2nd INDO-GERMAN WEEK OF THE YOUNG RESEARCHER

25th November – 1st December 2023

New Delhi / Dehradun

Field Guidebook

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WIHG · DST@50 1971-2021 Department of Science & Technology · SERB India · DFG Deutsche Forschungsgemeinschaft German Research Foundation

South-verging asymmetrical fold along the Himalayan Frontal Thrust in the Khajnawar Rao river valley, Sub Himalaya, @ Prof. RJG Perumal

Pre-meet field transect across the Mohand Anticline, Uttarakhand Sub Himalaya

Preamble

The Science and Engineering Research Board (SERB) has ventured into several schemes and programs in recent years to have far-reaching influence on the S&T landscape of our country. To further modernize research thoughts, SERB proposed a scientific bilateral conclave with DFG, the German Research Foundation, and an Indo-German SERB-DFG Week of the Young Researcher (WYR). The idea to organize this 2^{nd} WYR on this contemporary area of Geological Sciences is to invite young researchers from India and Germany to share their research interests and seek collaborations that will be supported through future bilateral R&D calls.

Senior mentors from India and Germany will facilitate this interaction. SERB and DFG have nominated Prof. Talat Ahmad and Prof. R. Jayangondaperumal as the Indian Conveners from the Wadia Institute of Himalaya Geology, and Prof. Bodo Bookhagen from the University of Postdam, Prof. Rasmus Thiede and Prof. Peter van der Beek as the as the German Conveners.

The 2nd edition of an Indo-German Week of the Young Researcher (WYR) is scheduled from 27th November to 1st December 2023 at the Wadia Institute of Himalayan Geology-Dehradun. The thematic area of the 2nd WYR is "**Geodynamics and Climate Science of Himalaya Region**." It includes plenary lectures by eminent researchers and participants and field visits to geological sites. As a part of the activity, this field guidebook provides a brief glimpse of Mohand transect (Pre-workshop on 26-11-2023) and one-day field transects across the outer Garhwal Lesser Hi

malaya on 29-11-2023).

Introduction

The workshop will commence with a field excursion in the vicinity of the Dehradun region, situated in the Sub-Himalaya and its adjoining areas. Between the HFT and the Main Boundary Thrust (MBT) depicted in Figure 1, there exist several structurally controlled valleys in the Sub-Himalayan region, commonly referred to as Doon (or Dun) valleys (Nakata, 1972). Dehradun is one of such valleys. The movement along the north-dipping MBT has created a cliff and elevated the Lesser Himalayan region to heights ranging from 2000 to 3000 meters. The Sub-Himalayan region comprises fluvial sediments from the Siwalik Group, which were deposited outward from the rising Himalayan range. The age of this Group spans from 0.5 to 18 million years. The sedimentary sequence transitions from mudstone and siltstone in the lower layers to mainly sandstone and conglomerates in the middle and upper layers (Kumar et al., 1983). Dehradun, or Doon Valley, is a late Quaternary intermontane basin shaped like a synformal depression. To the south, it is bordered by the Mohand anticline, and in the north by the Mussoorie range. The forelimb of the Mohand anticline meets the Indo-Gangetic Alluvial Plain, creating a significant active margin of the Himalaya shows a prominent physiographic-tectonic boundary. This boundary, known as the Himalayan Frontal Thrust (HFT in India) or Main Frontal Thrust (MFT in Nepal), signifies the location of fault scarps.

Transect across the Mohand Anticline

Activity along the HFT has elevated the Siwalik Hills on the hanging wall, placing them at elevations ranging from 500 to 1000 meters above the adjacent Indo-Gangetic plain south of Dehradun, as shown in Figures 1 and 2a. To the northeast of the Mohand Thrust, a segment of the HFT, the Siwalik Hills primarily consist of homoclinal strata with northward inclinations of 20-30° (Wesnousky et al., 1999). Within a relatively narrow zone along the HFT, there is a reversal in dip, giving rise to the Mohand asymmetric anticline (Rao et al., 1974). This anticline exhibits steep inclinations of 50° or greater on its southern side (figure 3). While the anticline's structure is well-defined west of the Yamuna River, in the area between the Mohand village and the Yamuna River to the east, it merges closer to the HFT and is characterized by numerous closely spaced and discontinuous folds (Rao et al., 1974; Raiverman et al., 1993).

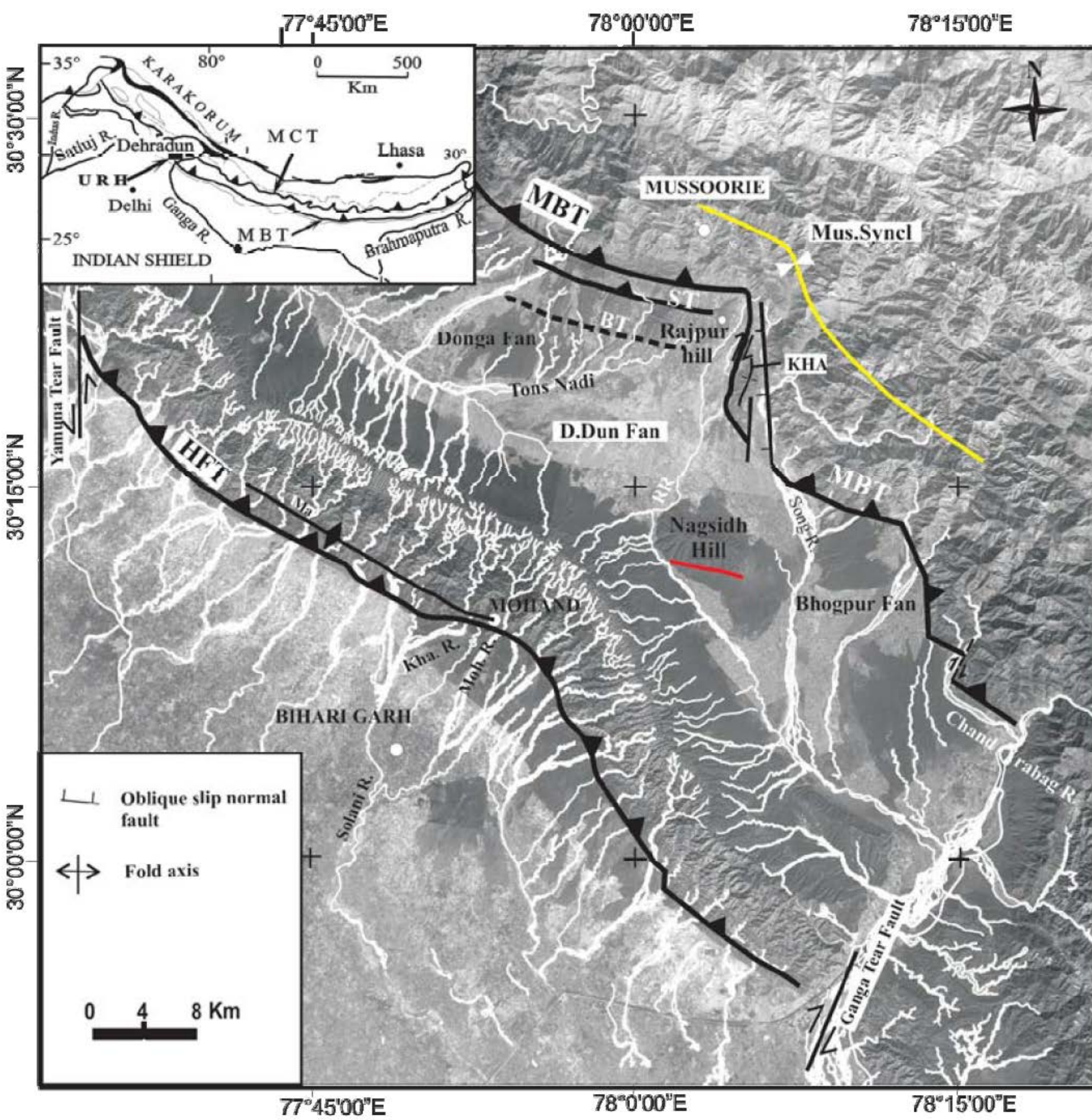

Figure 1. Satellite imagery showing the Mohand anticline and other structural elements between the HFT and MBT (Jayangondaperumal et al., 2010).

The Mohand Range in the northwestern Himalaya, situated within the Dehradun recess, presents a unique case where conflicting interpretations of available data have led to several proposed models regarding the evolution of the frontal fold. These models have been put forward by various researchers (Raiverman et al., 1994; Powers et al., 1998; Mishra and Mukhopadhyay, 2002).

Initially, the Mohand anticline was defined based on the distinction between homoclinal strata dipping at approximately 25°NE and strata dipping at about 50–65°SW in the Mohand Range (Rao et al., 1974; Wesnousky et al., 1999). Another early interpretation suggested the presence of multiple, steeply-dipping wrench faults that formed a flower structure, implying a strike-slip setting (Raiverman et al., 1983). A recent regional balanced cross-section indicated that the Main Frontal Thrust (MFT) décollement emerged at the current erosion surface with a fault-related anticline in its hanging wall (Powers et al., 1998). Furthermore, the Mohand anticline has also been proposed as a quasi-curved, multi-bend fault (Mishra and Mukhopadhyay, 2002; Mukhopadhyay and Mishra, 2004).

Divergent views exist on whether the MFT in the Mohand Range is considered blind or emergent. Some researchers have argued for it being blind (e.g., Raiverman et al., 1990; Mishra and Mukhopadhyay, 2002), while others have posited an emergent MFT (e.g., Powers et al., 1998; Wesnousky et al., 1999; Thakur, 2004; Jayangondaperumal et al., 2010). In a study by Srivastava et al. (2016), a 700-meter-wide fault core and a zone of damage in the surrounding rock were observed near Mohand. This led them to suggest that the MFT may be locally emergent. A subsequent study by Srivastava et al. (2018) interpreted the Mohand anticline as a fault-propagation fold, with a monocline exposed at the surface.

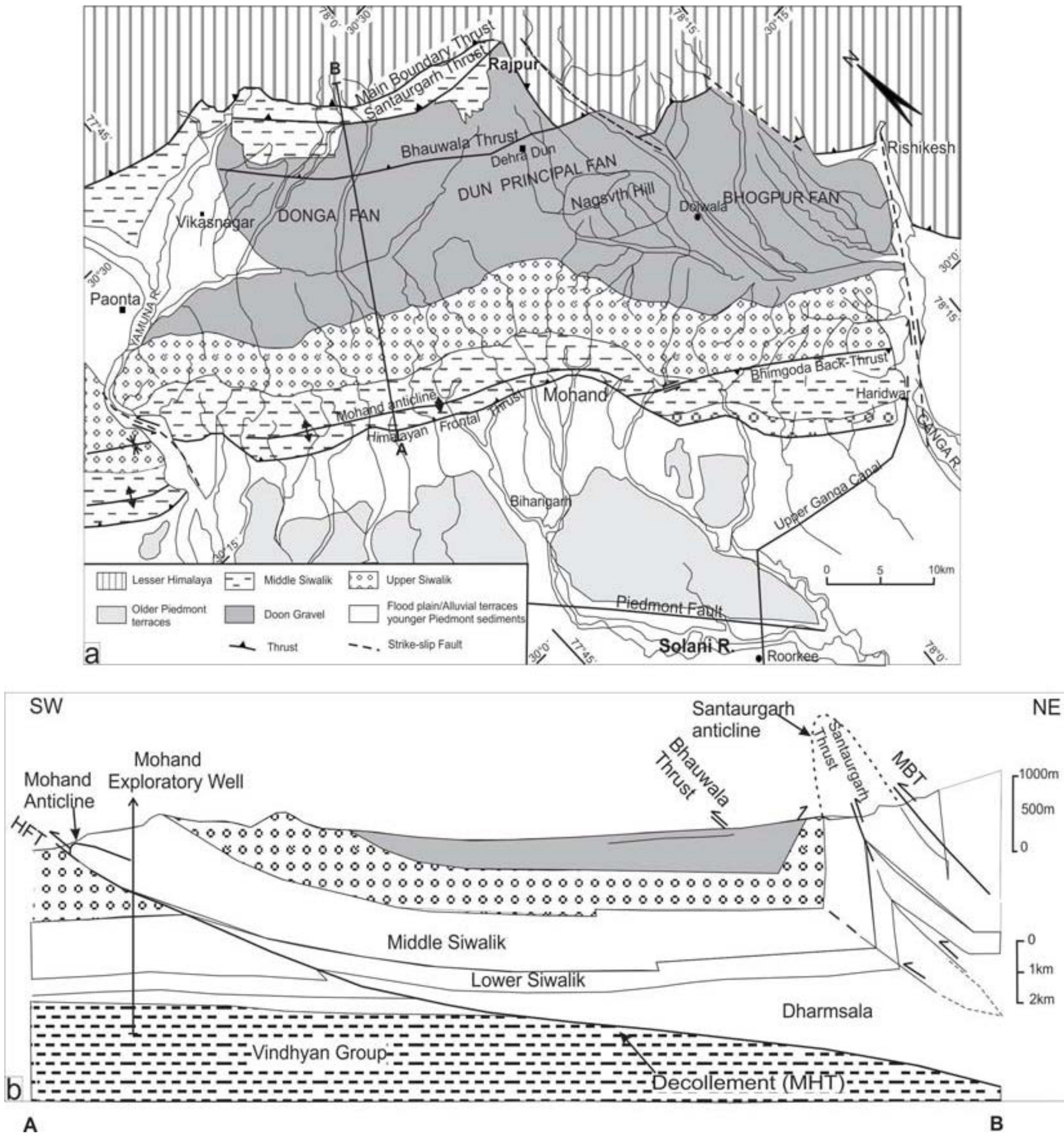

Figure 2. (a) Geological and Geomorphological mapping of Dehradun and adjoining regions. (b) A simplified cross section along A-B marked on top panel) (after Thakur et al., 2007).

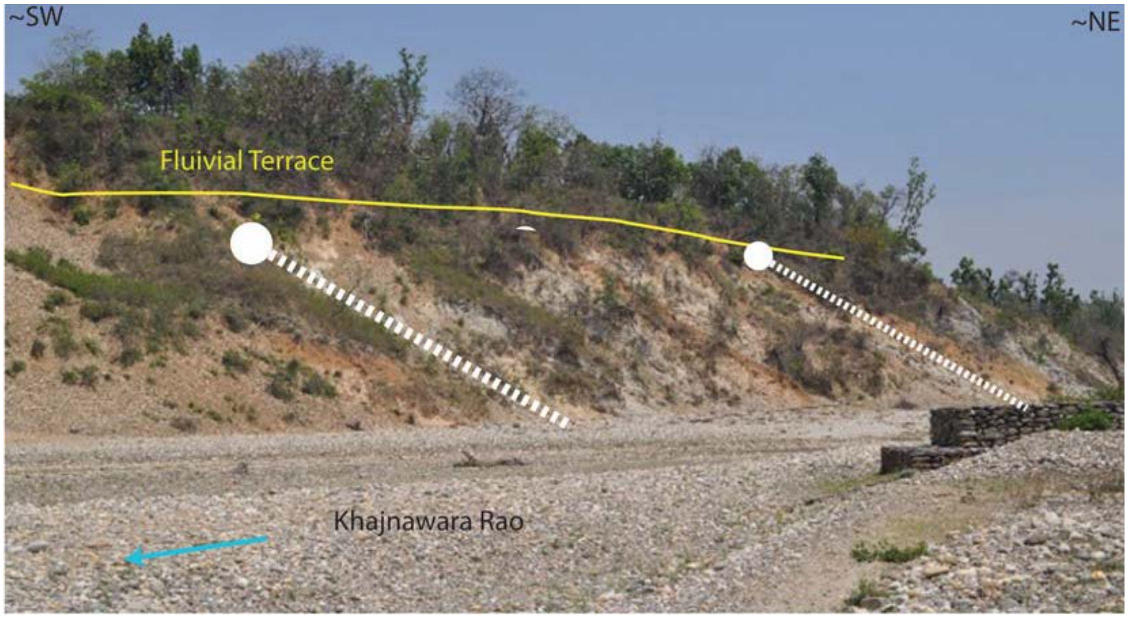

Figure 3. Mohand anticline showing north dipping Middle Siwalik Sandstone overlying with fluvial-strath terrace.

In the Mohand Range, the Main Frontal Thrust (MFT) is responsible for placing Middle Siwalik rocks over Quaternary Doon gravels, and locally, it is referred to as the Mohand thrust (Karunakaran and Ranga Rao, 1979). This geological feature is commonly depicted as a blind thrust within a fault-bend fold (Figure 2b) (Mishra and Mukhopadhyay, 2002; Mukhopadhyay and Mishra, 2004).

However, earlier representations of cross-sections showed the MFT as a zone of intense brittle deformation spanning over ~2 km (Srivastava and John, 1999) or as an emergent fault (Powers et al., 1998; Wesnousky et al., 1999; Thakur, 2004). Deformation along the MFT in the Mohand Range is believed to have commenced approximately 0.78 million years ago, which corresponds to the Brunhes-Matuyama boundary as recorded in the Boulder conglomerates or the youngest Upper Siwalik unit (Sangode et al., 1996, 1999; Kumar et al., 2003a, 2003b).

Figure 4. Southern limb of Mohand anticline showing meter scale asymmetric south verging fold.

Using a standard ratio of fault displacement to tip propagation, Barnes et al. (2011) estimated the age of the Mohand Range to be between 0.22 and 0.47 million years. Local deformation rates include vertical uplift of approximately 7 mm per year (Kumar et al., 2006), shortening of about 12 mm per year, and slip of around 14 mm per year (Powers et al., 1998; Wesnousky et al., 1999). Shortening rates have been reported at 11-14 mm per year (Thakur et al., 2014), while the long-term velocity in the northwest Himalayan region is approximately 18.5 ± 1.8 mm per year (Yadav et al., 2019).

Field Transect across the Outer-Garhwal Lesser Himalaya, Uttarakhand

Outer Lesser Himalaya of Uttarakhand

The Uttarakhand State constitutes the Garhwal and Kumaun regions, forming a part of the northwest Himalaya. The geology of the Lesser Himalaya of Uttarakhand is described in detail by Valdiya (1980) and of Higher and Tethys Himalaya by Sinha (1981). The geology of Garhwal and Kumaun is also summarized in 'Geology of Western Himalaya' (Thakur, 1992). The Lesser Himalayan zone lies between the Main Boundary Thrust (MBT) to the south and the Main Central Thrust (MCT) to the north. Two principal tectonic elements are recognized in the Lesser Himalaya Zone of the Kumaun–Garhwal Himalaya: the rock formations of the Lesser Himalaya basin and the klippen units of the crystalline thrust sheets, the latter overlying the former (Fig. 5). The Lesser Himalaya sequence consists of Chakrata and Rautgara Formations of Damtha Group at the base followed by the Deoban and Mandhali Formations of the Tejam Group, the Chandpur and Nagthat of the Jaunsar Group, the Blaini, Krol-Tal of the Mussoorie Group, and the Bansi and Subathu of the Sirmur Group (Valdiya 1980). These stratigraphic units are overlain by crystalline thrust sheets (called klippen) of Satengal, Lansdowne, Almora, Baijnath, Askot, Chaukori, and Chiplakot (Jayangondaperumal and Dubey, 2001). The klippen represents the eroded remnants of the Ramgarh and Munsiari thrust sheets, which are correlated with the thrust units underlying the Vaikrita Thrust (MCT–II) in the root zone. The linkage between the crystalline klippen in the Lesser Himalaya and the crystalline thrust sheets below the MCT is validated through the correlation of isotope geochemical signatures (Ahmad et al., 2000). In terms of structure, the Lesser Himalaya zone represents a duplex thrust system comprising horses of Berinag, Chakrata–Rautgara, and Deoban Formations overlain by the Ramgarh crystalline along the Ramgarh Thrust as roof thrust and the MHT as the floor thrust (Srivastava and Mitra, 1994; Celerier et al., 2009). Based on field, structure, and paleomagnetic/ anisotropy of magnetic susceptibility (AMS) data, an alternative model, negating large translation along the klippen detachment thrust from an assumed root zone in the Higher Himalaya, was also proposed (Jayangondaperumal, 1998; Jayangondaperumal and Dubey, 2001; Dubey and Jayangondaperumal, 2005).

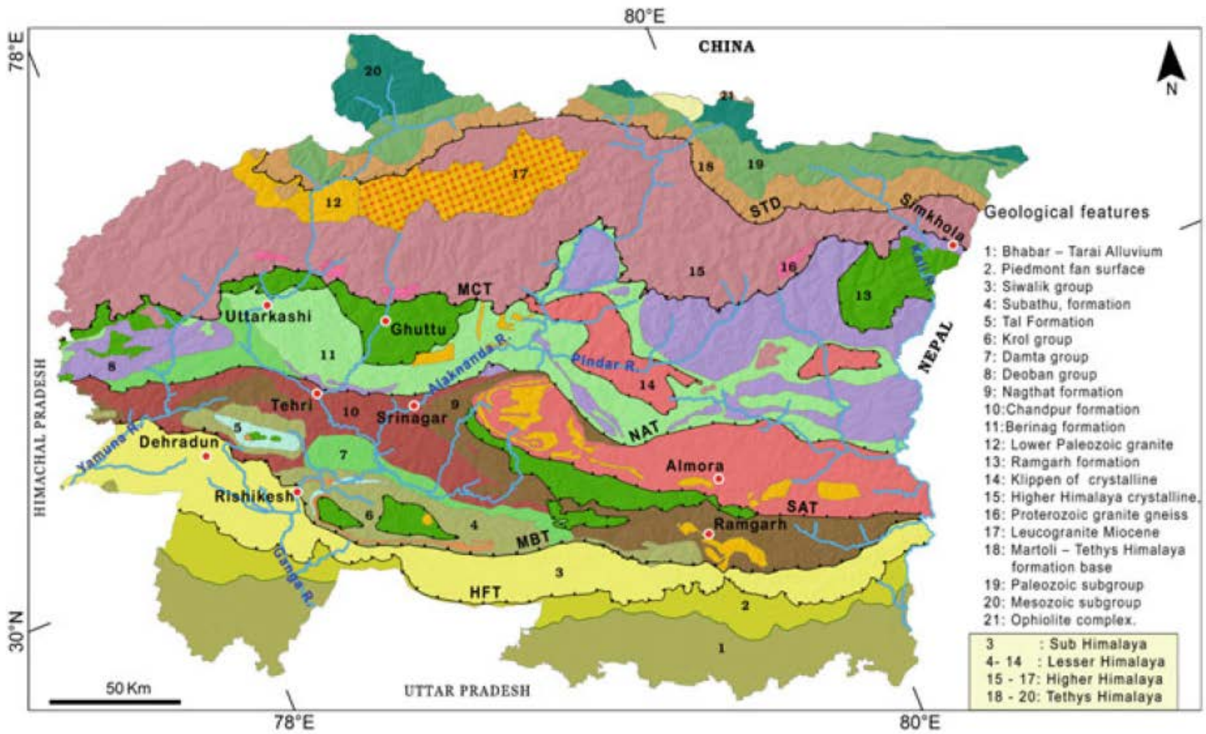

Fig. 5. Geological map of the Uttarakhand, Garhwal—Kumaun Himalaya (after Thakur and Rawat map in Thakur, 1992; Jayangondaperumal et al., 2018).

The Lesser Himalaya, which spans from 1500 to 2500 meters in elevation, is separated from the Krol Thrust, also known as the Main Boundary Thrust. In the Nag Tibba belt of the outer Lesser Himalaya, a significant geological event took place. The autochthonous Damtha in the north and the Siwalik in the south were overridden by a colossal 6000-meter thick layer of sedimentary rocks, forming what is now known as the Krol Nappe.

Within the Krol Nappe, several lithostratigraphic units are identified. At the base lies the Mandhali, composed of black and green phyllites, heavily deformed marble, and various quartzites. Above it, the Chandpur is a metaflysch formation consisting of olive-green and grey phyllite along with metasiltstones. The Nagthat is characterized by quartzarenites (orthoquartzites) with intermittent conglomerate beds in the Jaunsar Hills.

Toward a higher level, the Blaini section begins with a persistent layer of conglomerate interspersed with greywackes and siltstones, transitioning into carbonaceous slates and multicolored limestone. The Krol Formation mainly comprises carbonates, including limestone, marl, and slates in the lower portions and dolomites in the upper layers. The uppermost unit, the Tal, is a Permian formation with richly fossiliferous shales and conglomerates at the base and pyrite-rich and felspathic quartzites towards the top.

Beneath the Almora Nappe, which contains crystalline rocks, lies the third lithotectonic unit known as the Ramgarh Group. This unit, along with its extensions, forms overlapping sheets within the schuppen zone below the Munsiari Thrust, which is considered the root of the Almora Thrust. The Ramgarh Nappe represents the southeastward continuation of the Chail Nappe in Himachal Pradesh.

The route for the proposed field visit shown in Figure 6 falls within the outer Lesser Himalaya and is known as the Mussoorie Syncline (Jayangondaperumal and Dubey, 2001).

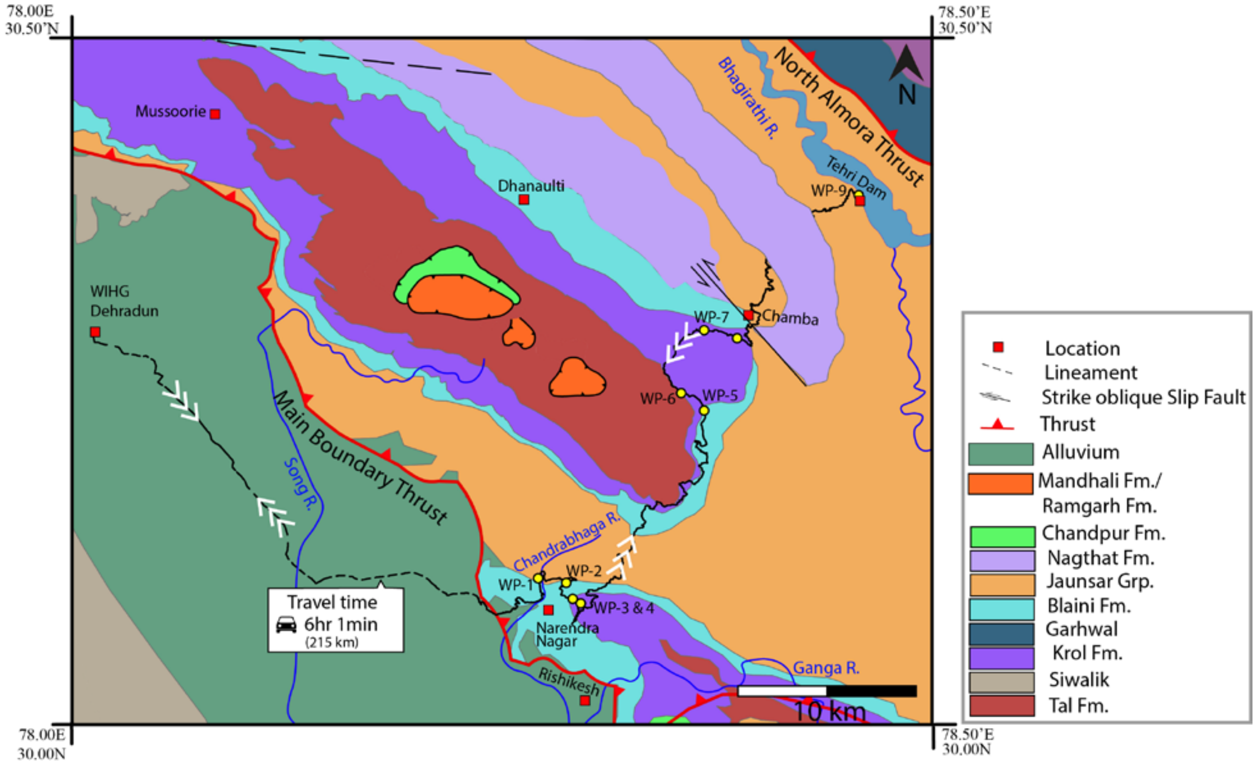

Figure 6. Map showing the proposed field transect from the WIHG, Dehradun to Tehri Dam and back.

The Mussoorie Syncline is a non-cylindrical fold, extending in an NW-SE direction and occurring as a hanging wall structure above the MBT. The footwall of the MBT abuts against the Sub-Himalayan fold-thrust belt (Jayangondaperumal et al., 2018). A structural map of the Mussoorie Syncline is shown in Figure 7.

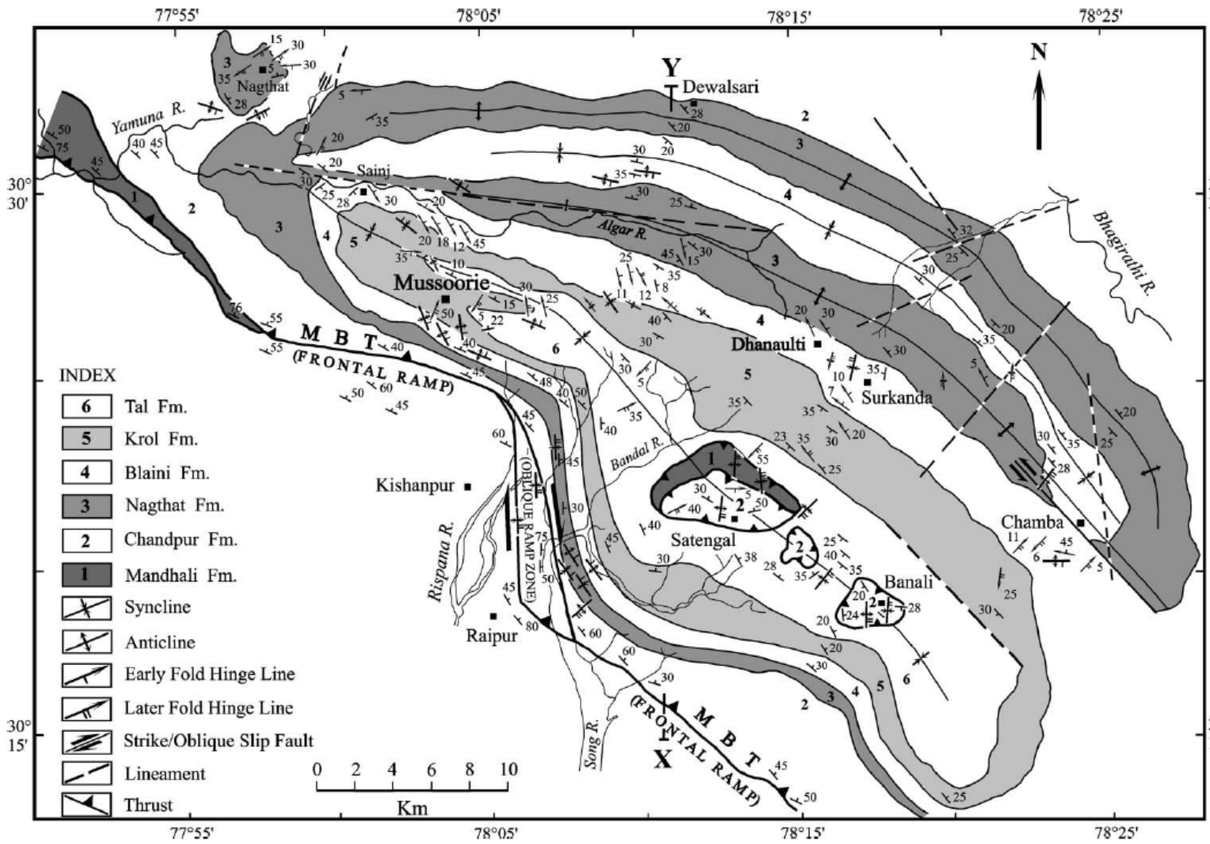

Figure 7. Structural Map of the Mussoorrie Syncline (Jayangondaperumal and Dubey 2001).

A detailed stratigraphic succession of the Mussoorie Syncline is given hereunder.

Formation	Lithology
Chandpur Formation	Low-grade, graying-green phyllite
Mandhali Fm.	Blue, grayish fawn arenaceous limestone, yellowish to white, gritty and slaty quartzite phyllite
Katu-ki-chail Thrust	
Subathu Fm.	Ferruginous purple to dark gray shale with laterite/limonitic nodules
Unconformity	
Tal Fm.	Orthoquartzite and calc-arenite with pebbly quartzite, brownish yellow siliceous limestone, dirty white to yellowish quartzite, greenish-gray shale, dark black phosphoriteic and cherty layers
Krol Fm.	Dark bluish-gray dolomitic limestone, fine grained carbonaceous limestone, limestone and shale alteration
Blaini Fm.	Slate and muddy quartzite, conglomerate, greywacke and limestone
Nagthat Fm.	Orthoquartzite with subordinate shale
Chandpur Fm.	Olive green and gray phyllite with subordinate shale
Mandhali Fm.	Blue, grayish fawn arenaceous limestone, yellowish to white, gritty and slaty quartzite phyllite
MBT (Krol Thrust)	
Siwalik/ Dagshai/ Simla slates	

The proposed transect covering different stops and the lithology are described hereunder.

Stop-1 (30.19° N, 78.27° E) – North of Narendra Nagar

At this particular location, the rock formations primarily consist of an amalgamation of quartzarenite in purple, fawn, white, and green hues, often called the Nagthat Quartzite. These quartzarenites, orthoquartzites, can occasionally exhibit pebbly or conglomeratic characteristics. They are intermingled with greenish and purple slates, which belong to the Nagthat Formation (Fig. 8)

The Nagthat Formation was initially identified by Auden (1934), mainly in the vicinity of the Nagthat mountain summit (located at approximately 30°34' latitude and 77°58' longitude), southeast of Chakrata. In the inner sedimentary zone, the Nagthat Formation's equivalent is called the Berinag Formation (Valdiya, 1980).

Figure 8. Field photograph showing the rock type of Nagthat Formation at stop-1 north of Narendra Nagar.

Stop-2 (30.18° N, 78.27° E**)** – Northeast of Narendra Nagar

At location Stop-2, the geological composition consists of various rock types, including slate, muddy quartzite, conglomerate, greywacke, and limestone. These rocks are collectively called the Blaini Formation and are positioned stratigraphically above the Nagthat Formation.

The Blaini Formation is recognized by the presence of conglomerate with shades of olive green and black, as well as occasional layers of purple or red limestone. These conglomerates are often found alongside purple slate and sandstone, overlaying the Nagthat quartzites in the Krol Belt region.

It's worth noting that this definition, as proposed by Valdiya (1973), excludes the conglomerates intermixed with the turbidites of the Simla Slates in the Baliana River valley, located northwest of Solan in Himachal. Valdiya (1980) identifies Dhanaulti on the Mussoorie-Tehri road, at 31° 1" latitude and 77° longitude, as the designated type area for the Blaini Formation. This location is where Rupke (1968) provided a detailed description of its typical lithology. The Blaini Formation forms a continuous belt around the Mussoorie-Lansdowne and Nainital Hills and comprises two distinct members. The lower member contains two horizons of polymictic conglomerate, comprising rounded and sub-rounded clasts ranging from pebble to boulder sizes. These clasts are derived from wackes, grey and black slates, phyllites, and variegated sandstones, along with purple-green shales and red limestone, all set within a grey carbonaceous pelitic matrix. The upper member consists of fine-grained muddy sandstone or wacke intercalated with predominantly olive green, grey, and black slates. These slates often display intriguing concentric color patterns on their cleavage, foliation, or joint planes, resulting from the decolorization (bleaching) of pyritic-limonitic pelites. The lithology at stop 2 is shown in Figure 9.

Figure 9. Field photograph of the lithology of Blaini Formation at Stop-2.

Stop-3 (30.17°N, 78.28°E**) –** East of Narendra Nagar

Stop-3 exhibits a lithological composition characterized by a succession of limestones, varying in shades of grey and greenish-grey, alongside purple slates, siltstone, and, in the upper section, substantial dolomites (Figure 10). This sequence directly follows the Blaini Formation without any discernible interruption. Medlicott (1864) attributed the name "Krol series" to this formation, derived from the prominent Krol Mountain (30° 32', 77° 51') near Solan in Himachal. This predominantly carbonate formation can be divided into three distinct members and constitutes the most conspicuous upper segment of the synclinal mountain range, extending over 200 kilometers from the Yamuna Valley to Nainital. The latter location (Nainital Hills) represents the highest unit within the Krol Belt.

The lower boundary of the Krol Formation lacks a clear-cut delineation, as previously mentioned. The lithology of the lower member (Lower Krol) shares many similarities with the upper member of the Blaini Formation (Infra-Krol). Consequently, the demarcation line is arbitrarily set at the level where the limestone prominently emerges within the slates.

Figure 10. Photograph showing the lithology at Stop-3.

Stop-4 (30.30° N, 78.35° E**)**

Figure-11 showing landslide in the Infra-Krol formation and Geotechnical engineers stabilizing the falls

Figure 11. Photograph showing a landslide at Stop-4. The lithology constitutes of the Krol limestone as encountered at Stop-3 east of Narendra Nagar.

Stop-5 (30.33° N, 78.37° E**)**

Another classical field site shows classical small scale Landslide along the road section (Infra-Krol Formation**)**

Figure 12. Photograph showing a landslide at stop-5. Here, the lithology comprises the Infra-Krol limestone as encountered at stop-3 east of Narendra Nagar.

Stop-6 (30.32° N, 78.38° E)

The lithology at stop-6 is characterized by olive green and grey phyllite interbedded and finely interbedded with metasiltstone and very fine-grained wackes, with local metavolcanics, which constitute the Chandpur Formation. It was named by Auden (1934) after the peak (30° 42"; 77° 40") in southeastern Himachal Pradesh. The bulk of the Nag Tibba Range in Garhwal, from the Eastern Nayar to the valley of Tons and beyond, is built up of the Chandpur Formation. The lithology of the Chandpur represents mildly metamorphosed flysch. The lithology is shown in

Figure 13.

Figure 14. Photograph showing the lithology at stop-6.

Stop-7 (30.41°N, 78.46°E) - Tehri Dam

Figure 15. Photograph showing the Tehri Dam at stop-7.

Tehri Dam is the tallest dam in India and the 12th tallest dam in the world, with a height of 260.5 m (855 ft). It is a multi-purpose rock and earth-fill embankment dam built on the Bhagirathi River in New Tehri, Tehri Garhwal district in Uttarakhand, India. It is the primary dam of THDC India Ltd. and the Tehri hydroelectric complex (Source: Wikipedia).

Acknowledgement

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Tehri-Dam in the Garhwal Lesser Himalaya