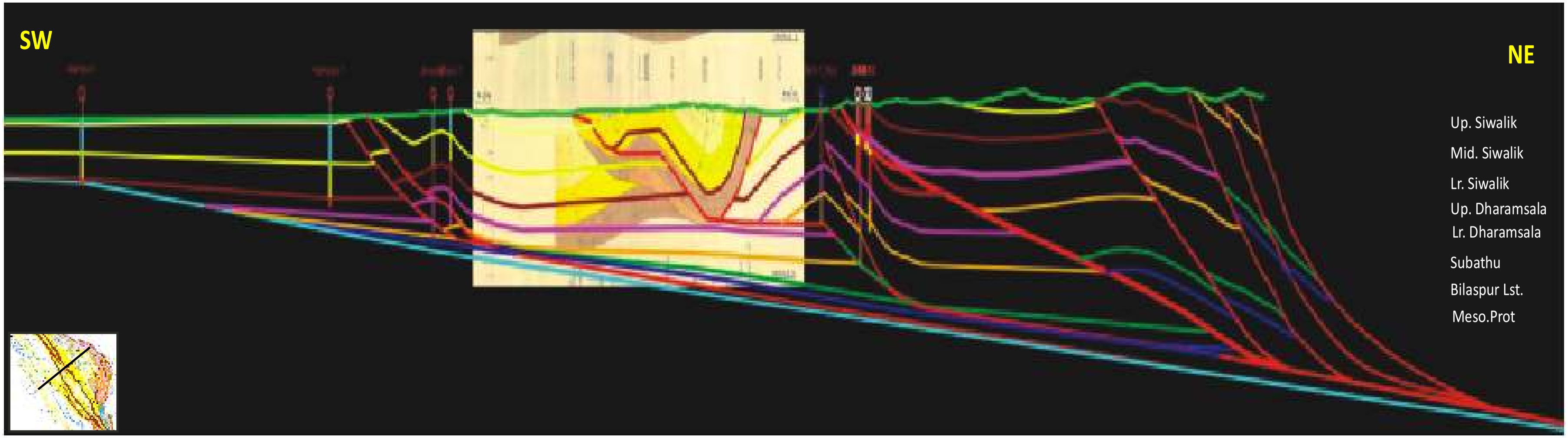


Fig. 10: In area of seismic data gap available geological cross section is used to complete the model in profile-2

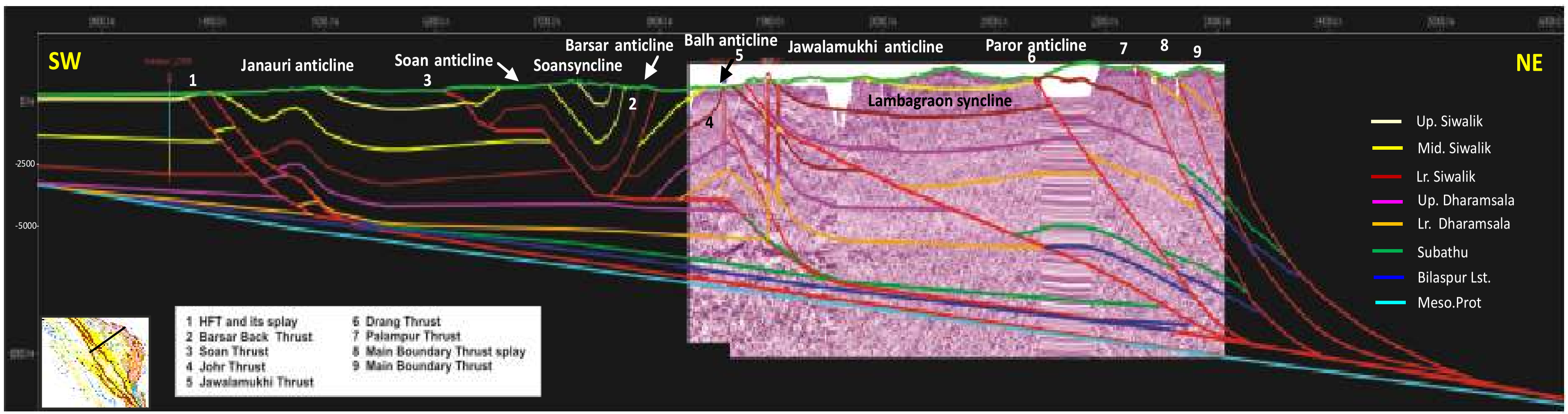


Fig. 11: Complete section of profile-2 showing the geometry and structural style from MBT to HOSR-A. Interpretation towards the hinterland is guided by TBI reprocessed seismic lines.

Sequential restoration of Profile-1 and its analysis

Here we will discuss in detail about the results of sequential restoration of the youngest thrust to the oldest thrust and finally will reach upto the stage of the initial basinal configuration in this part. Later on construction of the erosional profile will also indicate the erosion happened during this process. The dip of the decollement surface is 2-5 ° measured from the seismic in this area.

Himalayan Frontal Thrust restored

In this stage (Figure 12) Himalayan Frontal Thrust (HFT) is restored. The fault bend fold on the hanging wall of HFT has been generated by bending on HFT. The Restoration of the thrust removes deformation (fault bend fold) on the up-thrust of it and shows the nature of Upper Siwalik erosional surface when restored. The hollow space created in this process indicates erosion of Upper Siwalik. Shortening of 0.87 km occurred due to thrusting of HFT.

Lingur Thrust (Back Thrust) restored

In this stage (Figure 13) Lingur Thrust is restored as a back thrust. Restoration of this back thrust removes the hanging wall deformation by the Lingur Thrust and brings the erosional formation top of Upper Siwalik, Middle Siwalik and Lower Siwalik to the restored stage. Shortening of 0.67 km occurred due to thrusting of Lingur Thrust.

Lunkhar Khad Thrust restored

In this stage (Figure 14), Lunkhar Khad Thrust is restored as a back thrust. Restoration of this back thrust removes the hanging wall deformation of the Lunkhar Khad Thrust and brings Lower Siwalik Formation top to the restored stage. After restoration of the Lunkhar Khad Thrust a prominent high can be seen at Lower Dharamsala, Upper Dharamsala and Lower Siwalik levels on its hanging wall which indicates presence of structure before Lunkhar Khad Thrust deformation. Shortening of 1.32 km occurred due to thrusting of Lunkhar Khad Thrust.

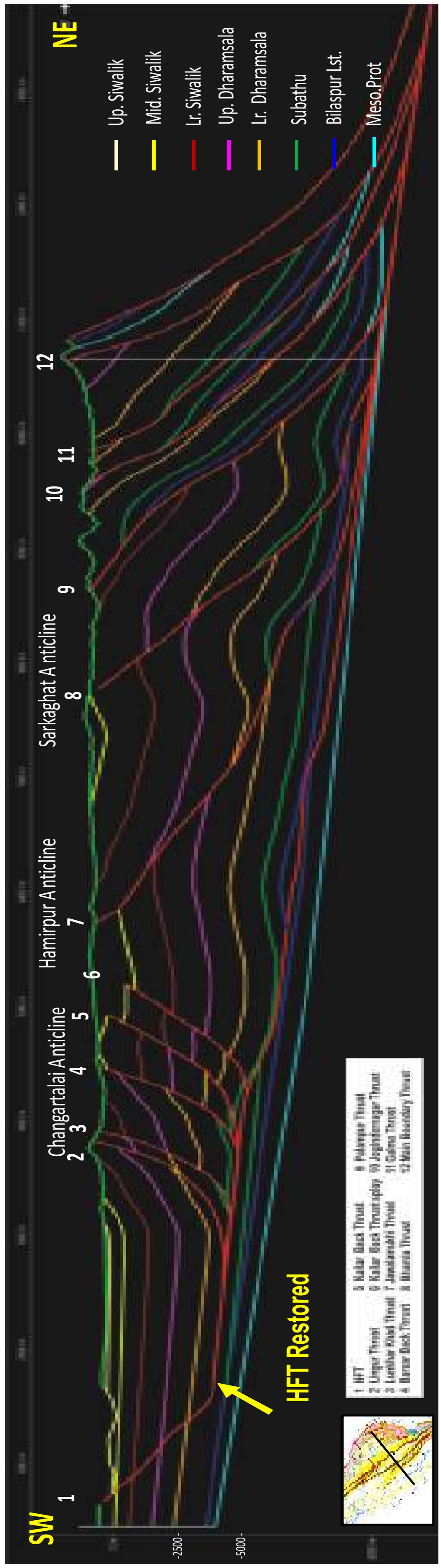


Fig. 12: Himalayan Frontal Thrust (HFT) restored

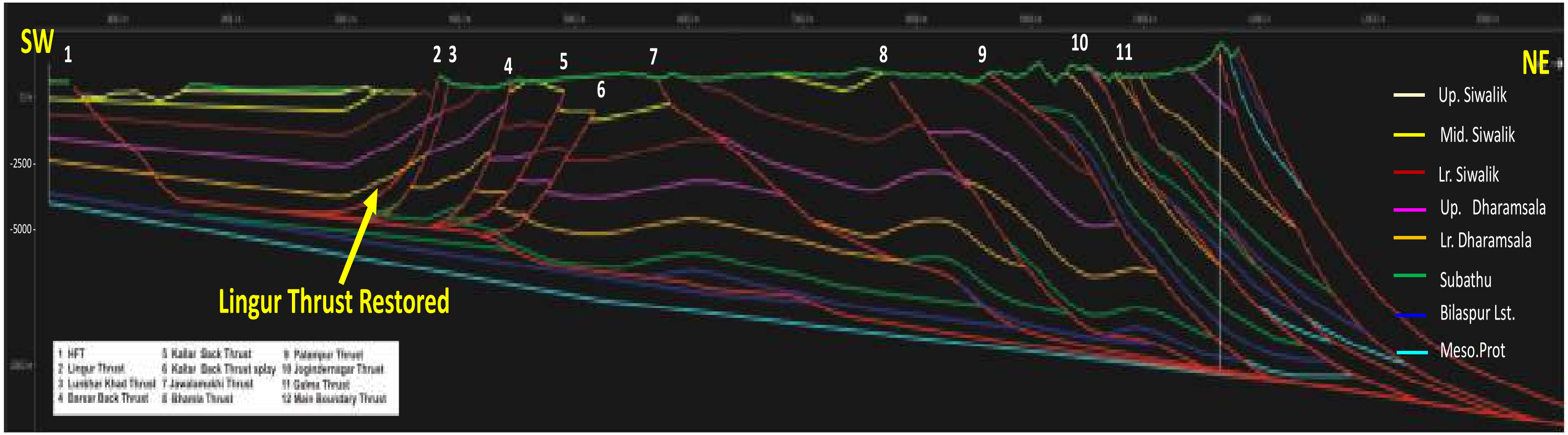


Fig. 13: Lingur Thrust restored

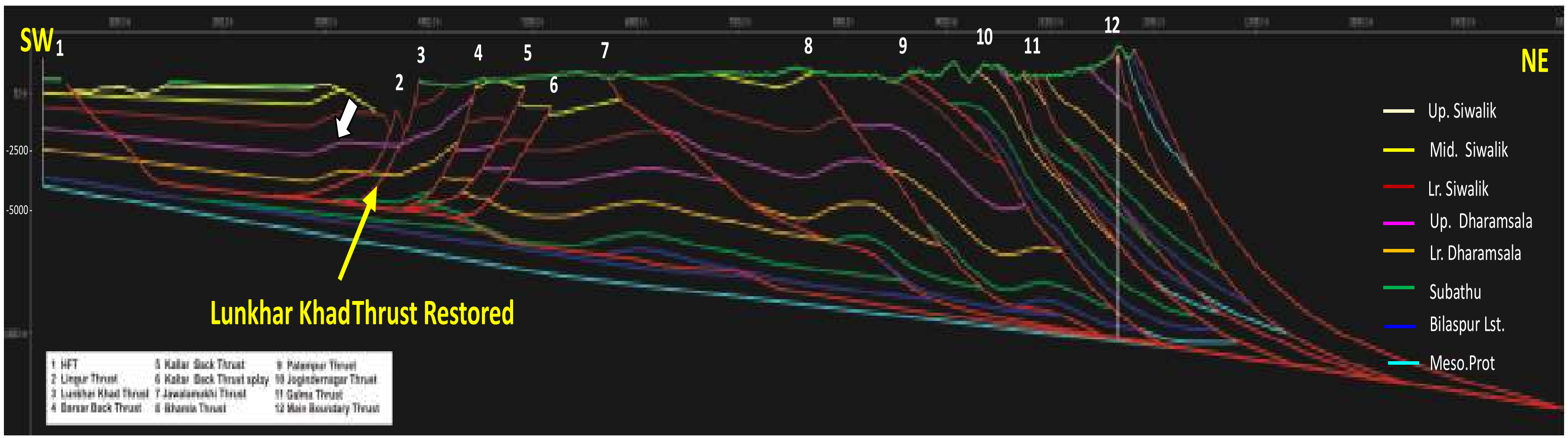


Fig. 14: Lunkhar Khad Thrust restored

Barsar Back Thrust restored

In this stage (Figure 15), Barsar Back Thrust is restored. Restoration of this back Thrust removes the hanging wall deformation of Barsar back Thrust and restores Middle Siwalik and Lower Siwalik erosional tops to the restored stage. The hollow space created by this process indicates the amount of erosion at Middle Siwalik and Lower Siwalik stage. After Barsar Back Thrust restoration it shows a small anticlinal structure appears at Subathu, Lower Dharamsala and Upper Dharamsala levels on the up-thrust of Barsar Back Thrust which indicates presence of structure before Barsar Back Thrust came into existence. The dip of the Barsar Back Thrust is almost 70-80 degree and out crop dip data has been used to model the thrust. Shortening of 1.68 km occurred due to thrusting of Barsar back Thrust.

Kallar Back Thrust restored

In this stage (Figure 16), Kallar Back Thrust is restored as a back thrust. Restoration of this back thrust removes the hanging wall deformation of the Kallar Back Thrust and brings Middle Siwalik erosional top to the restored stage. After restoration of Kallar Back Thrust a small anticlinal structure appears at Subathu, Lower Dharamsala and Upper Dharamsala levels on the up-thrust of Kallar Back Thrust which indicates presence of earlier structure before Kallar Back Thrust was formed. Shortening of 1.21 km occurred due to thrusting of Kallar Back Thrust.

Kallar Back Thrust splay restored

In this stage (Figure 17), Kallar Back Thrust splay is restored. Restoration of this back thrust removes the hanging wall deformation of the Kallar Back Thrust splay and brings Middle Siwalik erosional top to the restored stage. After restoration of all these back thrusts (Lingur Thrust, Lunkhar Khad Thrust, Barsar Back Thrust, Kallar Back Thrust and Kallar back Thrust splay) two broad anticlinal structures appear near the back thrusts area. Shortening of 0.56 km occurred due to thrusting of Kallar Back Thrust splay.

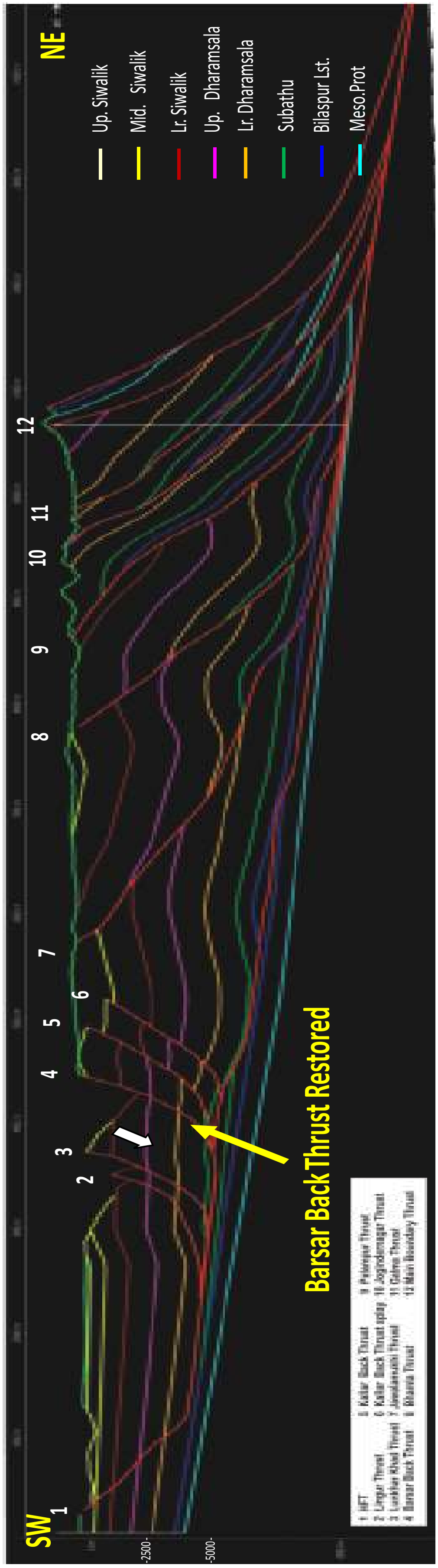


Fig. 15: Barsar Back Thrust restored

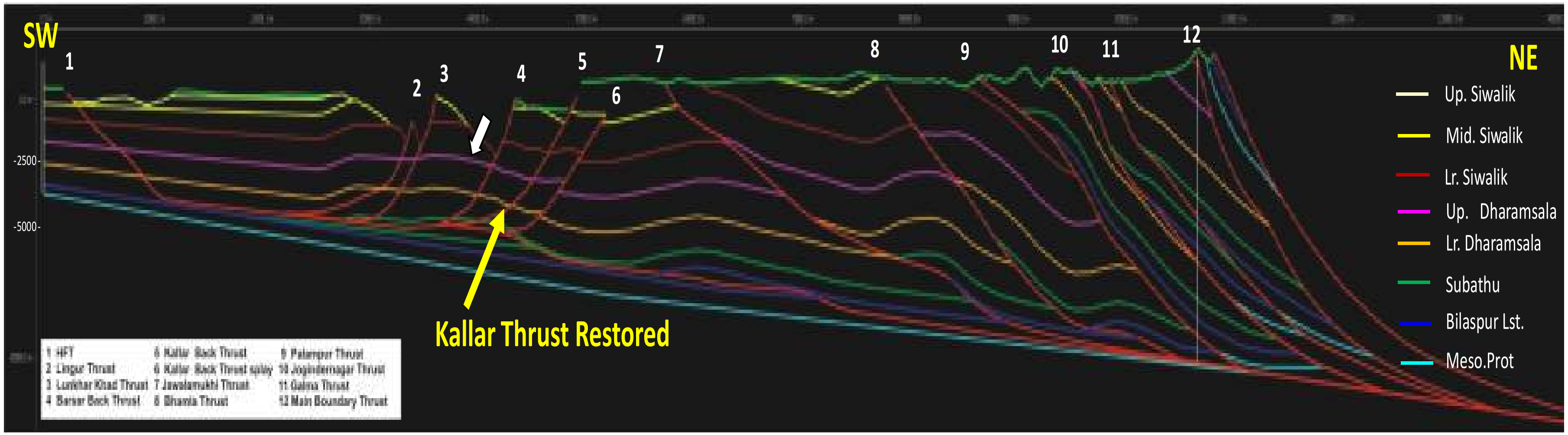


Fig. 16: Kallar Back Thrust restored

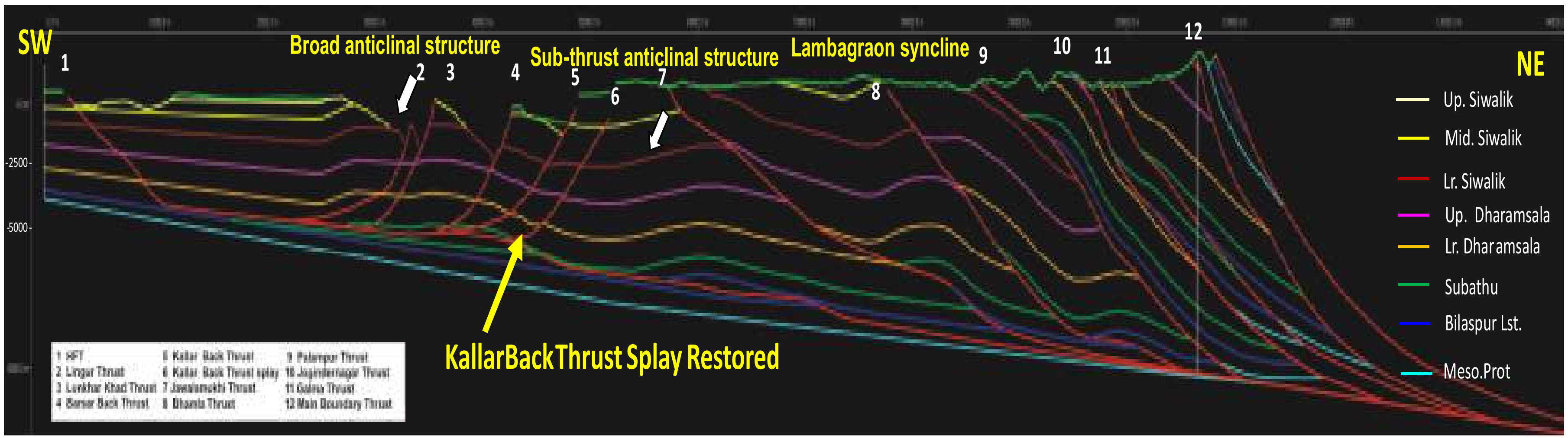


Fig. 17: Kallar splay restored

Jawalamukhi Thrust restored

In this stage (Figure 18), Jawalamukhi Thrust was restored. Restoration of this Thrust removes the hanging wall deformation of Jawalamukhi Thrust and brings Lower Siwalik, Middle Siwalik and Upper Siwalik erosional tops to the restored stage. After removal of deformation along the thrust a small anticlinal structure appears at Lower Dharamsala, Upper Dharamsala and Lower Siwalik levels which indicate formation of a folding prior to the thrusting of Jawalamukhi Thrust. This pre Thrusting structure is important in hydrocarbon exploration point of view as this is the pre-thrusting structure. Presence of gas in many drilled wells in Jawalamukhi area and surface gas shows in many places at the up-thrust of Jawalamukhi Thrust structure indicates presence of a petroleum system. Thus the result also indicates before initiation of Jawalamukhi Thrust two broad anticlinal structures were present at the foreland part of it near Changartalai and in Hamirpur areas. Wells CNGT-A and HMR-A are situated on these structures (Now breached by thrusting). Presence of Bilaspur Limestone and Subathu (envisaged source rock in this area) indicates pre-Jawalamukhi Thrust structures with petroleum system. Thrusting of JMI Thrust led to erosion of Lower Siwalik, Middle Siwalik and Upper Siwalik as evidenced above. It indicates timing of thrusting of JMI T from the restoration results is inferred after deposition of Upper Siwalik. Shortening of 7.44 km occurred due to thrusting of Jawalamukhi Thrust.

Bhamla Thrust restored

In this stage (Figure 19), Bhamla Thrust is restored. Restoration of this thrust removes the hanging wall deformation and brings Lower Siwalik and Middle Siwalik erosional tops to the restored stage. After removal of deformation along this thrust a small structure appears at Subathu and Lower Dharamsala levels, which indicates existence of a fold prior to the thrusting of Bhamla Thrust.Shortening of 5.96 km occurred due to thrusting of Bhamla Thrust.

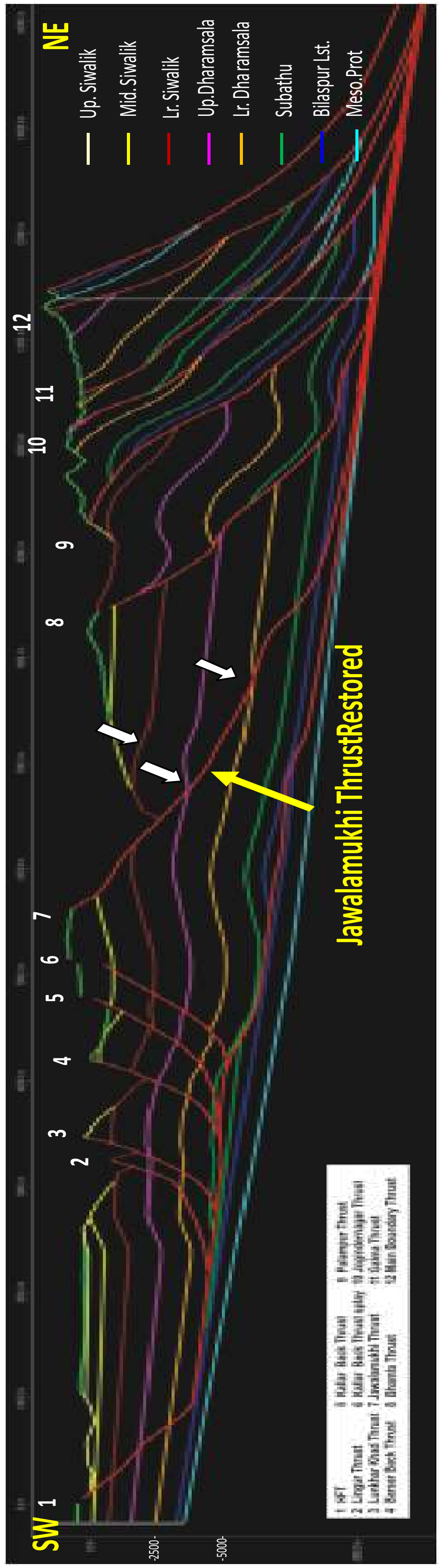


Fig. 18: Jawalamukhi Thrust restored

Fig. 19: Bhamla Thrust restored

Palampur Thrust restored

In this stage (Figure 20), Palampur Thrust is restored. Restoration of this thrust removes the hanging wall deformation of Palampur Thrust and brings erosional top of Lower Dharamsala and Upper Dharamsala formations to the restored stage. After removal of deformation along this thrust a small structure appears at Subathu level, indicates presence of a gently folded structure below Lower Dharamsala level prior to the thrusting of Palampur Thrust. Shortening of 15.03 km occurred due to thrusting of Palampur Thrust.

Jogindernagar Thrust restored

In this stage (Figure 21), Jogindernagar Thrust is restored. Restoration of this thrust removes the hanging wall deformation and brings Lower Dharamsala and Upper Dharamsala erosional tops to the restored stage. Shortening of 3.82 km occurred due to thrusting of Jogindernagar Thrust.

Galma Thrust restored

In this stage (Figure 22), Galma Thrust is restored. Restoration of this thrust removes the hanging wall deformation and brings Lower Dharamsala and Upper Dharamsala erosional tops to the restored stage. Anticlinal structure with a small relief appears at Subathu level after restoration. Shortening of 16.55 km occurred due to thrusting of Galma Thrust.

Restored bend at decollement

In this stage (Figure 23), the remaining deformation is restored and flattened the formations. For example two broad anticlinal structures i.e. Changartalai and Hamirpur structures and other small anticlinal structures on the hanging wall of various thrusts that were generated prior to the thrusting were almost flattened at this stage. Shortening of 0.32 km occurred due to restoration at decollement.

Construction of eroded profile

In this stage (Figure 24), the erosional tops are constructed (indicated as dotted lines) whereas the

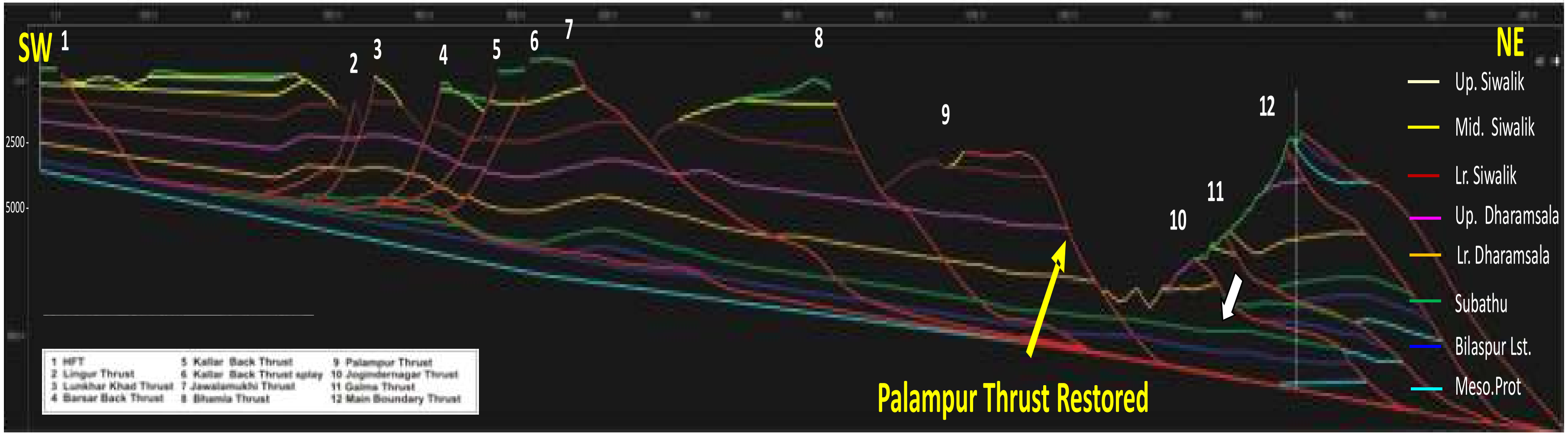


Fig.e 20: Palampur Thrust restored

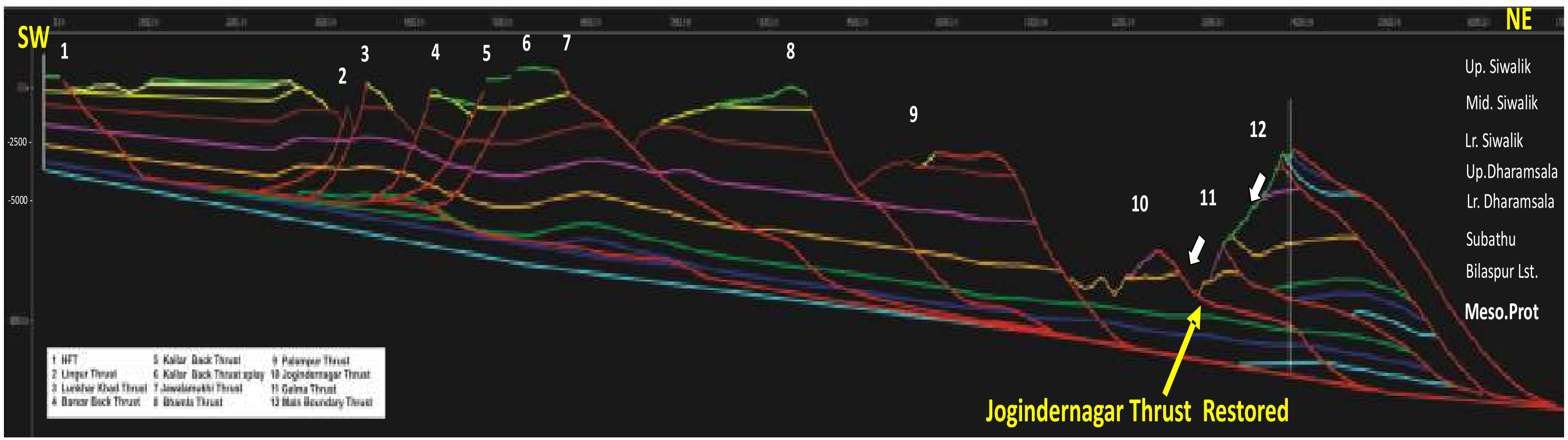


Fig. 21: Jogindernagar Thrust restored

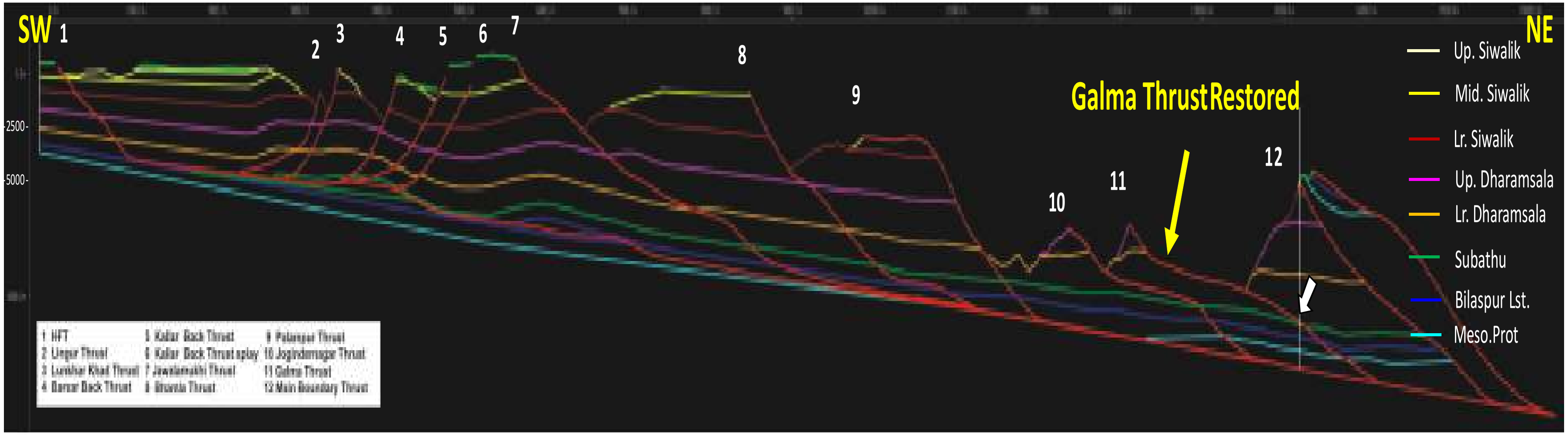


Fig. 22: Galma Thrust restored

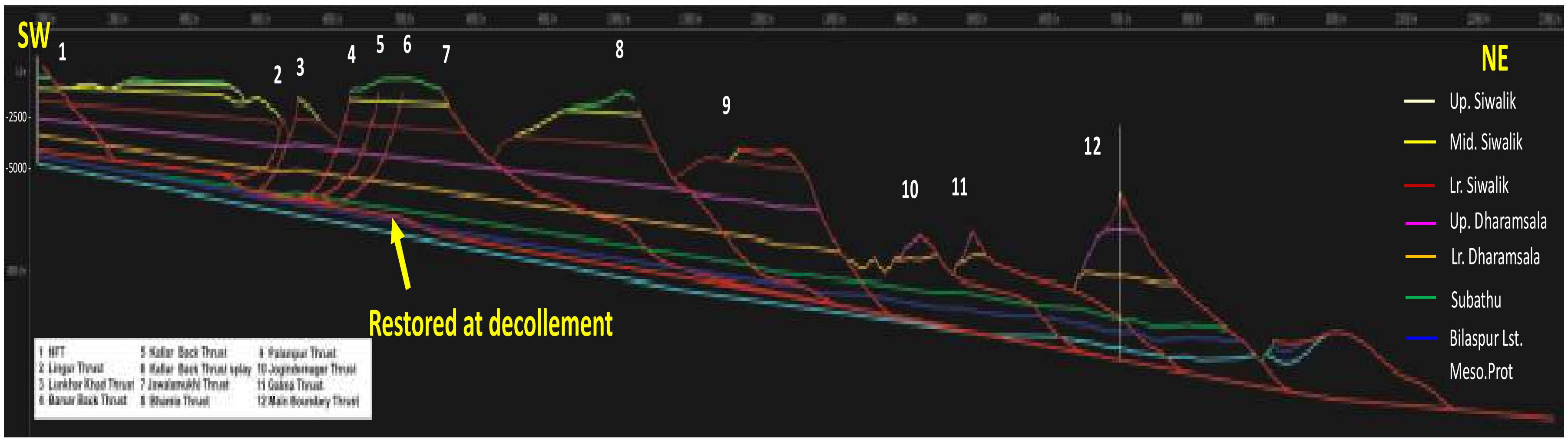


Fig. 23: Restored deformation at decollement

bold lines indicate the result of the sequential restoration of present day deformed formations. Joining of bold lines and the dotted lines indicate the initial basinal configuration though it is difficult to estimate the eroded volume of rock from a 2D line and we can only estimate the amount of shortening from this process.

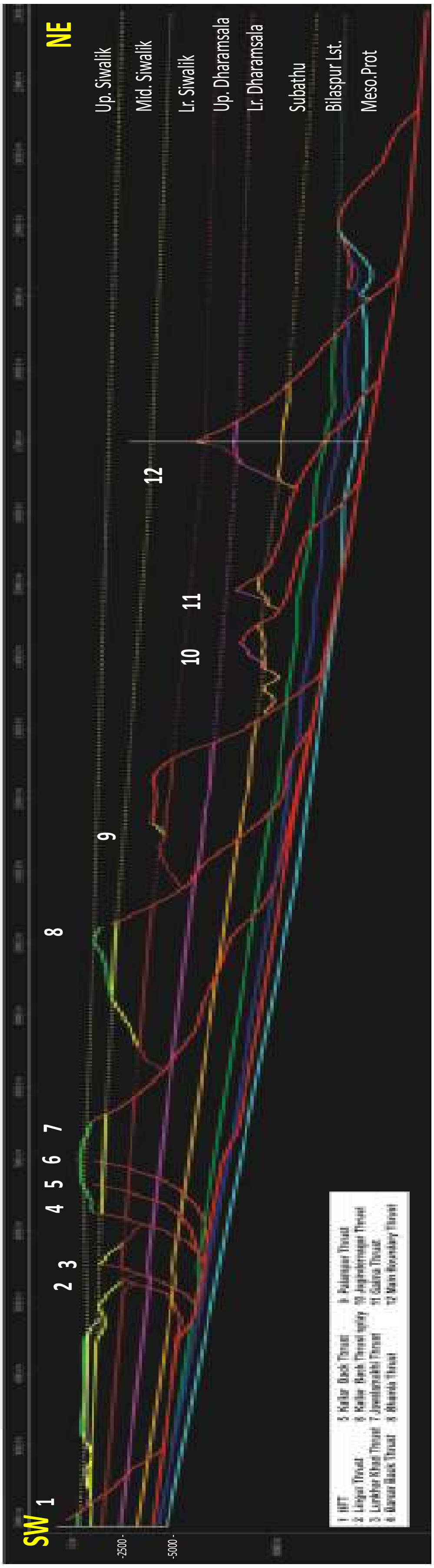
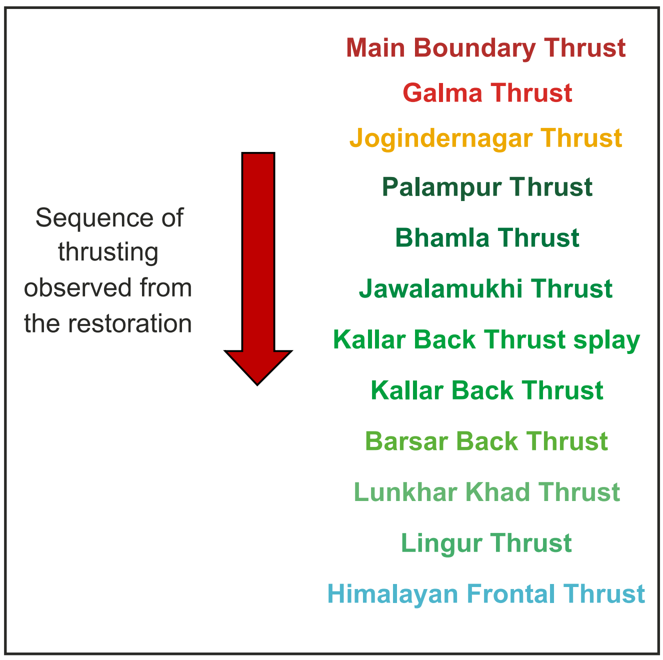


Fig. 24: Construction of the eroded section

Kinematic Analysis

This analysis suggests about the kinematics of the thrusts formation in this area. In this regard the Main Boundary Thrust (MBT) has been considered the northern most hinterland forethrust and Himalayan Frontal Thrust (HFT) has been considered the southernmost forethrust in instant study. Thus sequential restoration has been carried out from the youngest most forethrust to the oldest forethrust in this segment i.e. from HFT to MBT. The sequential restoration indicates following is the kinematics of thrusting from the oldest forethrust to the youngest forethrust. A measurement has been taken from deformed to undeformed stage between MBT and HFT. Kinematics analysis measures span of end thrusts, i.e. HFT and MBT. In the deformed stage (in present day section) the span is around 102 km, whereas in the undeformed stage the span is around 157 km. Thus percentage of shortening during the compression is around 35 %. No out of sequence thrusts have been used for modelling.



Sequential restoration of Profile-2 and its analysis

Now we will discuss in detail about the results of sequential restoration of the youngest thrust to the oldest thrust in instant study and finally will reach upto the stage of the initial basinal configuration in this part. Later on construction of the erosional profile will also indicate the erosion happened during this process.The dip of the decollement surface is 2-5 ° measured from the seismic in this area.

HFT and HFT Splay restored

Thickness of Upper Dharamsala in Janauri 2 suggests transportation of a slice of Upper Dharamsala in up-thrust of HFT which was brought riding over HFT splay to the West of HFT. In this stage (Figure 25) Himalayan Frontal Thrust (HFT) and HFT splay are restored. The fault bend fold on the hanging wall of HFT has been generated by bending on HFT. The restoration of the thrust removes deformation (fault bend fold) on the up-thrust of the thrust and shows the nature of Upper Siwalik erosional surface when restored. In deformed section a prominent low can be observed i.e. Una-Kalka low and the low trend can also be validated by the regional gravity data. After restoration, the remnants of the low exist, which is indicative of presence of existing low before deformation due to HFT. The low in this area exists even after the splay of MBT is restored. Therefore it can be revealed that the presence of source rock within the low may act as a kitchen for adjoining structures. Shortening of 1.56 km occurred due to thrusting of HFT and its splay.

Barsar Back Thrust (BBT) restored

As restoration order is from West to East in direction (from recent to past), accordingly Soan Thrust (ST) comes before BBT, so its restoration takes precedence. During this process hanging wall strata of BBT could not be satisfactorily restored. As BBT though in East of ST is an out of sequence thrust, so it is taken prior to Soan Thrust as far as restoration is

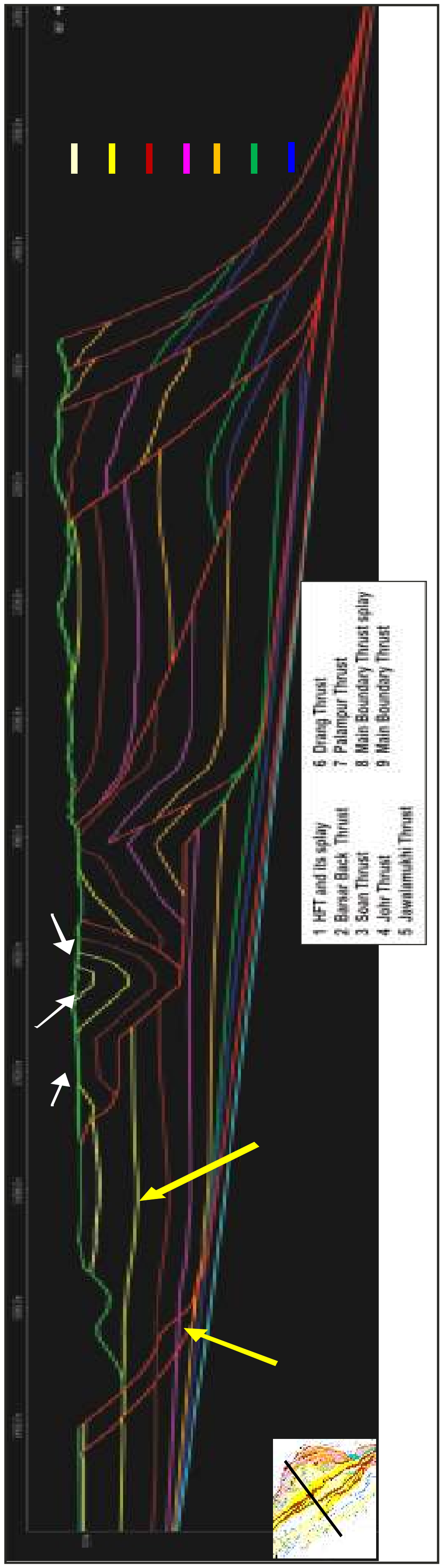


Fig. 25: Himalayan Frontal Thrust (HFT) and HFT splay restored

concerned. In this stage (Figure 26), Barsar Back Thrust is restored. Restoration of this back thrust removes the hanging wall deformation and restores Lower Siwalik, Middle Siwalik and Upper Siwalik erosional tops to the restored stage. The hollow space created by this process indicates erosion of Lower Siwalik, Middle Siwalik and Upper Siwalik during this stage. Restoration of Barsar Back Thrust shows that a structure prevails at the up-thrust of Soan Thrust (Soan Anticline) at Lower Siwalik level. Shortening of 0.17 km occurred due to thrusting of Barsar Back Thrust.

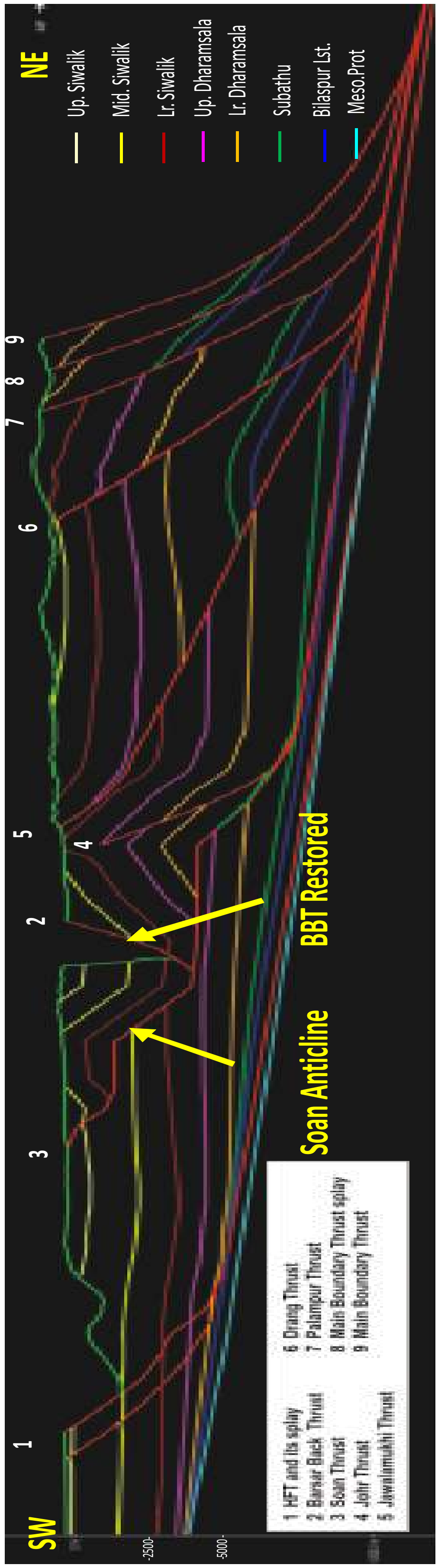


Fig. 26: Barsar Back Thrust restored

Soan Thrust restored

In this stage (Figure 27) Soan Thrust is restored. Removal of deformation along this thrust brings Middle Siwalik and Upper Siwalik erosional tops to the restored stage. Removal of deformation at the up-thrust of Soan Thrust reveals that Balh anticlinal structure came into existence during thrusting of Soan Thrust (present day Balh structure where high pressure gas was observed in well B-A @ 624 m3/day at a depth of 3616m-3610m in Lower Dharamsala and during drilling gas cut mud was observed at the depth of 2150m-2156m and 2955m-2961m in Upper Dharamsala. Presence of Subathu also indicates attendant petroleum system. Well J-G is also situated in this set up. During drilling of the well J-G gas shows were observed at depth about 1269m and 4024m. Shortening of 7.9 km occurred due to thrusting of Soan Thrust.

Johr Thrust restored

Ramp feature in up-thrust of Johr Thrust in Figure 28 suggests that beginning of Balh structure commenced at this time which culminated after thrusting of Soan Thrust. In this stage (Figure 28) Johr Thrust is restored. Restoration of this thrust removes the deformation at its up-thrust i.e. at Bilaspur limestone, Subathu, Lower Dharamsala, Upper Dharamsala, Lower Siwalik, and Middle Siwalik levels. The erosional gap that it creates indicates onset of Lower Siwalik erosion and continuation of Middle and Upper Siwalik erosion. During the stage of Johr Thrust restoration, an

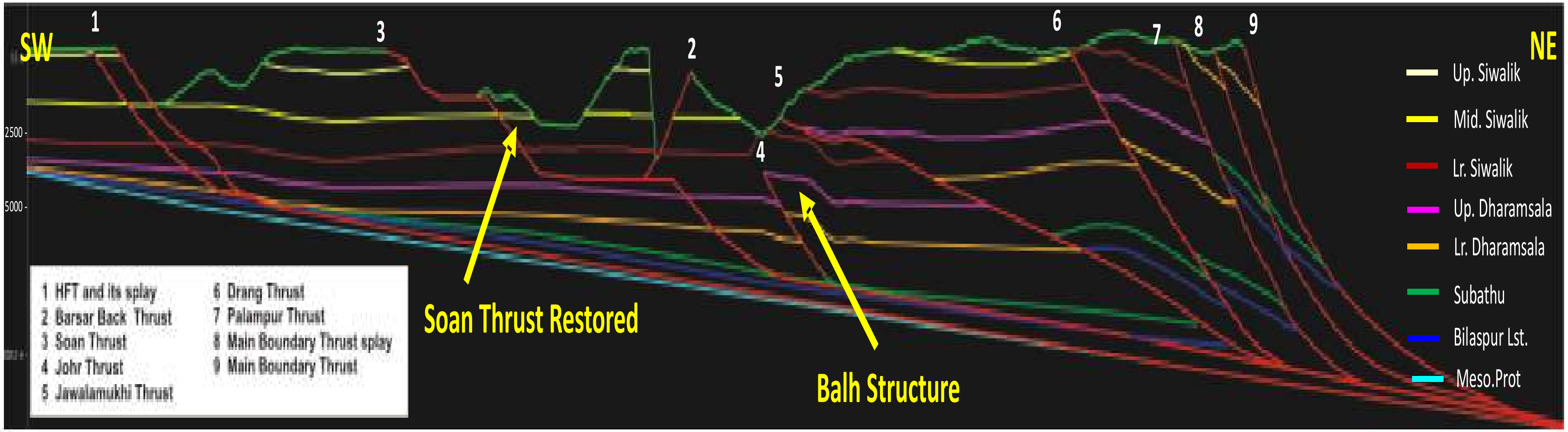


Fig. 27: Soan Thrust restored

Fig. 28: Johr Thrust restored

anticlinal structure can be seen at the up-thrust of Jawalamukhi Thrust at Upper Dharamsala level towards its leading edge and high also exists near the trailing edge at the sub-thrust of Drang Thrust (at Subathu and Lower Dharamsala levels). Shortening of 1.63 km occurred due to thrusting of Johr Thrust

Jawalamukhi Thrust restored

In this stage (Figure 29), Jawalamukh Thrust is restored. Removal of deformation along this thrust brings erosional surfaces of Lower Siwalik, Middle Siwalik and Upper Siwalik tops to the restored stage. After restoration of Jawalamukhi thrust, a gentle high in its up-thrust existed at Bilaspur Limestone and Subathu levels. Thus it indicates the structure must be older than the deformation of caused due to Jawalamukhi Thrust. Presence of an older structure at Bilaspur Limestone and Subathu levels is important in hydrocarbon point of view. Shortening of 13.93 km occurred due to thrusting of Jawalamukhi Thrust.

Drang Thrust restored

In this stage (Figure 30), Drang Thrust is restored. Removal of deformation along this thrust brings erosional top of Middle Siwalik to the restored stage. After restoration of Drang thrust, a gentle high in its up-thrust existed at Subathu level. Thus it indicates the structure must be older than the deformation of caused due to Drang Thrust. Presence of an older structure at Subathu merits importance in hydrocarbon point of view. Shortening of 1.37 km occurred due to thrusting of Drang Thrust.

Palampur Thrust restored

In this stage (Figure 31), Palampur Thrust (PT) is restored. Restoration of this thrust brings erosional tops of Lower Dharamsala and Upper Dharamsala formations upto restored stage. Restoration of PT reveals that before its genesis gentle structures existed to the East of PT in Bilaspur Limestone and Subathu levels. Shortening of 6.77 km occurred due to thrusting of Palampur Thrust.

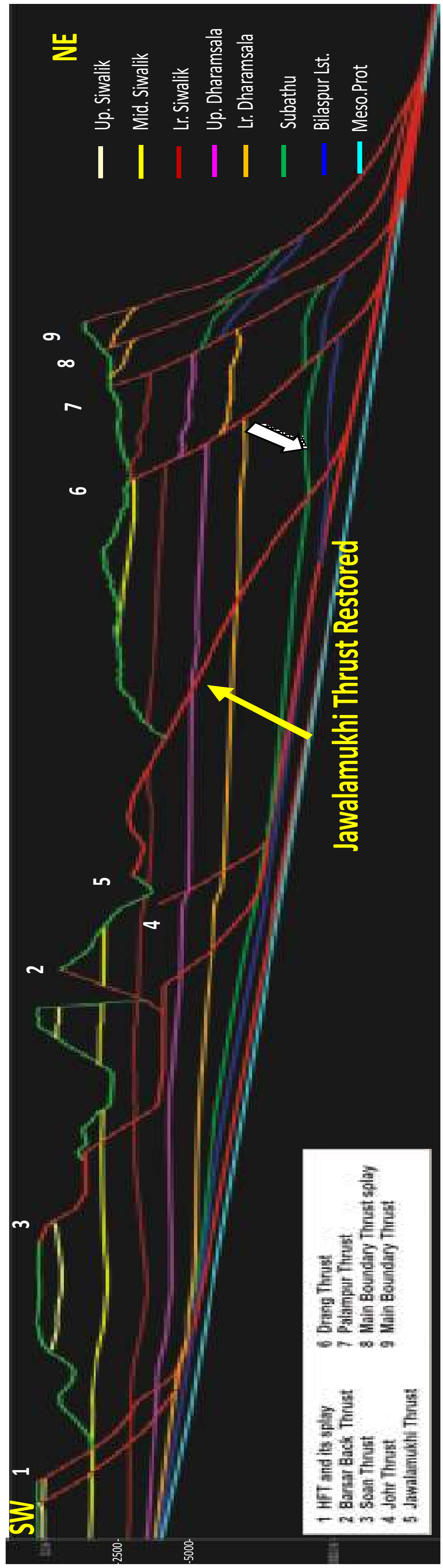


Fig. 29: Jawalamukhi Thrust restored

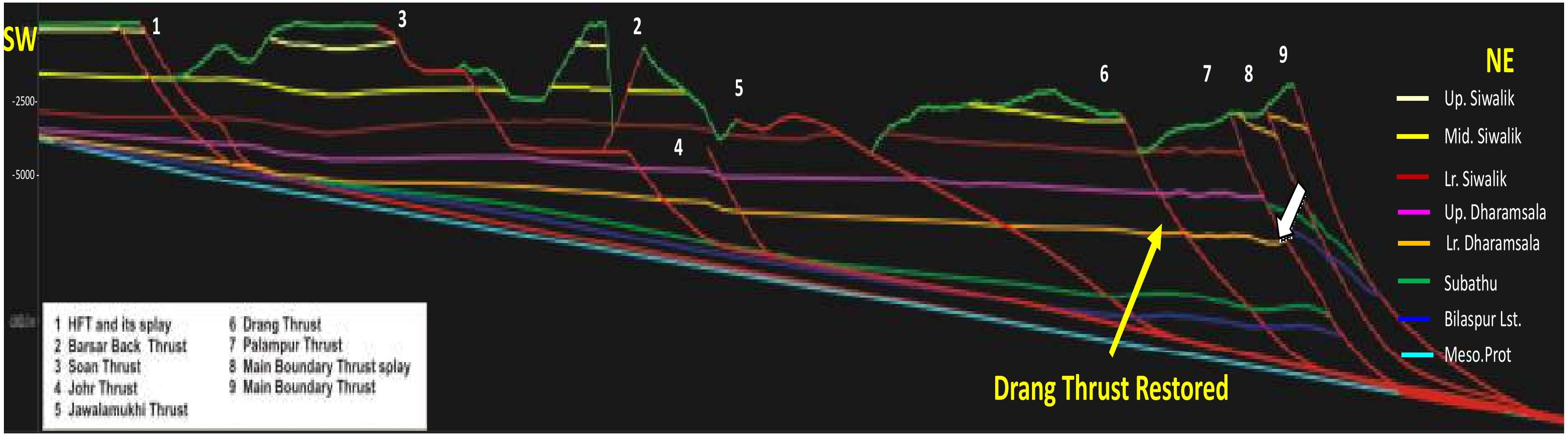


Fig. 30: Drang Thrust restored

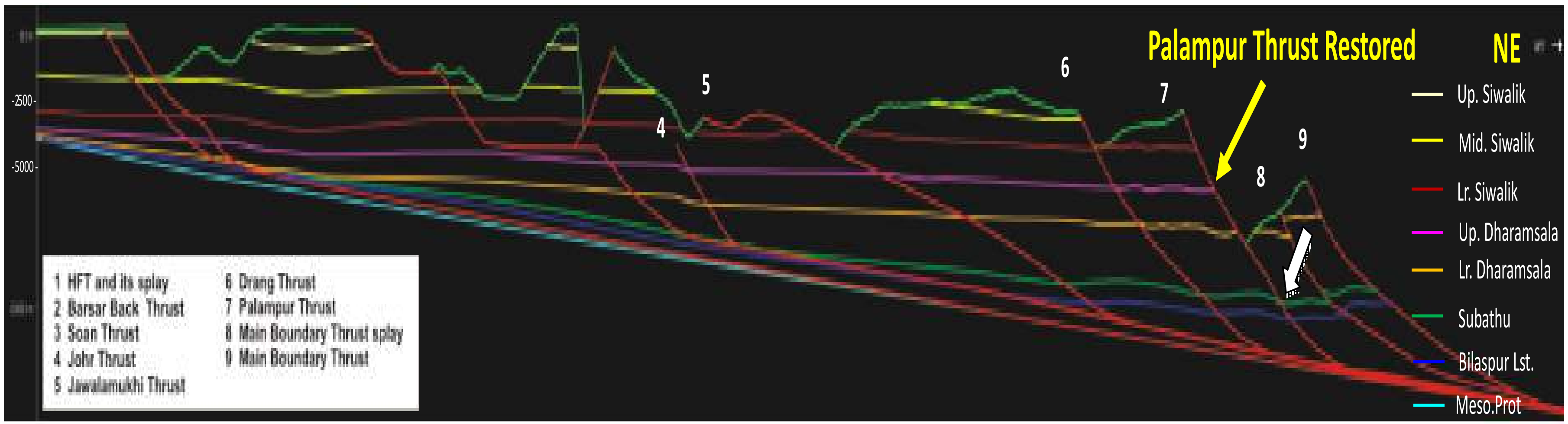


Fig. 31: Palampur Thrust restored

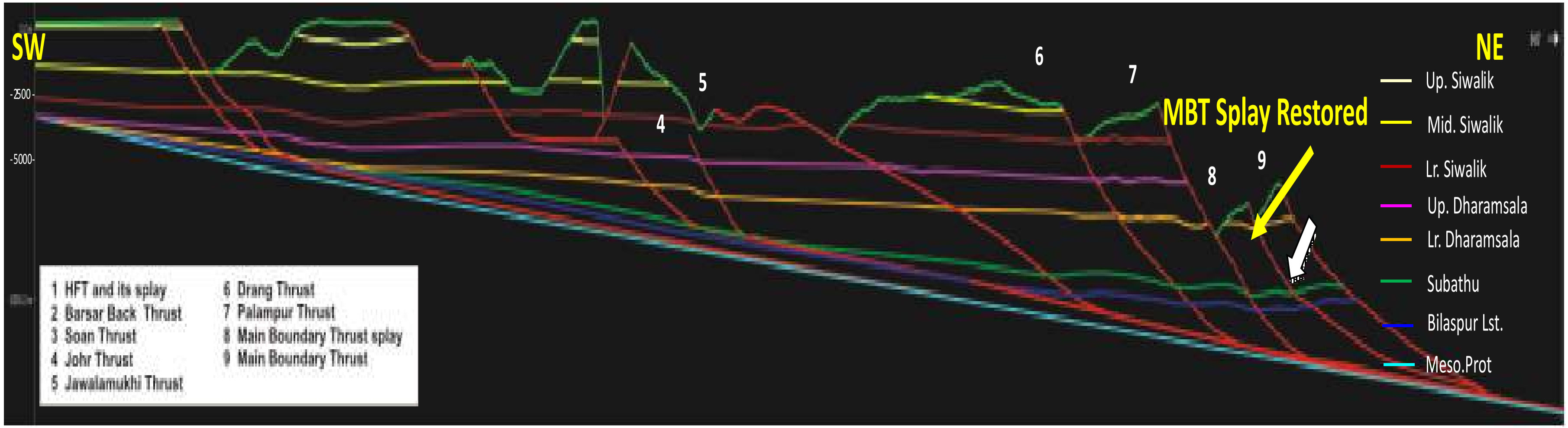


Fig. 32: Main Boundary Thrust splay restored

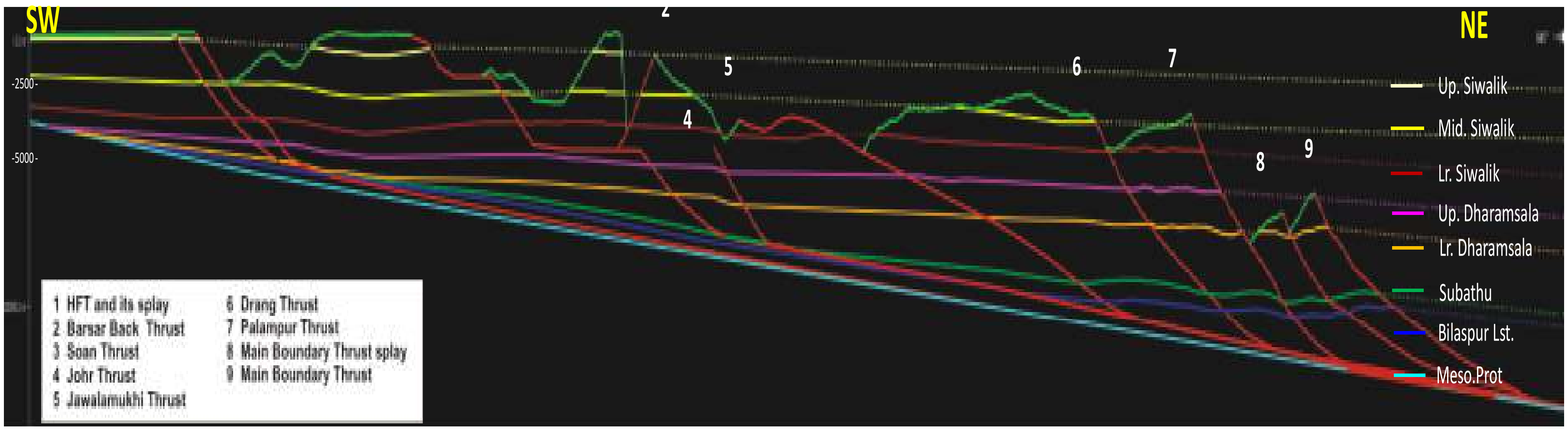


Fig. 33: Construction of the erosional surfaces

Splay of Main Boundary Thrust restored

In this stage (Figure 32), a splay of Main Boundary Thrust is restored. Restoration of this Thrust removes the hanging wall deformation and brings erosional top of Upper Dharamsala upto to the restored stage. Restoration of Splay of MBT reveals that before its genesis gentle structures existed to the East of Splay of MBT in Bilaspur Limestone and Subathu levels. Shortening of 3.77 km occurred due to thrusting of splay of MBT.

Construction of eroded profile

In this stage (Figure 33), the erosional formation tops are constructed (indicated as dotted lines) whereas the bold lines indicate the result of the sequential restoration of present day deformed formations. Joining of bold lines and the dotted lines indicate the initial basinal condition. Though it is difficult to estimate the eroded volume of rock from a 2D line and can only estimate the amount of shortening in this process.

Kinematics Analysis

This analysis suggests about the kinematics of

Sequence of thrusting observed from the restoration

- Main Boundary Thrust
- Main Boundary Splay
- Palampur Thrust
- Drang Thrust
- Jawalamukhi Thrust
- Johr Thrust
- Soan Thrust
- Barsar Back Thrust
- Himalayan Frontal Thrust

thrusting in this area. In this regard the Main Boundary Thrust (MBT) has been considered the northern most thrust towards hinterland and Himalayan Frontal Thrust (HFT) has been considered the southernmost thrust towards foreland. Thus sequential restoration has been carried out from the youngest most thrust to the oldest thrust i.e. from HFT to MBT. The sequential restoration indicates kinematics of thrusting from the oldest thrust to the youngest thrust in this segment of thrust belt. A measurement has been

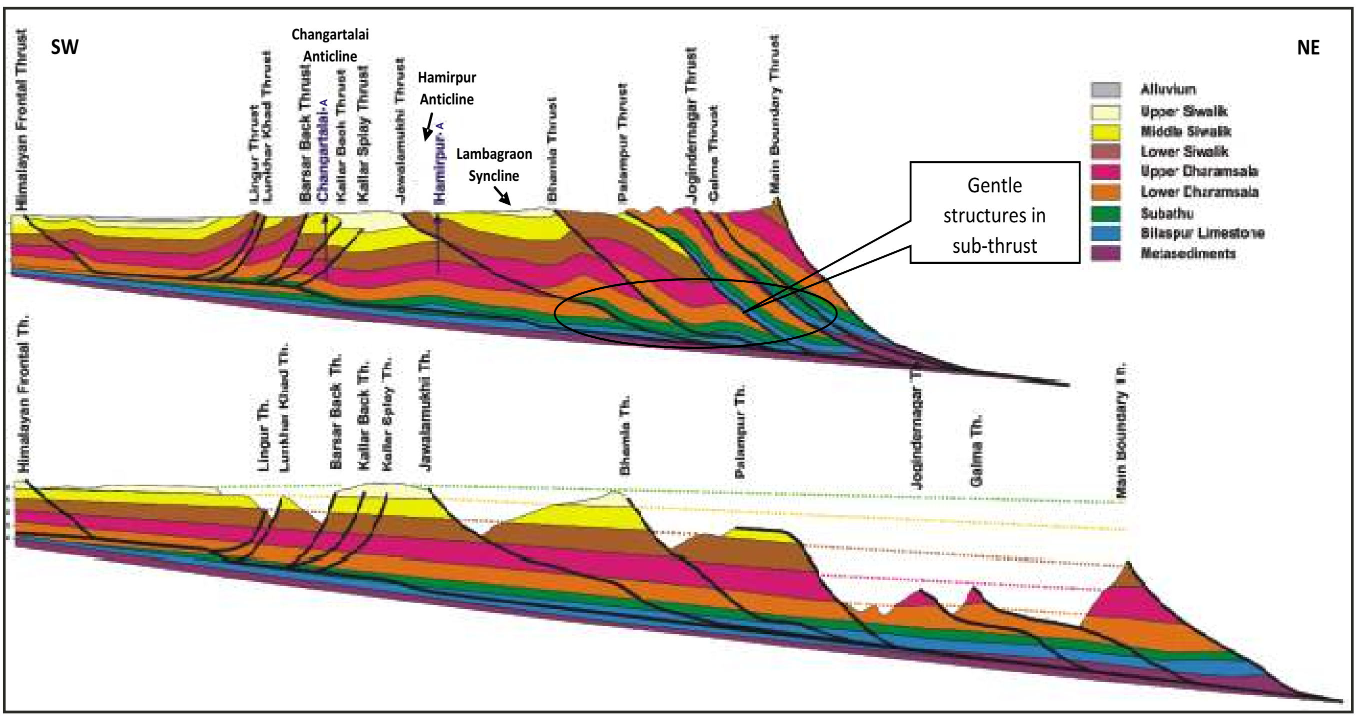


Fig. 34: Deformed and Restored Section profile-1

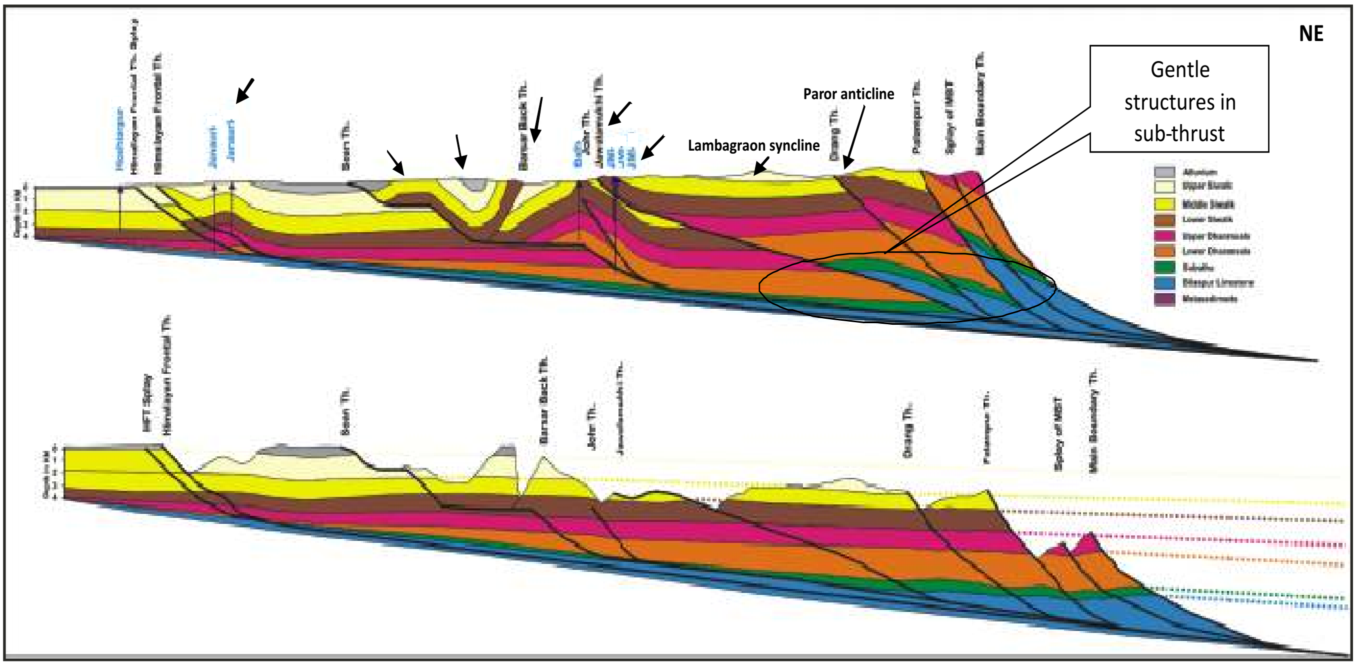


Fig. 35: Deformed and Restored Section profile-2

taken from deformed to undeformed stage between MBT and HFT. Kinematics analysis brings out shortening of span between MBT and HFT. In the deformed stage (in present day section) the span is around 93 km. whereas in the undeformed stage the span is around 130 km. Thus percentage of shortening during the compression is around 29 %. No out of sequence thrusts have been used for modelling.

Resolution of Issues in Himalayan Fold Thrust Belt

If we compare the models prepared by Bally (1997) and Powers et al., (1998) with the present models, it can be observed that in case of Jawalamukhi section Bally (1997) and Powers et al., (1998) used HP-BB-01 +HP-BB-01A seismic lines whereas HP-BB-02 + HP-DD-03 were used in the present study. But on the basis of geometry and structural style few observations can be made (Figures 36-38):

i. In case of Jawalamukhi section by Powers et al., (1998) a back thrust was modelled for Janauri anticline but no such back thrust is reported in

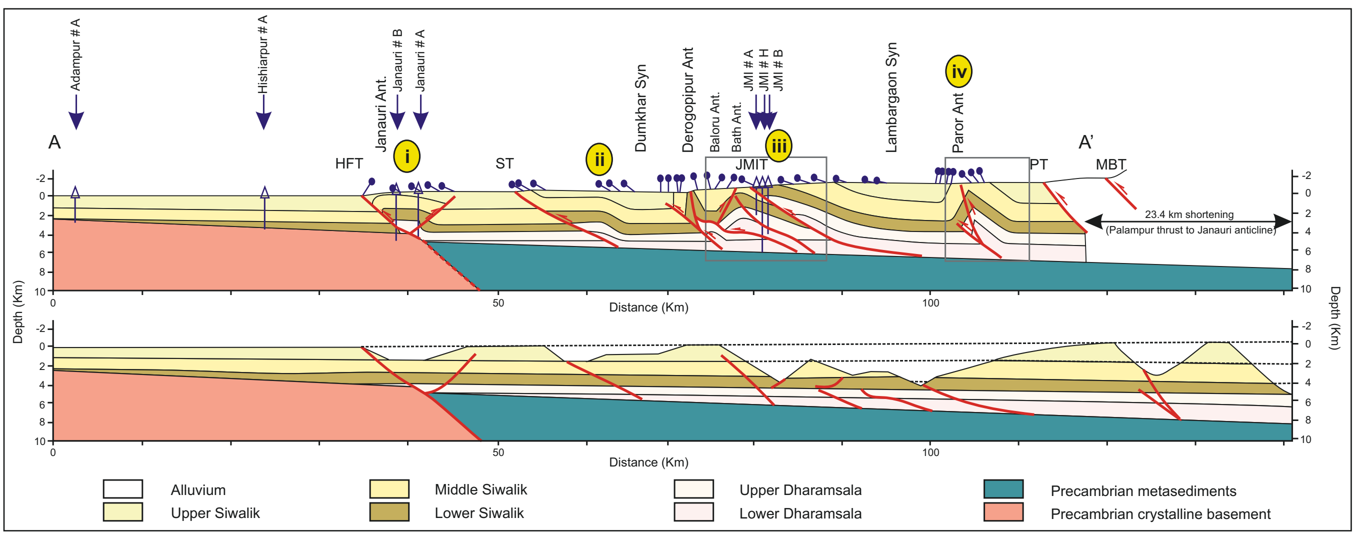


Fig.36: Preparation of Balanced cross section in Jawalamukhi area by Powers, Lillie and Yeats (1998)

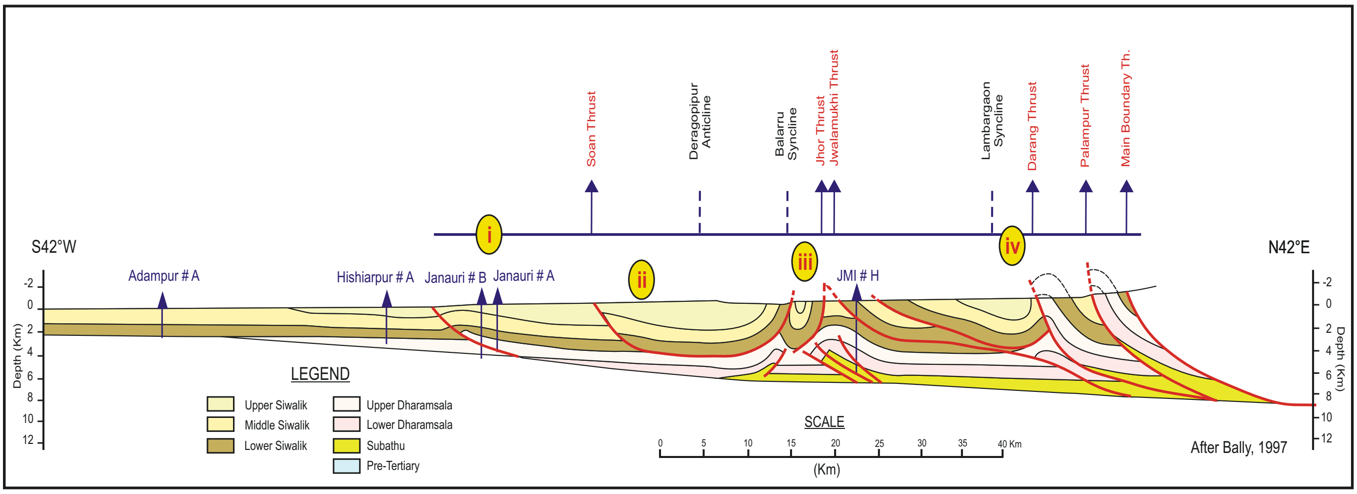


Fig. 37: Preparation of Balanced cross section in Jawalamukhi area by Bally (1997)

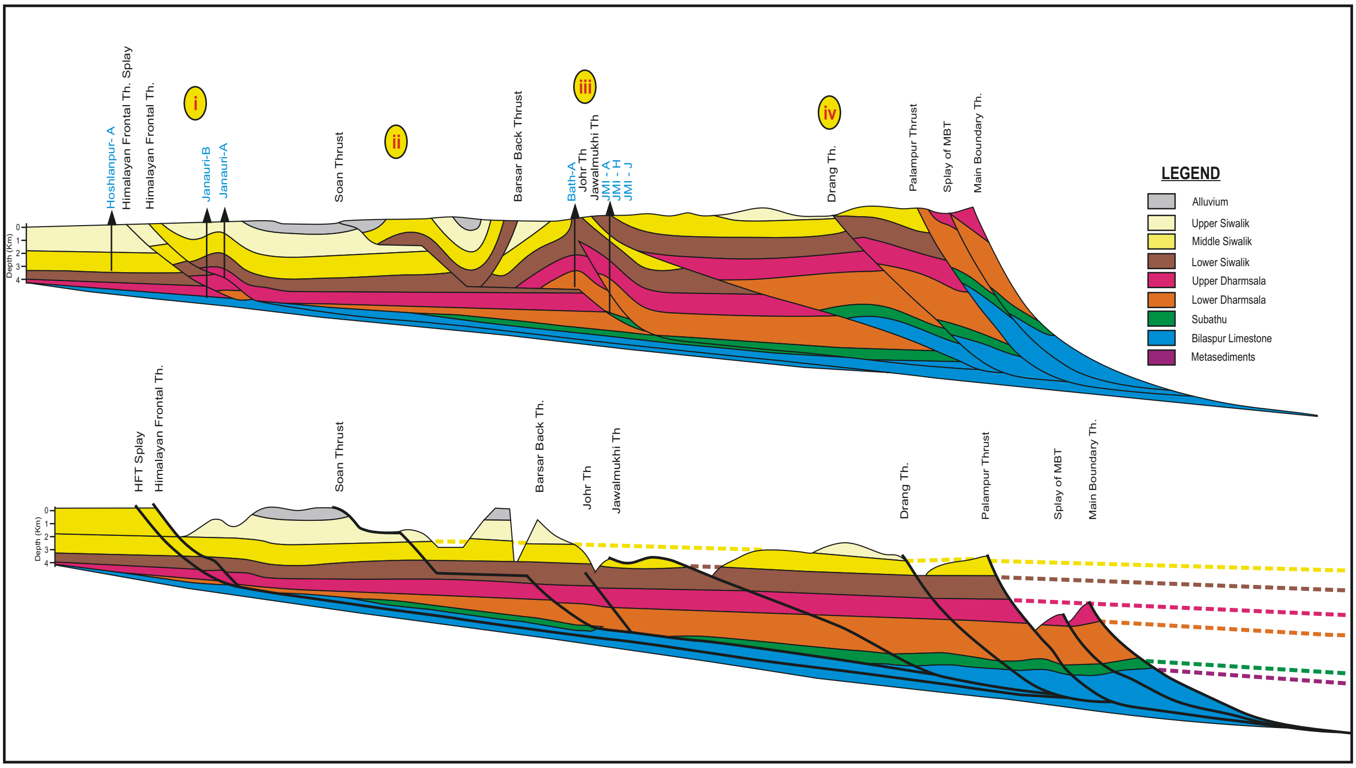


Fig. 38: Preparation of balanced cross section near Jawalamukhi area in the present study

this area and not been modelled by Bally (1997) and in the present model.

ii. In Case of Soan anticline which is a major anticline formed due to deformation caused by Soan Thrust as shown in the present studyappears bit steep in comparison with flat and gentle in the models of Powers et al., (1998) and Bally (1997).

iii. Multiple back thrusts have been modelled in Powers et al., (1998) and Bally (1997) models in West of Jawalamukhi area whereas a single Barsar Back Thrust is modelled in the present study as seen in the seismic section.

iv. Two thrusts were used to form Paror anticline (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.

The model prepared by Bally (1997) using seismic lines HP-16-03+HP-16-3A+HP-19-01 for Changartalai area and in the present study by using HP-AA-02+ HP-CC-04 have the following observations in models (Figures 39-40):

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

DISCUSSION

- Modeling and restoration have brought out gentle structures in sub-thrust which could be future exploration targets in North-West Himalaya (Figures 34-35). As per availability of seismic data above kinematics could be drawn up to MBT revealing thrusting processes and its aftermath. The same exercise requires repetition up to Indus Tsangpo Suture Zone (ITSZ) to understand kinematics of the Himalayan Orogeny. Comprehensive knowledge of kinematics will lead path to resolve complexity of Himalayas from bottom to top approach.

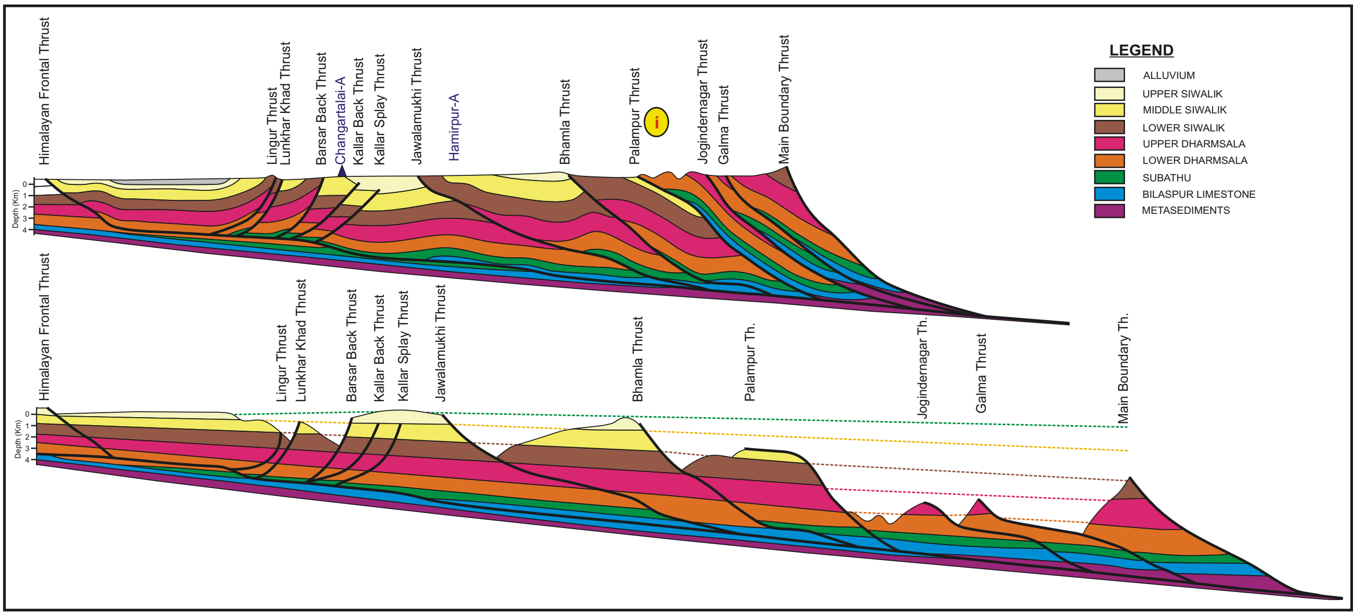


Fig. 39: Preparation of Balanced cross section near Changartalai area section in the present study

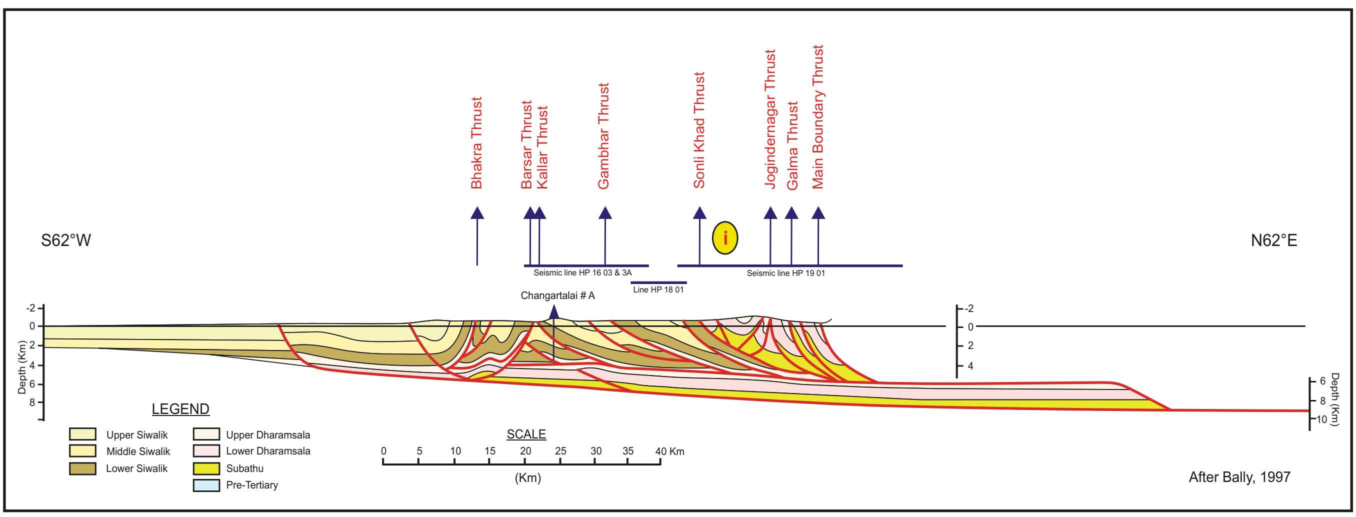


Fig. 40: Preparation of balanced cross section near Changartalai area by Bally (1997)

- 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 data 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.
- Parametric wells in different tectonic units will facilitate well-seismic calibration.

CONCLUSION

- Seismic Imaging and Structural Balancing till MBT helped us understand thrusting process and its associated structural evolution only in Sub-Himalaya.
- Similarly API of seismic profile covering Himalayan Frontal Thrust to Indus Tsangpo Suture Zone, thereafter modeling and restoration may resolve complexity of thrust fold belt during entire Himalayan Orogeny.

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