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Evolution and Kinematics of Bhimgoda Thrust and its Bearing on Hydrocarbon Habitat in Doon Recess, North-West sub-Himalaya

Abstract

Bhimgoda Thrust (BT) is situated in the Southeast of Mohand anticline and continues up to the western bank of Ganga River in Doon recess of North-West sub-Himalaya. The Thrust has a limited exposure (~18 km. in length) and thrusted Lower Siwalik Formation on to the Upper Siwalik Formation of Doon valley. Detailed geological mapping carried out during 1957-60 in Doon valley area by the geologists of ONGC and so far, many versions of geological models exist regarding the nature (hade) of Bhimgoda Thrust. A few workers believe that BT is a back thrust and there is no trace of Himalayan Frontal Thrust (HFT, fore thrust) in front of it. A few workers consider Bhimgoda is a back thrust with presence of Frontal Thrust (fore thrust) in front of it. A few opine that in this area both Bhimgoda and HFT are present as a fore thrust. Thus many versions of geological models are available regarding the nature of Bhimgoda Thrust and so its kinematic evolution. Robust geological model will have strong footing on evolutionary kinematics adopted by the worker. Based on the seismic interpretation a forward modeling in MOVE^{TM} software has been attempted to reveal the kinematic evolution of the Bhimgoda Thrust along with other thrusts. The study reveals that Bhimgoda Thrust is a back thrust without having a fore thrust associated with it. The back thrust originated due to strike slip movement caused by Ganga Tear Faulting.

Introduction

Doon Recess encompasses the Doon valley part of sub-Himalaya bounded by Main Boundary Thrust (MBT) in the North and HFT in the South. Doon valley is an inter-montane valley, extends 80 km in length and 20 km in width. There are two prominent transverse faults, called Ganga Tear Fault and Yamuna Tear Fault occurring on the eastern and western extremities of the valley. The recess is bounded to the North by MBT that separates pre-Tertiary rocks of Lesser Himalayas from the Cenozoic sediments of the sub-Himalayas. Lower Siwalik, Middle Siwalik and Upper Siwalik rocks are exposed in the area. Doon gravel, the Post Siwalik Formation was deposited with the evolution of Doon valley. Lower Siwalik and Dharamsala formations are exposed in isolated outcrops in northern part of Doon valley. Sudden topographic rise of the Siwalik ranges is demarcated by the genesis of Himalayan Frontal thrust (HFT) that brings Siwalik group rocks against recent alluvial sediments of Ganga Plain. HFT, locally called the Mohand Thrust dips towards NE. The Prominent exposed structure in the area is Mohand Anticline which lies in the South-West part of the Doon recess. It is thrusted against the alluvium in western part by the Mohand Thrust. The Bhimgoda Thrust that occurs in the West of Ganga Tear Fault dips towards South bringing Lower Siwalik Formation on to the Upper Siwalik Formation. In the present study, the nature of Bhimgoda thrust has been discussed. Most of the workers opine that it is back thrust having no indications of HFT/ Mohand Thrust in front of it. A few workers believe that Bhimgoda is a back thrust and there is a presence of fore thrust in front of it whereas a few consider it as a fore thrust and presence of HFT/ Mohand Thrust in front of it. Thus, there are some disparities in opinion regarding the nature as well in kinematic evolution of Bhimgoda Thrust. In this backdrop authors felt it necessary to study it further to reveal its true nature on surface and sub-surface interpretation.

Previous works

According to **G.C. Agarwal and V.S. Rao (1959)** **(Figures 1-3)** the Bhimgoda Thrust is known as Sukh Rao Fault in this area. The fault is seen in the Southeastern sector of the Doon area. This fault is well exposed in Sukh Rao river (a small stream 2 miles North of Haridwar) and thus its name is given. It is not well exposed throughout the entire length in Siwalik belt though near the faulted contact the beds show vertical dips. In Southeastern extent, Lower Siwalik is abutting against the pebble and boulder conglomerate of Upper Siwalik. Near the fault sandstone shows shattering and pulverization. Lower Siwalik is cut off and Middle Siwalik soft sandstone appear against the fault. The Northeastern limb of Mohand anticline takes a southerly trend and its Middle Siwalik abut against the Middle Siwalik of the Southwestern limb of the anticline. Finally the fault approaches very near to the plains of Binj Rao and Andheri Rao rivers, beyond which it is concealed under the alluvium. Considering Sukh Rao Fault hade towards South-West makes the explanation simple. The Sukh Rao Fault has brought the eroded surface of folded Lower and Middle Siwaliks over Upper Siwalik of the western part by shearing along an incompetent bed at the base of an Upper Siwalik. However, it is

interesting to note that in the East of the Ganges there is no trace of Sukh Rao Fault. Thus it is very interesting how Bhimgoda Thrust having such an immense throw, suddenly dies out in the Ganges. It may be due to presence of a transverse fault running along the Ganges River cutting off the Sukh Rao Fault resulting into its sudden disappearance.

According to **A. Ranga Rao and V. Sahadeva Rao (1958),** **(Figure 4)**, the structure West of the Ganga, where Southwestern limb exposes Lower, Middle and Upper Siwalik beds with a general dip towards SSW/ SW. The structure is gentle near the crestal part but the dips steepen in flank from 15° to 75-80°. However, due to the Sukh Rao Fault Upper Siwalik bed is juxtaposed against the Lower Siwalik bed. Although there are very high dips (up-to vertical) in the Upper Siwalik beds just near the fault. The axis of Mohand anticline is truncated by the Sukh Rao Fault in this area.

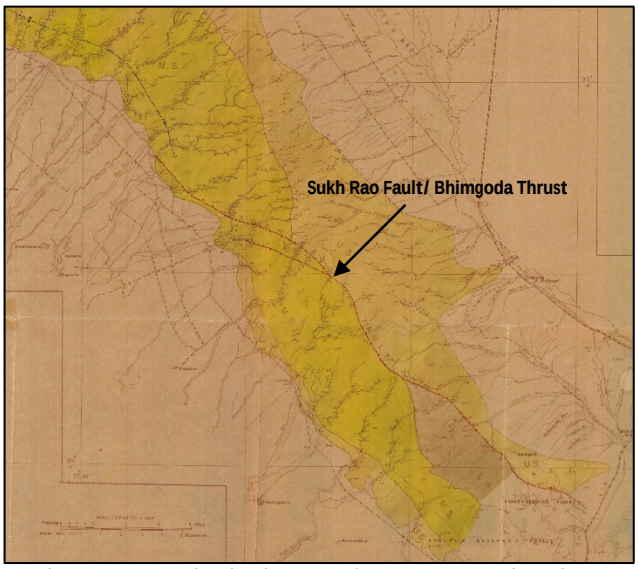

Figure 1: Geological map of Doon area showing Sukh Rao Fault at the western bank of the Ganga River (*G.C. Agarwal and V.S. Rao, 1959*)

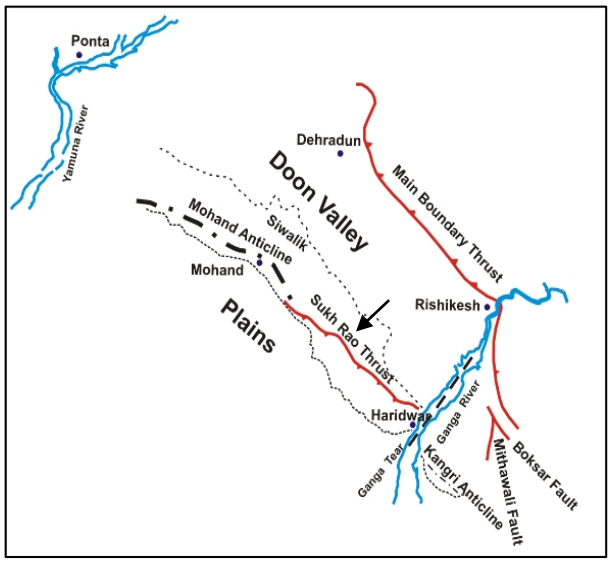

Figure 2: Reverse nature of Sukh Rao Fault (*G.C. Agarwal and V.S. Rao (1959)*

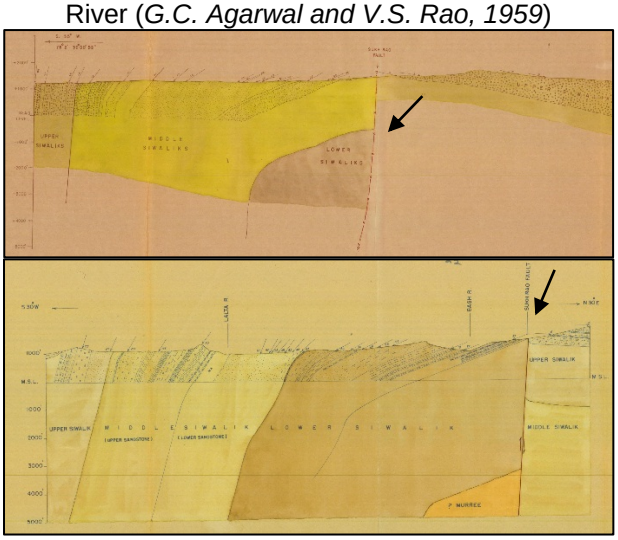

Figure 3: Cross section along Beatban-Kans Rao, North-West part of the Sukh Rao Fault (*G.C. Agarwal and V.S. Rao, 1959) and* Rao. A.R and Rao V.S (1957-58)

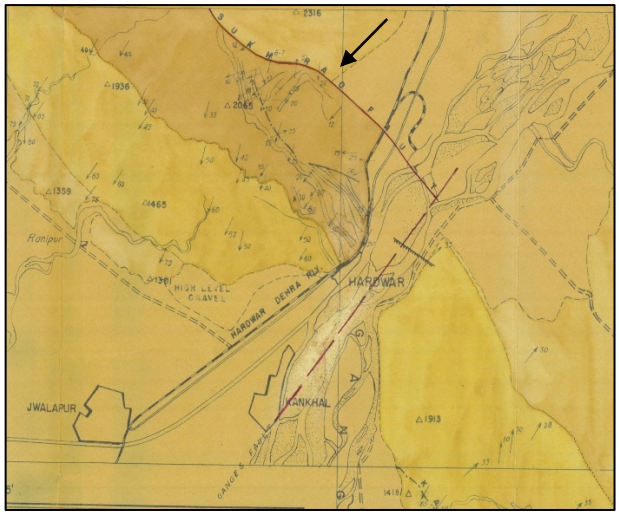

Figure 4: Geological map of East and West of Ganga River (*A. Ranga Rao and V. Sahadeva Rao, 1958*)

According to **V.C. Thakur and A.K. Pandey (2004),** **(Figures 5- 6),** Bhimgoda is a Back Thrust with a strike slip movement and there is a continuation of HFT/ Mohand Thrust in front of it. That means the Mohand anticlinal axis is continued all along the frontal part of Doon recess with a back thrust (Bhimgoda Thrust) at the Southeastern part of it. According to **V.C. Thakur and A.K. Pandey (2004)** the Bhimgoda Thrust juxtaposed Middle Siwalik against the Upper Siwalik of Doon valley which is again a different view than the previous workers.

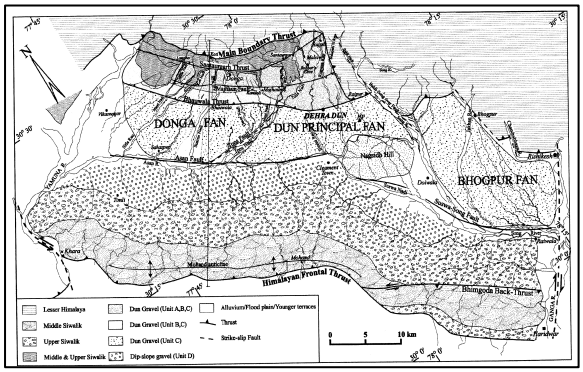

Figure 5: Geological map of Doon valley showing Bhimgoda Thrust

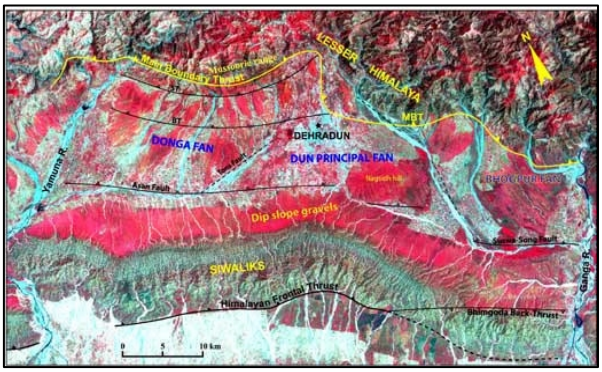

Figure 6: Digitally reprocessed IRS 1C LiSS image FCC of band 321 (RGB) of the Doon valley showing geomorphic expressions of different tectono stratigraphic units and faults

According to **K.S. Valdiya and Jaishri Sanwal, (2017)**, **(Figure 7)** Bhimgoda Thrust in the southern flank of Dehradun is a fore thrust and HFT/Mohand Fore Thrust is situated in front of it. Bhimgoda Thrust turns northwards and is linked with the dextral Haridwar Fault/Ganga Tear Fault. The Ganga River flows along this fault.

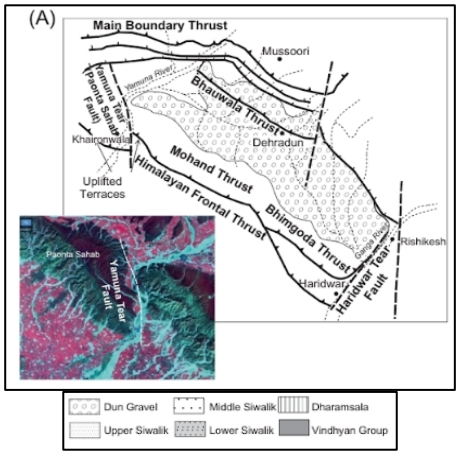

Figure 7: Bhimgoda and HFT/Mohand Fore Thrust in the southern flank of Dehradun

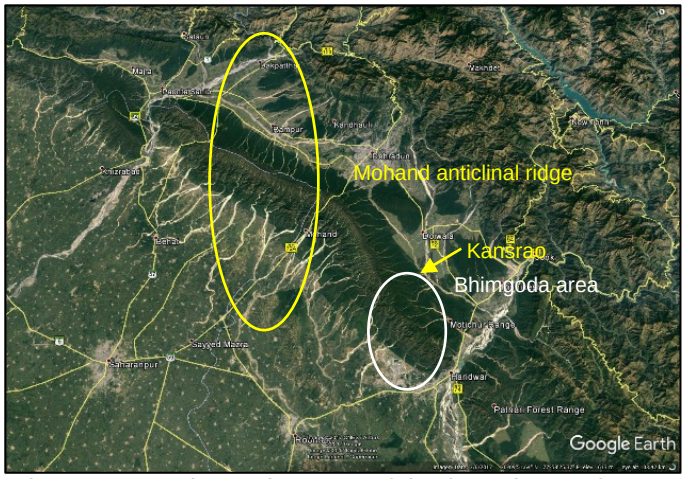

Figure 8: Google Earth Image of the frontal part of Doon recess showing two areas having distinct elevation differences

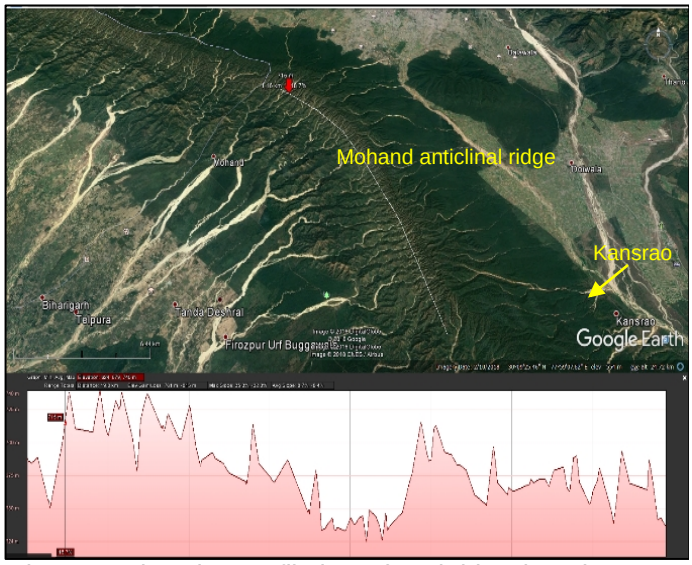

Figure 9: Elevation profile in Mohand ridge (South-West of Kansrao). The Avg. elevation is ~650-750m

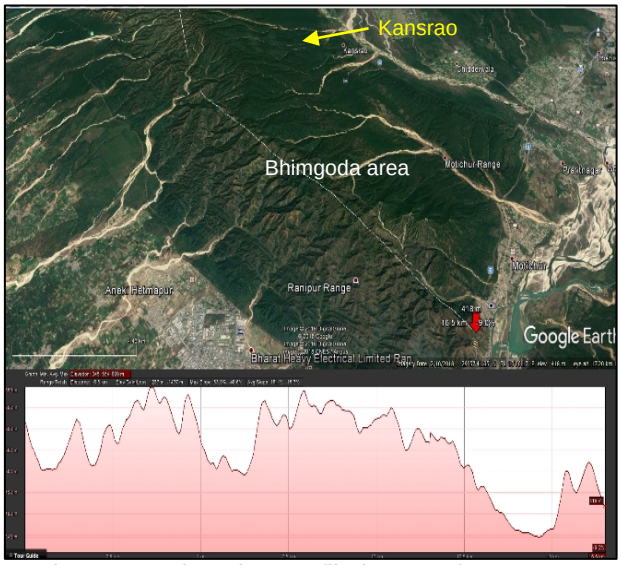

Figure 10: Elevation profile in SW of Kansrao (Bhimgoda area). The avg. elevation is ~500-

600m

Present work: Analysis of Google Earth Image

Elevation analysis of Google Earth Image (**Figures 8 - 10**) of the frontal part of Doon recess indicates that the axis of Mohand anticline, which continued from Poanta Sahib, reduces at the South-West of Kansrao. From South-West of Kansrao and upto Haridwar the axis shows a tonal variation in elevation and relatively lower than the extent from Poanta Sahib to Kansrao (~650-750m South-West of Kansrao and ~500-600m East of Kansrao (Near Bhimgoda Thrust). This may be an indication that Mohand anticline ended upto the South-West of Kansrao and another thrust (Bhimgoda Thrust?) originated from this point. However, the nature of the thrust whether it is fore thrust or back thrust is not possible to identify from this analysis.

Seismic interpretation

Seismic interpretation in Doon recess area indicates an exposure of Lower, Middle and Upper Siwaliks against Bhimgoda Thrust and juxtaposed against Upper Siwalik Formation of Doon valley. From seismic interpretation it appears Bhimgoda as a back thrust and it has truncated Mohand thrust/HFT (**Figures 11 and 12**). Other than Bhimgoda Thrust another back thrust appears to form at the hanging wall of HFT.

Time Structure Map of Lower Siwalik top in the up-thrust of Bhimgoda Back Thrust

Lower Siwalik formation is exposed in the up-thrust of Bhimgoda Thrust in the South-East of the Mohand area near Haridwar in the western bank of the Ganga River (**Figure 13**). In this area Bhimgoda Back Thrust exposes Lower Siwalik in the up-thrust placing it against Upper Siwalik of Doon valley. Due to exposure of the Lower Siwalik rock at high angle the formation is not forming any fault closure in the up-thrust of Bhimgoda Thrust. A high trend near the Bhimgoda Thrust can be observed in seismic lines UP-59-A, UP-59-B and in UP- 59-C at the leading edge and a low trend can be seen at the trailing edge of the thrust. The shallowest contour in this level can be seen at 0.350 sec. near the leading edge and the deepest contour can be seen at 2.050 sec. at the trailing edge.

Time Structure Map of Middle Siwalik top in the up-thrust of Bhimgoda Back Thrust

Middle Siwalik formation is exposed in the up-thrust of Bhimgoda Thrust in the South-East of the Mohand area near Haridwar in the western bank of the Ganga River (**Figure 14**). Due to exposure of the Middle Siwalik rock at high angle the formation is not forming any fault closure in the up-thrust of Bhimgoda Thrust. A high trend near the Bhimgoda Thrust can be observed in seismic lines UP-59-A, UP-59-B, UP-59-C and in UP-59-D at the leading edge whereas a low trend can be seen at the trailing edge of the thrust. The shallowest contour in this level can be seen at 0.300 sec. near the leading edge in North and the deepest contour can be seen at 1.350 sec. at the trailing edge of Bhimgoda Thrust.

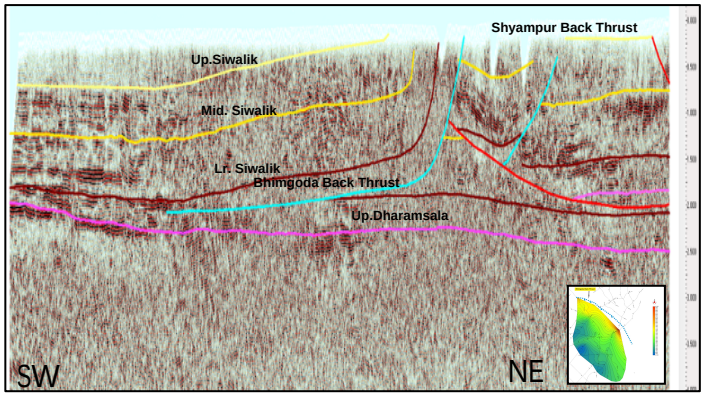

Figure 11: Seismic line UP-59-A showing Bhimgoda Back Thrust and another back thrust (Shyampur Back Thrust) at the hanging wall of HFT

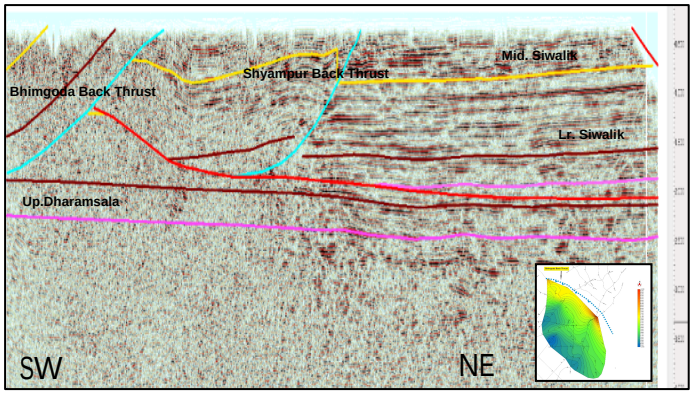

Figure 12: Seismic line UP-59-B showing Bhimgoda Back Thrust and another back thrust (Shyampur Back Thrust) at the hanging wall of HFT

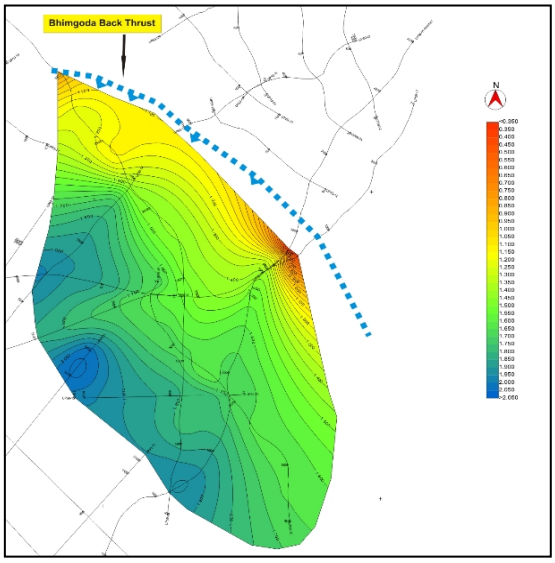

Figure 13: Time structure map of Lower Siwalik top in the up-thrust of Bhimgoda Thrust

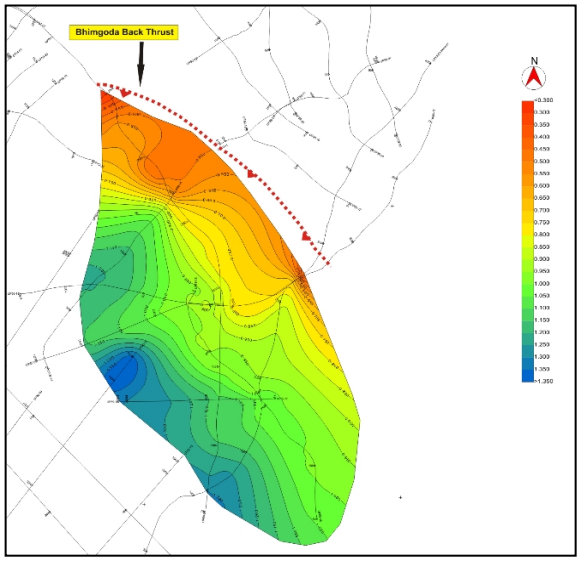

Figure 14: Time structure map of Middle Siwalik top in the up-thrust of Bhimgoda Thrust

Forward modelling in MOVE™ Software to generate present deformed section

A forward modeling approach (**Figure 20**) has been attempted to achieve present day deformed geometry near the Bhimgoda Back Thrust area.

- Digital Elevation Model (DEM) and seismic line UP-59-A were loaded in the project to obtain actual topography of the area (**Figure 15**).
- Geological map, interpreted horizons and faults were also loaded (**Figure 16**).
- Stratigraphy and Petro-physical properties of the area were populated in the table (**Figure 17**).
- Depth conversion (**Figure 19**) of the time section (**Figure 18**) has been carried out with rock prtro-physical properties of the area.
- For forward modeling, the initial undeformed thickness of Siwaliks have been considered from the Southwestern part of the seismic line whereas the thickness of Upper Dharamsala has been considered from the eastern part of the seismic line.
- In case of forward modelling (**Figure 20**) first HFT has been considered to be initiated in this area after Main Boundary Thrust.
- After initiation of HFT the Bhimgoda Back Thrust has been considered as a next phase deformation.
- After Bhimgoda back thrust another back thrust i.e. Shyampur Thrust has been initiated in the up-thrust of HFT.
- The total workflow has been mentioned in the **figure 20** with the considered parameter to achieve the present day geometry.

Hydrocarbon Habitat

In case of hydrocarbon exploration near the Himalayan Frontal Thrust area like in Doon recess, a few encouraging scenarios can be thought of. All over the world it is considered that:

- ✓ Hydrocarbons are produced closer to the frontal thrust where the structural complexity is comparatively less. Areas near frontal thrust are tectonically less disturbed zone thus there are a better chances of preservation of hydrocarbons.

- ✓ Near frontal thrust area occurrence of basement is relatively at shallower depth than hinterland side so there is chance to explore entire sedimentary column though thin in this part and up to basement. In the Doon low a complete sequence of Upper Siwalik to source facies Upper Subathu and Bilaspur Limestone can be present thus it can act as a kitchen area for hydrocarbon generation. Structures within this low can act as trap for hydrocarbon but the most crucial factor in fold and thrust belt is the presence of an effective source rock.

- ✓ A triangle zone has been generated due HFT and Bhimgoda Back Thrust. Triangle zones are very productive worldwide. Thus, the triangle zone region in the sub-thrust where the undisturbed sequences have been preserved may be potential target future exploration.

Discussion

Seismic data (**Figures 11-12**) shows HFT affecting basal part of Middle Siwalik Formation. In the late stage of Bhimgoda Thrust erosion of Lower, Middle and Upper Siwaliks has taken place. With the erosion of Middle Siwalik last traces of HFT have also been finished to the West of Bhimgoda Back Thrust.

Bhimgoda Thrust having such an immense throw, suddenly dies out in the Ganges. The plausible explanation may be due to presence of a transverse fault running along the Ganges River cutting off the Sukh Rao Fault resulting into its disappearance.

G&G interpretation (**Figures 11-12**) reveals that Bhimgoda Thrust is a back thrust which is further validated by MOVE™ forward modeling (**Figure 20**).

The generation of Bhimgoda Back Thrust may be linked with the dextral nature of the Ganga Tear Fault (**Sahoo, P.K , 2000**) due to which the left limb i.e. the Bhimgoda area has been affected. During the genesis of Ganga Tear Fault, the left bank of Ganga River received additional forces that may causes generation of back thrusts in this area.

Conclusions

- ➢ G&G interpretation (**Figures 11-12**) reveals that Bhimgoda Thrust is a back thrust which is further validated by forward modeling in MOVE™ (**Figure 20**).
- ➢ The forward modeling (**Figure 20**) also indicates that the age of the Bhimgoda Thrust is much younger than that of HFT as Bhimgoda Back Thrust has truncated HFT as evidenced (**Figures 11-12**) by overridden Siwalik sediments on to the HFT.

Acknowledgements

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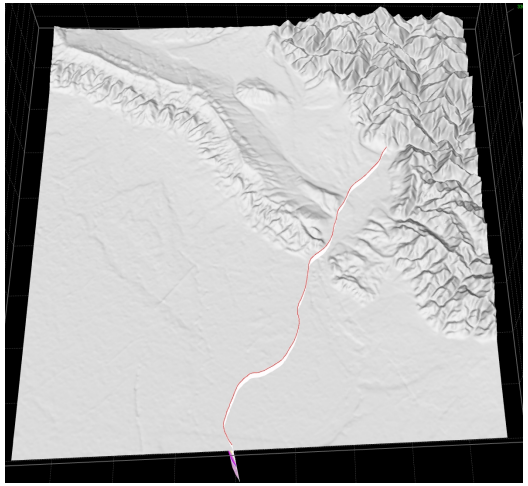

Figure 15: Elevation model of Doon area with seismic line UP-59-A

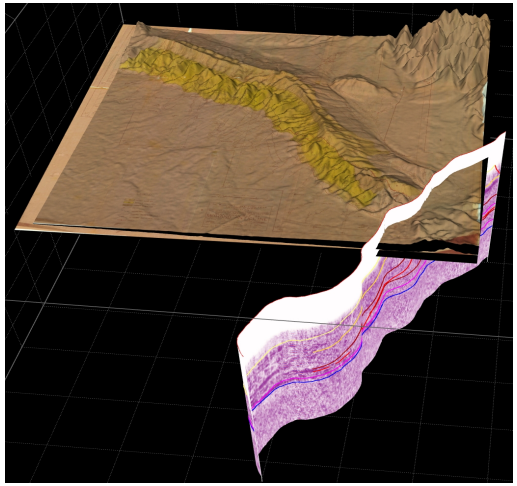

Figure 16: G&G data loaded in the profile

Rock Properties | Strat. Column | Compaction Curves

Horizon	Colour	Rock Type	Age	Thickness
Alluvium		Alluvium	0.5 Ma	300.0 m
Upper Siwalik		Upper Siwalik	1.8 Ma	1000.0 m
Middle Siwalik		Middle Siwalik	5.3 Ma	2000.0 m
Lower Siwalik		Lower Siwalik	11.0 Ma	2500.0 m
Upper Dha...		Upper Dharamsala	16.0 Ma	2000.0 m
Lower Dha...		Upper Dharamsala	23.0 Ma	2000.0 m
Subathu		Subathu	33.0 Ma	500.0 m
PT		PT	1500.0 Ma	2000.0 m

Figure 17: Stratigraphy and Petro-physical parameters of the formations

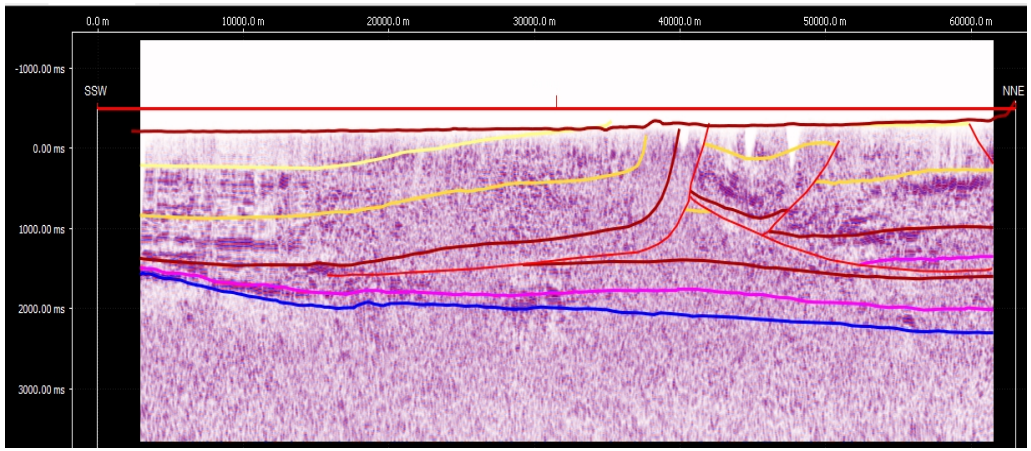

Figure 18: Time section of UP-59-A

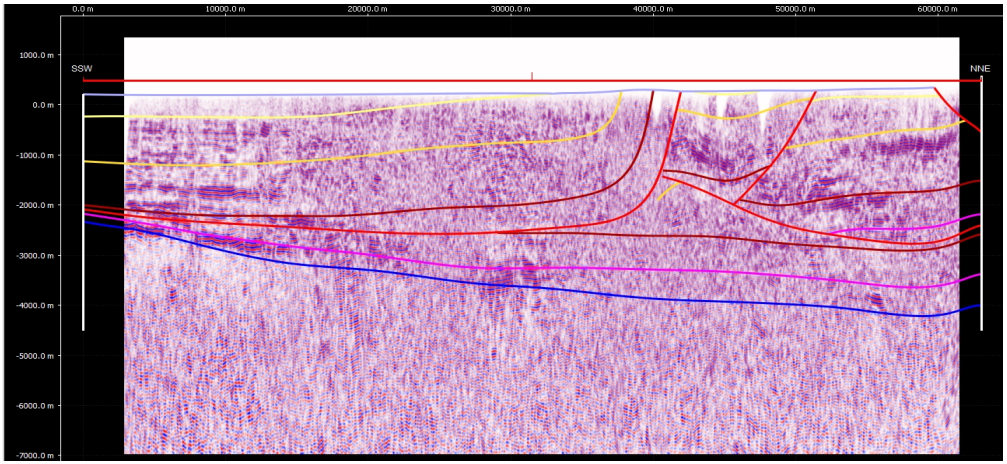

Figure 19: Depth converted Section UP-59-A

Method Simple Shear

Movement Type Heave

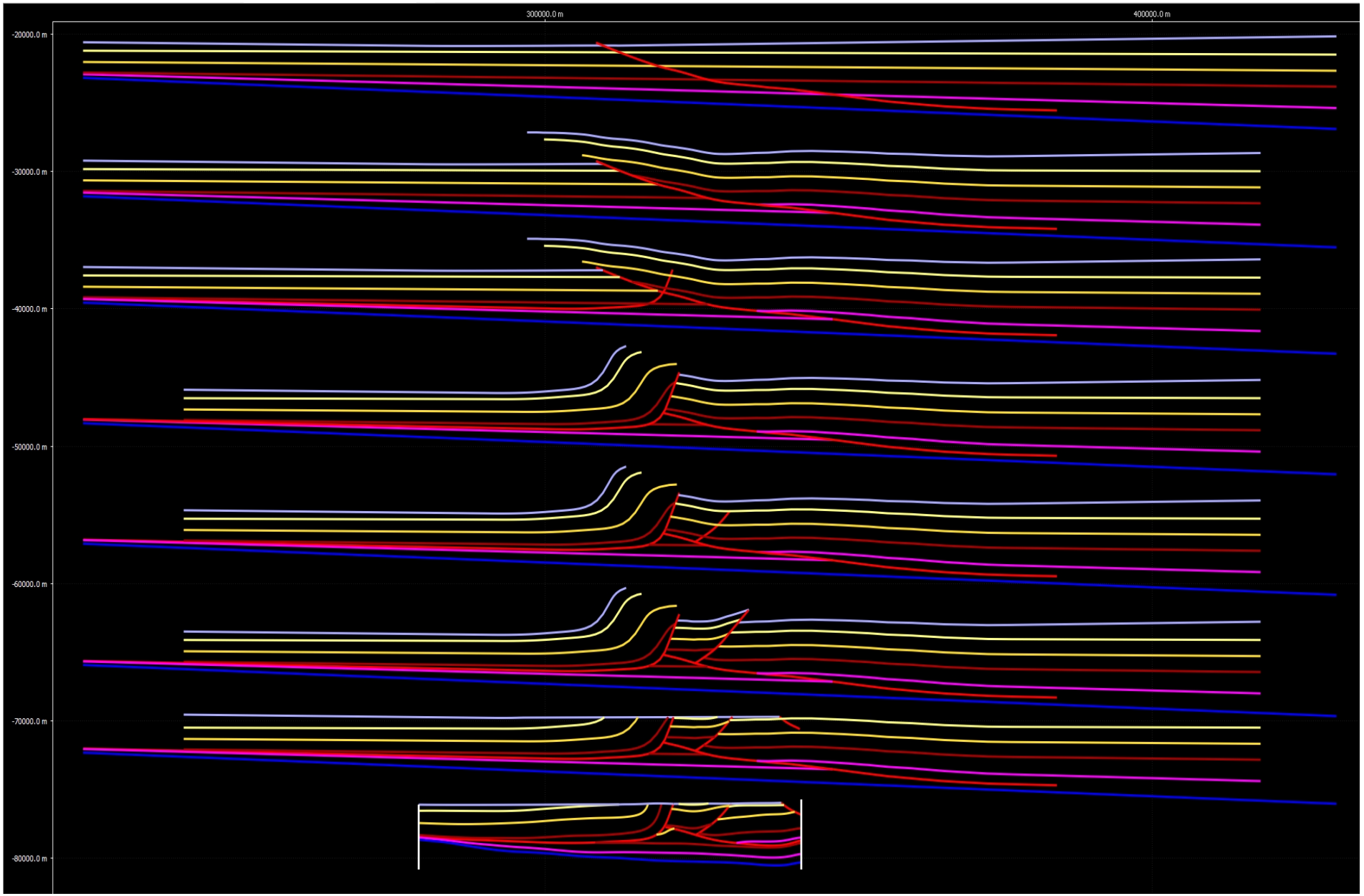
300000.0 m
400000.0 m
-20000.0 m
-30000.0 m
-40000.0 m
-50000.0 m
-60000.0 m
-70000.0 m
-80000.0 m

Figure 20: Forward modelling approach with the modeled parameter