ANNUAL REPORT 2023-24

WADIA INSTITUTE OF HIMALAYAN GEOLOGY
DEHRADUN

(An Autonomous Institute of Dept. of Science & Technology, Govt. of India)

Cover Photo: Lakes formation at the snout of glaciers in the Upper Nubra Valley, Karakoram Region, India

(**Courtesy:** Jairam Singh Yadav and Rakesh Bhambri)

ANNUAL REPORT
2023-24

WADIA INSTITUTE OF HIMALAYAN GEOLOGY

(An Autonomouσ Inσtitutε of Dεpartmεnt of Sciεncε & Tεchnology, Govεrnmεnt of Inδia)
33, Gεnεral Mahaδεo Singh Roaδ, Dεhra Dun –248 001
EPABX : 0135–2525100; Fax: 0135–2625212
Email: δir.off@wihg.rεσ.in; Wεb: http://www.wihg.rεσ.in

Contact :

Thε Dirεctor,
Wadia Institute of Himalayan Geology
33, Gεnεral Mahaδεo Singh Roaδ, Dεhra Dun −248 001
Phonε : 0135−2525103, Fax : 0135−2625212 / 2525200
Email : δirεctor@wihg.rεσ.in
Wεb: http://www.wihg.rεσ.in

CONTENTS

WIHG ORGANISATIONAL SET-UP

GOVERNING BODY

Talat Ahmad
Secretary to the Govt. of India
Shakil Ahmad Romshoo
Vishvajit Sahay
O.P. Mishra
M. Jayananda
Pulak Sengupta
N.V. Chalapathi Rao
Anupam Chatoopadhyay
Saibal Gupta
S.C. Patel
Kalachand Sain
Pankaj Kumar

RESEARCH ADVISORY COMMITTEE

Shailesh Nayak
T.N. Singh
D.C. Srivastava
Rajesh Kumar Srivastava
Rasik Ravindra
Rajesh K. Srivastava
Binita Phartiyal
Prakash Chauhan
O.P. Mishra
Prasun Jana
Kusala Rajendran
L.S. Chamyal
Santanu Banerjee
V. Balaram
Devesh K. Sinha
Saibal Gupta
Kalachand Sain
R. Jayangondaperumal

FINANCE COMMITTEE

Vishvajit Sahay
Anupam Chatoopadhyay
Kalachand Sain
Pankaj Kumar
Rahul Sharma

BUILDING COMMITTEE

Kalachand Sain
Vishvajit Sahay or his nominee
Representative of Surveyor of India (Hathibarkala, Dehradun)
Chief Engineer, CPWD, Dehradun (or his/her nominee)
Ashish Kumar Singh (ONGC, Dehradun)
R. Jayangondaperumal
Rajesh Kumar
Pankaj Kumar
C.B. Sharma

RESEARCH ACTIVITIES

Research Groups

- Structure & Tectonics
- Petrology & Geochemistry
- Biostratigraphy
- Geomorphology, Env. & Eng. Geology
- Sedimentology & Quaternary Geology
- Geophysics
- Glaciology & Hydrology

Activities

- 1A: Geodynamics of Indo-Eurasian collisional zone - Crustal evolution, carbon sequestration and mineralization
- 1B: Mantle upwelling, fluid circulation and metasomatic processes - Implications on fluid-rock interaction
- 2A: Subsurface interpretation - development of ML approach to geoscientific data from Himalaya and adjoining regions
- 2B: Geometry and rheological assessment of the MHT, lithospheric flexuring - Implications toward seismogenesis, deep earth processes
- 2C: Seismicity and seismic hazard assessment in the Himalaya
- 3: Biotic evolution with reference to Indo-Eurasian collision – Evidences for global events
- 4A: Climate variability and landscape responses in selected transects of NW and NE Himalaya
- 4B: Ecology and climate dynamics of the Himalaya – Cenozoic to Present
- 5: Geological and Geomorphic controls on Landslide for risk assessment and zonation in the Himalaya
- 6A: Glacial dynamics, glacier hydrology, mountain meteorology, and related hazard
- 6B: Hydrogeology - Himalayan fluvial system and ground waters
- 7: Quantification of strain accumulation/release rate along MHT at different time scales

UNITS ANCILLARY TO RESEARCH

- TCPME
- Publication & Documentation
- Library
- Museum
- Analytical Services
- Sample Preparation
- Consultancy

ADMINISTRATION

Registrar's Office

- Finance & Accounts
- Establishment
- Stores & Purchase
- Computer and Networking
- Works, Building & Maintenance
- Transport
- Guest House

EXECUTIVE SUMMARY

The Wadia Institute of Himalayan Geology (WIHG), Dehradun is an autonomous research Institute of the Department of Science & Technology, Govt. of India established in 1968. The Institute is devoted to unravel various scientific aspects of the Himalaya, including geodynamic evolution, seismogenesis, climate-tectonic interaction, biotic evolution, ore and mineral forming processes, glacial dynamics, fluvial system, geo-hazards (landslides, flash floods, avalanches, earthquakes), geo-resources (minerals/ores, hydrocarbons, cold springs, and geotherm), anthropogenic impact, etc. towards the well-being of the population and safeguarding the properties and structures in the Himalaya and adjoining areas. The Institute shed light on above themes not only based on field observations but also on analysis of data using sophisticated instruments and modeling of different sets of data on structural geology, petrology, geochemistry, paleontology, biostratigraphy, sedimentology, glaciology, hydrology, geomorphology, engineering geology, seismology, gravity & magnetic, seismic, well logs, environment & engineering geology, quaternary geology, and remote sensing, etc.

The institute has advanced analytical facilities, including Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICP-MS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Stable Isotope Mass Spectrometer, Electron Probe Microanalysis (EPMA), X-Ray Fluorescene Spectrometer (XRF), Scanning Electron Microscope (SEM), X-ray Diffraction (XRD), Raman Spectrometer, Thermoluminescence/Optically Stimulated Luminescence (TL/OSL), and a Magnetic Susceptibility meter, all managed by competent scientists and technicians. It also houses state-of-the-art laboratories for geophysical data acquisition, processing, modeling, and interpretation, along with an AI/ML Centre of Excellence for Geosciences. These facilities serve WIHG scientists as well as researchers from universities, institutes, and organizations. The institute operates a seismological network comprising 80 Broad Band Seismographs and 15 Accelerographs across Himachal Pradesh, Uttarakhand, Punjab, Haryana, Arunachal Pradesh, Jammu & Kashmir, and Ladakh. Additionally, about 14 GPS instruments are installed in Himachal Pradesh, Uttarakhand, Jammu & Kashmir, and Ladakh. The institute also runs a 'Multi-Parametric Geophysical Observatory (MPGO)' in Ghuttu, Uttarakhand, to study earthquake precursors in the Himalayan region. Further, the institute offers consultancy services for geo-engineering projects, groundwater surveys, natural hazards, and road/rail alignments in the Himalayas and neighboring areas.

The Institute is a national center of excellence for Himalayan geoscience education and research. It emphasizes nurturing young and dynamic talents to achieve a high level of competency through Ph.D. programs. The Institute also provides training in different fields of Earth sciences to students of Colleges/Institutes/Universities. The institute maintains a modern Geological Museum that showcases evolution of the Himalaya, rocks, minerals, and fossils across the different transects of Himalaya for educational purposes. It conducts outreach programs for science education and geo-hazards awareness and organizes popular lectures and National/International seminars. Additionally, the institute engages in collaborative research with various universities, industries, and other institutes focused on Himalayan geosciences.

Ongoing research activities are focused on "Characterization and Assessment of Surface and Subsurface Processes in the Himalaya (CAP-Himalaya): Implications on Geodynamics, Seismogenesis, Bioevents, Paleo-climates, Natural Hazards, and Natural Resources for Sustainable Development". The research program planned for the year 2023-2024 has been grouped into 12 programs or activities. The significant outcomes from each activity are summarized below:

Activity-1A:

Geodynamics of Indo-Eurasian collisional zone and crystalline thrust sheets-crustal evolution, carbon sequestration, and economic mineralization

- Lithospheric evolution in the collisional orogen of the Himalaya witnesses the subduction of Indian continental crust penetrate beneath the Eurasian plate and equilibrated in the ultrahigh-pressure condition at c.45 Ma, in consequence of the failure at the leading edge of the Indian plate following the upward trajectories through the subduction channel and exhumed back at the mid-crustal level c. 42 Ma.

- Fission-track (FT) ages from the granite body associated along the Main Boundary Thrust (MBT) hanging wall suggests the mid-Miocene (~13–14 Ma) development of the MBT and responsible for the exhumation of the Amritpur Granite body to the surface as 'Tectonic Slivers'. Moreover, the Apatite fission track (AFT) age of ~5 Ma from the contact zone indicates the MBT and associated faults reactivation during the Pliocene periods.
- Mafic dykes of the Banjar Formation likely represent a Palaeoproterozoic mafic intrusive activity linked to Columbian Supercontinent.

Activity-1B:

Mantle upwelling, fluid circulation, metasomatic processes – Implications on fluid-rock interaction

- The Higher Himalayan Crystalline rocks of Dhauliganga Valley, Garhwal Himalaya, have attained the metamorphic condition in the range of 648–801°C and 8–11 kbar.
- The High Himalayan Discontinuity divides the Himalayan metamorphic core into two units.
- Two types of fluid inclusions were observed in the exotic blocks of Zildat ophiolitic mélange (ZOM): carbonic and aqueous-carbonic, which entrapped between 435 and 370 °C at 386–323 Mpa.
- The zircon U–Pb age (~925 Ma) of the Chaur granitoids of the Jutogh Thrust (JT) sheet provides evidence of the Neoproterozoic magmatism in the NW Himalaya.
- The detrital U–Pb ages (range 550–2750 Ma) from the JT sheet provide two prominent peaks of ~825.0 and ~910.0 Ma, which suggest two episodes of magmatic processes. It advocates that the first subduction was an unknown micro-continent under the Indian Plate and the magma generated through partial melting (~925 Ma); the second was the intrusion of magma in an extensional tectonics setup of the northern edge around ~825 Ma.

Activity-2A:

Subsurface interpretation - Development of ML approach to geoscientific data from Himalaya and adjoining regions

- The subsurface geological environment of the Upper Assam foreland basin has been investigated using high-quality 3D seismic and borehole data and deciphered the geometry and kinematics of subsurface structures that compartmentalized the geologic formations with special reference to the Tipam and Barail litho-units.
- Design of new meta-attributes (e.g. Fluid Cube, and Reef Cube) using machine learning approaches for automatic interpretation of subsurface geologic structures and associated geological processes. These meta-attributes can be efficiently used in subsurface interpretation of the geologic environment from worldwide sedimentary basins.
- Usage of seismic attributes and the approach of common contour binning prominently elaborated the fluid contact zones in subsurface reservoirs, which are crucial for the exploration of hydrocarbons. These studies carried out in the onshore basin (Upper Assam basin, NE India) can be effectively extended to offshore areas.
- The subsidence curves were computed for the Upper Assam basin, which highlighted the subsidence history and quantified the amount of subsidence that the Upper Assam basin underwent during its evolution.
- Employed machine-learning techniques for the prediction of missing geophysical logs within the intervals of Lakadong-Therria formation in the Upper Assam basin, NE India.

Activity-2B:

Geometry and rheological assessment of the MHT, lithospheric flexuring - Implications toward seismogenesis, deep earth processes

- Sedimentary structures have been imaged in the western part of the Indo-Gangetic Plain (IGP) that reveal soft alluvials with extremely low shear wave speed at the top ~400–700 m of the surface which is useful information for earthquake hazard estimation in the highly populated cities over the IGP.
- A high-resolution ambient noise tomography in the Garhwal-Kumaon region detects a thick sedimentary layer in the IGP and reveals a low-velocity zone around the MCT at ~10–15 km depth, which is interpreted as the presence of fluid that causes micro-to-moderate size earthquakes in the Himalayan Seismic Belt. Moho depth is found

between 40 km depth near the HFT to 47 km depth beneath the MCT.

- The magnetotelluric investigation along the Rohtak–Delhi section characterizes the junction of the contact zone of the Delhi–Hardwar Ridge (DHR) and Delhi–Sargodha Ridge (DSR). The DHR has been found striking NE–SW with a very shallow central axis (less than 400 m) having a width of 12–15 km forming half grabens on both limbs supported by shallow faults. The seismicity in the Rohtak and surroundings is located at the bifurcation points of DHR and DSR and at a reverse fault.

- Investigated attenuation quality factors for *P*–waves ($Q\alpha$), *S*–waves ($Q\beta$), and coda waves (Qc) using a dataset of 1944 micro to moderate earthquakes ($2.5 \leq Mw \leq 5.0$) in the NW Himalaya and found highest attenuation in the Lesser Himalaya compared to IGP and Higher Himalaya.

- A ground motion prediction equation (GMPE), has been developed for the Northwest Himalaya and its surrounding region: $\log_{10} PGA = 1.889 + 0.3996*M - 0.95736 \log_{10} \bullet (HD + \exp^{(0.4114*M)}) \pm 0.3646$, where, PGA is peak horizontal acceleration in gal of strong ground motion, M is the magnitude, and HD is the hypocentral distance from the source.

Activity-2C:
Seismicity and seismic hazard assessment in the Himalaya

- The semi–empirical technique of simulation has been modified for the site–specific attenuation properties. Modeling of the 1991 Uttarkashi (Mw 6.8) and 2011 Indo–Nepal (Mw 5.4) earthquakes validate this modification, which discovered more consistent simulated results.

- Seismic data (1999–2020) has been analyzed to estimate stress drops, b–value, fractal dimension, and focal mechanisms using a local network of 14 broadband stations. A brittle–semi–brittle transition zone at 12–14 km depth is identified in the Garhwal region, which is capable of generating noteworthy stress accumulation for future significant rupture.

- The intra–crustal low–velocity layer and the upper mantle discontinuities have been explored beneath the Kumaun–Garhwal, north–west Himalaya. The crustal thickness varies from 44 to 54 km beneath the study region. The 2D image of the P–wave receiver function proposed the mantle transition zone at a depth between 410 and 660 km.

Activity-3:
Biotic evolution with reference to Indo-Eurasian collision – Evidences for global events

- A diverse assemblage of micro–mammals has been reported for the first time from the Siwalik sediments exposed around Pathankot District. The taxonomic assessment provides useful information on the age of the fossiliferous locality exposed at Dunera based on rodent biostratigraphy.

- A significant assemblage of Ichnofossils has been described, for the first time, from the Miocene Siwalik sediments. These ichnofacies indicate well–oxygenated, low–energy deposition exposed to air and represent the fluvial environment.

- A significant assemblage of Miocene planktonic foraminifers, including fourteen species from eleven genera were recorded from the Surma Group in the Naga Hills. Biostratigraphy, paleoenvironment, and paleogeography of the assemblage provide a basis for widespread regional and global correlation constraining the timing of elimination of the final remnants of the Neotethyan seaway between India and eastern Eurasia.

Activity-4A:
Climate variability and landscape responses in selected transects of NE and NW Himalaya

- A significant wet phase was witnessed in NE India between ~3.5 and 2.9 kyr BP. An abrupt and pronounced weakening of summer monsoon rainfall is observed at around 4.2 kyr BP that lasted for around 200 years whereas the same events lasted longer in the western and northwestern part of the Indian subcontinent.

- The overall reduction of ~21 km^2 (~21%) of the total glacier area of the basin with an ice volume loss of ~46% and ~46 m upward shifting of the Equilibrium Line Altitude (ELA) with an average retreat rate ranges from ~ 18 to 41 m per year between 1990 –2021.

- The glacial history of the Panchachuli glacier, in Darma Valley shows that the oldest glacier advance occurred during MIS 3 followed by the Last Glacier Maxima (LGM) and Holocene.

- The study shows a regional synchronicity of glacier response to climate variability since MIS 3 and was following the climatic perturbation triggered by the North Atlantic millennial-scale climate oscillations.
- The addition of a northern (ophiolitic) provenance during Subathu sedimentation as opposed to the sole cratonic input in the case of Nilkanth sedimentation in a passive margin setup has been identified from Lesser Himalaya.
- Electric resistivity tomography (ERT) carried out in Pangong Tso Delta sequences shows the channel avulsion, delta accretion, and channel bifurcation.

Activity-4B:
Ecology and climate dynamics of the Himalaya – Cenozoic to Present

- The Tree-ring chronology of *Abies pindrow* from Joshimath region, Uttarakhand, and the tree-ring chronologies of *Cedrus deodara* from Malari region, Uttarakhand revealed the direct influence of precipitation over the growth of trees in the region.
- The sediment core/ profile samples from the north-western Himalaya, processed for multi-proxy paleoclimatic analysis, have been providing centennial to millennial-scale climate and vegetation history during the late Holocene period.

Activity-5:
Geological and geomorphic controls on landslide for risk assessment and zonation in the Himalaya

- Extracting landslide information from remote sensing imageries holds significant importance for prompt assessment and recovery efforts. To address such issues convolutional block attention module (CBAM), efficient channel attention (ECA), global attention mechanism (GAM), and coordinate attention (CA) have been introduced. A novel attention-based YOLOv5 model has been developed to extract landslide events from multi-source remote sensing platforms of diverse geological environments. The prediction accuracy of YOLOv5+CBAM (f-score=98%) is found to be the supreme.
- Studies on the ground and analyses of the LiDAR data show that, in Joshimath, chronic slides are attributed to several contributing factors. The role of surface and sub-surface water plays a significant role in accelerating the slides.
- In Joshimath, lithographic units with at least 1 set of joint planes along the slope, provide a slide-plane. LiDAR data shows that 33% of the slope falls under the 30-50º slope angle, and 53% of the land falls under the east-to-northeast aspect, conforming to the slide direction. Overall, the data shows the structure of a slow-moving, deep-seated landslide.

Activity-6A:
Glacial dynamics, glacier hydrology, mountain meteorology, and related hazard

- The annual mass balance of Pensilungpa Glacier for seven years shows a negative trend with an average rate of specific balance of about -0.57 m w.e. and annual mean mass balance was about -5.7 $x10^6$ m^3 w.e. The study reveals ~31.47 $x10^6$ m^3 w.e. cumulative volume loss between 2016 and 2023, whereas the depression of equilibrium-line altitude (ELA) was ~27 m between 2016 and 2023.
- Glaciological investigations reveal a 61% increase in the total area of supraglacial lakes (SGLs) over the three decades, with the most notable growth occurring in the last decade (2010-2020). The Central Himalaya region, especially around Everest, observed the most significant rise.
- As per the MSI image of 2020, the total area of the Companion Glacier is 2.08 ±0.1 km^2. In 2001, the total area of the glacier was 2.11 ± 0.1 km^2. Thus, the glacier area has only slightly reduced by −0.03 ±0.1 km^2 (−1.3% ± 2.8%) in the last 19 years.
- The volumetric assessment of the Badrinath geothermal field suggests that this geothermal field can produce at least 3 MWe (electricity) and 39 MWt (Thermal power) after the successful drilling of geothermal wells in the future.

Activity-6B:
Hydrogeology-Himalayan Fluvial System and Groundwaters

- Intense chemical weathering causes the Teesta River sediments to have the lightest δ^7Li values.
- Climate-tectonics interaction controls the erosion and weathering distribution in the Himalaya.
- The primary locus of CO_2 consumption appears to be the mountainous sector
- Prominent recharge zone for Doon ground waters lie at 1500-2500 m asl.

Activity-7:

Quantification of strain accumulation and strain release rate along the MHT at different time scales

- The inter-seismic geodetic observations from the frontal part of the Siwalik hills as well as within the Dehradun basin show that the crust is undergoing periodic annual and semi-annual loading/unloading in both vertical and horizontal components apart from their secular variations. The causes of such characteristic nature of loading/unloading at the frontal part of the mountain and non-mountainous regions are different.
- The geometry of the MHT is revealed for the Lohit Valley region, NE India, using inverse thermochronological 3D Pecube modeling. The MHT forms a 28° ramp with two 8° flat components in this region.

Academic Pursuit

During 2023-2024, the Institute researchers published 107 research papers in peer-reviewed SCI journals, 6 book chapters, 2 conference proceedings, 2 reports, and 1 field guide. The Academy of Scientific and Innovation Research (AcSIR) at WIHG takes the initiative in educating Ph.D. scholars through experienced scientists of the Institute. A total of 11 research scholars were awarded the Ph.D. degree and 4 theses were submitted by the scholars for the award of the Ph.D. degree. The Institute had the privilege to organize the (i) 7th National Geo-Research Scholar's Meet during September 12-14, 2023 which was attended by about 100 research scholars from different organizations across India, (ii) A one-day workshop on "Himalayan Hazards and Way Forward-2023" on November 24, 2023, and (iii) A Special Session on "Joshimath Disaster: A Geoscience Outlook" was organized at Graphic Era University, Dehradun by Wadia Institute of Himalayan Geology, Dehradun, as part of the Special Feature Event on November 29, 2024, in the 6th World Congress of Disaster Management (WCDM) and (iv) 2nd Edition of Indo-German young researcher's meet on "Geodynamics and Climatic Science of the Himalaya Region" during November 25, 2023, to December 01, 2023, at WIHG, Dehradun.

The scientists of the Institute were recognized by awards and felicitations on various platforms. Dr. Kalachand Sain, Director, WIHG received the "Excellence in Research Award (2023)" by the Dehradun International Science & Technology Festival. Dr. M. Rajanikanata Singh received the International Young Scientist Award 2023 by the International Science Community Association in collaboration with Graphic Era Deemed to be University, Dehradun. Dr. Pankaj Chauhan and Dr. Parveen Kumar received the SERB International Research Experience (SIRE) fellowship for 2023-2024. Dr. Naveen Chandra received the INSA (Indian National Science Academy) Visiting Scientist grant (2024-2025).

Other Highlights

The institute has participated and displayed its scientific exhibits at various forums in different parts of India. The Institute participated in the 9th India International Science Festival (IISF) 2023 held at Faridabad, Haryana during January 17-20, 2024. The Institute organized several awareness programs related to earthquakes and other geohazards for school children and common people. The Institute strictly followed the Rajbhasha guideline and took various steps to promote the use of Hindi in routine office work as well as in Scientific Research publications. The Hindi Pakhwara was celebrated from 14 to 28, September 2023. The Annual Report of the Institute for the year 2022-23 was published in bilingual (Hindi and English) form, along with its in-house Hindi magazine 'Ashmika'. As a part of celebrating 'Azadi ka Amrit Mahotsav', the institute organized several talks by eminent scientists and professors.

Kalachand Sain
Director

ACTIVITIES

Activity:1A

Geodynamics of Indo-Eurasian collisional zone and crystalline thrust sheets: crustal evolution, carbon sequestration and economic mineralization

(Barun K. Mukherjee, Paramjeet Singh, Pratap Chandra Sethy, Hiredya Chauhan, M. Rajanikanta Singh and Kunda Badhe)

Rapid return of subducted Indian crust until c.42 Ma

Realizing that a large volume of continental crust can subduct to great depth in the same orogenic cycle and return to the shallow Earth is one of the important findings of the last decades. Studying exhumed deep crust is important in geodynamics because it informs the patterns and rates involved in the transfer of mass and heat during orogeny. The study of the Tso Morari gneissic (TMG) dome has documented how the Indian crustal component evolved in the high-grade metamorphic regime and how the recycled crust has transformed from deep to shallow Earth surface. This study is carried out with the help of geochemical and isotope methods. To address this, a large number of zircons were recovered from the Tso Morari continental gneiss of the Indus Suture Zone (ISZ), Himalaya. Through the systematic study of zircons, the pressure-temperature-time path of the subducted Indian continental plate has been estimated, leading to the construction of a related tectonic model for the subducted Indian lithosphere. The study also suggests that when the broken edge of the Indian continental plate reaches the sub-surface that is equilibrated at the high-pressure and ultrahigh-pressure eclogite stages, the record of such condition is completely or partially erased. The recovered dataset from the zircons helped reveal the tectonic interpretation, which concludes that the ISZ gneiss and mafic UHP eclogite in the Tso Morari Gneiss, were coupled and both have coevally participated in the entire subduction process deep down at >100km c.45 Ma (Fig. 1), which subsequently exhumed back rapidly to the mid-crustal level until c. 42 Ma. The last stage of exhumation and emplacement history of gneisses at the ISZ can be detected through

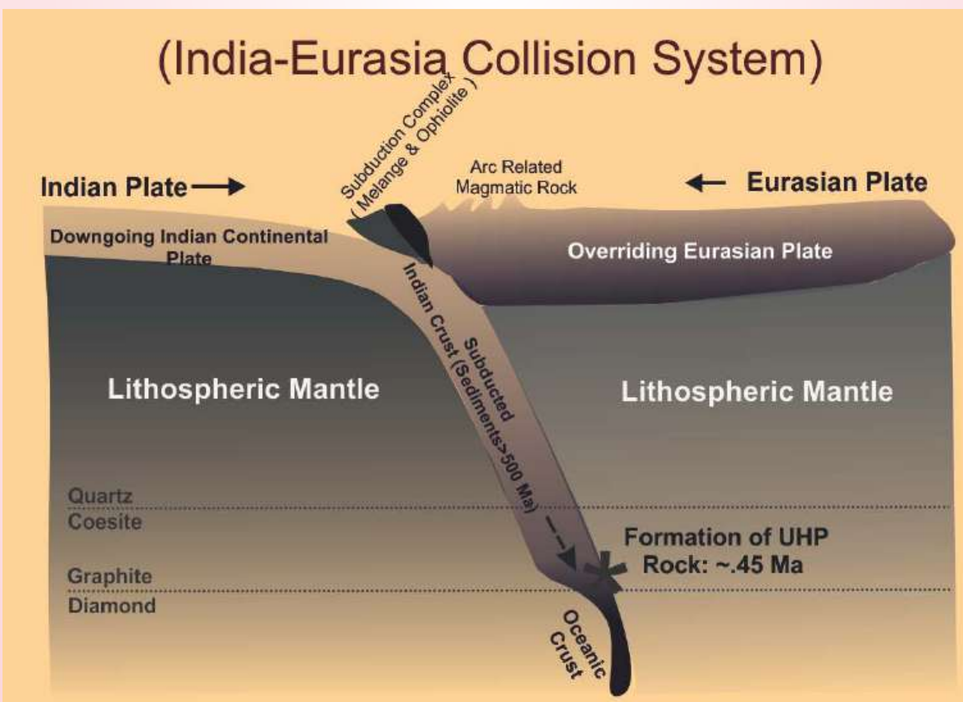


Fig. 1: Lithospheric evolution in the collisional orogeny of the Himalaya witnesses the subduction of Indian continental crust penetrate beneath the Eurasian plate and equilibrated in the ultrahigh-pressure condition at c.45 Ma, in consequence of the failure at the leading edge of the Indian plate follow the upward trajectories through the subduction channel and exhumed back at the mid-crustal level (Mukherjee & Saha 2024 JGS, London).

the study of the outer rims of the zircon if the outer rim of the zircons is found to be thicker.

Assessing exhumation of Amritpur granite

The Main Boundary Thrust (MBT) is studied along the Baliya-Amritpur-Jamrani road section of the Baliya Nala-Gola River valley, including an isolated granite body associated with MBT hanging wall in the Kumaun region of the NW-Himalaya. In this study, the available Fission-Track Thermochronological ages and seismicity data, in combination with the new field evidence and geomorphological data, have been used to understand the mechanism for the exhumation of the Amritpur Granite Body (AGB) and the tectonic movement history along the MBT (Fig 2a). Furthermore, the timing of the tectonic activity along the MBT and its role in the exhumation of the AGB are explored. The study focused on two different locations where the Amritpur Granite is in direct contact with the Siwalik rocks along the MBT. The apatite and zircon Fission-Track (AFT/ZFT) ages range between 11.3 Ma and 14.7 Ma with a mean of 13.4 Ma, 12.4 Ma, and 15.4 Ma with a mean of 13.9 Ma, respectively. Mean AFT and ZFT ages of the AGB have similar age trends from the MBT to the Salari Thrust, which indicates that the AGB was rapidly uplifted and exhumed along the MBT from the basement at a depth of ca. 8-10 km during the middle Miocene (ca. 14-13 Ma). Whilst, the AFT ages of the sandstone samples from the contact zone of AGB and middle Siwalik (MBT's footwall side) are completely reset, and age ranges between 4.4 Ma to 5.5 Ma with a mean of ~5.0 Ma, which clearly revealed the evidence of the tectonic reactivation of the MBT during Pliocene-Quaternary period (Fig.2b, c). Similarly, the morphometric trends suggest that the AGB has a lower erosion susceptibility than the rocks available on the northern side of AGB. Furthermore, an aggregated map and morphometric index revealed that the AGB has aligned along the regional faults (i.e., MBT and Salari Thrust), which also indicates the demarcation of the dendritic drainage pattern of the watershed with low susceptibility to erosion. Moreover, the scattered pattern of seismicity data also indicates that the tectonic activity along the MBT has almost ceased after the Pliocene-Quaternary period. Based on the morphometry, field evidence, and FT thermochronological age data, this study envisages that the AGB was exhumed to the surface from the basement as 'Tectonic Slivers' during the development and reactivation of the MBT between Miocene to Pliocene period (Fig. 2d).

Geochemical Study of the Banjar mafic dyke

The Kullu-Rampur Window zone of Himachal Pradesh comprises metavolcanics, dykes, metasedimentaries, and granite-gneisses of the Paleoproterozoic Rampur-Larji group and Bandal-Jeori-Wangtu complex. Although these metavolcanic and dykes are present as interbedded with phyllites and quartzites, the lack of adequate geochemical and radiometric studies put serious constraints on evaluating the evolutionary pattern of mafic magmatism in this terrain and their possible tectonic implications. Therefore, a preliminary study has been carried out using petrological, major, and trace element geochemical data of mafic dykes of the Banjar Formation. Petrography indicates a typical metabasalt with porphyritic and interseptal textures marked by phenocrysts of clinopyroxene, plagioclase, and amphibole, as well as a groundmass that has undergone metamorphism ranging from greenschist to lower amphibolite grade. Major, trace and rare earth element compositions of these rocks are characterized by low-medium SiO_2 (47.89-49.73 wt%), MgO (~10 wt%), Mg# (37-47), Nb (2.5-4.2 ppm), Zr (39-60 ppm), Th (0.69-2.12 ppm), and Rb (2-17 ppm) suggesting fractional crystallization, minor crustal contamination and evolved nature of the basaltic parent melts possibly derived from sub-continental lithospheric mantle. They exhibit flatLight Rare Earth Elements (LREE), enrichment of Large-Ion Lithophile Elements (LILE) (except Nb), depletion of High Field Strength Element (HFSE), and negative anomalies at Zr and Ti that are consistent with the magmatic regime of a subduction zone. The high Nb content and positive Nb anomalies of the rocks are attributed to the inflow of asthenospheric melts containing old recycled subducted slab components and/or fusion of subducted slab materials caused by the upwelling of the hot asthenosphere. Their low Ce/Y (<1), Dy/Yb (<2), and Gd/Yb (~1.5) contents, as well as the Sm/Yb and La/Sm ratios, indicate a depleted mantle source with 8%-15% mantle melting at depth, corresponding to spinel to garnet lherzolite. According to trace element ratios and their relationship, the studied rocks developed under an arc-tholeiitic tectonic regime. These findings lead us to the conclusion that the mafic dykes from the Banjar Formation may represent a Palaeoproterozoic mafic intrusive activity in the northwest Himalaya during the Columbian Supercontinent.

Behaviour of fluid inclusions in the barite hosted by quartzite

Barite is an industrial mineral hosted within Neoproterozoic Nagthat quartzite rocks of the Outer

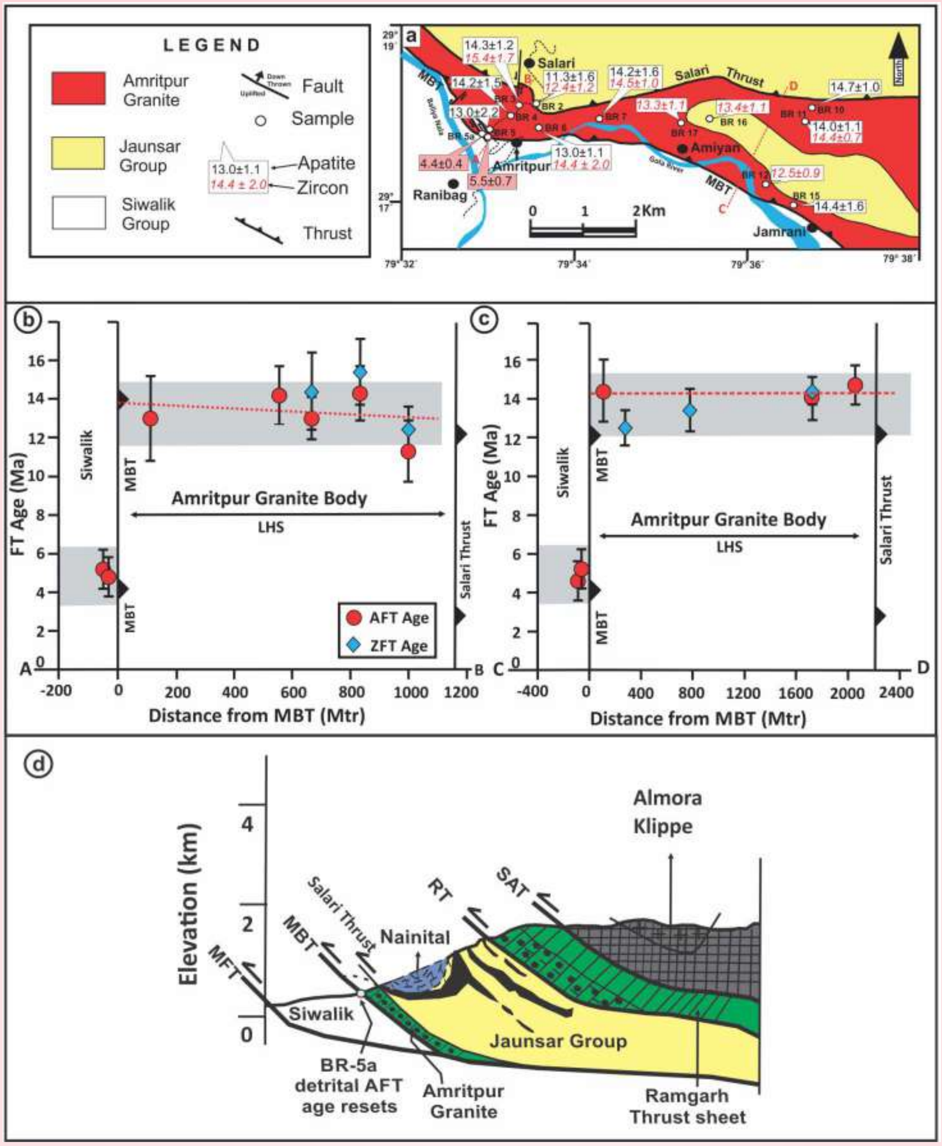


Fig. 2: (a) Detailed geological map around the Ranibag–Amritpur–Amiyan–Jamrani section along with AFT/ZFT ages of samples collected from the AGB area (after Kumar et al. 2006; Shah et al., 2012; Singh & Patel 2022), (b–c) AFT/ZFT ages vs horizontal distance from the MBT plots along two traverses (A–B and CD) across the AGB, (d) Emplacement mechanism of Amritpur Granite as 'Tectonic Silver' from the basement as a sandwich between MBT and Salari Thrust during Mid Miocene (i.e. 14–13 Ma).

Lesser Himalaya. A brief account is presented here, emphasizing their genesis. Barite mineral textures, fluid inclusion, sulfur, and strontium isotopic studies have helped in genetic understanding. In the present study, a fluid inclusion proxy has been applied in a barite mineralization study. Fluid inclusion studies have been carried out on the Nagthat siliciclastics and barite from the Tons Valley to determine their genesis during the Proterozoic and their recrystallization during exhumation. Barite ($BaSO_4$) is the main barium (Ba) ore mineral and is characterized by high density (4.2–4.7 g/cm^3) and low hardness (2.5–3.5). It occurs as lenses and pockets in the Nagthat formation of siliciclastic rock in the Tons River valley area.

Barite and siliciclastic Nagthat quartzite had undergone deformation, which is seen in the photomicrographs. Two phases of deformation are evident: firstly, they exhibit detrital quartz, and secondly, they consist of deformed grains of barite and recrystallized quartz grains. The fluid inclusion study represents low to medium salinity, suggesting changes in the marine environment during the deformation/diagenesis period.

ACTIVITIES

Activity: 1B

Mantle upwelling, fluid circulation, metasomatic processes-Implications on fluid-rockinteraction

(Koushik Sen, S.S. Thakur, Saurabh Singhal, Aditya Kharya, C. Perumalsamy and Pramod Kumar Rajak)

Tectonic evolution of Higher Himalayan Crystalline Sequence, Dhauliganga Valley, Garhwal Himalaya

The Higher Himalayan Crystalline Sequence (HHCS) of Dhauliganga Valley, Garhwal Himalaya, has been studied in terms of the metamorphic aspect. The HHCS has been divided into three litho units, i.e., Joshimath Formation, Pandukeshwar Formation, and Badrinath Formation, with increasing structural levels. The study shows that the HHCS has undergone metamorphism from kyanite to sillimanite–K–feldspar grade with increasing structural level. The metamorphic temperature gradually increases from 646ºC at the lower structural level to 800ºC at the upper structural level, whereas, the pressure decreases from 10.3 kbar to 5.5 kbar from the lower to middle structural level and then increases to 10.2 kbar at the higher structural level (Fig. 3). The textural evidence of partial melting has observed in the Badrinath Formation. Both muscovite dehydration melting and biotite dehydration melting reactions are responsible for the partial melting in the Badrinath Formation. The P–T pseudo section modeling approach suggests 15 mole% partial melting in the Badrinath formation. In Dhauliganga Valley, a metamorphic discontinuity known as the Badrinath Shear Zone (BSZ) has been demarcated within the Badrinath Formation. The BSZ discontinuity is demarcated on the basis of the following petrological and geochronological criteria: (1) lower *P–T* conditions of peak metamorphism in the lower HHCS compared to the upper HHCS; (2) distinct decompression *P–T* trajectory in the upper HHCS; (3) a sharp decrease in geothermal gradient (T/depth ratio) from the lower to upper HHCS; and (4) older exhumation age (22–18 Ma) for the upper HHCS (Metcalfe, 1993; Sen et al., 2015; Iaccarino et al., 2017) and younger exhumation age (9–6 Ma) for the lower HHCS (Metcalfe, 1993; Montemagni et al., 2019).

The position of the BSZ in the Dhauliganga Valley proposed here differs from that recognized in the Alaknanda Valley by Benetti et al. (2021). In this study, the discontinuity occurs within the Badrinath Formation, whereas Benetti et al. (2021) located it between the Badrinath and Pandukeshwar Formations. The study by Benetti et al. (2021) was confined to the lower Badrinath Formation and, thus, did not incorporate thermo–barometric constraints from the upper Badrinath Formation. Benetti et al. (2021) reported a decrease in pressure and uniformity of temperature upsection across the BSZ in the Alaknanda Valley, which implies that the geothermal gradient increases upsection across the discontinuity. On the other hand, the results from the Dhauliganga valley show a sharp increase in both *P* and *T* and a decrease in geothermal gradient upsection across the proposed position of the BSZ.

The BSZ divides the HHCS into lower and upper HHCS. The upper HHCS shows a clockwise *P–T* path with decompression trajectory from kyanite to sillimanite stability field. Corona texture of plagioclase around relict kyanite in the uppermost part of the Badrinath Formation indicates decompression following peak metamorphism. The decreasing trend of P–T conditions of peak metamorphism and younging of metamorphic ages southward from the upper to lower HHCS is compatible with the critical taper model for the exhumation of the HHCS. A tectonic model for the evolution of the HHCS in the Dhauliganga Valley is presented in figure 4.

Tectonic evolution of the Zildat ophiolitic mélange elucidated through pseudo section modeling and fluid inclusion analysis

The Zildat ophiolitic mélange lies in the eastern part of Ladakh and represents the part of the Indus Suture Zone. This ophiolitic mélange is constituted of low–grade metasediments, ultramafic rocks, and exotic limestone blocks. The exotic blocks are comprised of calcite, which shows various types of twinning patterns that indicate dynamic recrystallization up to 300°C.

The $\delta^{13}C$ values of the exotics in ISZ ranged between 2.1 and 4.3 ‰ VPDB (with an average of 3.2 ±1.1‰ VPDB). This carbon isotopic composition was adjacent to that of the global seawater of the Permian Time. The fluid inclusion preserved in the exotic blocks indicates that they were formed at a depth of 13 Km. It suggests that the exotic carbonates are of deep marine water in origin. The enriched stable $\delta^{13}C$ ratio of exotic blocks indicates a good population of marine invertebrates with calcareous shells and their fast and continuous organic carbon during this period. These carbonates originate from deeper marine conditions and are further deposited as a platform in the Zanskar shelf.

The exotic block of limestone in the Zildat ophiolitic mélange may be emplaced by extensional faulting and break–up of the platform edge of the Zankar platform. Such a phenomenon was also observed for the

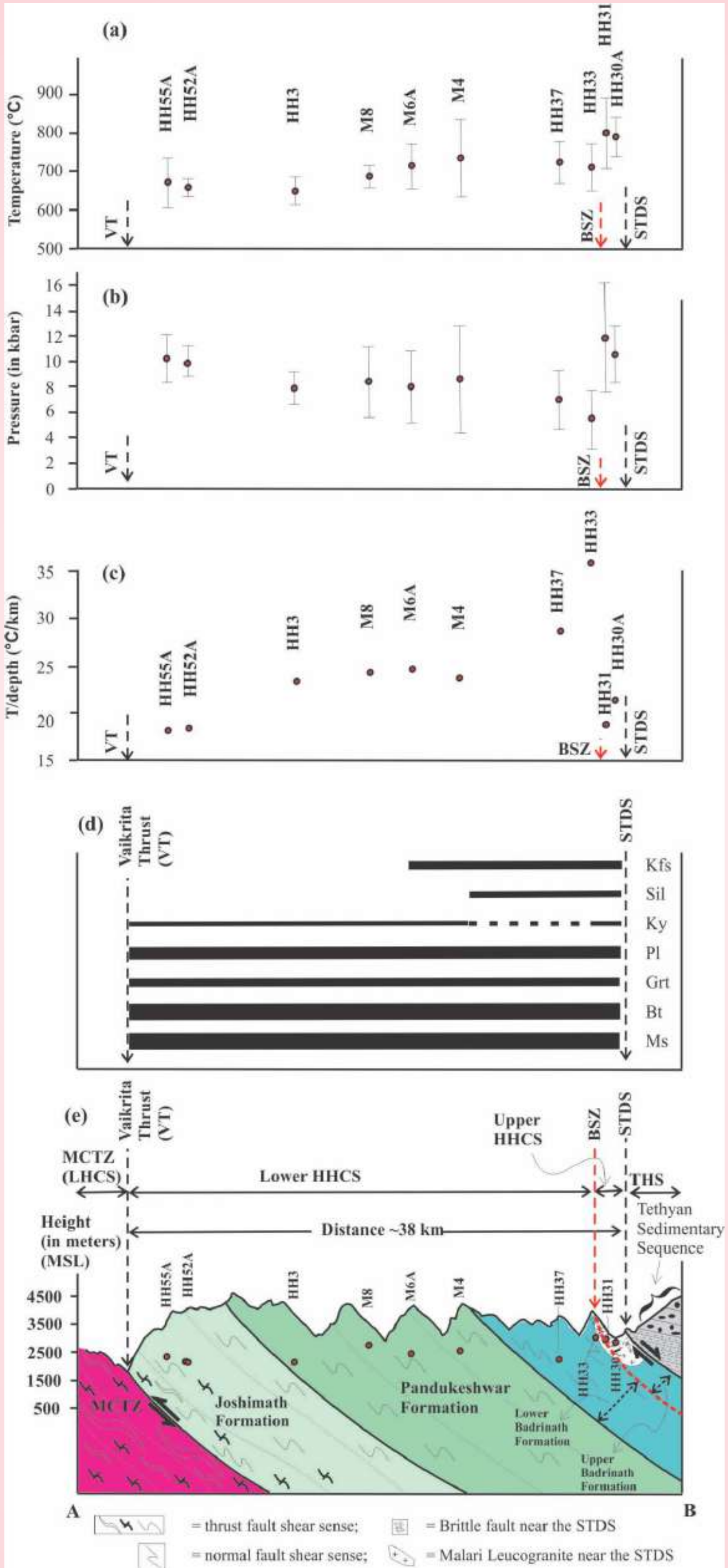


Fig. 3: Diagram showing temperature variation (a), pressure variation (b), T/depth variation (c), mineral stability (d), and cross-sectional view (e) of the HHCS in the Dhauliganga valley. *P–T* values are from the average *P–T* calculation method. BSZ (Badrinath Shear Zone) marked in (e) is after Benetti et al. (2021), who proposed it in the HHCS in the Alaknanda valley.

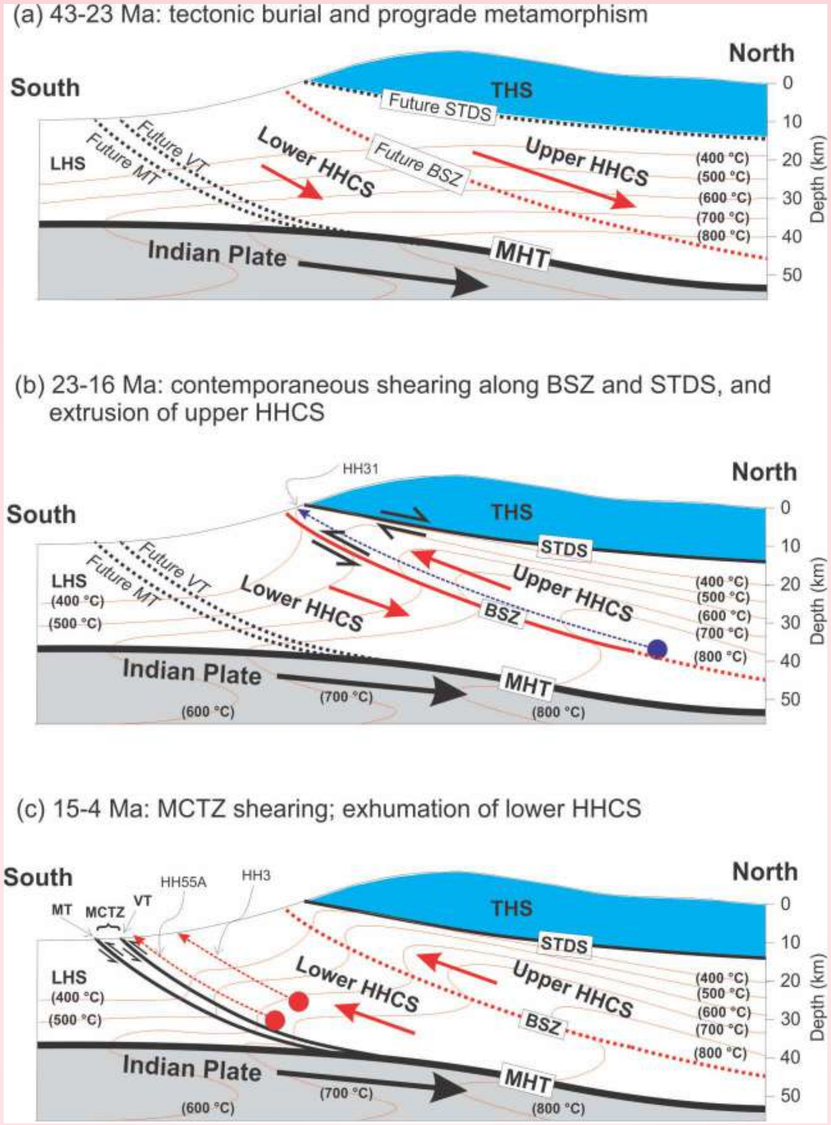


Fig. 4: Schematic diagram showing different stages of tectonic evolution of the HHCS in the Dhauliganga valley. (a) 43–23 Ma: tectonic burial and prograde metamorphism; (b) 23–16 Ma: contemporaneous shearing along BSZ and STDS, and extrusion of upper HHCS; (c) 15–4 Ma: MCTZ shearing; exhumation of lower HHCS. Abbreviations: BSZ: Badrinath Shear Zone; MHT: Main Himalayan Thrust; STDS: South Tibetan Detachment System; THS: Tethyan Himalayan Sequence; VT: Vaikrita Thrust; MT: Munsiari Thrust; MCTZ: Main Central Thrust Zone.

ACTIVITIES

exotic blocks present in western Ladakh (Robertson and Degnan 1993). Two types of fluid inclusions were observed in these exotic blocks: carbonic and aqueous–carbonic entrapped between 435°C and 370°C at 386 to 323 MPa and advocates for deep-seated marine carbonates and exhumed from 13 km depth below the sea surface, which got deposited in the Zanskar shelf. The exotic blocks in ophiolitic melange were probably derived from the Zanskar shelf (platform), having salinity between 20.37 and 11.22 wt % NaCl, similar to the Permian time seawater (Fig. 5).

Standardization and chronology obtained from U-Pb isotopic analysis of zircon and application in understanding pre- and syn-Himalayan tectonics

The U-Pb zircon geochronology for spatial resolutions of ≥ 10 µm is standardized for three different reference standards, namely Z91500, GJ-1, and Plesovice standards, using different LASER pulses. The percentage offset and precision are better than 2–3% for all spatial resolutions of 15 µm for 150 LASER pulses. However, for 10 µm spatial resolution, the percentage offset is greater than 4% due to large variations in the percentage DHF (Down-Hole Fractionation) of the

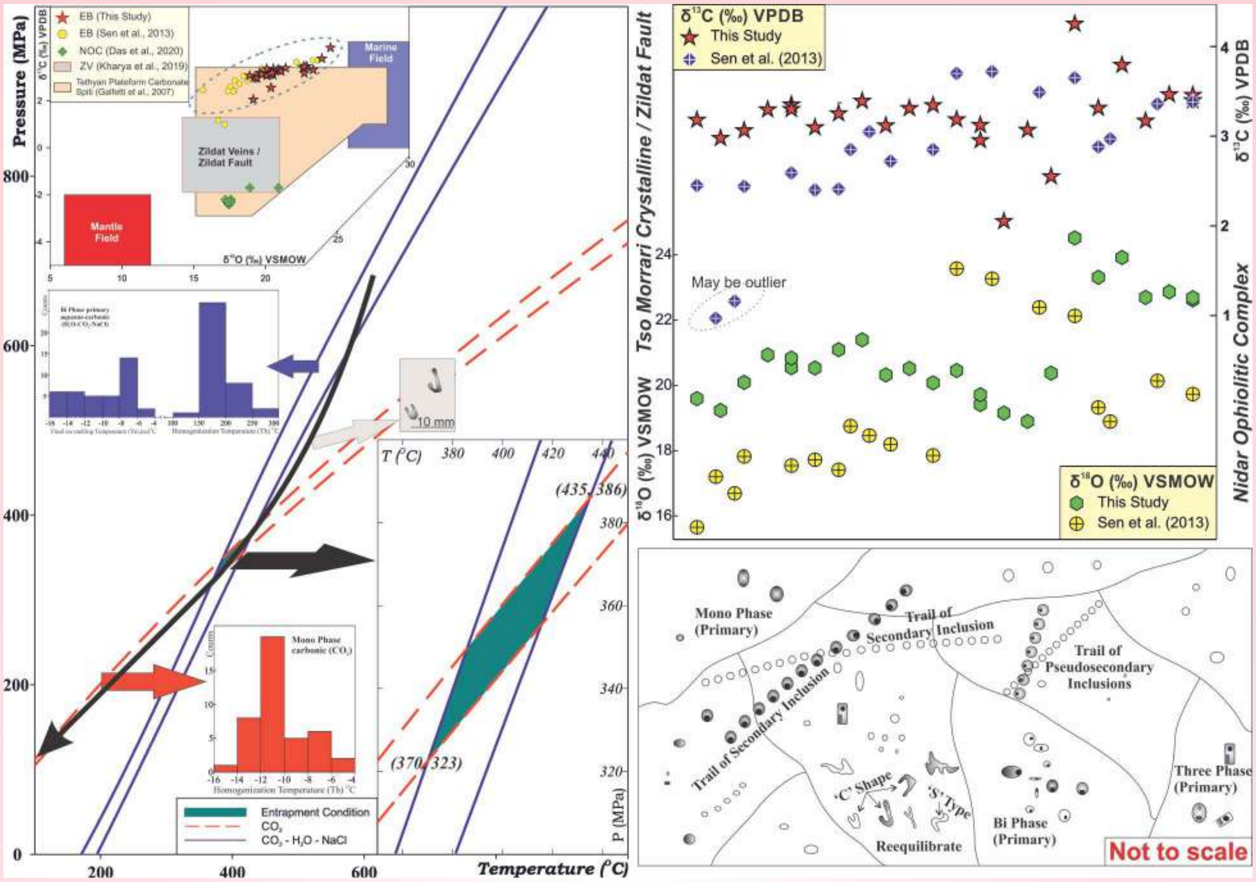


Fig. 5: P–T diagram showing isochores of primary carbonic (CO_2) Monophase (Group–Ia) and aqueous-carbonic (H_2O–CO_2–NaCl) Biphase (Group–IIa) inclusions along with their histograms and fluid inclusion textures give at left side. The intersection of carbonic and aqueous-carbonic isochore defines the entrapment conditions for the primary fluids. The number above the isochore shows the density of various isochores. Further, the Distribution of stable isotope ($\delta^{13}C$ and $\delta^{18}O$) data set between Tso Morrari crystalline and Nidar Ophiolitic Complex for this study along with Sen et al.(2013) is given at right upper side. A Schematic diagram of various types of fluid observed is given at the bottom right.

reference standard and standard used for validation. It is also observed that the DHF pattern for two different zircons is not the same, even when all ablation parameters are the same. To reduce the difference in % DHF variation between primary and secondary standards, the number of laser pulses was reduced, and validated this approach for higher spatial resolutions before applying it to 10 µm spatial resolution. For spatial resolutions > 15 µm, there is no degradation in % accuracy and precision. However, the internal precision of the individual analyses has decreased slightly but is still acceptable. Following validation, this approach was applied to a spatial resolution of 10 µm and processed the corresponding U–Pb data for 75 LASER pulses. The difference in percent DHF between primary and secondary standards is now within the range, and the percent offset for all three standards is less than 2%, which is acceptable for zircon geochronology.

The Wangtu Granite Gneiss is a Paleoproterozoic body exposed along Sutlej Valley, Himachal Himalaya. In this work, scientists revisited the body for the U–Pb zircon age by LA–MC–ICP–MS and obtained two major clusters at 1876 and 1967 Ma, respectively, which is in conjuncture with earlier published work. However, all U–Pb ages show significant Pb–loss. The Pb–loss modeling has been applied for the first time in the Himalayas to understand the post-crystallization thermal events. The modeling indicates two age clusters and the thermal event starts around ~500 Ma (Cambro–Ordovician) and peaks during ~@45Ma (Cenozoic). This indicates thermal events related to the pre-collision and post-collision of indenting the Indian Plate with the Eurasian Plate.

New U–Pb zircon geochronology from the Jutogh Thrust (JT) sheet of eastern Himachal Pradesh, NW

Himalaya, in order to explain the tectono-magmatic environment in which they formed. The zircon U–Pb ages of granite range between 883.0 ± 15.0 Ma and 1260.0 ± 10.0 Ma, with a consistent peak of ~925.0 Ma. The available zircon U–Pb ages of the JT sheet range between 550–2750 Ma. The magmatic nature of zircons, with two peaks of ~825 Ma and ~910 Ma, suggests that episodic magmatic processes have taken place during the Neoproterozoic. This study revealed that the Higher Himalayan Crystalline Sequence was a meta-sedimentary sequence and was deposited in an active margin set-up of the northern edge of the Indian Plate.

Activity: 2A

Subsurface interpretation – Development of Machine Learning approach to geoscientific data from Himalaya and adjoining regions

(Kalachand Sain, Priyadarshi Chinmoy Kumar, Bappa Mukherjee, and Jitender Kumar)

Sedimentary basins within fold-and-thrust belts preserve the structural record of complex deformations and are essential to many orogenic systems worldwide. One of the components of such deformations is strike-slip tectonics. This research uses high-quality, three-dimensional seismic reflection data to investigate the geometry and kinematics of strike-slip faults developed within a geologically complex region in the Upper Assam foreland basin, NE India. The faults in the basin have a dominant NE-SW trend, with most faults in the SE and SW parts exhibiting sinistral strike-slip. These lateral movements are evidenced by extensional horsetail splay faults, negative flower structures, and minor transfer faults (Fig. 6).

The displacement profiles of the strike-slip faults also reveal complex segmentation, linkage, and mechanical interactions at different structural levels, indicating their prolonged histories and development. These findings contribute to our knowledge of sedimentary basins within fold-and-thrust belts and their structural records of complex deformations.

Subsurface fluid flow: an example from the onshore Ganga basin

Subsurface fluid flow involves the migration of fluids from source to surface through a wide range of geologic structures. Their study is significant in sedimentary

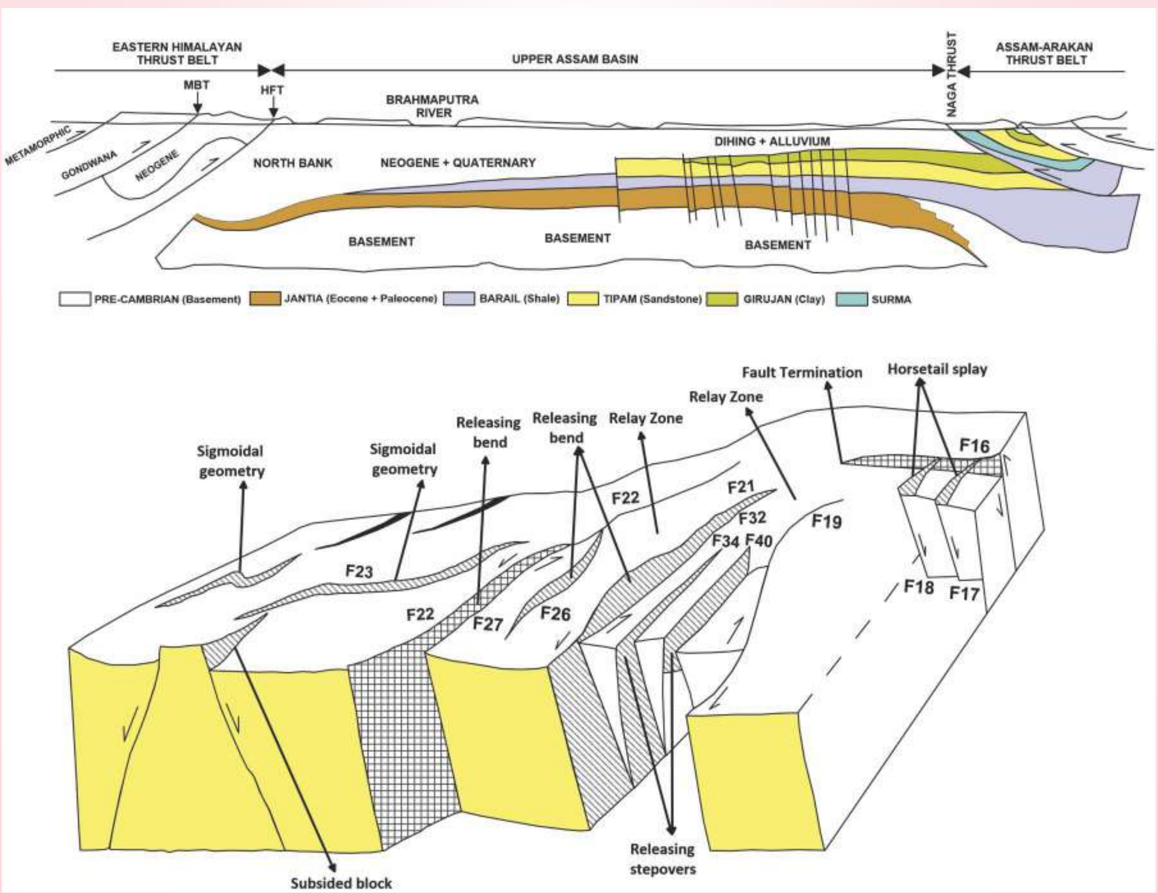


Fig. 6: 3D subsurface block diagram shows the geometry and pattern of studied faults.

basins, as they play a crucial role in unlocking potential hydrocarbon plays. Such research mainly focuses on the marine environment that uses high-resolution reflection seismic data to unravel fluid flow systems but is very limited to on-land and remains poorly documented. This research uses high-quality three-dimensional (3D) seismic reflection data to explore fluid flow activity onshore in the petroliferous Indo-Gangetic peripheral foreland basin. Seismic attributes are effectively used to describe subsurface fluid flow structures from seismic reflection patterns. Furthermore, responses of different seismic attributes are amalgamated through an artificial neural network to design a new hybrid attribute called Fluid Cube to elucidate a realistic visualization of subsurface fluid migration routes. The Fluid Cube hybrid attribute highlighted that subsurface fluid migrates (Fig. 7) vertically from the Neoproterozoic strata through minute fracture networks and weaker strata of the Tertiary sequences. The results of a surficial geochemical anomaly in the study area corroborate well with these observations.

Buried carbonate reefs interpreted using neural nets: an example from offshore Australia

A carbonate build-up or reef is a thick carbonate deposit consisting of mainly skeletal remains of organisms that can be large enough to develop a favorable topography. Delineation of such geologic features provides important input in understanding the basin's evolution and petroleum prospects. A new attribute called the Reef Cube (RC) meta-attribute is computed by fusing suitable seismic attributes that are characteristics of the reef through a supervised machine-learning algorithm (Fig. 8). The Reef Cube meta-attribute has efficiently captured the anatomy of carbonate reef buried at ~ 450 m below the seafloor from high-resolution 3D seismic data in the NW shelf of Australia. The novel approach not only picks up the subsurface architecture of the carbonate reef accurately but also accelerates the process of interpretation with a much-reduced intervention of human analysts.

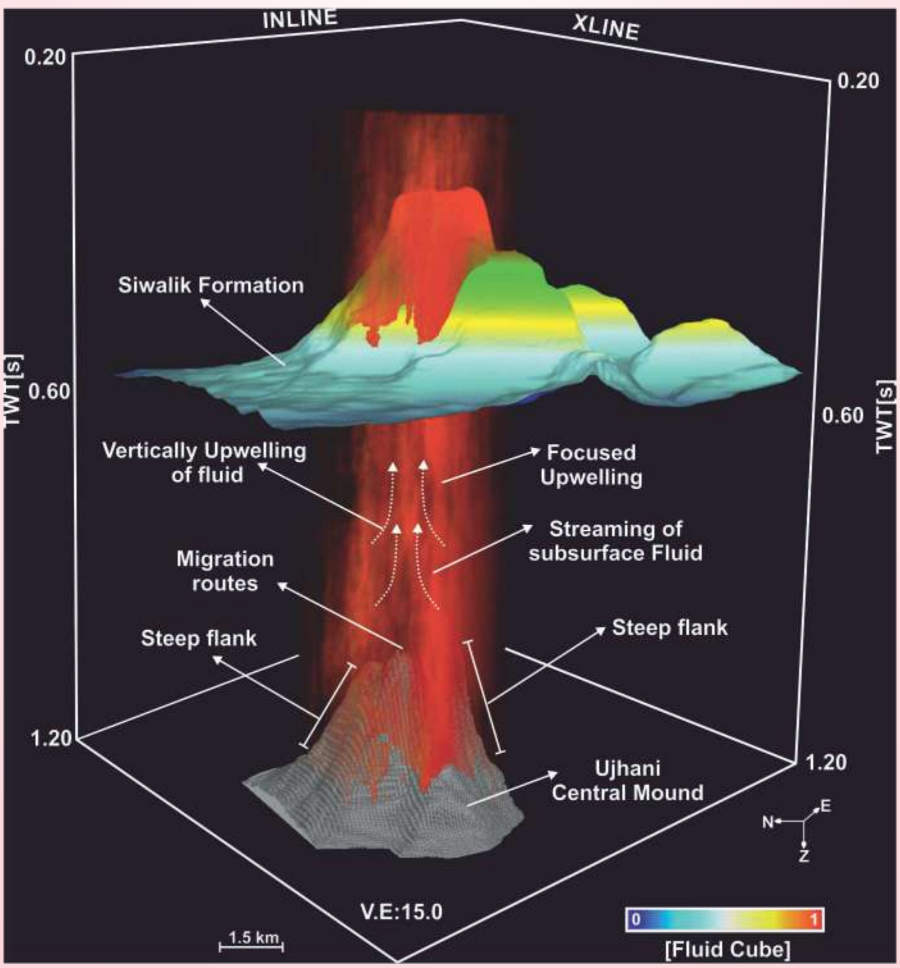


Fig. 7: 3D view of subsurface fluid expulsion captured using Fluid Cube hybrid attribute.

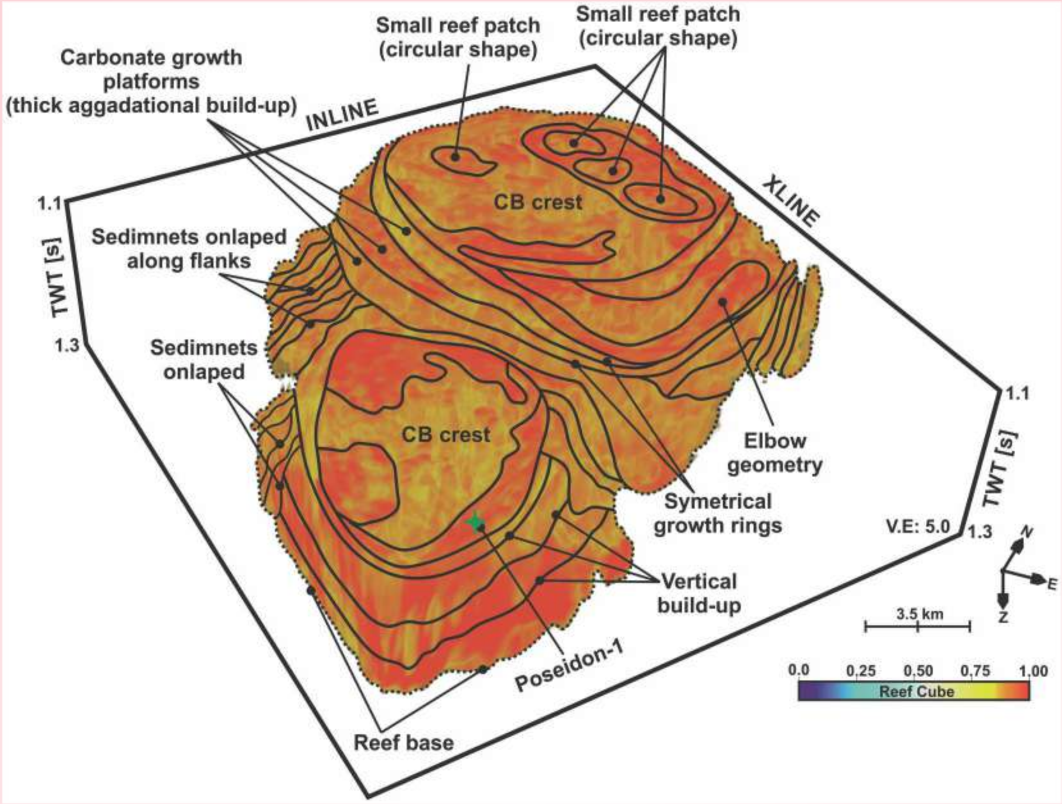


Fig.8: 3D view of buried carbonate reef as elucidated by the reef cube meta-attribute.

Appraisal of reservoir porosity using a machine learning approach

Porosity is an essential petrophysical property that determines the amount of fluid present within the rock, which includes oil, water, and gas. It measures the capacity of the reservoir to engage the fluid within the pore spaces of the rock and has a howling effect on reservoir characterization, estimation of reserves, and production forecasting. Estimation of reservoir porosity is essential for the exploration of hydrocarbons in sedimentary basins, which are affected by several factors such as the burial depth, lithology changes, sedimentary environment, and diagenetic degree.

Hence, a detailed understanding of reservoir porosity is essential for estimating potential economic reserves and developing an explored hydrocarbon field. A case study in the Dibrugarh seismic survey region of the Upper Assam foreland basin, NE India has been carried out to characterize the properties of subsurface reservoirs using an ensemble-based machine-learning approach. The case study showed that the subsurface-targeted intervals (i.e. the Kopili–Barail–Tipam formations) contain plausible porous zones with varying porosity of 0.28–0.42 (Fig. 9). The analysis of the results from this research further showed that the Miocene intervals (Tipam litho-units) are favorable leads for the exploitation of hydrocarbons. The workflow designed for this study can be effectively used for appraising subsurface reservoir properties from onshore/offshore basins worldwide.

Fluid contact zones in subsurface reservoir

Delineating fluid contact boundaries, for example, gas–oil contact (GOC), gas–water contact (GWC), and oil–water contact (OWC), remain crucial for characterizing a hydrocarbon reservoir and monitoring the movement of fluids within the reservoir system. Fluid contacts within a reservoir can vary either because of compartmentalization by faults, lithological variations, hydrocarbon fill history, or changes in the hydrodynamic activity of fluids. Their detailed interpretation is significant for estimating potential reserves and developing an explored hydrocarbon field. However, while attempting to delimit fluid contact boundary from seismic reflection data, it becomes intriguing for an interpreter to interpret a particular reflection event corresponding to a contact boundary of fluids or rock types. Hence, such a problem very often remains challenging. A case study in the Chandmari seismic survey region of the Upper Assam foreland basin, NE India for delimiting fluid contact within

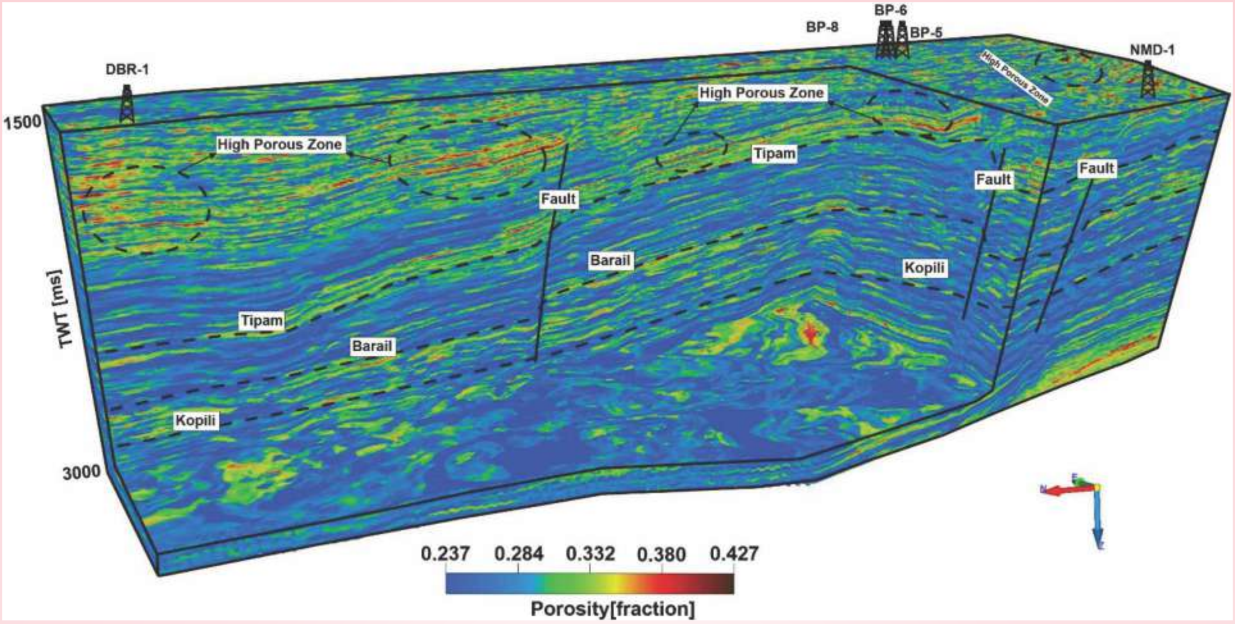


Fig. 9: The porosity volume highlights variation in porosity within the studied interval. High porous zones are marked with black oval. The well locations are marked using a black tripod.

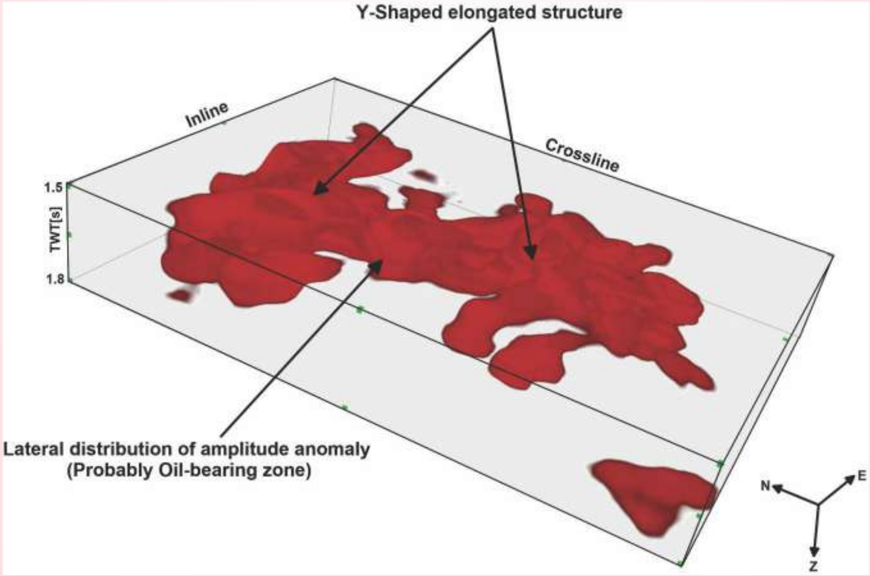


Fig.10: 3D view highlighting the laterally elongated structure (probably y-shaped) of the amplitude anomaly within the reservoir.

subsurface reservoir. Fluid contact analysis indicated that the SW part of the Tipam reservoir (Fig. 10) contains hydrocarbon fluids separated by water underneath. The dominant trend of this contact is observed to be NE–SW within the reservoir. A correlation with the petrophysical logs of the drilled wellbore within the survey region further confirms the presence of oil-bearing zones underlain by water in the SW part of the Tipam reservoir.

Prediction of geophysical logs at missing data intervals in Lakadong Therria formation of the Bhogpara Oil Field, Upper Assam basin

In the field of reservoir characterization and management, the completeness and accuracy of geophysical logs are pivotal. Often, these logs are marred by missing segments or distortions due to logistical and environmental challenges in boreholes.

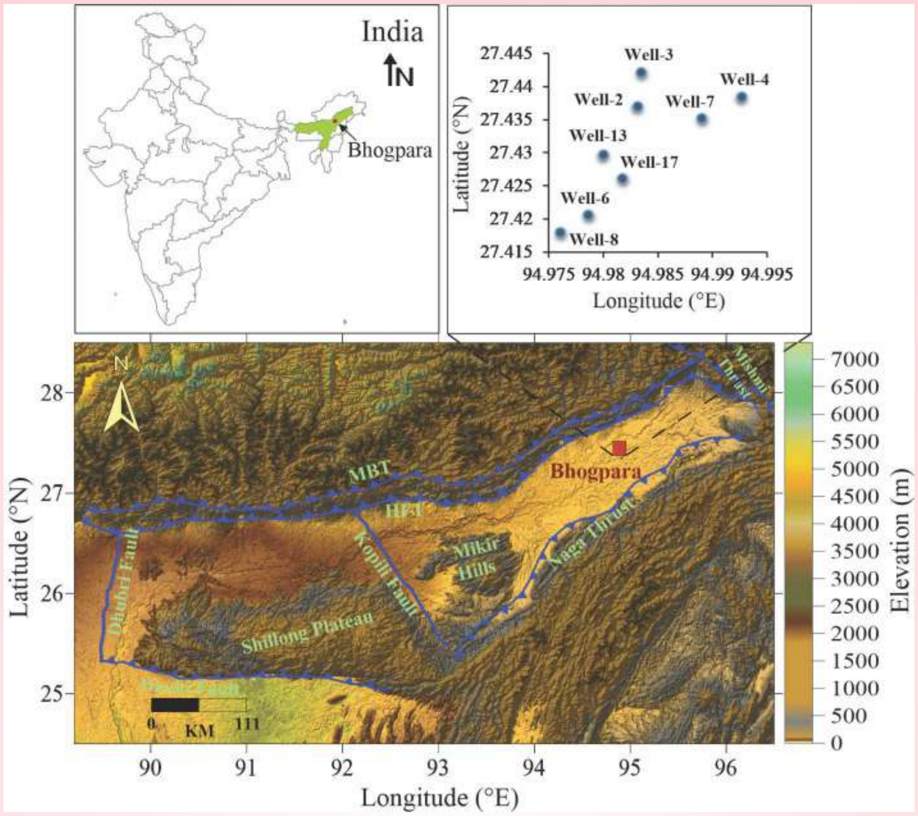


Fig. 11: Geographical location of the Bhogpara oil field in the Assam–Arakan basin with the latitude and longitude of specified wells that have been used for this study.

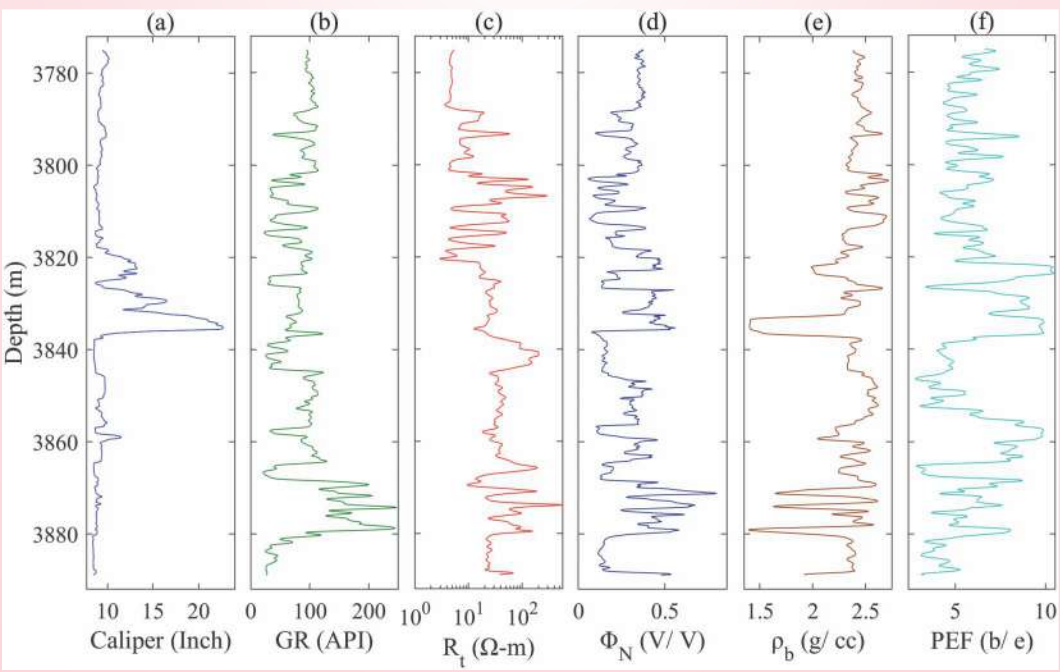


Fig. 12: Wireline log responses at well 2: (a) caliper, (b) gamma-ray (GR), (c) laterolog deep resistivity (R_t), (d) neutron porosity (Φ_N), (e) bulk density (ρ_b), and (f) photoelectric factor (PEF) log.

Addressing this, the present study introduces an innovative, synergistic method combining log data preconditioning with advanced machine learning (ML) techniques including k-nearest neighbors, support vector machine, decision tree, random forest, extreme gradient boosting, Gaussian process regression, and artificial neural networks. Focus has been made on uncovering the complex, nonlinear relationships inherent in geophysical logs through a robust analysis involving a correlation matrix and F-test for predictor significance and ranking. This approach has been applied to the wireline logs of the Lakadong–Therria Formation in the Bhogpara oil field, India, to demonstrate the effectiveness of ML in reliably predicting missing logs. Notably, the ML models adeptly forecast bulk density (ρ_b) logs using data from gamma-ray (GR), deep resistivity (R_t), neutron porosity (N_Φ), and photoelectric factor (PEF) logs. The high correlation coefficients achieved (over 0.88 in training and 0.85 in testing phases) attest to the accuracy of our predictions. This study not only proves the efficacy of ML in enhancing reservoir analysis but also offers a cost-effective tool for accurately reconstructing any geophysical log, opening the way for more informed decisions in reservoir management.

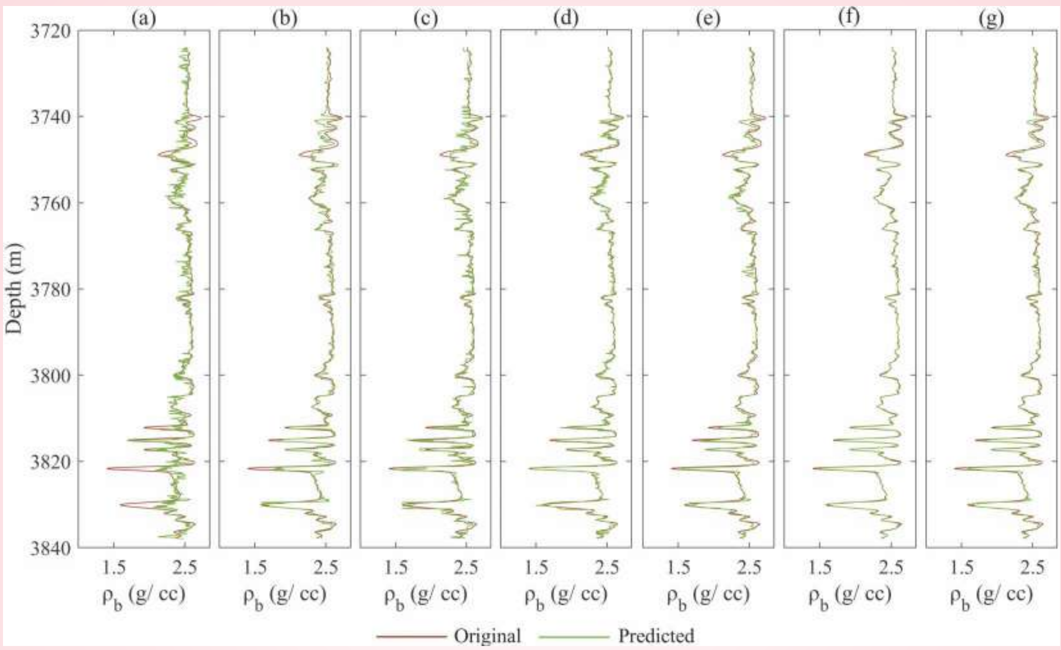


Fig. 13: Overlay of original and predicted ρ_b logs at well 6: (a) original and kNN predicted ρ_b, (b) original and SVM predicted ρ_b, (c) original and DT predicted ρ_b, (d) original and RF predicted ρ_b, (e) original and XGBoost predicted ρ_b, (f) original and GPR predicted ρ_b and (g) original and ANN predicted ρ_b.

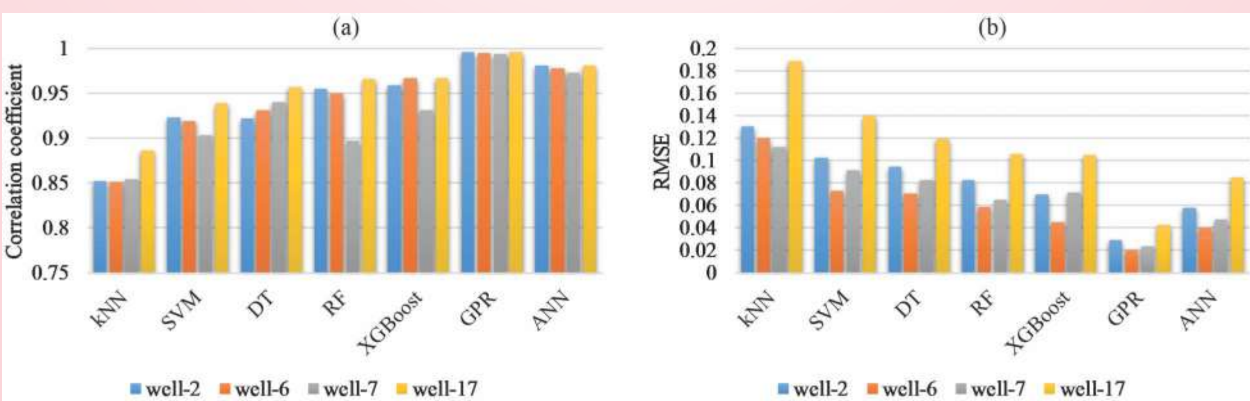


Fig. 14: Shows the accuracy score obtained for each predictive model at the test phase through (a) correlation coefficient (b) root mean square error (RMSE).

ACTIVITIES

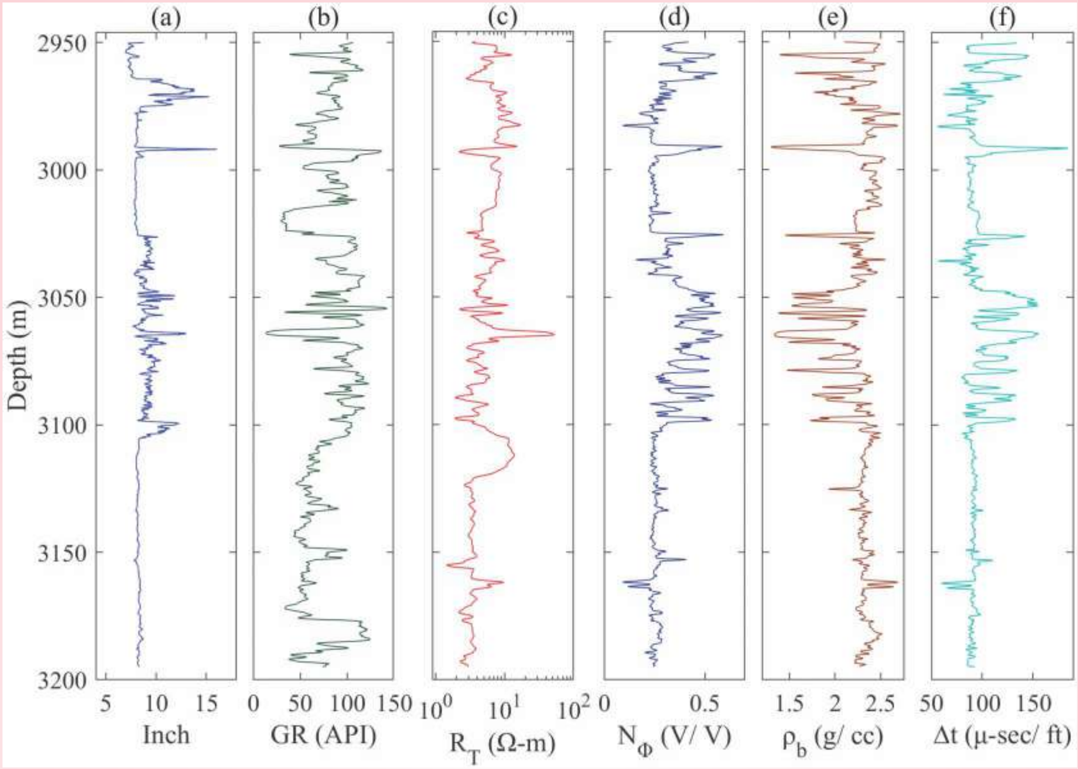


Fig. 15: Wireline log responses at well RDS-83 (a) Caliper log, (b) gamma-ray (GR), (c) resistivity (R_T), (d) neutron porosity (N_Φ), (e) bulk density (ρ_b) and (f) sonic transit time (Δt).

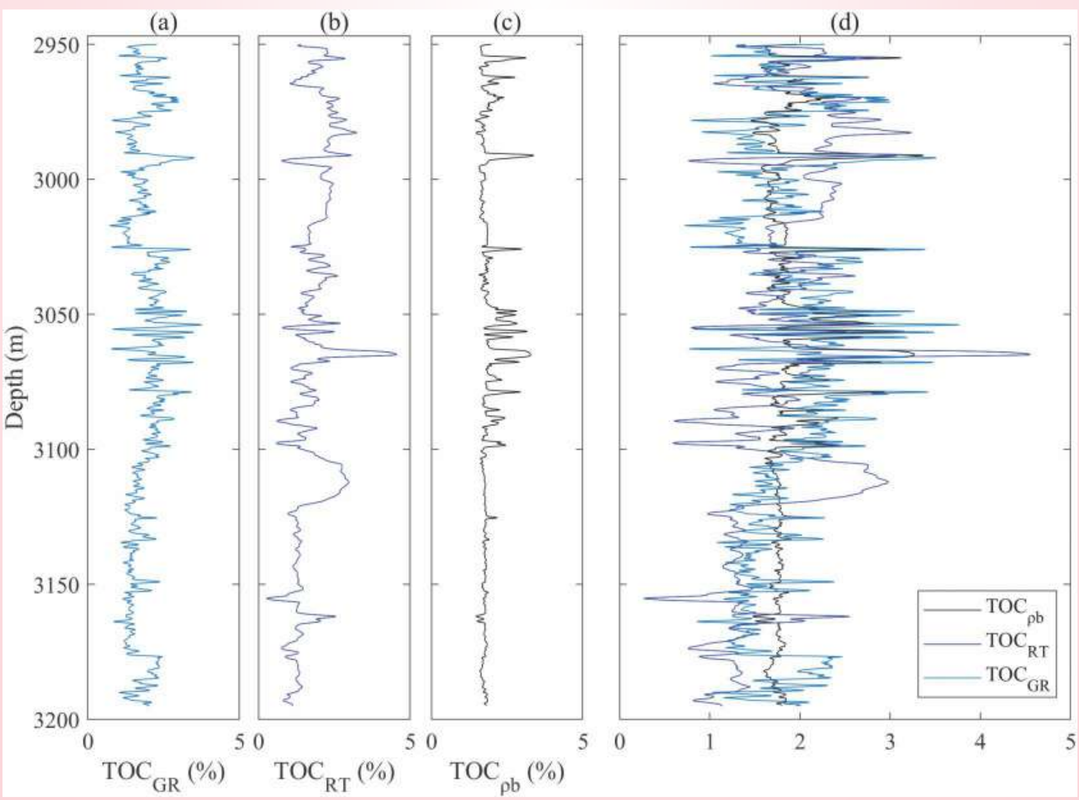


Fig. 16: (a) total organic carbon (TOC) obtained from gamma-ray log, (b) TOC obtained from resistivity log (c) TOC obtained from bulk density log (d) comparison of TOC obtained from gamma ray, resistivity and bulk density logs.

The geographic location of the study area and wells under study are presented in figure11. In the present analysis, the wireline logs (gamma ray, resistivity, bulk density, neutron porosity, and photoelectric factor) from eight wells, situated in the Bhogpara oil field were studied. A totalof eight wells were analyzed, namely wells 2, 3, 4, 6, 7, 8, 13, and 17. The geophysical log responses at well 2 are shown in figure12. Wells 3, 4, 8, and 13, are chosen as training wells based on the data availability and these wells skirt the study region, and rest of the wells 2, 6, 7, and 17 are treated as test wells, where we want to predict the missing log. Subsequently, the model training and validation steps were continued. After reaching a satisfactory level of accuracy in the training phase of the machine learning algorithms, these trained predictive models were deployed to forecast the ρ_b logs using GR, R_t, N_Φ, and PEF logs at the test wells where the ρ_b log was absent. Subsequently, the log data (GR, R_t, N_Φ, and PEF logs) was fed from the test wells into the trained models to predict the ρ_b logs at their respective locations. For example, the ρ_b logs obtained from the ML models at well 6, are presented in figure13. The accuracy of the ML predictive models is assessed through the correlation coefficients and root mean square error (RMSE) values. The correlation coefficients and RMSE values between the actual and predicted ρ_b logs at the test wells are shown in figure14.

Computation of Total Organic Carbon (TOC)

To compute the Total Organic Carbon (TOC) the gamma-ray log (GR), resistivity log (R), bulk density log (ρ_b), neutron porosity log (N_Φ), and sonic transit time logs (Δt) have been analyzed. The implemented algorithms along with their analytical steps are discussed below. Presently, the wireline log data have been analyzed from the well RDS-83 using various methods such as the Passey's Delta Log R method, Clay Indicator Method, and Density Log Method. The wireline log responses at well RDS-83 are depicted in figure15. The TOC values estimated using Passey's Delta Log R method, Clay Indicator method, and Density Log method at well RDS-83 are shown in figure16.

Activity: 2B

Geometry and rheological assessment of the MHT, lithospheric flexuring - Implications toward seismogenesis, deep earth processes

(Naresh Kumar, Devajit Hazarika, Gautam Rawat and Vandana)

Shear wave crustal velocity structure beneath Garhwal-Kumaun Himalaya

Noise cross-correlation tomography utilizing the ambient seismic noise data is widely used to characterize the crustal structure. The 3D shear wave crustal velocity structure beneath the Garhwal-Kumaon Himalaya has been obtained using the noise tomography technique. The tectonics of the Garwal-Kumaon Himalaya is characterized by thrusts, tectonic windows, and klippen. The studied region encompasses the Kali River valley in the east to Satluj valley in the west, with the adjoining Indo-Gangetic Plain in the south covering the northern part of the Delhi-Haridwar ridge. The fundamental mode group velocities of Rayleigh waves are extracted from cross-correlation data of 33 broadband seismological stations from a regional seismic network. A total of 374 dispersion curves with a period range of 4–29 s show a group velocity variation between ~2.3 and ~ 3.4 km/s. The shear wave velocity structure of the uppermost lithosphere down to ~50 km obtained by non-linear inversion of the Rayleigh wave dispersion data provides new insight into the geometry of the crust (Fig. 17). A large variation in Vs in the range of ~2.8 to ~4.7 km/s corresponds to a variety of changes in the tectonic deformation, structure, and crustal thickness of the Himalayan wedge. Thick low-velocity sedimentary formations are identified beneath the Indo-Gangetic Plain and the frontal Himalaya. Anomalous low Vs zones are also observed in the mid-crust beneath the Higher Himalaya and southern Tibet, indicating the presence of aqueous fluid zones and/or partial melting. A broad low-velocity zone beneath southern Tibet has been expressed by many previous surface wave tomography studies. The high-velocity anomalies may be correlated with duplex structures beneath the Lesser Himalaya and with lithospheric flexure.

Seismic periodicity associated with strong earthquakes

WIHG has updated the earthquake catalogue of NW Himalaya till 2017, which includes earthquake information from 1500 onwards along with historical records. The largest instrumentally recorded seismic event is the Mw 7.8 Kangra earthquake of 1905, and the list includes 5 major earthquakes ($M \geq 7$) recorded since 1800. After the year 1800, there were 32 earthquakes of more than 6 magnitude, of which the frequent occurrence is in the Garhwal-Kumaon region. Most recently 45 earthquakes have $M \geq 5.5$ occurred since 1960. The recent records of the catalog denote the periodicity of earthquakes in the seismic activity in some parts of the NW Himalaya. In particular, spatiotemporal patterns in the distributions of earthquake occurrence have been identified (Fig.18).

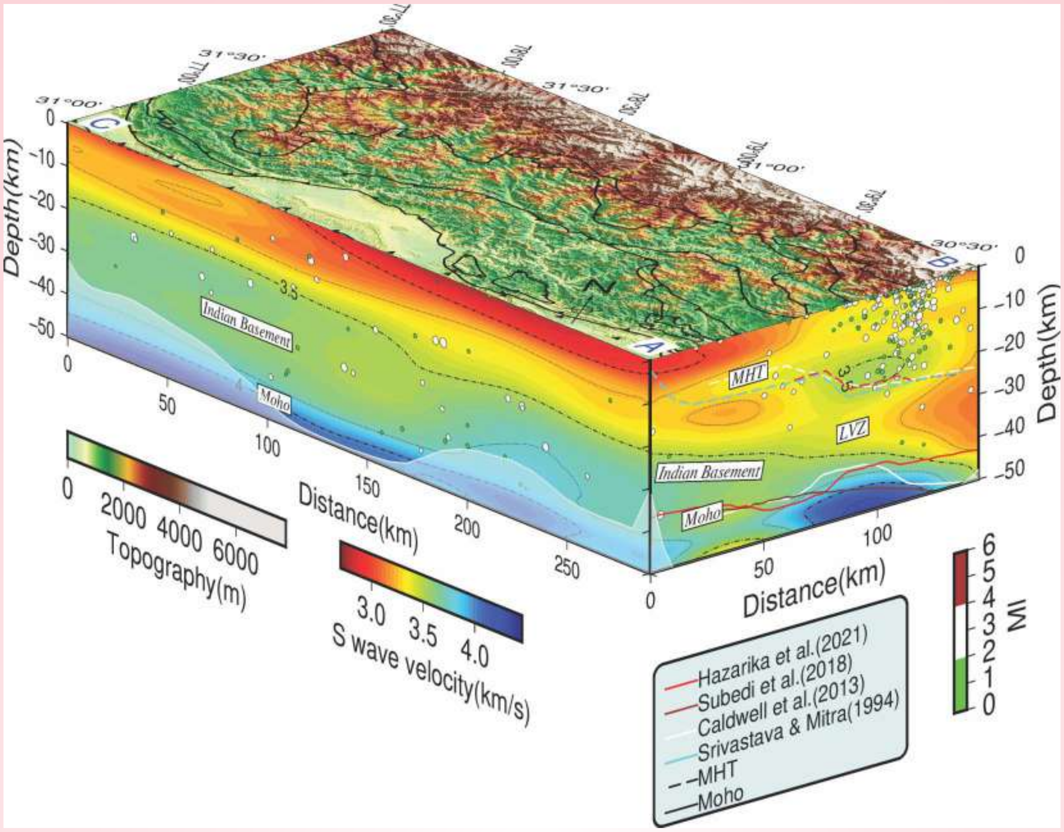


Fig. 17: 3D S-wave velocity variations along two vertical cross-sections (parallel and perpendicular to the Himalayan arc), and earthquakes are projected on cross-sections with a lateral extent of 0.2° to both sides of the vertical slices. Increasing size and colour scale indicate the magnitude of the earthquakes.

Earthquake sequences from 1963 to 2017 and 1991–2017, complete for magnitudes M ≥ 4.3 and M ≥ 3.3, respectively, are used to inspect the spatial b-value variation and hidden periodicities for three different regions. The thrust-dominated tectonic block of the Garhwal–Kumaon Himalaya favours more frequent occurrence of strong (large) earthquakes than the Kangra–Kinnaur sector dominated by nappe tectonics. Accompanied by the well-defined pattern of seismic quiescence-enhancement, the time-evolution periodicities have different behaviour associated with strong earthquakes, namely, the Mw 6.6 Chamoli earthquake of 1999 and Mb 6.6 Uttarkashi earthquake of 1991. An increase in the amplitude of the periodicity in the period range of ~500 days appears ~0.5 years before the mainshock. The pre- and co-seismic periods of the 2012 earthquake of M 5.1 in the Delhi–Haridwar region highlight a strong high-amplitude periodicity in the range of ~500–1000 days. This indicates that monitoring time frequency dynamical spectra in near real-time can serve as a helpful guide in identifying hidden periodicities in earthquake sequences.

Sedimentary thickness and basement geometry of the western part of the Indo-Gangetic Plain and adjoining Siwalik Himalaya

The huge compressive force resulting from the India-Asia collision and the vertical load of the Himalayan thrust-fold belt caused the flexing of the Indian lithosphere. The formation of the Indo-Gangetic foreland sedimentary basin or Indo-Gangetic Plain (IGP), is the consequence of this lithospheric flexing. The IGP is a widespread alluvial Plain of the Ganga, Indus, and Brahmaputra rivers and their tributaries (Fig. 19). The IGP and the Siwalik Himalaya (SH) are highly vulnerable to seismic hazards due to their proximity to the Himalayan Seismic Belt (HSB). The thick sedimentary layers of the foreland basin can amplify seismic waves propagating through it, causing huge devastation. The IGP has experienced rapid urban population growth and infrastructure development in the last two decades and thus the seismic hazard is the most significant and grave concern in the region. Understanding detailed sedimentary and basement structures is crucial for seismic hazard estimation,

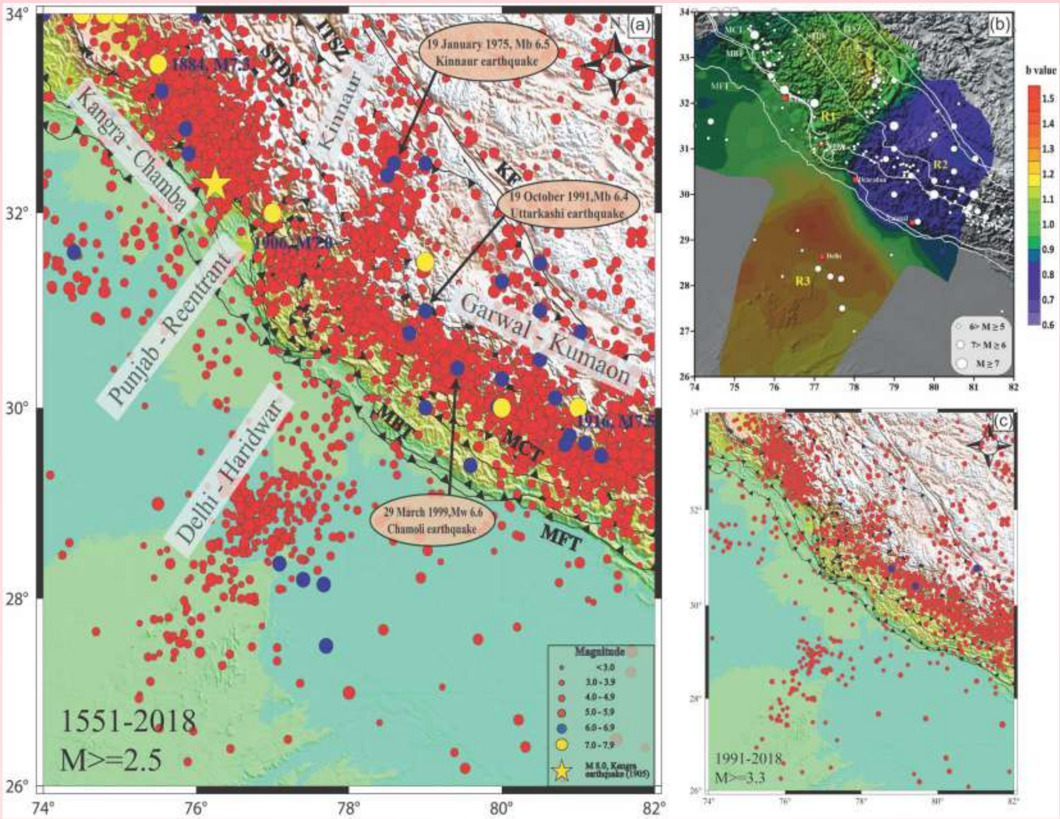


Fig. 18: Results of seismic catalogue of the northwest Himalaya. (a) Distribution of earthquake epicenters, star indicates the location of the devastating M 8.0 Kangra earthquake of 1905. Yellow and Blue circles represent the bigger earthquakes of magnitude range 7.0–7.9 and 6.0–7.0, respectively. (b) Spatial variation of b-value based on earthquake M ≥ 3.3 of recent data of 1991–2017. (c) Recent earthquake activity of M ≥ 3.3 occurred during 1991–2018. Abbreviation. MFT: Main Frontal Thrust, MBT: Main Boundary Thrust, MCT: Main Central Thrust, STDS: South Tibetan Detachment System, ITSZ: Indian-Tsangpo Suture Zone, KF: Karakoram Fault.

micro-zonation, and in designing earthquake resistance structures.

Although several studies have been made in some specific areas/profiles to estimate basement topography in the IGP, a large part of the western IGP (covering Punjab and Haryana Plains) is still unexplored due to the paucity of high-resolution geophysical data. Most of the previous studies are based on field methods, such as gravity and magnetic surveys covering larger areas which provide a regional perspective in contrast to point measurements. Despite previous drilling operations, a comprehensive assessment of basement topography has not been reported. Hence, site-specific geophysical investigations are necessary. In this study, an attempt is made for the first time to characterize the sedimentary structure of the western part of IGP and Siwalik Himalaya based on passive seismological data. The receiver function (RF) inversion using the Neighborhood Algorithm has been carried out at 20 broadband seismological stations (Fig. 19) to estimate the thickness of different sedimentary layers, corresponding Vp/Vs ratio, and shear wave velocities up to a depth of 10 km. The RFs of stations over IGP show typical characteristics of sedimentary basins. Examples of RFs at the Amritsar (AMSR) station are shown in figure 20.

The basement depth in the IGP has been characterized based on 1D velocity models (Fig. 21). The estimated basement depths suggest an increase in sedimentary thickness from southwest to northeast. The southernmost stations ZIND and JAKH show shallow basement depths (~1.5–1.7 km) with extremely low Vs (~0.4–0.5 km/s) and high Vp/Vs values (~2.75–2.90) at the top ~400 m followed by an underlying consolidated sedimentary layer with Vs ~2.65 km/s. The basement depths are observed to be higher at stations of the Zone of Terminal Fan (ZTF) area (KTHL, SAMN, AMBL, and BHAD stations). The KTHL and SAMN stations of the distal part of the Fan suggest basement depths of ~2.2 km and ~1.8 km respectively, while AMBL and

ACTIVITIES

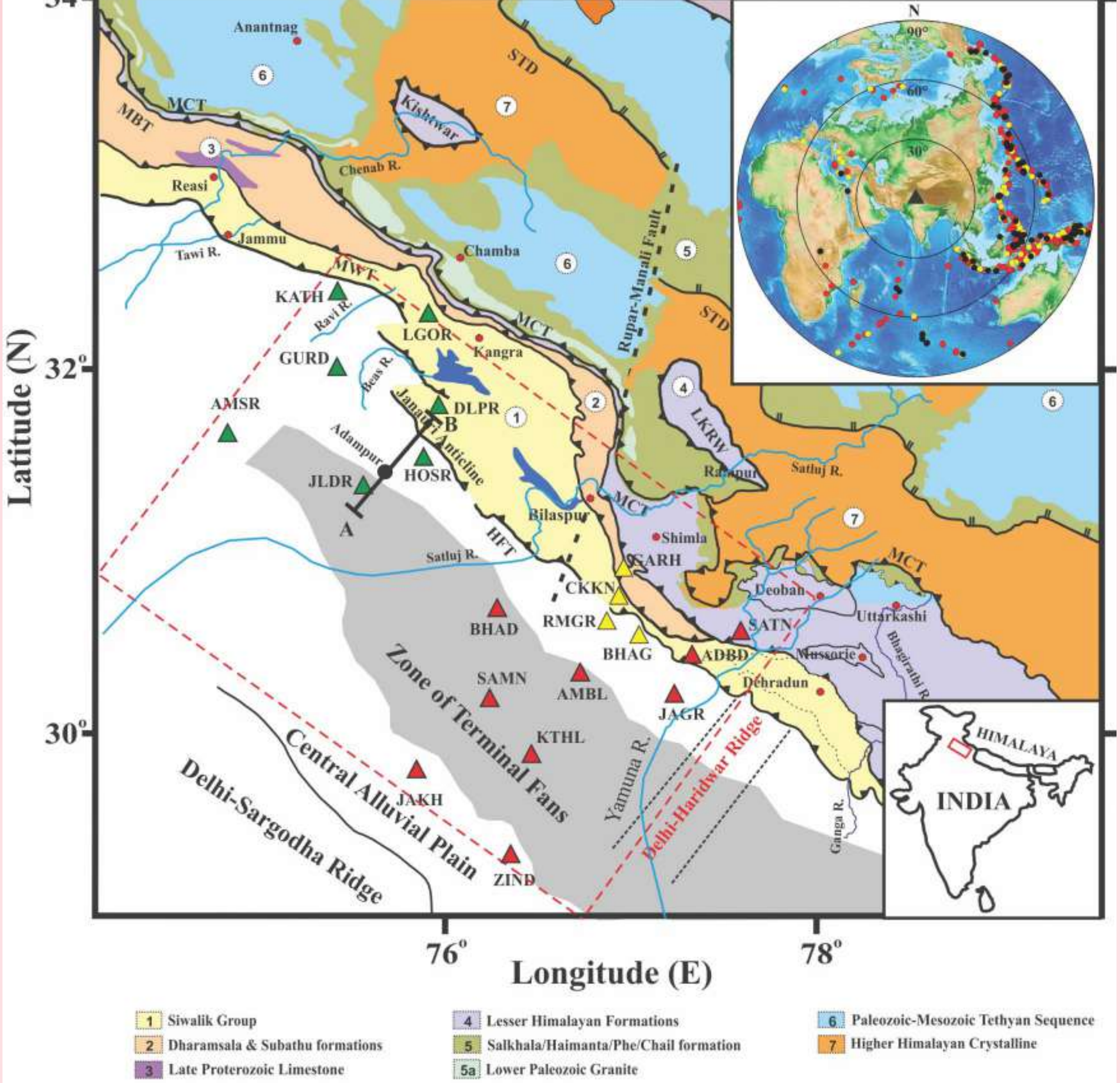


Fig. 19: Simplified geological map of the northwest Himalaya showing the major tectonic features. The broadband seismological stations of the Ambala-Chandigarh network, Satluj network, and Jammu network are shown by red, yellow, and green triangles respectively. The red dashed rectangle shows the study region. The major litho-tectonic units depicted are Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), South Tibetan Detachment (STD), Medlicott-Wadia Thrust (MWT), Larji-Kullu Rampur Window (LKRW). The inset at the top right corner shows the azimuthal distribution of teleseismic earthquakes used in this study. The earthquakes of the Ambala-Chandigarh network, Satluj network, and Jammu network are shown by red, black, and yellow dots respectively. The black triangle marks the center of the networks. The location of a borehole profile (AB) is marked.

BHAD in the proximal part show ~2.8 km basement depth. The JAGR, BHAG, RMGR, and CKKN stations to the north of the ZTF show comparatively larger basement depth (~3.5-3.7 km) which can be attributed to the high slope gradient formed during a period characterized by higher sediment and water budgets. The JLDR and AMSR stations of the western proximal part of the ZTF show a comparatively shallower basement depth of ~1.8 km which is possibly due to the presence of concealed features such as the HFT and the Bharwain anticline beneath the Punjab alluvium. The GURD and HOSR stations record a deeper basement depth of ~3.6 and ~3.7 km respectively. This region is characterized by multiple blocks separated by ridge structures like the Adampur and Hoshiarpur ridges converging towards the northwest and creating a prominent depression around Gurdaspur. The SATN and GARH stations near the MBT, show basement depths around 1.8 km and 2.1 km, respectively whereas the LGOR station shows a 3.4 km basement depth.

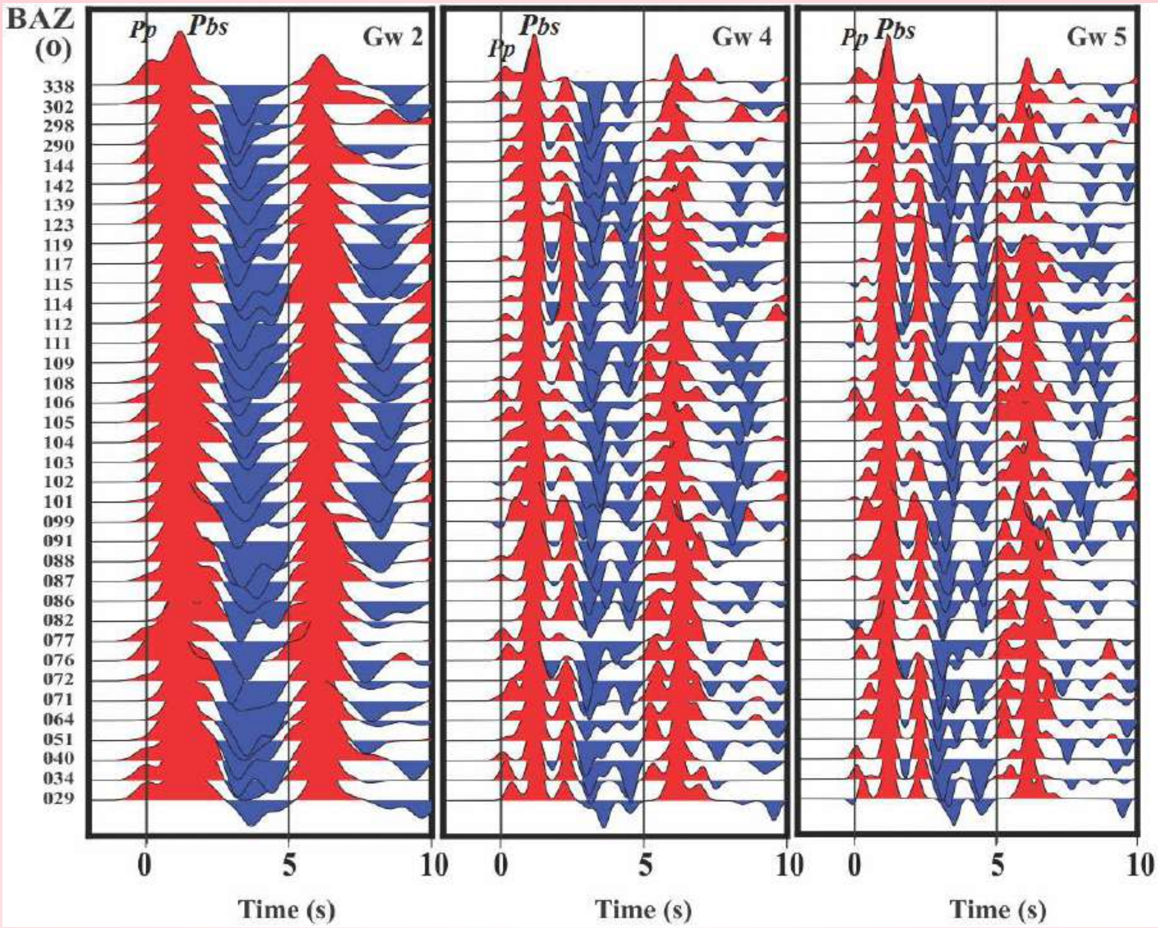
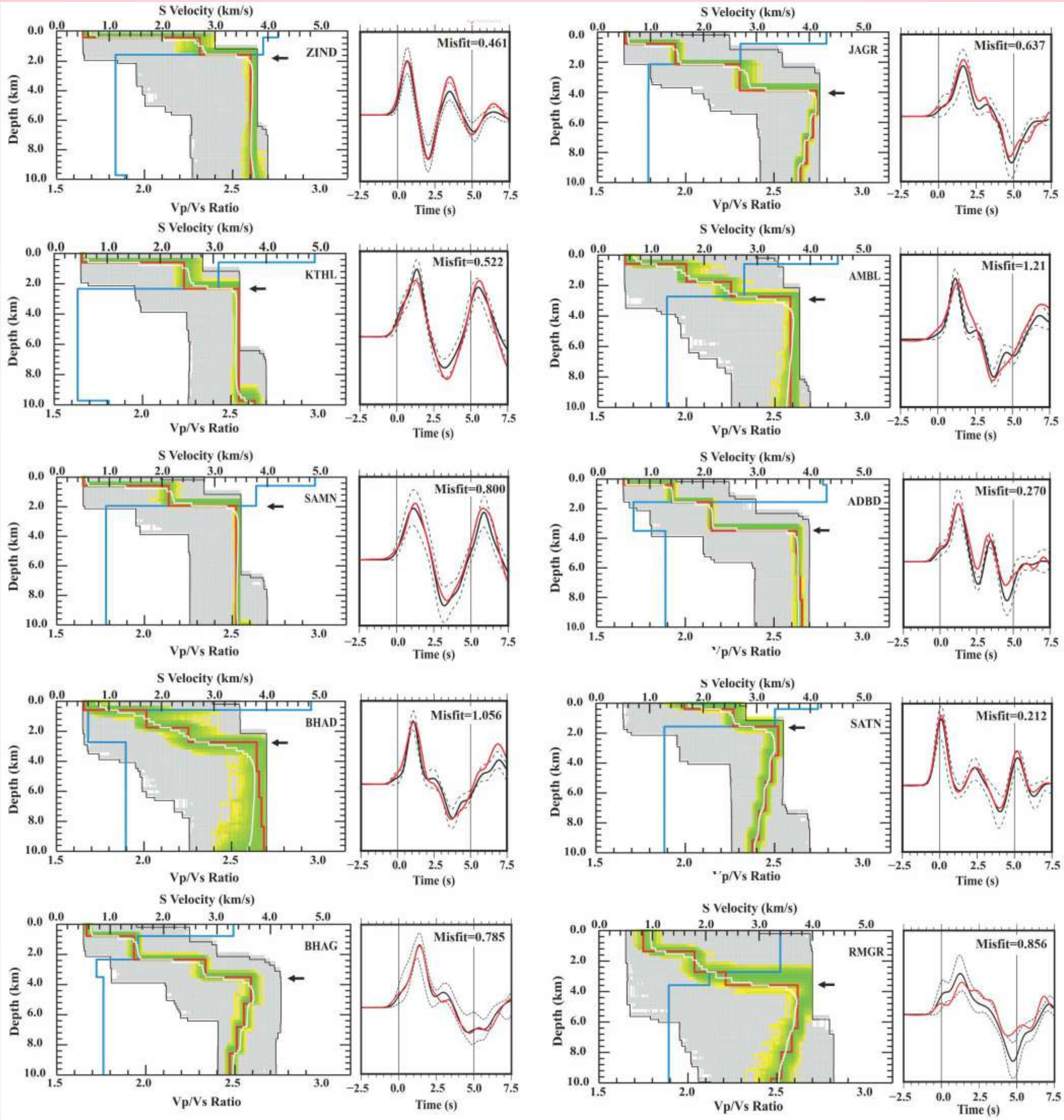


Fig. 20: Example of radial receiver functions of AMSR station plotted as a function of back azimuths for Gaussian widths (Gw) of 2.0, 4.0, and 5.0. The P_{bs} phase depicts *P*-to-*S* conversion at the sediment–basement boundary.

The velocity-depth models provide valuable insights into the physical properties and structure of the shallow subsurface and the evolution of the IGP. Close to the HFT, the stations (ADBD, JAGR, AMBL, BHAG, RMGR, CKKN, BHAD, GURD, HOSR, and KATH) suggest three-layer sedimentary structures with varying S-velocity profiles. Moving southward, the stations JLDR, AMSR, KTHL, SAMN, ZIND, and JAKH exhibit a two-layer sedimentary structure which indicates a different layering of the subsurface compared to the stations near the HFT. The SATN, GARH and LGOR stations close to MBT display two-layer structure but shear wave velocities are comparatively higher at the surface. To assess the reliability of the layered models in representing the subsurface geology, the velocity models obtained from the JLDR and HOSR stations are superimposed onto the AB cross-section (Figs. 19 and 22) constructed based on borehole data by previous studies (Powers et al., 1998; Singh et al., 2005). The velocity structure beneath the JLDR station exhibits a two-layer subsurface structure. A thin layer of ~0.7 km thick, with low Vs ~0.5 km/s can be correlated with the Upper Siwalik sediments, which typically have unconsolidated nature at the surface. The lower layer, (~1.1 km thick), with increasing Vs ~1.74 km/s, indicates the presence of compact sediments comparable to the Middle Siwaliks. The borehole data doesn't show Lower Siwaliks, supporting the justification of two sedimentary layers in the velocity model.

A basement depth contour map (Fig. 23) is prepared based on results from this study and available published data adjacent to the region. Most of the stations of IGP show soft alluvial at the top ~400–700 m of the surface characterized by extremely low Vs < 0.5 km/s and high Vp/Vs ~2.5–3.0. The Vs of the surface sedimentary layer in the northern stations e.g. SATN, CKKN, and GARH are comparatively higher (~0.9–1.6 km/s) suggesting the presence of compact sediments. The LGOR station shows very high Vs of 2.76 km/s at the surface, indicating the absence of surface sediments. The velocity–depth structure obtained in this study is important for evaluating the seismic hazard of the densely populated urban areas spread over this region.



(Figure continued…)

Magnetotelluric investigation along Rohtak-Delhi profile

Magnetotelluric data collected in collaboration with NCS, New Delhi at 8 sites along the Rohtak-Delhi profile characterize the junction of the contact zone of NNE-SSW striking Delhi Hardwar Ridge (DHR) and NW–SE trending Delhi Sargodha Ridge (DSR) in the Rohtak area, Haryana which has experienced 15 earthquakes of M~2.0–4.4 from April to August 2020. In the geo-electrical section derived from the 2D MT data inverse modeling, the DHR and DSR are characterized by equal values of moderate resistivity of 100 Ohm m at two depths. The resistivity variation for DHR corresponds to 100 Ohm m from the surface to the depth of 20 km, while DSR is found associated with the same value of resistivity extending in the NW direction.

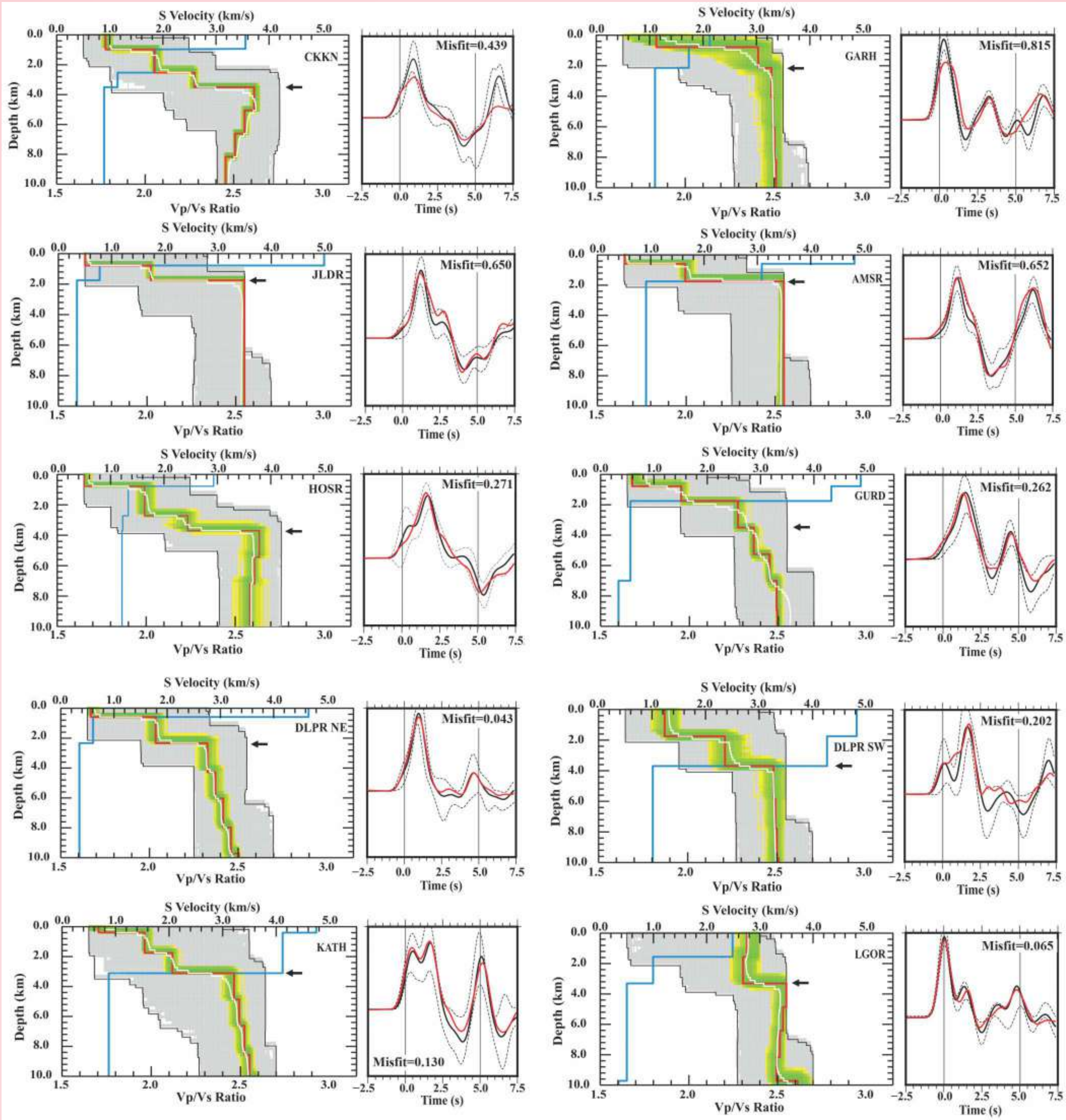


Fig. 21: 1-D shear wave velocity models obtained at individual stations using NA inversion of receiver functions. The left panels display 1-D S-wave velocity models and Vp/Vs ratios. The grey-shaded area represents the range of all sampled models, while the green-colored areas indicate the best 1000 models with the lowest misfit. Red trace: represents the model with the lowest misfit, which is the best-fit model among the sampled models. Blue trace: represents the best-fit Vp/Vs ratio. White trace: represents the average of the best-fit model. The black arrow marks the basement of the sedimentary column. The right panels show the compariison of obsserved (black) and the synthetic receiver functions (red line) for the model with the lowest misfit with ±1 standard deviation bounds.

The DHR has been found striking NE–SW with a very shallow central axis (less than 400 m) having a width of 12–15 km forming half grabens on both limbs supported by shallow faults. The DSR has been found bifurcated

ACTIVITIES

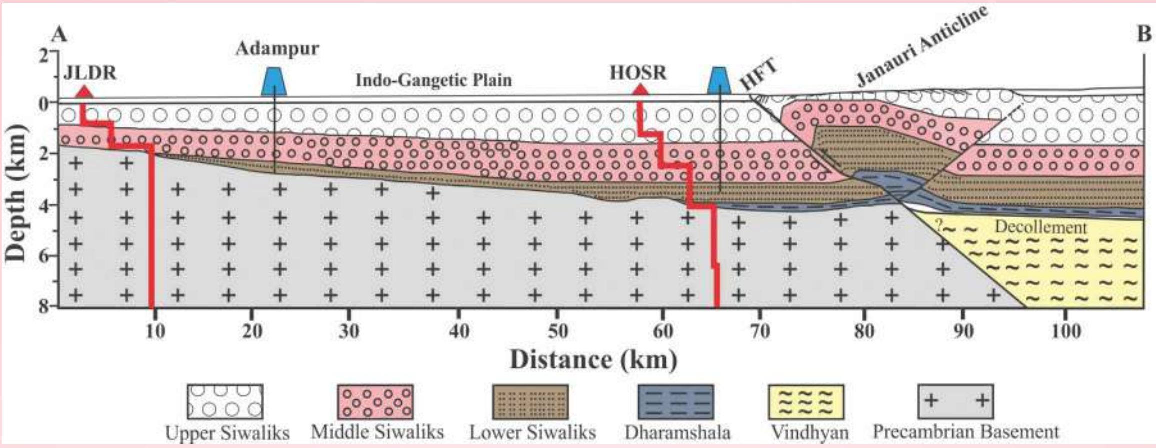


Fig. 22: Seismological cross-section along the AB profile (Fig. 19) of the study area (modified after Powers et al. 1998; Singh et. al., 2005). Shear wave velocity models (shown by red lines) computed at JLDR and HOSR stations have been projected on the cross-section. The models can be correlated with the information obtained from seismic refraction studies and borehole data near Adampur and Hoshiarpur regions (AB profile). Minor discrepancies may be due to deviations in the geographical locations of the seismological stations.

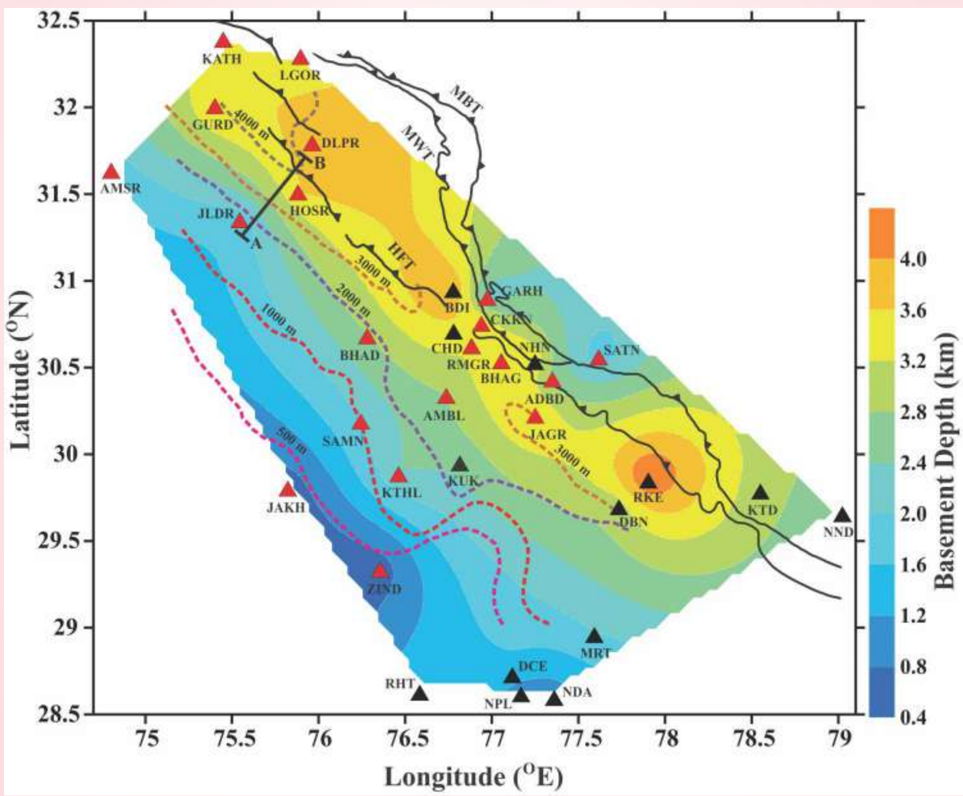


Fig. 23: Contour plot showing the spatial variations of basement depth along and across the strike of the Himalayan foreland basin and the Siwalik Himalaya. The red and black triangles represent the locations of broadband seismological stations from the present study as well as from the previous study. The major tectonic features i.e. the Himalayan Frontal Thrust (HFT), Medlicott–Wadia Thrust (MWT), and Main Boundary Thrust (MBT) are shown.

from DHR at a depth of 12–13 km and extended in the NW direction. The DSR has been generated due to flexure bulging caused by collision and anticlockwise rotation of the Indian plate in the Eocene period. A NE striking steep dipping reverse fault (F1) has also been identified about 15 km west of the DHR. It is inferred that the DSR got up thrusted along this fault and became shallower in the NW region. The seismicity in the Rohtak and surroundings is located at the bifurcation points of DHR and DSR and the contact zone of DSR and reverse fault F1. The reverse fault F1 is also active and has generated micro-seismicity in the past.

ERT survey in the Joshimath area

In the Second phase of the Joshimath ERT survey, a few other sites were investigated and one profile of Manohar-Bagh was repeated. The repeated profile modeling reveals the same subsurface features expect the reduced area of low resistivity feature. The high resistive features are boulders in the matrix of fluvioglacial sedimentary deposits of the Joshimath region (Fig. 24).

This low resistive zone is identified as a signature of the presence of ground water. The reduced area of this low resistivity feature in a three-month interval time indicates the seepage of groundwater from this place to other places. The resistivity section of the subsurface obtained after inverting the observations provides significant information. No hard rock is seen up to a depth of 35 m at every site except at Parsari village.

Assimilation of seismic attenuation model of NW Himalaya

The seismic wave attenuation characteristics may be correlated with the seismic hazard potential of the northwest Himalaya and its surrounding parts. The study of the frequency-dependent attenuation relationship is conducted using recent earthquake data (Fig. 25). The NW Himalaya is a part of the India-Eurasia collision zone that witnessed a number of earthquakes. The region has high seismic risk potential as witnessed by the past damaging earthquakes. The attenuation characteristics for P-waves (Q_α), S-waves (Q_β), and coda wave (Q_c) have been investigated using a dataset of 216 micro to moderate magnitude ($2.5 \leq Mw \leq 5.0$) earthquakes recoded between 2008 and 2015 by 7 broadband seismic stations. The central frequency range considered in our analysis varies from 1.5 to 12 Hz. The study showed that the structural heterogeneities that govern the nature and extent of seismogenesis, enabling more accurate assessments of attenuative characteristics of the sub-surface to shed light on seismic hazards and earthquake risk potential. These assessments, based on estimates of strong ground motion and earthquake source parameters, are important to enhance the region's resilience to seismic events. In summary, the schematic model obtained in this study demonstrates that the attenuative characteristics of different tectonic blocks linked to structural heterogeneities, and both local and regional fault systems found very much different and unevenly distributed in the NW Himalayan region. Also, it indicates that earthquake risk potential in different segments of the geo-tectonic blocks from south to north are conspicuously different because of varying estimates of seismic attenuation. It corresponds to the

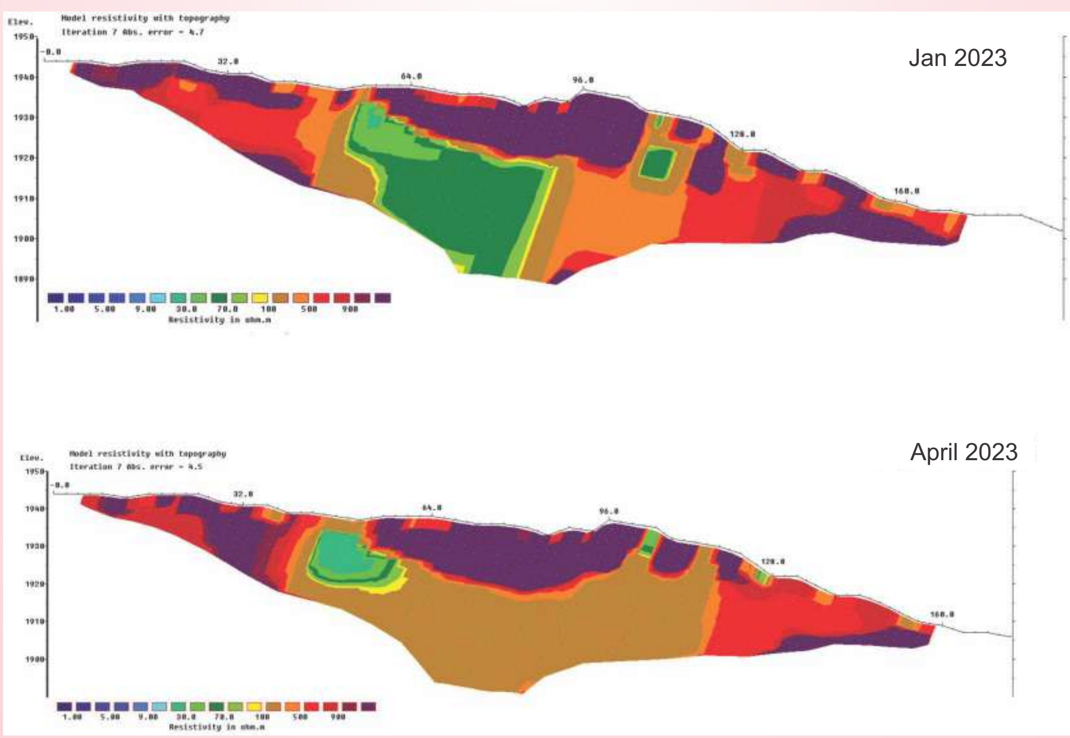


Fig. 24: Temporal resistivity variation in Manohar Bagh (Joshimath).

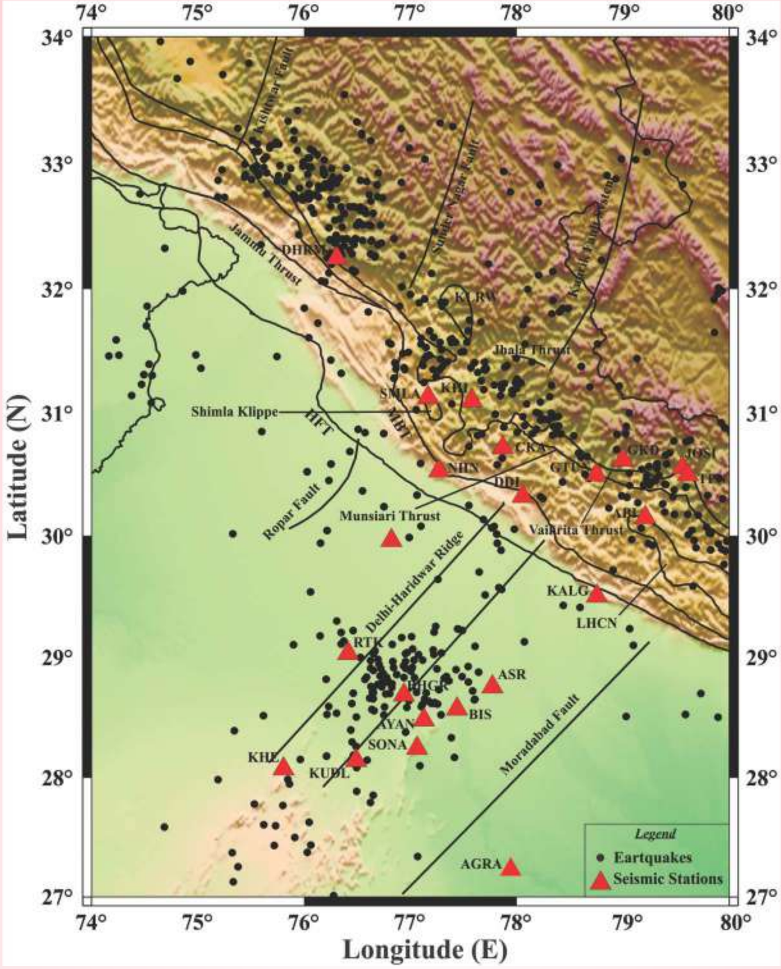


Fig. 25: A map showing tectonic features of the NW Himalaya and its surrounding region. Tectonic features (lines) are shown and include MBT; MCT, HFT, Munsiari thrust, Vaikrita thrust; Jammu Thrust, Lesser Himalaya Crystalline Nappe, Kullu Larji Rampur Window, Jhala thrust. Filled triangles depict the network stations and filled circles show the epicenters (source: Catalog of International Seismological Center).

structural heterogeneities due to the tectonic faults, material compositions, compactions, and the extent of strain energy level, indicating that the Higher Himalaya has crystalline rock materials with the least seismic risk. The earthquake risk may be higher for the zones with comparatively higher attenuation due to high loss of seismic energy and strata amplifications. These are the zones of less compact material mainly sedimentary zones such as sub-Himalaya and Indo-Gangetic plains. Contrary to this attenuation is lower in the Higher Himalaya with lesser amplifications. This information may be useful for decision-making towards an earthquake risk resiliency system for the Himalayan region.

The relationship in terms of the variability of Q_c^{-1}, Q_α^{-1} and Q_β^{-1} as: Q_c^{-1}(LH)>Q_c^{-1}(SH)>Q_c^{-1}(IGP)>Q_c^{-1}(HH); Q_α^{-1}(LH)>Q_α^{-1}(SH)> Q_α^{-1}(IGP)> Q_α^{-1}(HH) and Q_β^{-1}(LH)> Q_β^{-1}(SH)> Q_β^{-1}(IGP)>Q_β^{-1}(HH) as illustrated in figure26. The interpretation of this study suggests that the average attenuation in the Lesser Himalaya (LH) exhibits greater attenuation values compared to the Sub-Himalaya (SH), the Indo-Gangetic Plain (IGP), and the Higher Himalaya (HH). However, the Higher Himalaya, particularly the Higher Himalayan Crystalline (HHC) formations, shows lower seismic attenuation due to its 30-km-thick medium- to high-grade metamorphic sequence of meta-sedimentary rocks, often intruded by granites of Ordovician and early Miocene age. It's worth noting that along the Satluj River, the Higher Himalayan Crystalline rocks display an inverted metamorphic field with distinct mineral units. This study also implies a conspicuous variation in earthquake risk potential across different segments of the geo-tectonic blocks from south to north, influenced by diverse structural heterogeneities, fault associations,

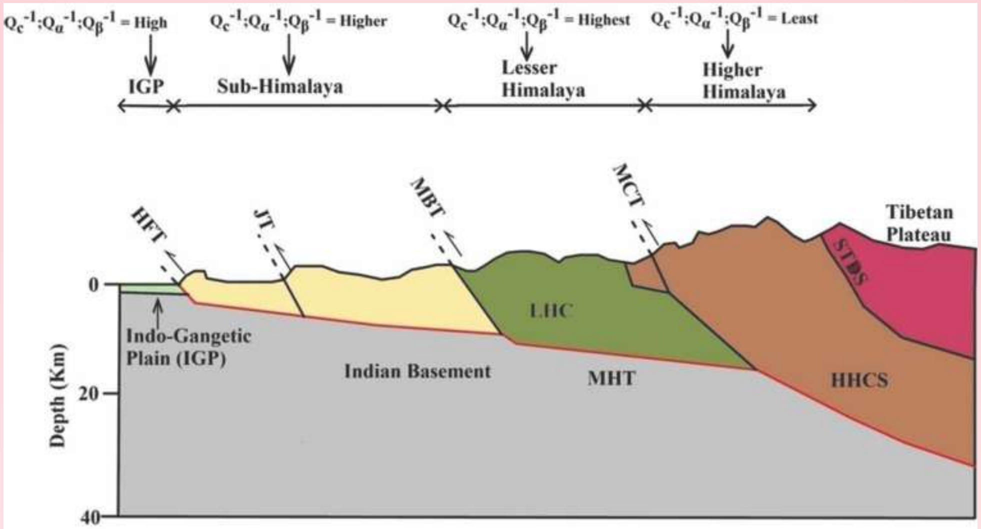


Fig. 26: A schematic model deduced from this study showing the distribution of attenuative property in the NW Himalayan region.

material compositions, compactions, and strain energy levels. This aligns with historical observations, such as the 1803 Garhwal-Kumaon earthquake (Mw 8.1). Conversely, the Indo-Gangetic Plain (IGP) exhibits lower seismic attenuation compared to the Sub-Himalaya (SH) and the Lesser Himalaya (LH). This is attributed to the surrounding Delhi Haridwar Ridge and Moradabad fault, which mark transversal zones indicating neotectonics and recent activity. The Delhi-Haridwar Ridge (DHR) is considered a vulnerable area due to the development of E-W trending tensional stress and a high concentration of earthquake epicenters. The Uttarkashi region's strike-slip faulting is also linked to the extension of the DHR. The Sub-Himalaya (Himalayan foreland) zone, consisting of clastic sediments deposited during the uplift and erosion of the Himalaya, experiences higher seismic attenuation due to faulting and folding of molasse. The Lesser Himalaya, south of the Greater Crystalline Himalayan sequence, bounded by the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT), consists mainly of Proterozoic and lower Paleozoic sedimentary rocks. This region, with its Paleocene-Eocene limestone, shale, synclinal outliers, and anticlines, contributes to the highest degree of attenuation in the Lesser Himalaya. The vulnerability of the IGP to earthquake risk is attributed to the amplification of thicker Indo-Gangetic alluvial strata during earthquake shaking, even for shallower micro to moderate earthquakes, making it susceptible to structural damages and loss of lives if structures collapse during shaking.

Ground motion prediction equation for NW Himalaya and its surrounding region

An attenuation relationship, also known as a ground motion prediction equation (GMPE), has been developed for the Northwest Himalaya and its surrounding region (Fig. 27). This GMPE utilizes strong motion data recorded by two networks: the National Center for Seismology Network and the PESMOS strong motion network. For the development of this GMPE, 400 strong motion records from 87 earthquakes that occurred between 2005 and 2021 were considered. The selected earthquakes have magnitudes ranging from 3.0 to 6.9. In this study, the maximum peak ground acceleration (PGA) of two horizontal components was used to develop the new attenuation relationship. A two-step stratified regression model was chosen for the analysis. The proposed attenuation relationship is:

$$\mathrm{Log}_{10}\ PGA = 1.889 + 0.3996*M - 0.95736\ \log_{10}\left(HD + \exp^{(0.4114*M)}\right) \pm 0.3646$$

Where PGA is peak horizontal acceleration in gal of strong ground motion, M is the magnitude, and HD is the hypocentral distance from the source. The standard error of the proposed relationship is 0.3646. This newly developed attenuation relationship holds significance for various applications, including site-specific studies, seismic hazard estimation, ground motion simulation, earthquake early warning (EEW), and engineering applications. It provides valuable insights into the behaviour of ground motion in the Northwest Himalayan region, allowing for better preparedness and mitigation strategies against seismic hazards in the area.

ACTIVITIES

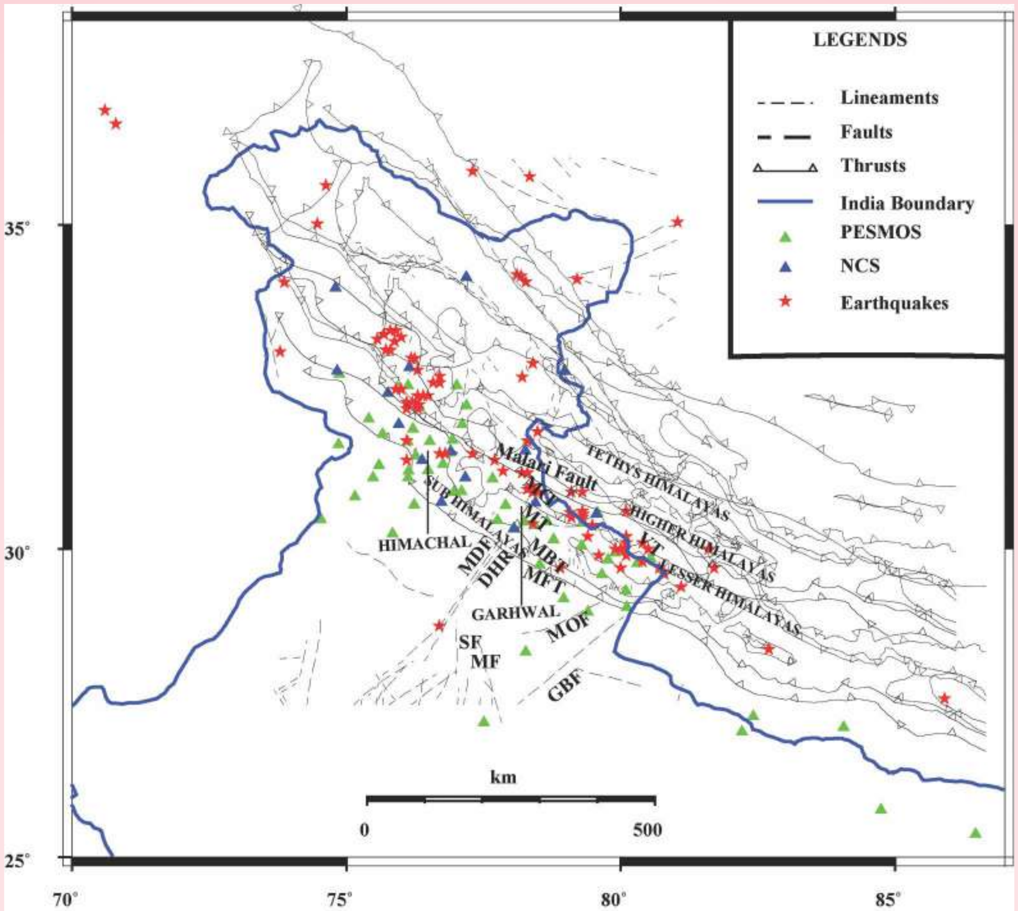


Fig. 27: The map illustrates the geographical distribution of strong motion sensors from the National Center for Seismology (NCS) Network, indicated by blue triangles, and the PESMOS stations, represented by green triangles. The locations of significant earthquakes used in this study are denoted by red stars.

The validation of the newly developed Ground Motion Prediction Equation (GMPE) for the NW Himalayas focused on predicting Peak Ground Acceleration (PGA) values for a magnitude 5.8 earthquake across distances from 10 to 570 km. Several existing attenuation relationships by different authors were also considered for comparison, noting their specific limitations in magnitude and distance ranges due to data availability constraints. The study found that the developed GMPE closely matched recorded PGA values for earthquakes of similar magnitude and distance, suggesting its accuracy within the analyzed range. However, due to the lack of near-source data, comparisons for higher-magnitude earthquakes were not possible. This highlights the ongoing need for more comprehensive ground motion data collection, especially for stronger earthquakes and various distances from seismic sources. It's important to note that the GMPE's accuracy can vary due to factors like earthquake depth and local site effects, which may lead to overestimations or underestimations of PGA values in specific circumstances. Continued validation and refinement of the GMPE will be crucial as additional strong-motion data becomes available in the future.

Activity: 2C

Seismicity and Seismic Hazard Assessment in the Himalaya

(Dilip Kumar Yadav, Narendra Kumar, Praveen Kumar, Chinmay Haldar and Ajay Paul)

Modeling of strong earthquakes using the modified semi-empirical technique

In this work, strong earthquakes have been modeled in the Uttarakhand region. Strong ground motion simulation is a reliable tool for seismic hazard assessment and mitigation of any region. The distribution of hazards during an earthquake is greatly influenced by the attenuation properties of the medium. Typically, regional attenuation characteristic is employed for strong motion simulation rather than site-specific attenuation. In the current study, the newly developed semi-empirical simulation technique (SET) is modified to use a site-specific attenuation relation. Initially, the medium attenuation characteristics are quantified by estimating the frequency-dependent S-wave quality factor ($Q_\beta(f)$) at each recording station. These obtained $Q_\beta(f)$ relations at each station are further utilized to estimate the regional relation for the Garhwal and Kumaon regions as $(90\pm4)f^{(0.86\pm0.05)}$ and $(54\pm2)f^{(0.89\pm0.1)}$, respectively. These values suggest that the Garhwal region is relatively less attenuative and more credible for seismic hazards compared to the Kumaon region. The $Q_\beta(f)$ obtained at each recording station are further used to simulate the 1991 Uttarkashi (M_w 6.8) and 2011 India-Nepal (M_w 5.4) earthquakes. An improved match is perceived between the observed and simulated records with site-specific $Q_\beta(f)$ values instead of regional ones (Fig. 28). This comparison successfully validates the present modification in SET. This work provides great insight into getting more realistic simulated results and explores recent trends in strong motion seismology for seismic hazard evaluation.

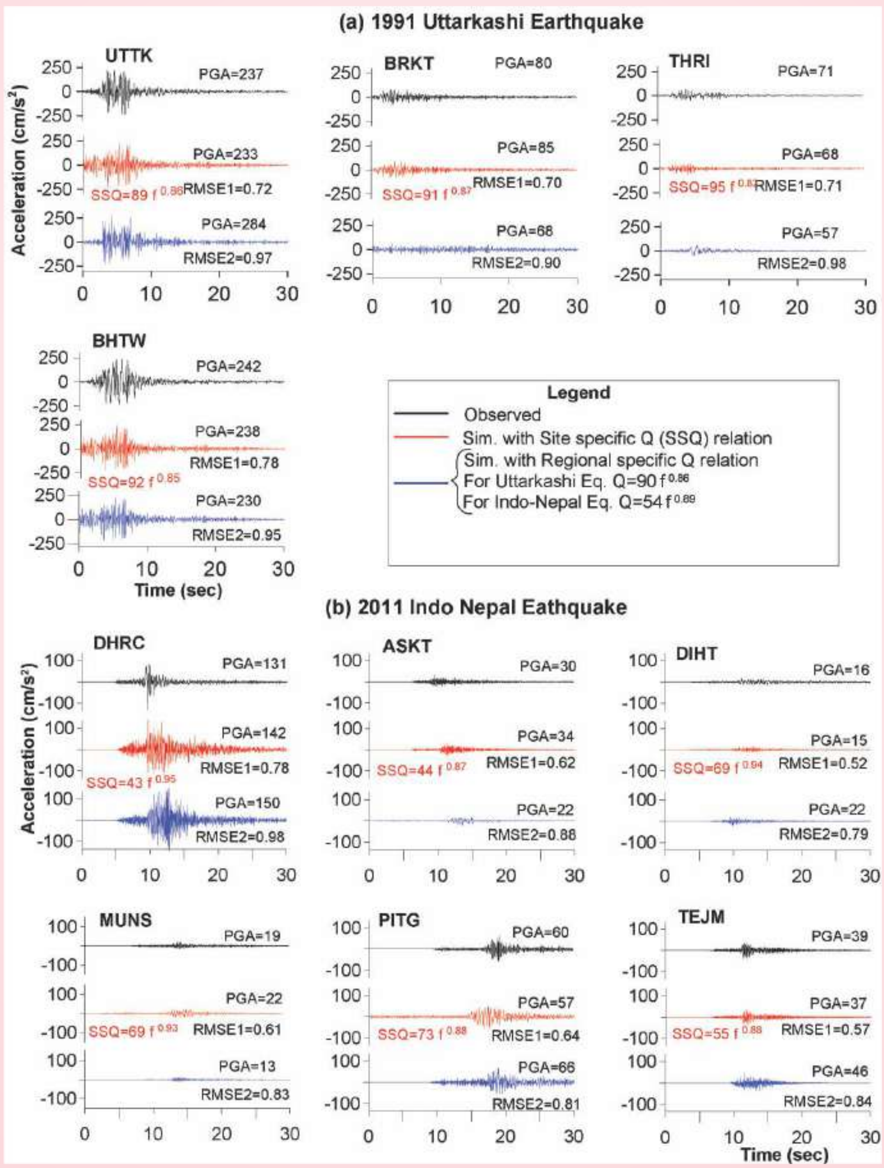


Fig. 28: Comparisons of observed records (in black) with simulated records using the site-specific quality factor ($Q_\beta(f)$) (in red) and regional-specific $Q_\beta(f)$ (in blue) of (a) 1991 Uttarkashi earthquake (M_w 6.8) and (b) 2011 Indo-Nepal earthquake (M_w 5.4). RMSE1 and RMSE2 are the root mean square errors for site-specific and region-specific simulated accelerograms with observed accelerograms, respectively.

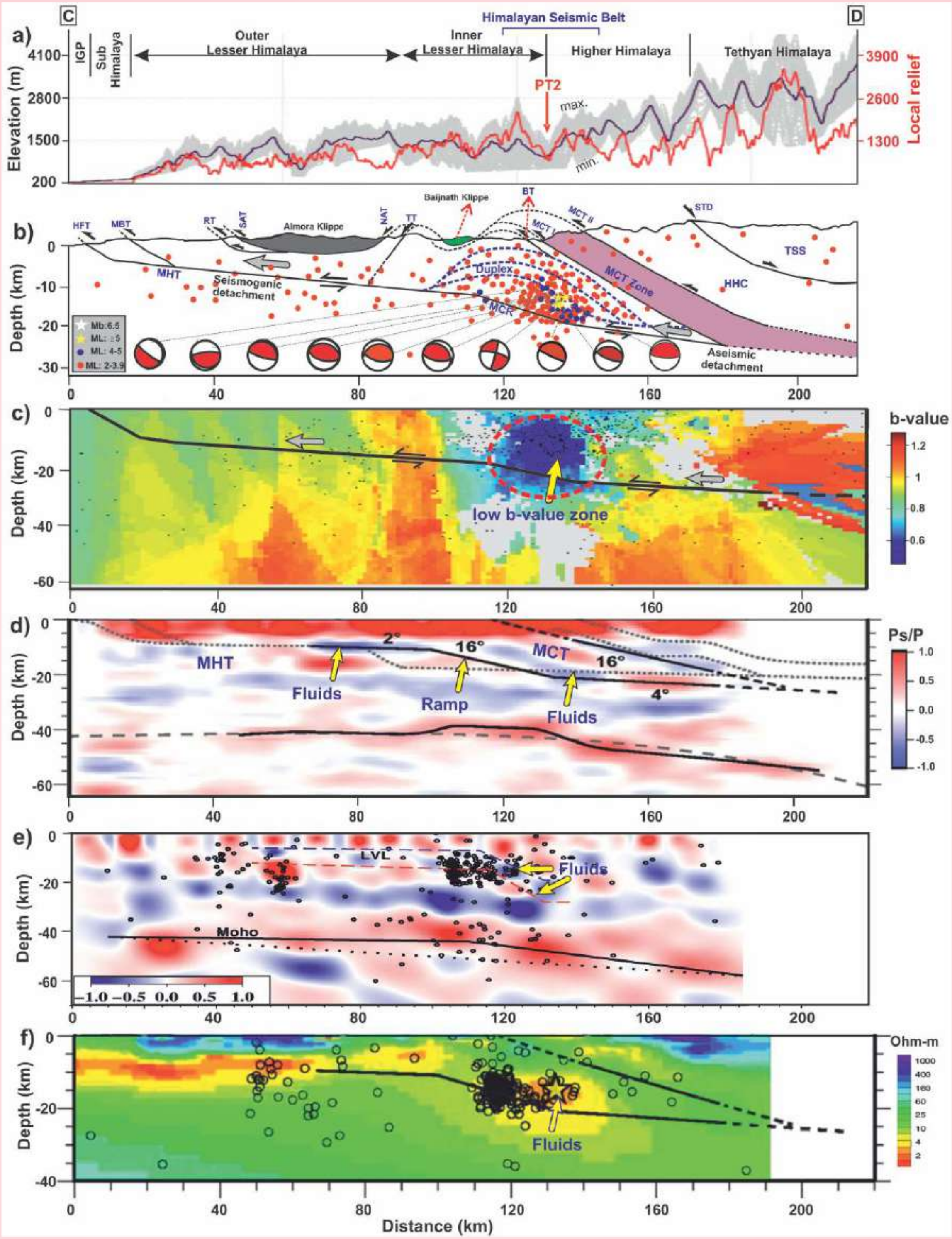


Fig. 29: The cross-sections show the correlation of different parameters below the Chamoli region. (a) The plot depicts swath profile along C-D section, (b) a geological cross-section with seismicity and depth distribution of fault plane solutions which depicts thrust mechanisms of earthquakes, (c) b-value mapping along the profile shows the high-stress accumulation near MCR, (d-e) common conversion point (CCP) stack of receiver function (Caldwell et al., 2013; Kanna and Gupta, 2020), results of Common Conversion Point (CCP) stack are in agreement of fluid interaction with high-stress accumulation zone, and (f) electrical conductivity along the profile C-D (Rawat et al., 2014), local seismicity is located by (Mahesh et al., 2013).

Correlation of seismic anomalies to fluid-driven crustal structure in Garhwal region

The stress drops, b-value, fractal dimension (Dc) and focal mechanisms have been analyzed using data recorded by a local network of 14 broadband stations in the Garhwal Himalaya during 1999–2020. Seismic periodicity on a Himalayan major thrust above a locked zone involves a long period of stress accumulation and interseismic strain. There exists a good spatio-temporal-depth correlation between the estimated results which indicates the positive anomaly at 12–14 km (stress transition) beneath the Chamoli region. Interestingly, this region shows a maximum geodetic strain rate with comparatively high-stress drop, low coefficient friction value, and very low b- (0.583±0.02) and Dc- (1.20±0.01) values. The majority of moderate to strong earthquakes and swarm activity have occurred in this region with maximum crustal accommodation. It is also observed that the significant temporal decrease in *b*-value is always followed by moderate earthquakes. The observed correlations strongly support the evidence of entrapped fluid-faults interaction which alters pore pressure and generates numerous ruptures. The outcomes of this study have been portrayed in the vertical cross-section based on the current investigation and past observations (Fig. 29). The plots show that the earthquake cluster is more evident towards the mid-crustal ramp (MCR) above the MHT.

Crustal structure beneath the Kumaon-Gharwal Himalaya using converted waves

The Himalayan region witnesses several natural hazards like earthquakes and landslides due to the continental collisions between the Indian and Eurasian plates. This has given rise to extreme topographic variations throughout the Himalayan belt. The Kumaun–Garhwal region is a classic example of such geological consequences and is prone to several earthquakes. High-quality three-component teleseismic waveform data recorded at seven seismological stations operated by the Wadia Institute of Himalayan Geology (WIHG) are used to investigate the detailed subsurface structure of the crust, the intra-crustal low-velocity layer (LVL) (Fig. 30). The results, derived from the inversion of individual stations' stacked P-receiver functions (PRFs) using the neighborhood algorithm approach show that the crustal thickness varies from 44 to 54 km beneath the study region (Fig. 31). The depth of LVL observed beneath six stations from individual and stacked PRFs, varies from 9 to 24 km. The LVL zone with a high Vp/Vs ratio may be due to fluid, leading to shallow seismic activity within the study region. The presence of fluid or partial melts in the LVL may be due to the shear heating, cooling, and decompression.

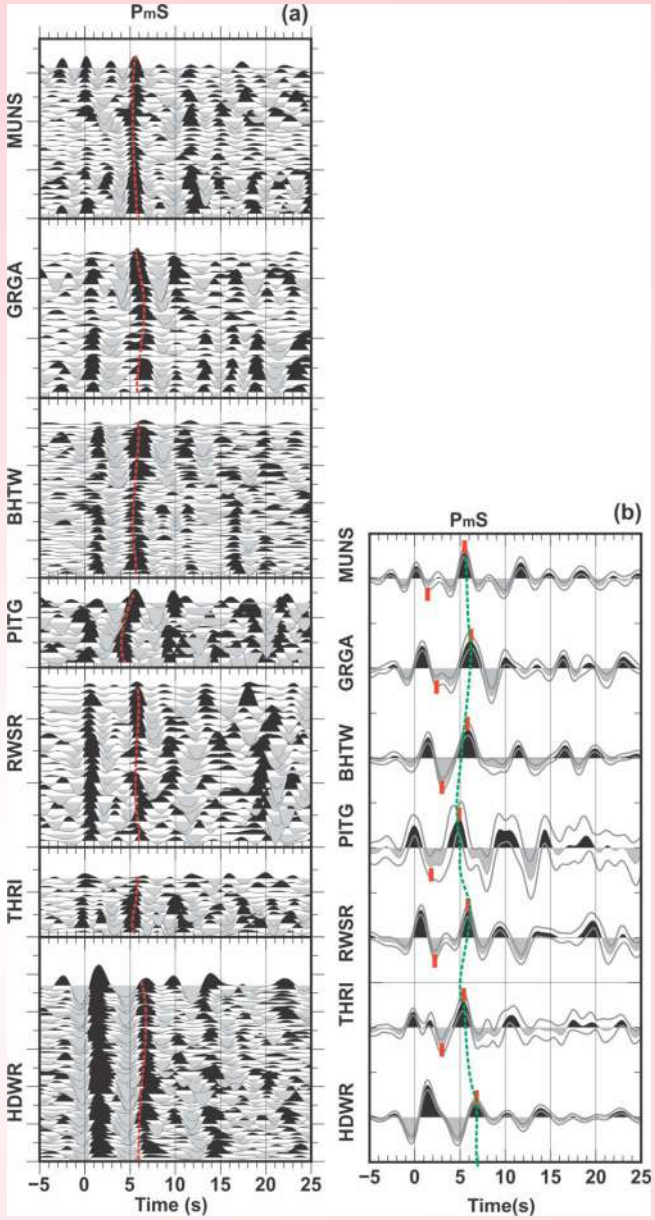


Fig. 30: (a) Move out corrected receiver functions with one second low pass filtered. Stations are arranged with increasing order of distance from HFT. Black and gray colors denote positive and negative peaks, respectively. Red lines show P-to-S conversion times (Pms) from Moho. (b) Stacked receiver functions of all seismic stations. Two bounding grey lines on both sides of the PRF represent PRF amplitude added and subtracted with 2 sigma standard errors.

Earthquake source studies in the Siang Valley of Northeast India

Earthquake source parameters are important to understand seismotectonics and seismic hazard

ACTIVITIES

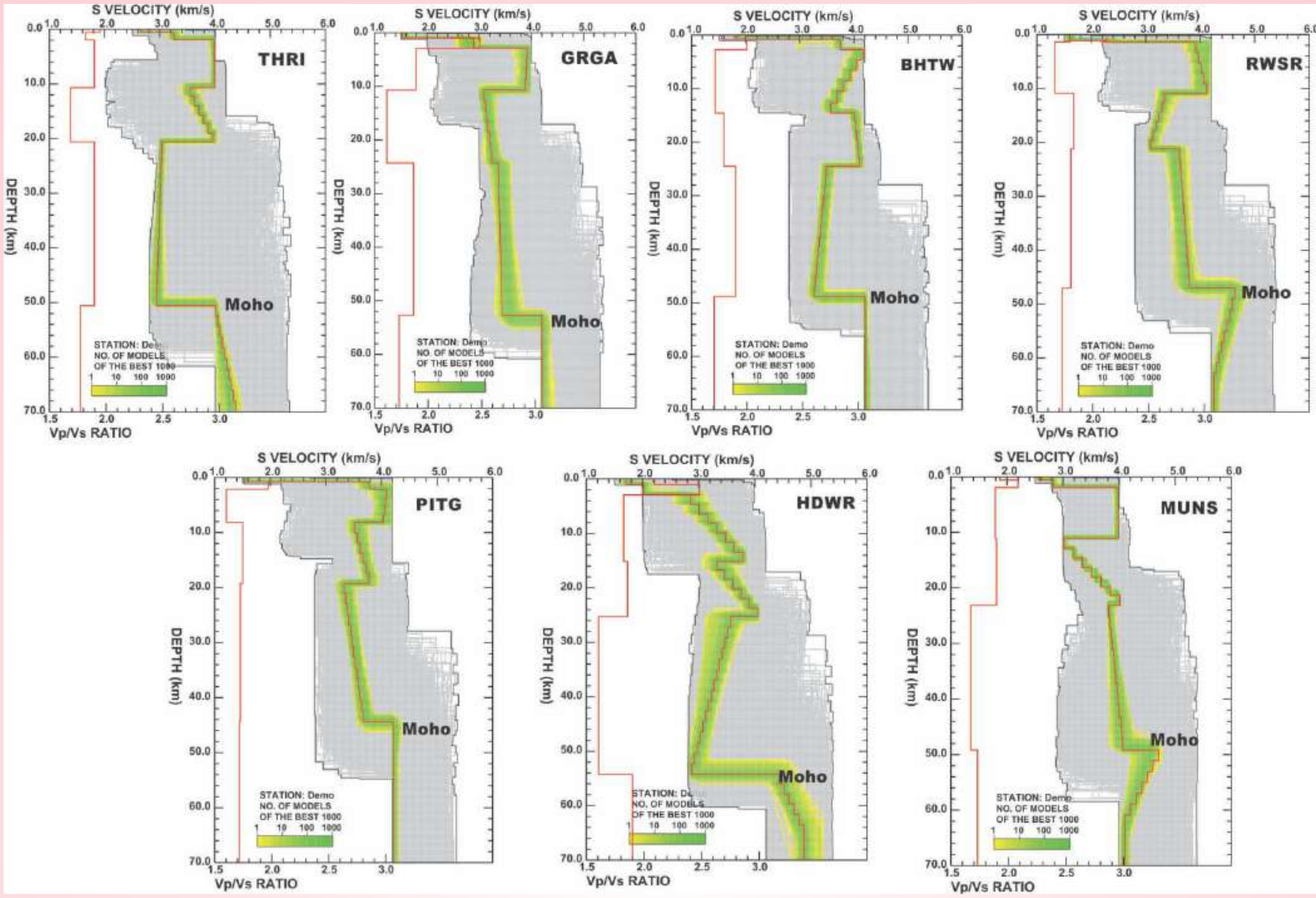


Fig. 31: Shear wave velocity models at different stations using Neighbourhood Algorithm (NA) method located at the study region in the Northwest Himalaya. The solid red line on the left side represents the Vp/Vs ratio. Stations' names are shown in bold at the top right side of each plot. Best fit 1000 models (green area) having the least misfit between the observed and synthetic receiver functions are shown within the total 20000 models (grey) generated by this study.

assessment. The Siang Valley BBS Network of WIHG has recorded 191 local earthquakes that have been analyzed to study earthquake source parameters and seismotectonic. The spectral source parameters seismic moment, source radius, and stress drop are calculated using Brune's spectral model. The radial (R) and transverse (T) components of the S-wave spectrum were utilized to determine the source parameters using waveform data with a window length of five seconds chosen from the start of the S-wave period (Fig.32a-b) and the selected window and its associated displacement spectrum for the magnitude M_L 5.9 earthquake. The estimated seismic moment (M_o) ranges from 2.44 x 10^{11} Nm to 6.86 x 10^{16} Nm, source radii (r) from 172.90 to 1392.41m, M_w ranges from 1.52 to 5.16, corner frequency (f_c) ranges from 1.03 to 8.04 Hz and stress drop ($\Delta\sigma$) value ranges from 0.05 to 114.71 bars. The linear relation obtained by least square regression analysis between $\Delta\sigma$, M_o, f_c, and r, with respect to the M_L and Mw for the Siang Valley of Arunachal Pradesh region are elaborated. Corner frequency as a function of Mo and Mw, Richter magnitude (M_L) obtained from S-wave spectra shows the decreasing trend with Mo, MW, ML (Fig.33a-b).

The spectral analysis performed for the micro-earthquakes that occurred during the studied period show slow-stress drop values. The stress drop value for most of the earthquakes is below 10 bars, and the largest value is 114.71 bars. The results indicate an increase in the stress drop with the size of the earthquake (Fig. 33b). This reveals that lower magnitude earthquake releases less energy and stress drop increases with the increase of magnitude for the events. The source radius and low-stress drop values represent the shallower brittle part of the crust in the region which is unable to hold the stress and releases in the form of low-magnitude earthquakes. The study also observed that the events are confined between MBT, MCT, and other thrust zones in the region.

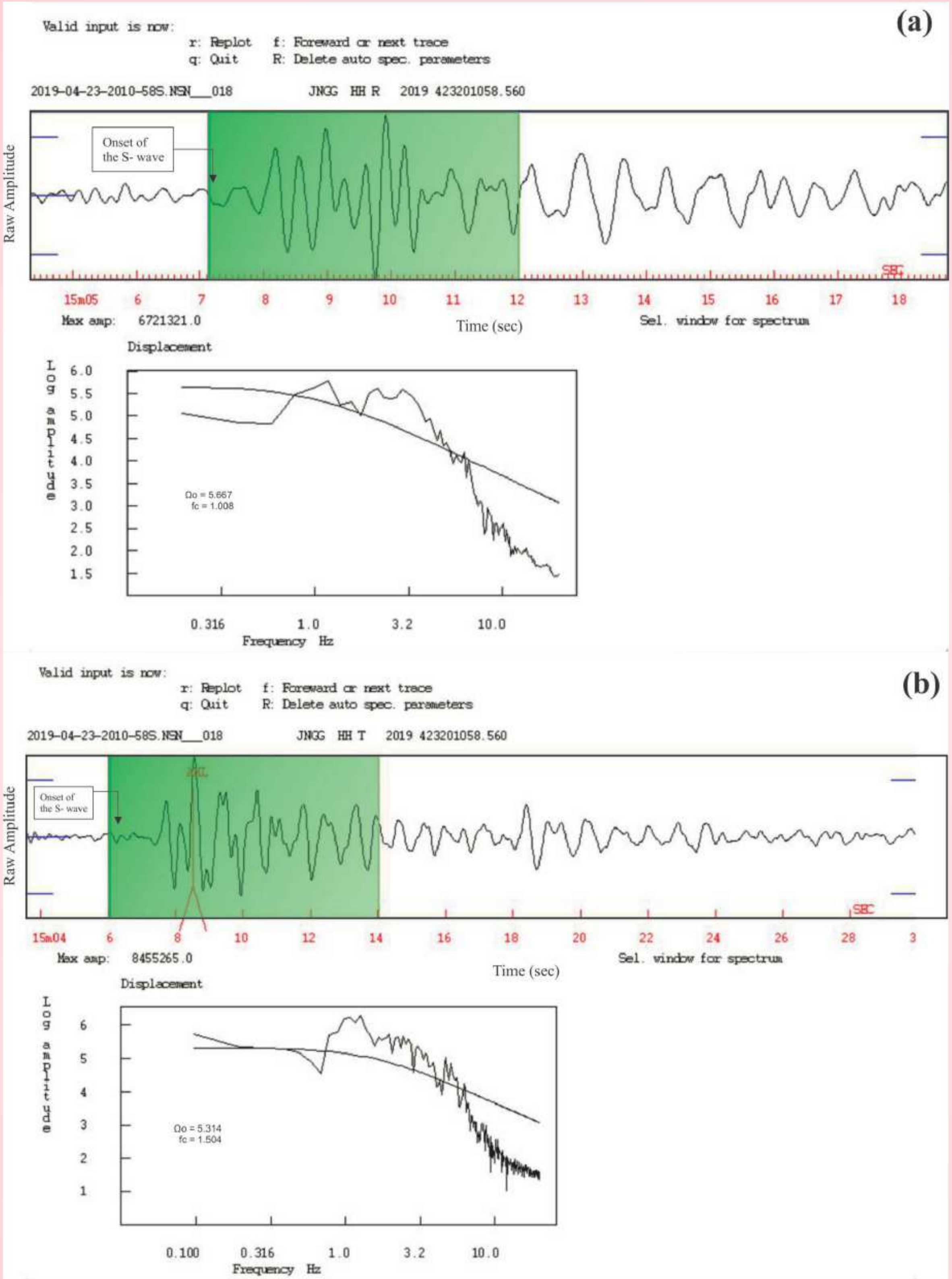


Fig. 32: The window of shear wave spectra is shown by the green area of the (a) Radial (b) transverse components of Mw 5.9 Mechuka earthquake recorded at Jengging Seismic station (JNGG) and the spectra of this window are in the lower panels of both figures (a and b). Ω0: long period spectral level and *fc* is the corner frequency.

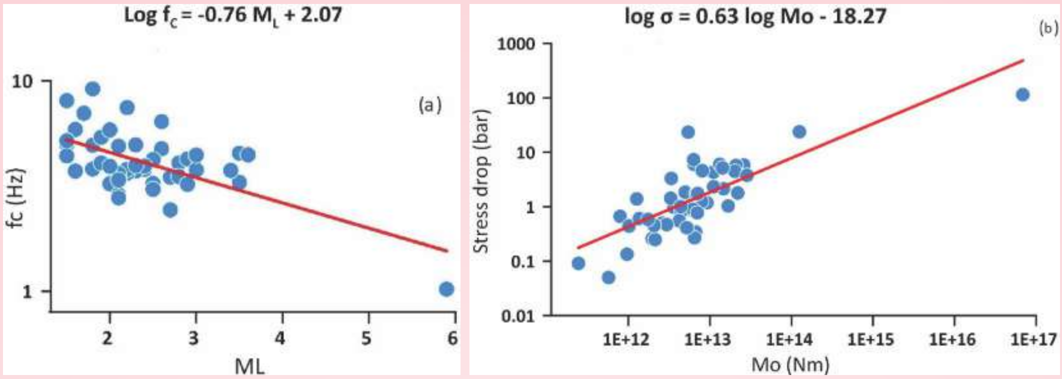


Fig. 33: Plots (a) The plot of stress drop (Δσ) vs seismic moment (Mo) and (b) The plot of corner frequency (fc) as a function of the M_L obtained from S-wave spectra.

Activity: 3

Biotic evolution with reference to Indo-Eurasian collision, evidence for global events

(R.K. Sehgal, Kapesa Lokho, Suman Lata Srivastava and Ningthoujam Premjit Singh)

A diverse assemblage of micro-mammals has been reported for the first time from the Siwalik sediments exposed around the Dunera region of Pathankot District. Although the Dunera area is known for a few previously described macro-mammals such as tragulids (*Dorcatherium* sp.), giraffids (*Giraffokeryx* sp.), and bovids (gen. et sp. indet.) no micro-mammals have yet been reported. Consequently, due to the absence of chronologically informative fauna, the precise age of the Dunera deposits beyond a general correlation to the Chinji and/or Nagri formations has remained uncertain. Recently, chronologically informative micro-mammals were recovered from Dunera belonging to four rodent families: Muridae, Ctenodactylidae, Cricetidae, and Sciuridae. These specimens represent the first rodents documented from this region. Additionally, a preliminary taxonomic assessment of these fossils is provided. This information is used to discuss the age of the fossiliferous locality exposed at Dunera based on rodent biostratigraphy that has already been established throughout the Lower and Middle Siwaliks of the Potwar Plateau. Based on our assessment, it appears that the Dunera locality correlates with the lower half of the Nagri Formation in the Middle Siwaliks and thus samples the early Late Miocene rather than the late Middle Miocene in the Middle Siwaliks.

About 500 kg of sediments were macerated in the Biostratigraphy Laboratory to recover microfossils. Fossils were identified and separated under a binocular microscope using a fine brush. The specimens mentioned here are housed in the repository of WIHG with the catalog extension WIMF/A. High-resolution micro-CT (µCT) scanning was utilized to create a three-dimensional (3D) surface rendering to facilitate the study of these micromammal teeth. Obtaining µCT scans also facilitated digitally removing the matrix on the occlusal surface of some specimens. All scanning was done at the Molecular Imaging Center of the Keck School of Medicine of the University of Southern California (Los Angeles, CA, USA) using a Nikon XT H 225 scanner. Each tooth's standard dental measurements of maximum mesio-distal length (MD) and bucco-lingual breadth (BL) were recorded from 3D surface renderings. Comparative measurements on relevant micromammal taxa were obtained from the literature. To examine intraspecific and interspecific variation in dental shape and size data across known micro-mammal species, bivariate plots were created using the square root of tooth area (MD x BL) and tooth shape (BL/MD), thereby expressing these variables in the same linear units.

The micromammal material from the Dunera region was identified as the murine *Progonomys* cf. *hussaini*, the ctenodactylid *Sayimys sivalensis*, the cricetid *Democricetodon fejfari*, and the sciurid cf. *Tamias urialis*, all of which are documented for the first time in this area (Figs. 34 & 35). Based on the biostratigraphic ranges of these rodents from well-dated localities in the type localities of Siwaliks of Pakistan along with previously collected magnetostratigraphic data, Dunera locality best correlates to between ~11-10 Ma (early Late Miocene), approximately equivalent to the lower half of the Nagri Formation. Micromammals, especially rodents, contain numerous time-sensitive species and have thus been heavily used in biostratigraphic analyses because they can help accurately estimate the geological age at a high resolution for localities where other geochronological dating methods are not available. Thus, they offer an independent estimate that

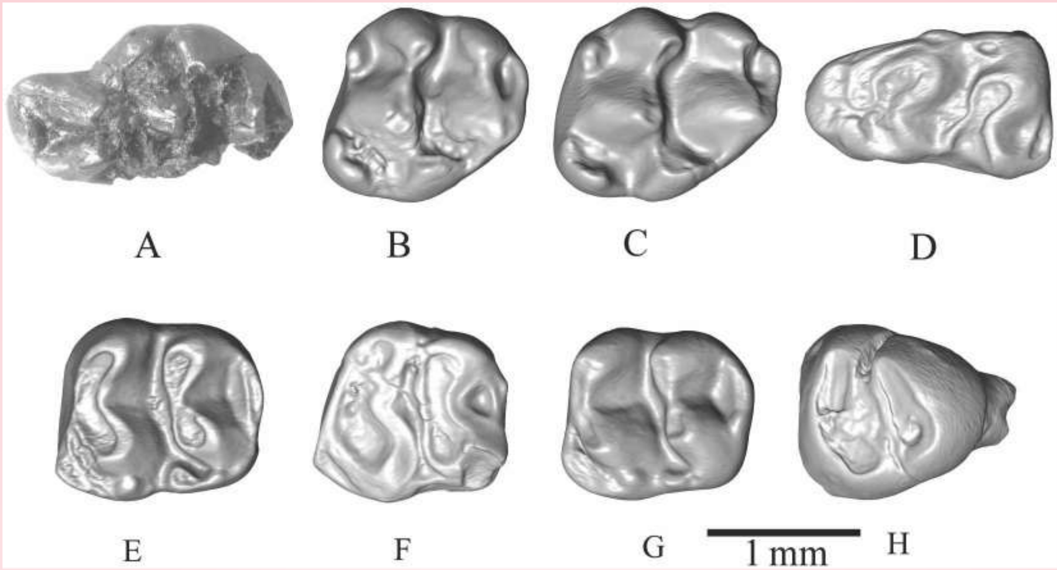


Fig. 34: *Progonomys* cf. *hussaini* in occlusal views. Leica stereo zoom Microscope image: A) WIMF/A 4745, right M1. 3D surface models: B) WIMF/A 4746, left M2; C) WIMF/A 4747, left M2; D) WIMF/A 4739, right m1; E) WIMF/A 4737, left m2; F) WIMF/A 4738, left m2; G) WIMF/A 4748, left m2; H) WIMF/A 4736, right m3. Note: Mesial towards the left and distal towards the right in all panels.

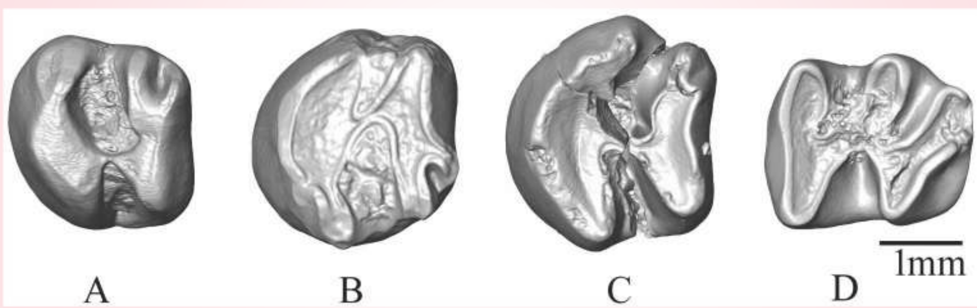


Fig. 35: 3D surface models of *Sayimys sivalensis* in occlusal views. A) WIMF/A 4733, left M2; B) WIMF/A 4750, right M2 C) WIMF/A 4731, left M2 or M3; D) WIMF/A 4732 left m1 or m2. Note: Mesial towards the left and distal towards the right in all panels

can be used with other time-sensitive macro-mammal species and paleomagnetic data to determine the geological age accurately. Furthermore, they are susceptible to climatic changes, which lead to changes in community structure, allowing an analysis of the migration and reduction or extinction of certain groups.

Due to its proximity with the type sections of the Siwaliks, Dunera was likely part of the same biogeographical province as the Potwar Plateau during the Middle to early Late Miocene. Thus, the potential age range extensions of *P.* cf. *hussaini* and cf. *T. urialis* almost certainly reflects increased sampling of an under represented time period in the greater Siwaliks region rather than documenting these species spanning a drastically different time period in a different biogeographic region. Further work at Dunera will be important in elucidating this under-sampled period in Siwalik's mammalian evolutionary history.

Ichnofossils were also collected and described, for the first time, from the rocks exposed along the Katilu Khad section, Dunera, Punjab (India) of Miocene succession. About 40 slabs of grey-buff colour medium to fine-grained sandstone and reddish-brown mudstone were collected for ichnofacies analysis. Eight ichnotaxa with twelve ichnospecies have been recorded including *Arenicolites* isp, *Beaconitescoronus, Helminthopsis tenuis, Lockeiasiliquaria*, *Palaeophycus tubularis, Palaeophycus* isp, *Planolitesannularis, P. beverleyensis, Skolithos linearis, Taenidium barretti, T. cameronensis,* and *T. serpentinum* (Fig. 36). According

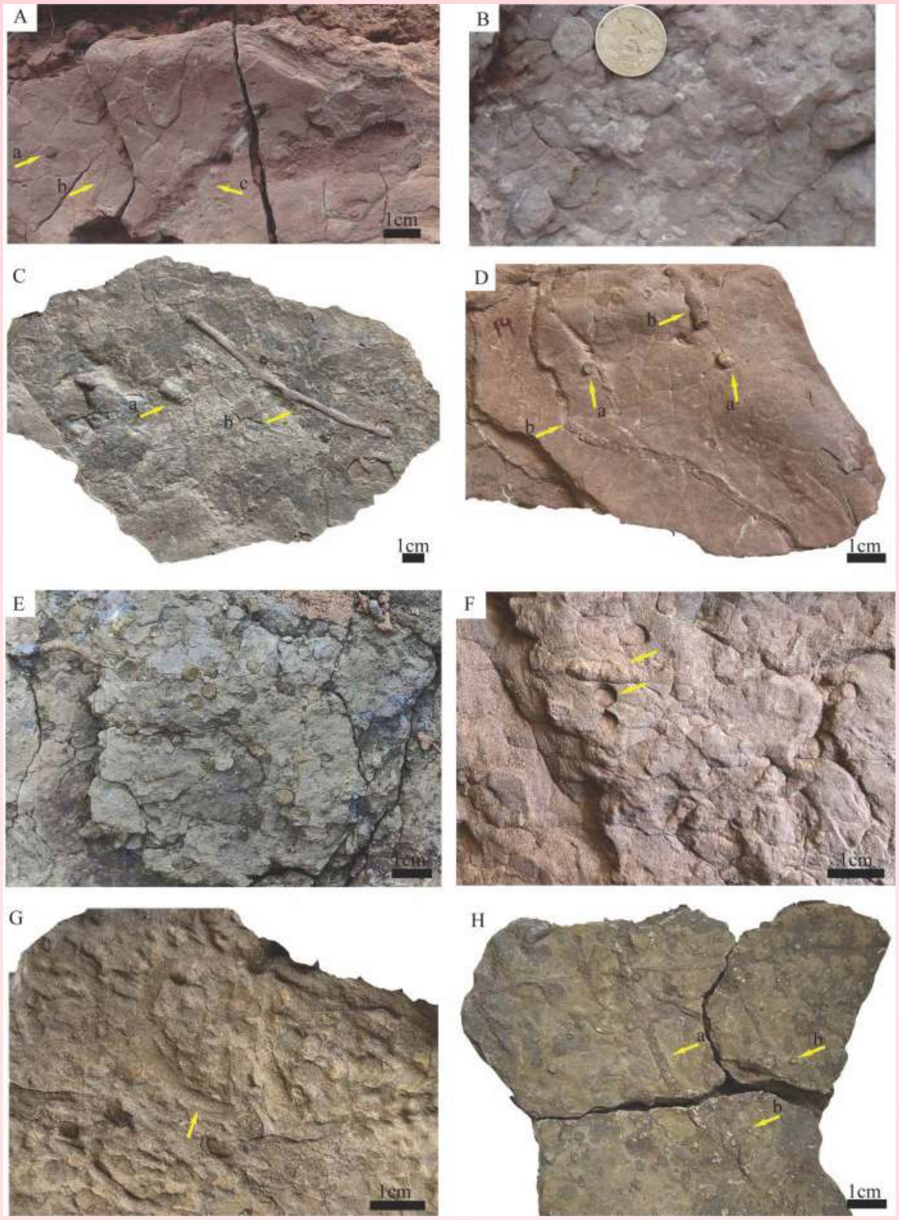


Fig. 36: (A–a, B, C–a, E, F) *Palaeophycus tubularis*; (A–b) *Planolites annularis*; (A–c) Burrow; (C–b) *Planolites beverleyensis*; (D–a) *Skolithos linearis*; (D–b) *Taenidium barrette*; (G) *Palaeophycus* isp.; (H–a) *Planolites annularis*; and (H–b) *Skolithos linearis*.

to I.C.Z.N (International Code of Zoological Nomenclature), the ichnofossils have been identified and described. The ethological classification of ichnofossils given by Ekdale *et al*. (1984) is adopted in the present study. The described specimens are stored in the Museum of Wadia Institute of Himalayan Geology, Dehradun, with repository numbers assigned from WIF/4861 to WIF/4894 (abbreviation: Wadia Institute Fossils). The present ichnofossil assemblages have been recognized by two ichnofacies –Scoyenia and Mermia.Mermia ichnofacies is typified by high diversity grazing and feeding traces with low abundance whereas Scoyenia ichnofacies shows less diversity but a high abundance of meniscate burrow (*Taenidium* and *Beaconites*). These ichnofacies indicate well-oxygenated, low-energy deposition exposed to air and represent the fluvial environment.

Plate tectonic-driven collision between the Indian subcontinent and Eurasia and the attendant uplift of the Himalayan Mountain was the prime cause for the disappearance of the Tethyan seaway. This tectonic event is strongly linked to global changes in ocean circulation, biotic evolution and extinction,

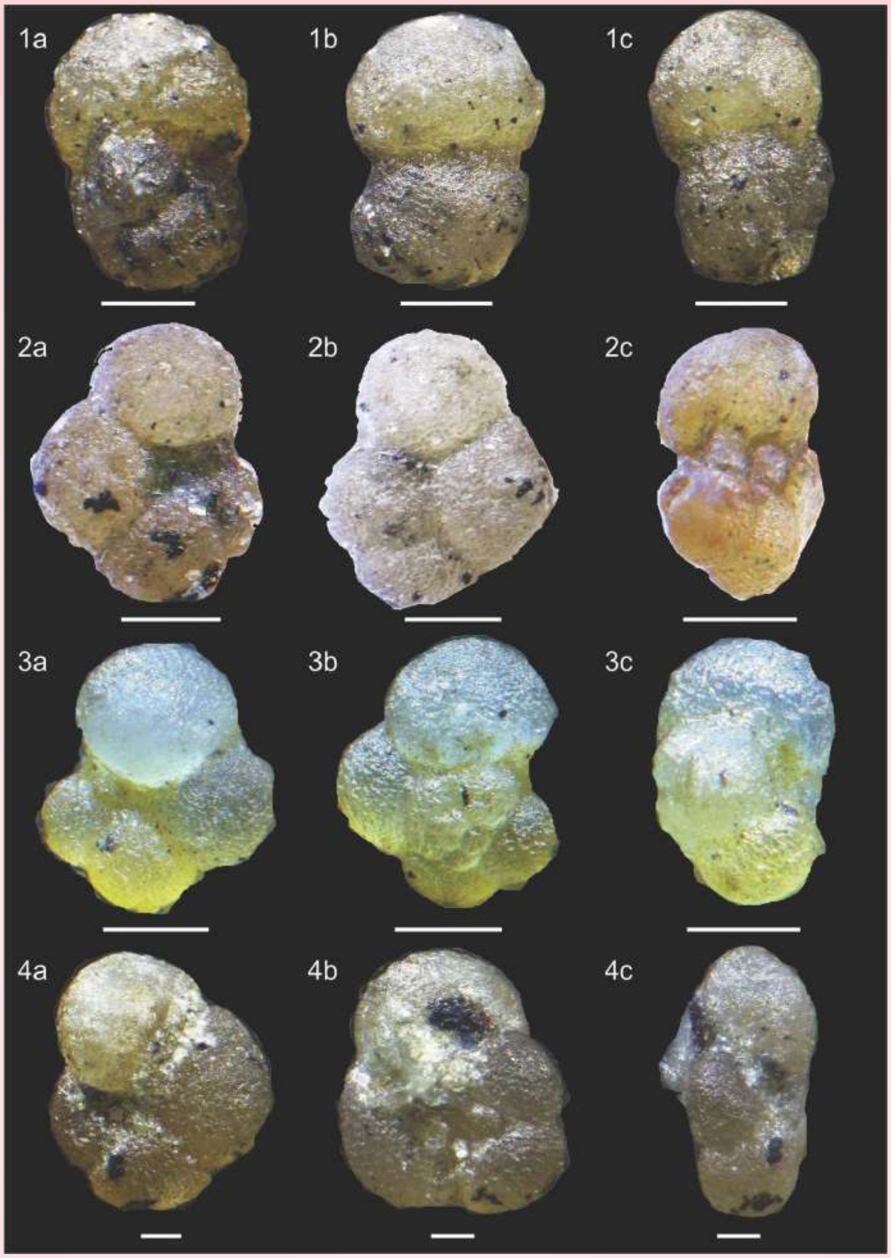


Fig. 37: 1(a–c) *Praeorbulina curva,* P.8, WIMF/A4893; 2(a–c) *Globigerinella obesa,* P.4. WIMF/A4894; 3(a–c) *Tenuitella munda*, P.4, WIMF/A4895; 4(a–c) *Paragloborotalia continuosa,* P.4, WIMF/A4896. All scale bars are 100 µm.

geodynamics, paleogeography, and paleoclimate. Subduction along the southern margin of Eurasia, accompanied by northward migration of the Indian plate, progressively consumed the Neotethyan ocean lithosphere, with the final closure of this ocean occurring as the Indian subcontinent collided with Asia to the north. The present finding of the Miocene planktonic foraminifers (Figs. 37 & 38) occur in shale intercalated with thinly bedded siltstone and sandstone of the Surma Group in the foothills of the Naga Schuppen Belt of the Indo–Myanmar Ranges. Fourteen species from eleven genera are the first clearly imaged middle Miocene foraminifers recorded from the Surma Group in the Naga Hills. This new M5–M6 assemblage from the upper unit of the Bhuban Formation correlates to the uppermost Burdigalian to Langhian (16–14 Ma). Biostratigraphy, paleoenvironment, and paleogeography of the assemblage are all significant. They provide a basis for widespread regional and global correlation constraining the timing of elimination of the final remnants of the Neotethyan seaway between India and eastern Eurasia. Results indicate that, unlike the

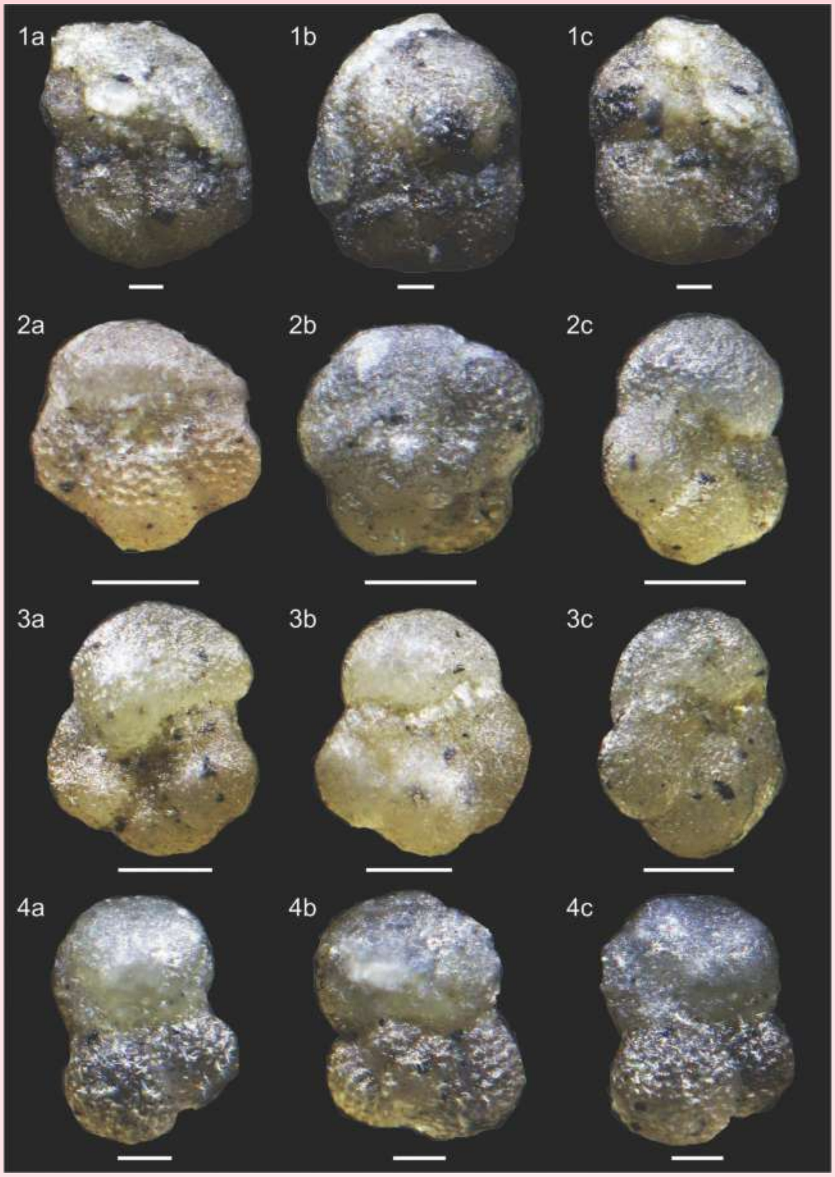


Fig. 38: 1(a–c) *Trilobatus sicanus*, P.12, WIMF/A4897; 2(a–c) *Globigerinella obesa*,P.5, MF/A4898; 3(a–c) *Paragloborotalia continuosa* 8, WIMF/A4899; 4(a–c) *Trilobatus immaturus,* P.8, WIMF/A4900. All scale bars are 100 µm.

western and Tibetan Himalayas, where similar seaways disappeared before the Miocene, a shallow marine embayment connected to the Indian Ocean endured in eastern parts of the India–Eurasia collision zone until the Middle Miocene.

The study of vulnerable marine ecosystems, such as seamounts and oceanic islands, is critical for the conservation and management of marine ecosystems. Echinoderms are exclusively marine invertebrate organisms and mostly bottom dwellers. So, they are good paleoenvironmental and ecological indicators. They have well-developed organ systems which are ecologically and geologically important. This phylum contains about 7,000 known living species and more than 20,000 fossil species with 15 classes of extinct species, which has the most extinct classes than any other animal. They are found from the poles to the equator and from the intertidal zone to depths of more than 5,000 m. Echinoderms appeared first around 530 Ma in the Cambrian and rapidly diversified into many groups but were not as successful as the crinoids subjugated during the Paleozoic. Many echinoderm groups either decreased in abundance and diversity or became extinct by the early Mesozoic era. Rear occurrences are known in the early Jurassic and then diversified and thrived to date (Srivastava, 2014). The present finding reports two echinoid taxa viz. *Ilarionia*

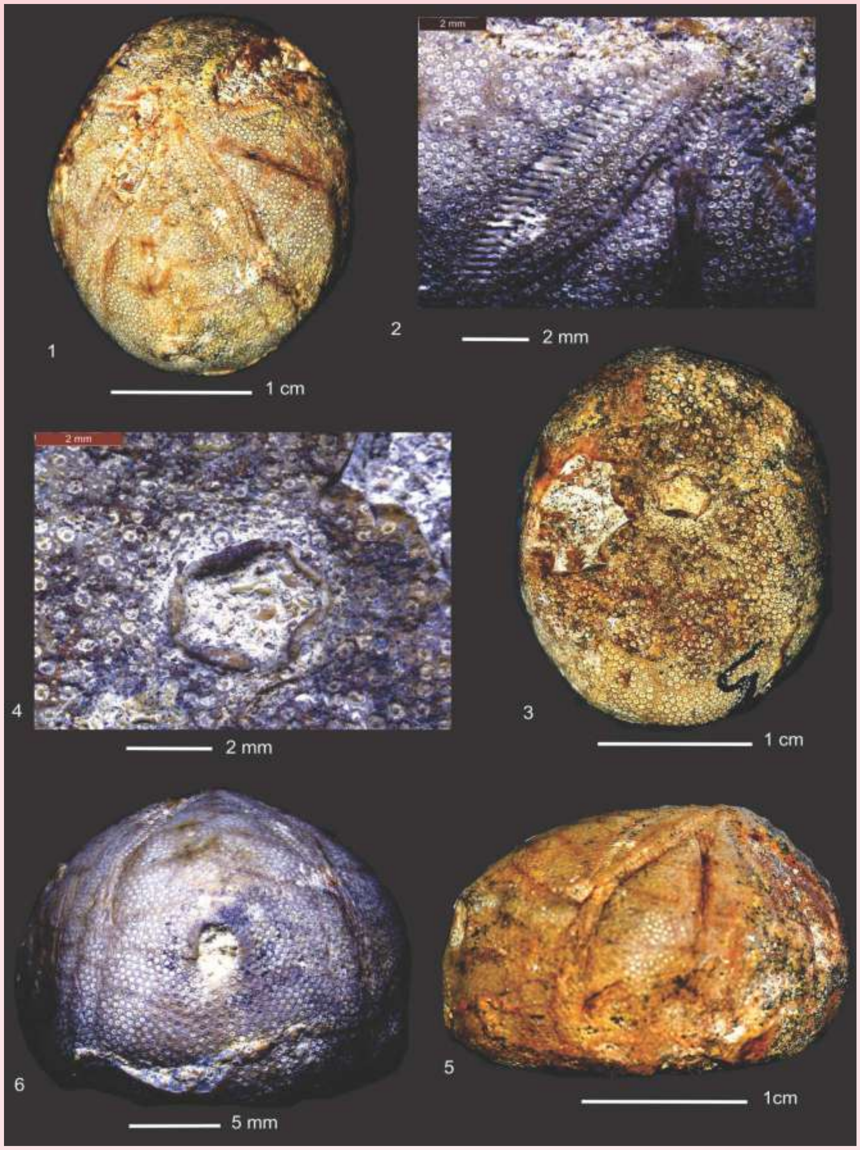


Fig. 39: *Ilarionia sindensis*. (1) Apical view; (2) Petal I; (3) Oral view; (4) Oral area; (5) Posterior view; (6) Lateral view (anterior to right).

sindensis Duncan and Sladen (1884) (Fig. 39) and *Porocidaris schmidelii* Münster in Goldfuss(1830) (Fig. 40) from the middle Eocene Sylhet Limestone of Mikir Hills, Assam. *P. schmidelii* is found from the Lutetian (middle Eocene) to the Priabonian (upper Eocene) in the following regions: NE of Spain, Biarritz (Southwestern France), Angoumé (Southern Aquitaine, France), Carinthia (Southern Austria), Venetian region of Italy Provence, Southern Alps of French, Istria (Croatia), Persian Gulf, Oman and Egypt. *I. sindensis* was first reported from the Eocene of Sindh province from the Khirthar Series (Pakistan) and Madagascar. It is also recorded from the Bartonian–Priabonian in the following regions: NE Spain, Biarritz in Southwestern France, Angoumé in Southern Aquitaine–France, Carinthia in Southern Austria, the Italian region of Veneto, Provence and southern French Alps, Persian Gulf, Oman, Egypt, and Istria. They are systematically described to determine their stratigraphic, paleoenvironment, and paleogeographic distribution. The material studied herein represents the first report from the middle Eocene of India, and it significantly expands the geographical extension of Eocene marine echinoids in the northeastern part of India.

Developed past 1100 years of climate and vegetation history from the Deoriatal Lake, Mandakini basin. The reconstructed vegetation and climate record indicated strengthened monsoon precipitation from ~1110–950, ~690–560, and ~290–130 cal yr BP, whereas

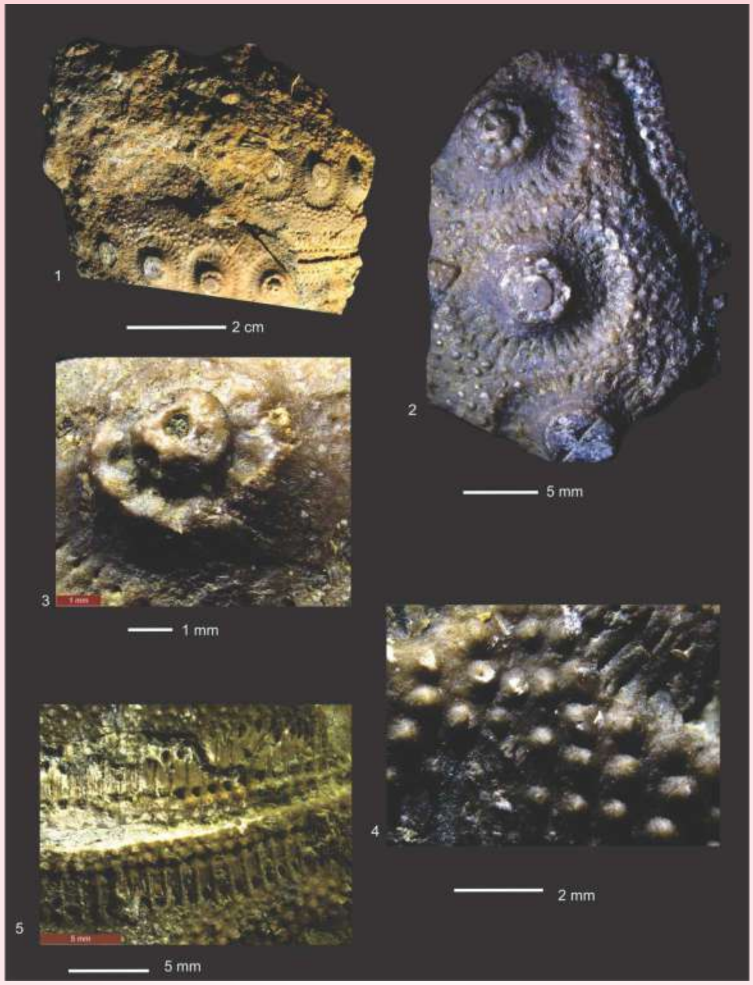


Fig. 40: *Porocidaris schmidelii.* (1) Partial view of an ambulacrum and contiguous interambulacral areas; (2) Detail of interambulacral tubercles; (3) Detail of a primary interambulacral tubercle; (4) Detail of interambulacral surface; (5) Detail of an ambulacrum.

the decreased ISM strengths were recorded during ~950–690 and ~560–290 cal yr BP. The strengthened monsoon from ~1110 to 950 cal yr BP corresponds with the globally warm medieval climate anomaly, and the decreased monsoon strength from ~560–290 cal yr BP corresponds with the Little Ice Age.

Activity: 4A

Climate variability and landscape responses in selected transects in the NE and NW Himalaya

(Khayingshing Luirei, Som Dutt, Anil Kumar, Chhavi Pandey, Pinkey Bisht and Subhojit Saha

Active deformation and landslides in the MBT– MCT zones, Garhwal Himalaya

Active ground deformation of the Mussoorie hills and Dehradun region is estimated using the ascending Sentinel–1 radar data set (acquired between 16–09–2015 and 10–07–2021). A higher rate of ground subsidence is observed in the form of co–seismic creep toward the south–facing hill slope with a velocity of –2 to –10 mm/y. Similarly, the surrounding regions of Kanditalli show co–seismic creep of –9 to –10 mm/y. Furthermore, a ~6 km wide and 20 km long N–S oriented zone of uplift with a relative velocity of 2 to 5 mm/y with a cumulative displacement of ~2 cm has been identified between Kandhauli and Tarauli. Moreover, toward the footwall block of the MBT, a wide region covering an area of 164 km^2 (surrounding regions of Rajpura–Premnagar–Dehradun–Donkwala–Araghar–Raipur–Dwara–Chironwali–Kaulagarh) is subsiding with a velocity of –3 to –10.5 mm/y with a cumulative displacement of 3.5 cm (Fig. 41). The results of ground subsidence (co–seismic creep) are well corroborated with the extensional fractures and fault patterns observed on the ground. The details of the field evidence are presented in the proceeding active deformation in the MBT zone section. The SAR image of 16–09–2015 of Mussoorie Hills shows there is a significant uplift with a velocity of

ACTIVITIES

5 mm/y. However, the velocity-time series for the period 22-9-2016 to 10-07-2010 shows dominant subsidence with a velocity of -3 to -10mm/y in and around Mussoorie hills. Similarly, the Kanditalli-Kimoi regions north of Mussoorie hills also show a significant amount of coseismic creep with a velocity of 2 to -5 mm/y. Similarly, the Rajpura-Kandhauli-Premnagar-Dehradun-Rajpura-Donkwala and adjoining regions show a significant amount of subsidence (Fig. 42).

In the Inner Kumaun Lesser Himalaya, the cumulative time series deformation has been estimated from 7th February 2017 to 10th February 2021. A total of 119152 PS points were extracted from the Persistent Scatterer Interferometry (PSI) analysis. The positive values indicate that the distance between the target region and the SAR sensor in its line of sight (LOS) is reducing, therefore implying an uplift, while the negative values represent that the distance between the target and radar sensor in its LOS is increasing, hence denoting subsidence. The total cumulative displacement that occurred during this period is ±55 mm. The average cumulative displacement observed is ±40 mm with a standard deviation ranging from 2.7-7.95 mm. Three main zones of active uplift were observed: a) Uplift between Pindari Thrust, MCT, and MT; b) Uplift towards NE of THF; c) patches of uplift between Pithoragarh and Champawat. In these three zones, the uplift gradually increases through time, which indicates a buildup of stress. Prominent subsidence is observed at AT near Gwaldam, to the south of Munsiari, at the lower reaches of the Goriganga River, and in the Nepal region. The LOS mean

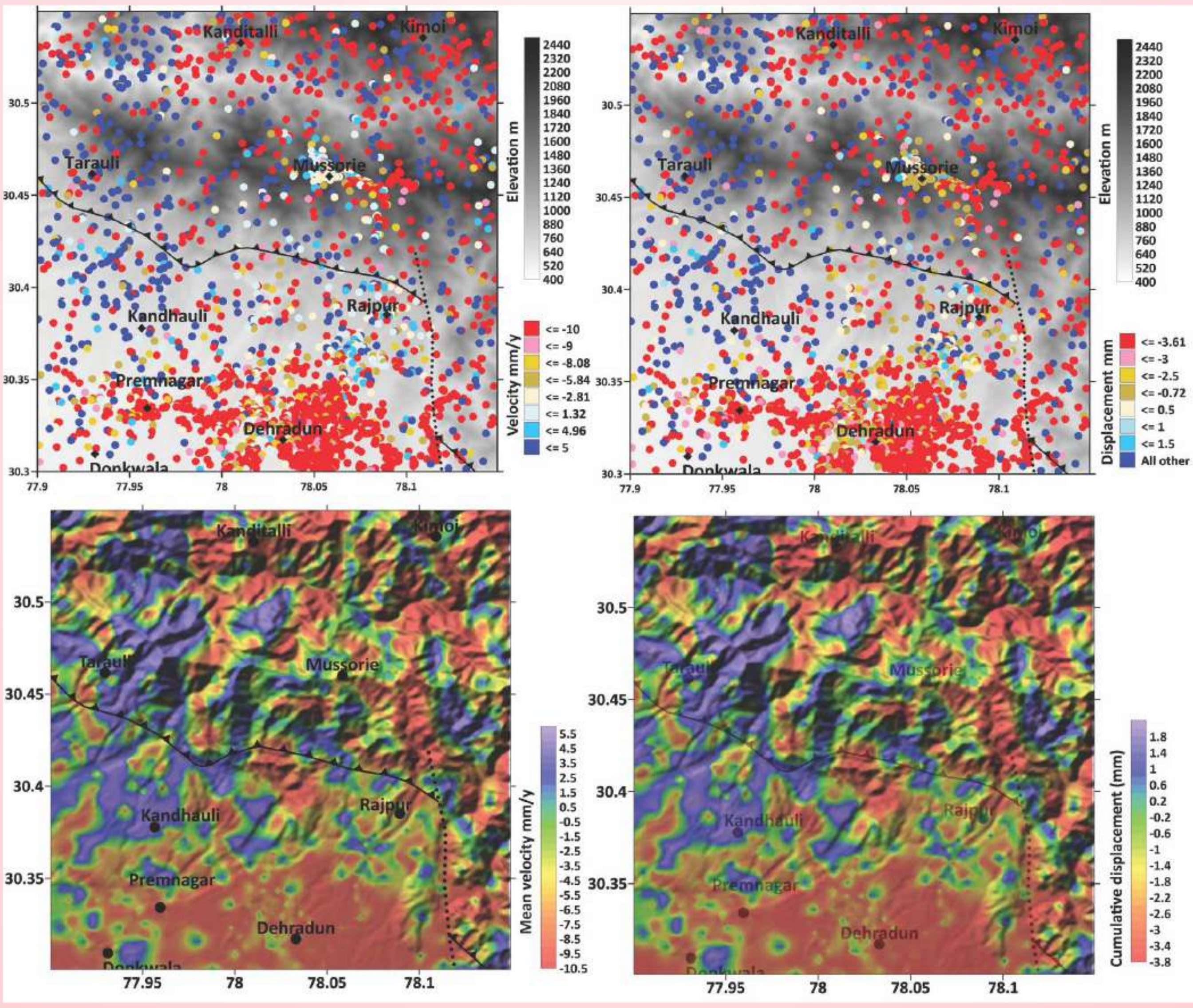


Fig. 41: PSI mean velocity (mm/y) and cumulative displacement (mm) of the area estimated using the SARPROZ software.

ACTIVITIES

deformation velocity is estimated to be ±10mm/yr with a 1σ deviation ranging from 0.55-5.63mm. Only those PS points were considered whose 1σ deviations ranged from 0.55-0.8 mm for better precision. Except for a few regions, the deformation in the study area lies in the range of ±7mm/yr. The central part of the study area around the Bageshwar locality is relatively stable and shows very low deformation compared to other regions.

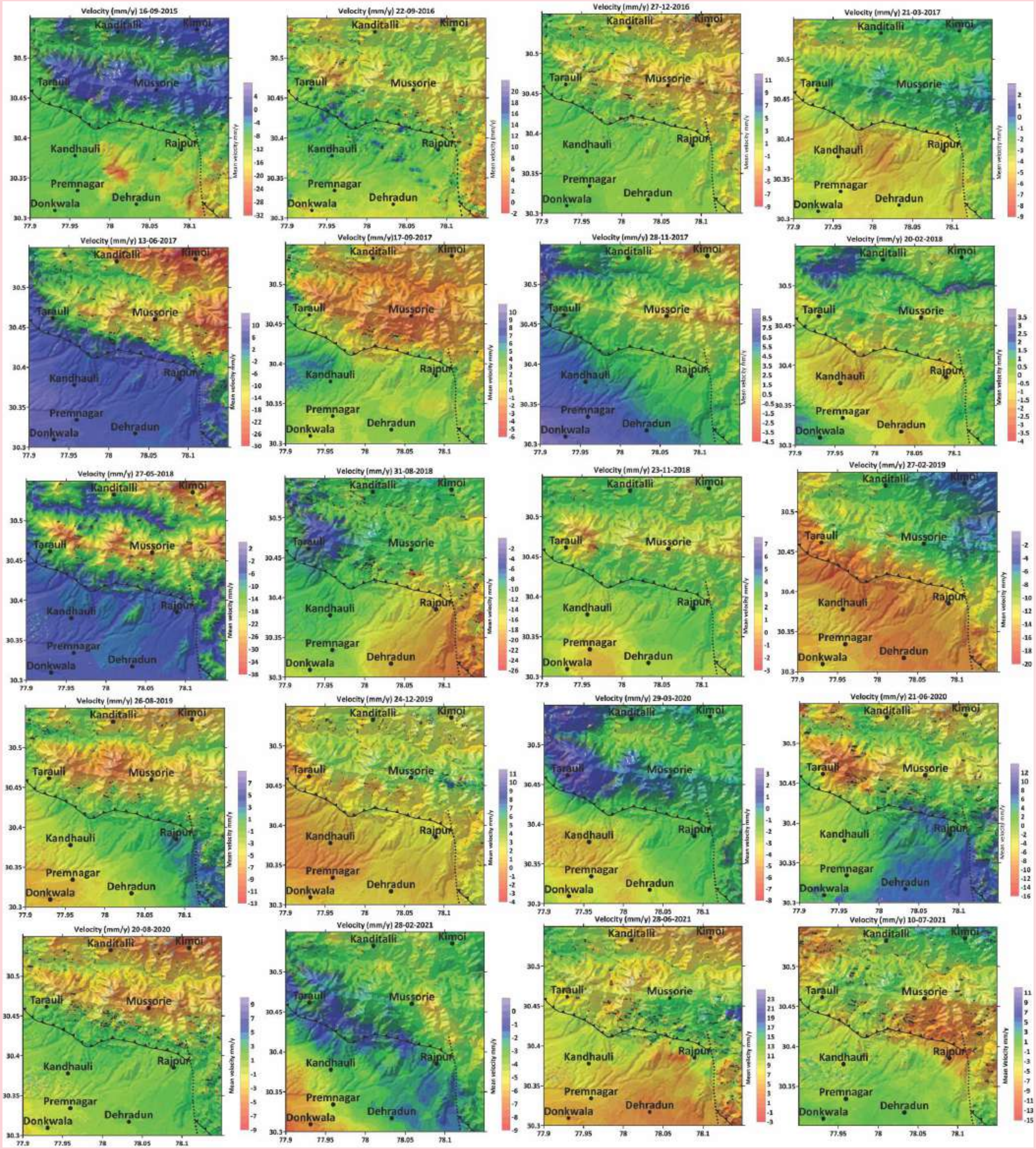


Fig. 42: SENTINEL-1A driven time series analysis estimated for the period between 16-09-2015 and 10-07-2021 using the GAMMA version 5.1.4, ASF DAAC HyP3 2022.

ACTIVITIES

The Goriganga and Kali rivers show major subsidence along their flow paths. The rivers Saryu, Ramganga, and Goriganga exhibit uplift in between VT/MCT and MT. Panar River shows uplift along its path whereas the Ladia and Lohawati Rivers are dominated by subsidence trends along their paths. The outer lesser Himalayan region is dominated by subsidence whereas, the inner lesser Himalaya is dominated by uplift in the central part and subsidence by eastern and western parts. The Higher Himalayan region does not show any distinct pattern of uplift or subsidence.

Landslide in the MBT zone of the Bhitarli-Chhoti area

The tectonic factor is one of the main causes of the instability of the slopes in the MBT zone of the Bhitarli Chhoti area, and the development of multiple joint sets and highly crushed rocks are its manifestations. The most common types of slope failure in the presented investigated area are rockfalls, toppling, and sliding. Debris slides are not common as the slope failures take place mostly in bedrock slopes. In Mussoorie, the areas falling under high and moderate landslide-susceptible zones are limestone terrain that is highly fractured where the slope ranges between 65° and 77°. Field observations indicate that the most vulnerable lithology to various types of landslides is the shales. The shales are thinly bedded, and the landslides take place along the bedding planes. Lateral movements along the bedding planes in the shales also facilitate the development of open fractures, which, in due course, becomes an important factor in the instability of the slopes. Large open fractures that are steeply dipping to almost vertical are the main causes of toppling in shale bedrocks and have been supported by road construction as a result of the removal of support. The other bedrock is relatively more stable than the shale, or it may also be because of the maximum stretch of the road sections constructed in the shale terrain. A section of road passes through an old landslide in the carbonate terrain; the landslide debris has been cemented together by carbonate-rich water. This cementing process by the carbonated water has stabilized the portion of the slope to a great extent. Wedge analysis of the joints suggests the formation of multiple wedges that open towards the daylight slope. Faults, joints, and favorable bedding planes constitute one of the most important factors for the instability of the slopes.

Middle to late Holocene climatic variability in northeastern India and wildfire occurrences in Ladakh

A late Holocene wildfire record from Leh Valley reconstructed through a ~2.8-m long peat sedimentary profile from Stagmo, Indus Valley, Ladakh Himalaya was published. The results bring new insight into the interaction between vegetation, fire, and human activity in the Ladakh Himalaya during the past ~ 2.8 calkyr BP. Three paleo fire events were registered in the peat sequence: (a) 2.81 – 2.55 cal kyr BP, (b) 1.65 – 1.54 cal kyr BP, and (c) ~1.38 cal kyr BP (Fig. 43). These phases are correlatable with the intensified Indian Summer Monsoon (ISM) advancing to Trans-Himalaya, which will lead to increased human settlement in the region.

ACTIVITIES

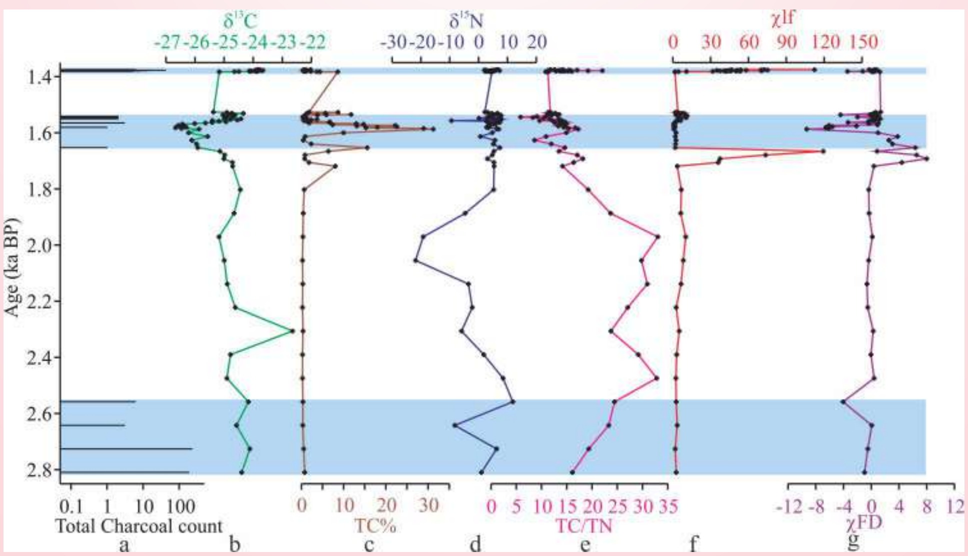


Fig. 43: Depth profiles of sedimentary section (A) Charcoal specks count (B) $\delta^{13}C$, (C) TC, (D) $\delta^{15}N$, (E) TC/TN, (F) χlf and (G) χFD%. Higher values of TC and TC/TN and lower $\delta^{15}N$ represent warmer conditions. $\delta^{13}C$ values ~ 23.5‰ to 26.5‰ (VPDB) indicate the presence of C-3 plants in peat deposits.

A study was conducted using a speleothem sample from the Mawmluh cave, northeastern India suggesting significant regional variability of the Indian summer monsoon during the middle to late Holocene. A significant wet phase was witnessed in northeastern India between ~3.5 and 2.9 kyr BP, which was also observed in other parts of the country (Fig. 44). Northeastern India observed an abrupt and pronounced weakening of summer monsoon rainfall at around 4.2 kyr BP that lasted for around 200 years, whereas the same events lasted longer in the western and northwestern parts of the Indian subcontinent. Some speleothem samples are under investigation for microfabric and architectural elements study to understand the regional climate change history in northeast India. Preliminary petrographic changes reveal significant mineralogical changes in the samples occurred mainly due to major shifts in the regional climate. Identification and popularization of the geo-tourism potential of sites in India have been initiated, especially in the Himalayan region. A study from Uttarakhand highlights the geo-tourism potential of Bhiar Dhar cave. The Bhiar Dhar cave is one of the very few caves in the Himalayas, showing a variety of speleothem features and forms. The cave encompasses stalagmites, stalactites, flowstones, straw, columns, cave curtains, diapirs, etc., and has immense potential to be developed as a geo-tourism site and demands immediate actions for its conservation for education and scientific studies.

Landscape responses to climate variability and tectonics

In this work, characterization of the Pleistocene capture of the Zhada Basin, a ~23000 km² extensional basin in southern Tibet has been done. The magnitudes and time scales of capture-driven erosion have been quantified using knickpoint celerity modeling, paleotopographic reconstructions, ^{10}Be-derived denudation rates, and topographic analyses of drainage divides. It is found that the capture has removed 2010 ± 400 km³ of sediment from the Zhada Basin, increasing sediment supply to the Satluj network by 17%–29% since 735 ± 269 ka. Pangong Tso, a ~140 km long hypersaline lake, is sensitive to changes in air temperature, precipitation, and snow-glacier melt over the southwestern TP. The incised tributaries entering the lake expose deltaic sequences constituting the top-set, forset, and bottom-set. The elevation of the top-set represents past lake-high stands from where mollusks were also recovered. Three-phased lake level changes have been observed during the past 3 ka. The first high-stand (+1.4 – 3.0 m) was at ~2.8 – 2.0 ka when lake surface salinity and temperature were 4.67 – 6.01 ppt (parts per thousand) and 5 – 7 °C, respectively, against the modern average values of 7.7 ± 0.09 ppt and 16.1 ± 2.0 °C. Followed by a brief decline, another high stand (+3.0 – 3.6 m) is observed at 1.1 ka when the salinity is reduced to 4.03 – 5.72 ppt and lake surface temperature to 5 – 8 °C. A corresponding increase in freshwater diatom concentration is also observed here. Over the past 1 ka,

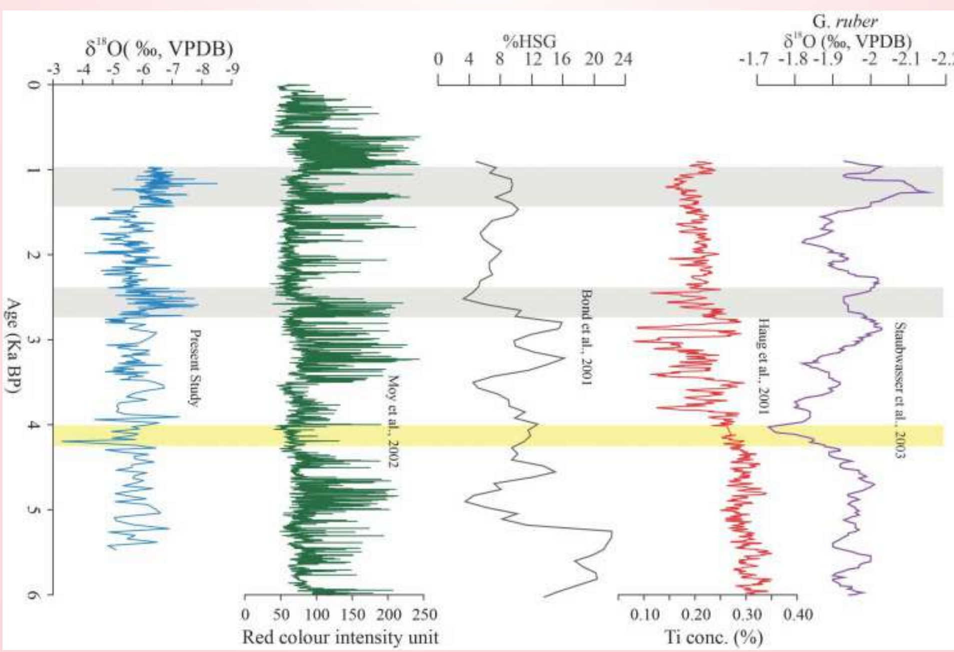


Fig. 44: A comparison between A) δ^{18}O series of present study from the Mawmluh cave, northeastern India, B) ENSO series (Moy et al. 2002), C) North Atlantic ice rafting events (Bond et al. 2001), D) migration of ITCZ (Haug et al. 2001), E) *G.ruber* upwelling index (Staubwasser et al. 2003).

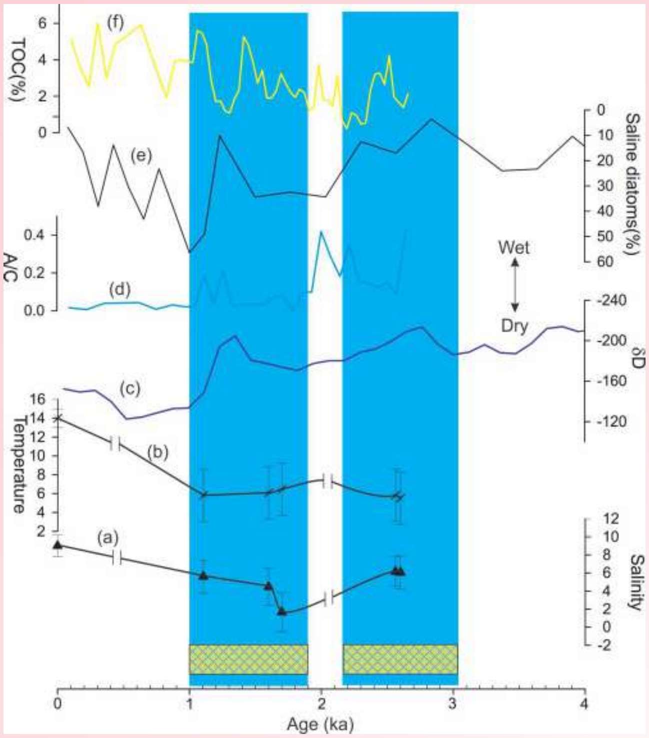


Fig. 45: Lake level fluctuation of Pangong Tso lake, climate proxy record from peat section of NW Himalaya and Pangong Tso lake. (a,b) Hydrology (temperature and salinity) (c) δD derived from leaf wax of Pangong Tso sediments (Hou et al., 2017), (d) Artemisia/ Chenopodiaceae ratio (A/C ratio) from the peat section at the Leh valley (Sharma et al., 2020) (e) salinity loving diatom species (Gasse et al., 1996), and (f) TOC from the peat deposit of NW Ladakh Himalaya (Sharma et al., 2020) over the past 3 ka.

the third phase witnessed a fall of ~3.6 to 6 m in lake level, which is attributed to an abrupt rise in aridity over the TP (Fig. 45). It is demonstrated that lake level variation in the region is a function of the variability of the Indian Summer Monsoon (ISM) and the westerlies; however, during the high stand, the hydrology of the lake was dominated by ISM precipitation.

Transport of black carbon towards Gangotri glaciers

The Himalayas hold a unique place in the mountainous ecosystems of the globe, and they are the most diverse ecosystem. Nowadays, Himalayan glaciers are facing a growing environmental challenge due to the increasing concentration of light-absorbing carbonaceous aerosols (LACAs). These LACAs mainly include black carbon (BC) and brown carbon (BrC). BC primarily originates from incomplete combustion of fossil fuels, biofuels, and biomass, while BrC co-exists with BC whenever there is combustion of organic matter. A comprehensive investigation has been conducted on the characteristics and optical properties of BC particles. This study primarily focuses on monitoring the influence of meteorological conditions and transportation and the impacts of equivalent black carbon (eBC) in a higher altitude region, Bhojbasa (near the Gangotri glacier). To quantify eBC concentration, the Aethalometer AE-33 is used, which computes the concentration of light-absorbing aerosols from the light intensity change on transmittance across the particle-filled filter. Analyses have been done daily, monthly, and diurnal time scales to understand eBC variations. The meteorological data, air-mass trajectories, and various satellite-based datasets have also been interpreted to examine the influence of various parameters on eBC. The daily mean concentration of eBC at Bhojbasa was observed to be 0.290 ± 0.217 µg m^{-3} for a period of 7 months (June to December 2016). Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and backward air-mass trajectory using Potential Source Contribution Function (PSCF) and Concentration-Weighted Trajectory (CWT) further show the possible transport pathways of BC particles towards the pristine regions of the Himalayan glacier valley. The presence of BC in such pristine higher-altitude regions could lead to reduced albedo, positive radiative forcing, snow and ice melting, changes in hydrological cycles, and monsoon circulation. Monitoring eBC over a long period can help us understand its effects by improving our understanding of optical, chemical, and morphological aspects (Fig. 46).

Glacial chronology of the Panchachuli glacier using field survey and OSL dating

The late Quaternary glacial history has been investigated in the Panchachuli glacier (3600 masl), Darma Valley (30° 14′ 5.75″N and 80° 29′ 52.286″ E.), Pithoragarh district, Uttarakhand, Central Himalaya, using field mapping, geomorphic analysis of landform, and Optical Stimulated Luminescence dating (OSL) (Fig. 47). The valley has preserved glacial and glacio-fluvial landform deposits that record the glacial activity of the late Quaternary period. Three events of glaciation were recognized and assigned the name Panchchuli Stage (PS) -1 corresponding to MIS-3, PS-2 corresponding to LGM, and PS-3, which corresponds to early to mid-Holocene, respectively. Further, to elucidate the Late Pleistocene glacial history of the Panchachuli glacier, OSL dating was applied to fluvial deposits. Periods of glacier recession were indicated by the presence of fluvial deposits depicting the deglaciation history of the glacier in the valley. The oldest chronology acquired from the fluvial sediments

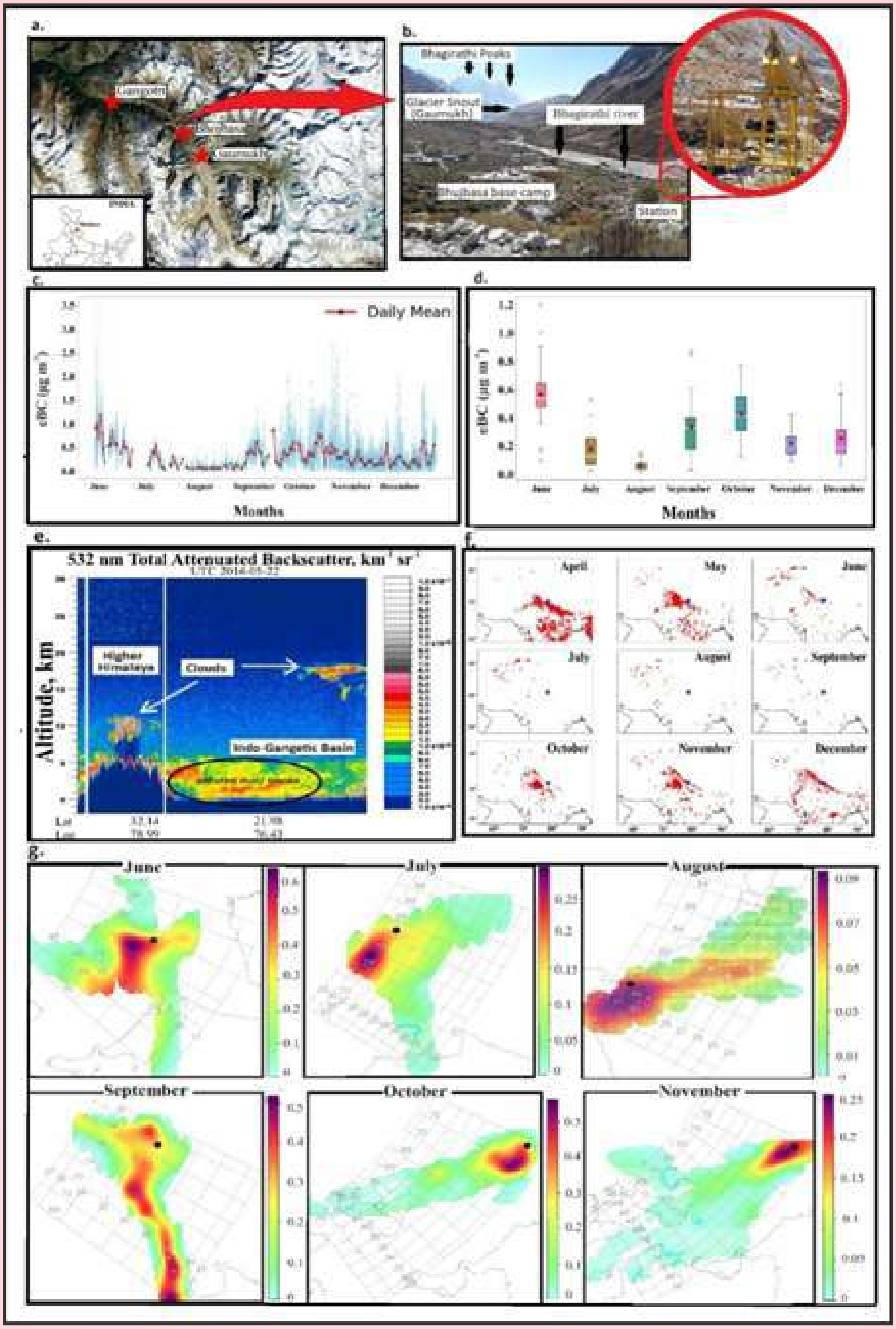


Fig. 46: Investigating Black Carbon (BC) in the Bhojbasa Region: (a) Satellite view of the Gangotri glacier valley encompassing the study area (Bhojbasa, 3800m amsl). (b) Field deployment of the AE33 air quality monitoring station at Bhojbasa. (c) Daily variations in eBC concentration measured by the station. (d) Monthly levels are visualized through a box-whisker plot. (e) CALIPSO satellite imagery unveils the vertical distribution of aerosols and clouds. (f) Fire events (April–December) mapped to identify potential black carbon sources. (g) Utilizing the Hysplit model to track long-range black carbon transport pathways.

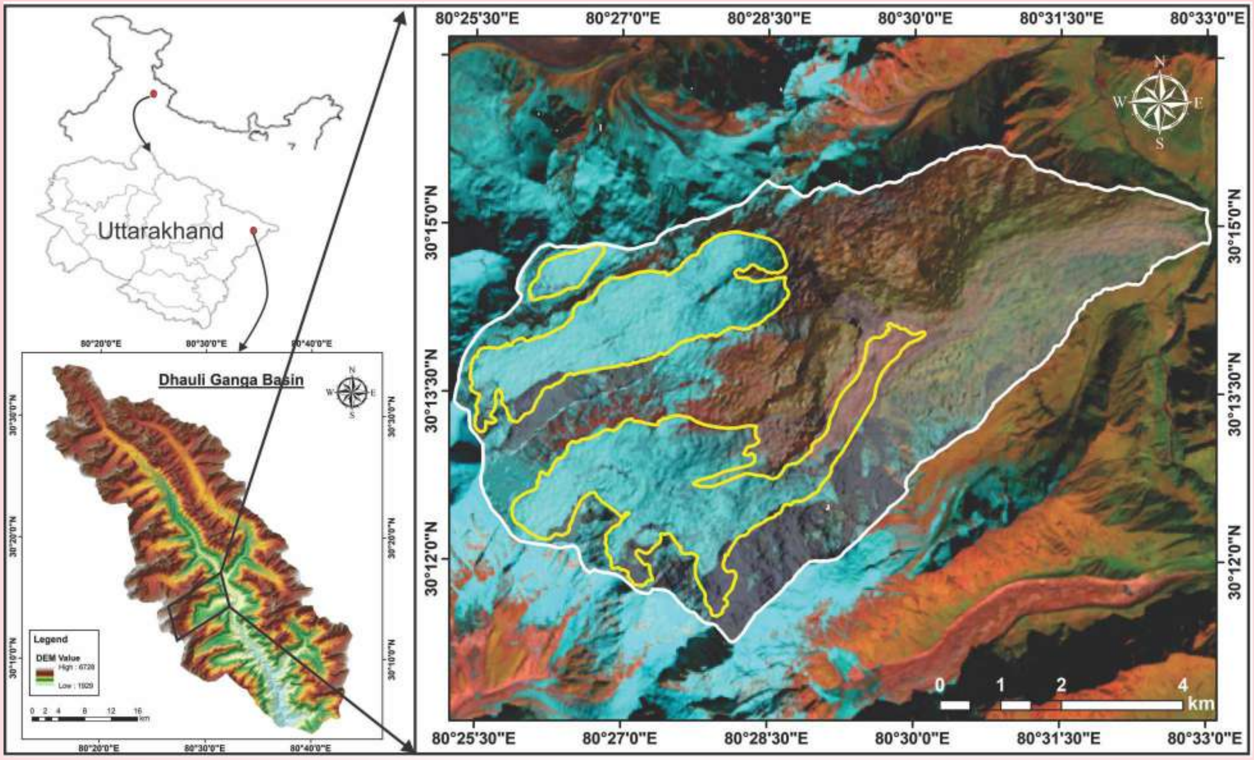


Fig. 47: Study area and the location of the samples dated using Optical Stimulated Luminescence (OSL) Dating.

is ~32 ka, indicating the deglaciation during the late MIS 3 when there was high insolation high monsoon period, ~14 ka age acquired from the fluvial terrace indicating the Bolling Alleroid warm period, and a fluvial deposit dated ~8 ka indicating the early Holocene high insolation period. The overall pattern of glaciation and deglaciation across the region suggests that stronger westerlies in the transitional zone of Central Himalaya supported glacier expansion during the Last Glacial Maximum (LGM). Remarkably, glacier advance is also documented in the MIS 3 and mid-Holocene, suggesting that the Himalayan glaciers have responded over millennia to a combination of mid-latitude westerlies and the ISM.

Pre-Cryogenian evolution from the Lesser Himalayan (LH) basin

Nagthat Formation, Lesser Himalayan basin: Detailed documentation from the lower part of Nagthat Formation (i.e., Chandpur-Nagthat contact) identified five facies types possibly deposited in three different bathymetric settings. Black siltstone (facies I) and shale (facies II) represent the deepest bathymetry and are possibly deposited below the storm wave base (STB), as these facies lack any signature of the storm. Possibly, these facies represent outer shelf deposits. Thin bedded fine-grained sandstones (facies III) with isotropic and anisotropic hummocky convex-up laminations indicate deposition above the storm wave base (STB). A few of the beds show well-preserved symmetrical ripples and wave-reworked tops, facies III sandstone, which might have extended up to a fair-weather wave base. That means they are deposits of the inner shelf to the lower shoreface setting. Coarse-grained sandstones (facies IV) with coarsening up character and planar tabular or low-angle lamination have been attributed to subtidal to intertidal settings and identified as delta mouth bars. Though no distributary channels have been identified, very coarse grain size and poor sorting of the facies IV sandstone support nearby supply and dominance of fluvially supplied sediments. Similarly, the lenticular conglomerate (facies V) mostly overlies the facies IV sandstones and is identified as the product of debris flow, which is common in lower delta plain settings. Therefore, the deposition of the lower part of the Nagthat formation occurs in a lower delta plain to the pro-delta setting.

Cretaceous-Paleogene Nilkanth and Subathu sedimentary succession of the Garhwal foreland basin, NW Himayala, have been studied using sediment geochemistry and U-Pb detrital zircon geochronology. From geochemical proxies, the present study deciphers the addition of a northern (ophiolitic) provenance during Subathu sedimentation as opposed to the sole cratonic input in the case of Nilkanth sedimentation in a passive margin setup. The Nilkanth sedimentation was terminated by Cenomanian. The sediments of the Subathu Formation, particularly Subathu shales, with anomalous Ni (159 ppm) and Cr (301 ppm) concentrations, substantiate the addition of an ophiolitic provenance from the north (the Kohistan-Dras Island arc, including granitic plutons in the arc roots). The detrital zircon age data from both Nilkanth and Subathu Formations justify the contention; whereas ~100 and 120 Ma aged grains from the Nilkanth Formation suggest cratonic input from the south, documentation of ~ 91 Ma zircon grain from the Subathu sandstone bear undoubted indication for an additional sediment source present in the north. The evolution of the Subathu basin in the Garhwal foreland spanned over a period of ~25 Ma. The fore-bulge created around 55 Ma with the collision between the Indian and Eurasian plates paved the way for foreland sedimentation.

Activity: 4B

Ecology and Climate Dynamics of the Himalaya – Cenozoic to Present

(Narendra K. Meena, Jayendra Singh, Sudipta Sarkar and Prakasam M.)

Study on lake/paleo-lake/ peat/ soil profile or cores

Chronologically constrained multi-proxy data sets from the multi-archival records have been developed to reconstruct the centennial to millennial-scale climate and vegetation history, esp. during the Holocene period from the north-western Himalaya and Indo-Gangetic Plain. To reconstruct the late Holocene paleoclimatic changes in the North-Western Himalaya, samples from two study areas, located in the Lahaul-Spiti region of the Himachal Himalaya have been analyzed for sedimentological and geochemical proxies. At the Miyar Valley, around one-meter deep peat/soil profile, the siliciclastic grain size percentage data representing the down-depth sand, silt, and clay fractions, along with magnetic susceptibility parameter and Total Organic Carbon (TOC) data corroborate each other while indicating a gradual shift from higher to low energy depositional conditions towards the younger and recent period during the late Holocene. The last four minnenia's multi-proxy record from the SS-Tso Lake in the Himachal Himalaya provides evidence of significant variations in the climate and environment throughout time. The multi-proxy data from this lake reveal several dry and wet events in the region. The SS-Tso lake's $\delta^{18}O$ record indicates warm and moist conditions during ~2524 –2259 BC, ~2024 –49 BC, and ~942-1462 AD and cold and dry conditions during ~2259 – 2024 BC, ~49 BC – 942 AD, and ~1462 – 2022 AD.

Paleoclimatic studies have also been initiated in the Himalayan Foreland basin. To reconstruct the Holocene paleoclimatic changes in the Ganga Plain, samples from the Hastinapur area have been analyzed for sedimentological and geochemical parameters. Few samples have been analyzed for OSL age dating.

The profile/core samples from lake/paleolake, and peat/soil deposits were collected from the Lahaul-Spiti region of Himachal Pradesh during the reporting period for multi-proxy analysis, including biotic and abiotic proxies, as well as AMS ^{14}C dating and OSL age dating. The resulting multi-proxy datasets will provide valuable insights into the centennial to millennial-scale climate and vegetation history during the Holocene period.

Study on Sea sediment cores

Ten microfossil samples (mixed planktic foraminifera) from the SE Arabian Sea and the Andaman Sea were processed for AMS Dating at the Inter-University Accelerator Centre (IUAC), New Delhi. Results indicate approximately 38 kyr last age for the Arabian Sea samples and around 32 kyr for the Andaman Sea. These samples are being prepared for multi-proxy analysis to reconstruct the Late Quaternary climate and Himalayan weathering. Additionally, fifty samples (~70 kyr) from the SE Arabian Sea have been analyzed for planktic foraminifera, total organic carbon (TOC), and stable isotope geochemistry.

Dendrochronological Study

A 332-year-long tree-ring chronology of *Abies pindrow* was developed from the Joshimath region, Uttarakhand. Tree-ring chronology revealed a direct relationship with precipitation, whereas it has an inverse relationship with temperature. Further analysis also revealed the species' potential in developing regional drought records.

Cedrus deodara tree core samples originated from the Malari region, Uttarakhand were also precisely dated to the level of the calendar year and further used to develop several centuries' long ring-width chronologies for the region, the longest tree-ring chronology extended back to 828 years (1194-2021 CE). To understand the climate signal present in the chronologies, tree growth, and climate analysis was performed. The analysis revealed the presence of strong precipitation signals in the chronologies. The chronologies were also tested for use together in dendroclimatic analysis, which captured the existence of strong similarity in growth patterns among each other, indicating that a common forcing factor (i.e., climate) influences the growth of trees growing in the region. A fieldwork was also carried out in the Lahaul-Spiti region of Himachal Pradesh, while tree core samples from 110 trees were collected to develop climate-responsive tree-ring chronologies and climate records for the region.

Activity: 5

Geological and Geomorphic controls on Landslide for risk assessment and zonation in the Himalaya

(Kalachand Sain, Swapnamita C. Vaideswaran, Naveen Chandra and Tariq Anwar Ansari)

Extracting landslide information from remote sensing imagery holds significant importance for prompt assessment and recovery efforts. Furthermore, it plays a crucial role in generating accurate and present landslide inventories. The advancement of computational resources, particularly graphical processing units (GPUs), has propelled the rapid development of deep learning in computer vision, particularly, single-staged models like YOLO (You Only Look Once) models due to their speed and accuracy. To address the challenges in landslide analysis attention mechanisms, particularly convolutional block attention module (CBAM), efficient channel attention (ECA), global attention mechanism (GAM), and coordinate attention (CA) have been introduced. A novel attention-based YOLOv5 model (namely YOLOv5+ECA, YOLOv5+CBAM, YOLOv5+CA, and YOLOv5+GAM) is developed to extract landslide events from multi-source remote sensing platforms in diverse geological environments in the Himalayan region. The proposed architecture is shown in figure 48. The prediction accuracy of YOLOv5+CBAM (f-score=98%) is found to be supreme (Fig. 49). According to the experimental findings, the CBAM stands out as the most effective attention module for integration within convolutional neural networks for investigating hazards especially, landslides. The suggested method can be applied in dynamic landslide detection systems for updating the database precisely. Researchers have developed various methods for Landslide Susceptibility Mapping (LSM) of Uttarakhand. The quantitative results are based on the utilized data set, distribution of the model/method, primary study locations, percentage utilization of the conditioning factors, adopted validation approach, and worldwide contribution. In addition, based on the social and economic parameters, the current status of the landslide risk exposure has been presented at a few locations in Uttarakhand.

Landslide Risks Assessment in Tons Catchment, District Dehradun (Uttarakhand)

The Tons Valley, located in the states of Himachal Pradesh and Uttarakhand, is a geomorphic unit of the Garhwal Himalaya situated at an average altitude between 2000 and 3000 m (Fig. 50). In this catchment, landslides mostly occur in the rocks of the Chakrata and Rautgara Formations, with few exceptions in the Mandhali Formation. Anthropogenically induced landslides, mainly because of road constructions, are

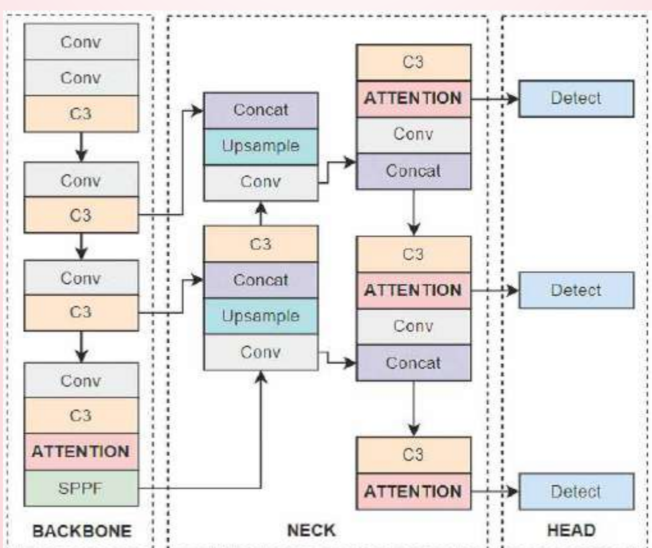


Fig. 48: Architecture of the proposed attention-based YOLOv5 (You Only Look Once Version 5) network for landslide mapping. (Conv: Convolution, C3: Concentrated-Comprehensive Convolution, SPPF: Spatial Pyramid Pooling Fast, Concat: Concatenation).

ACTIVITIES

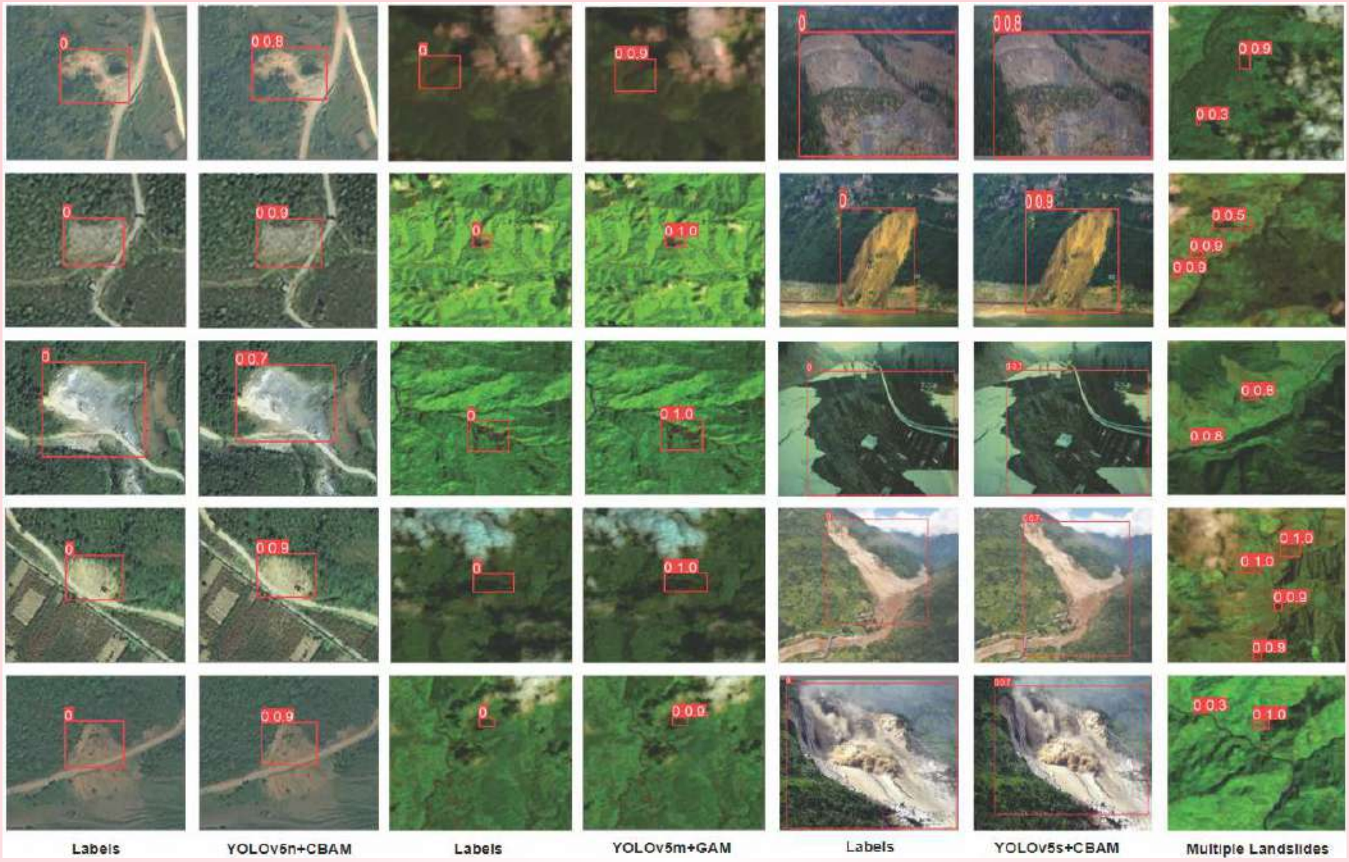


Fig. 49: Visual representation of the extracted landslides by the proposed YOLO+CBAM model.

observed in many sections of the road. The Jutogh Thrust passes through the upper catchment, and the Main Boundary Thrust passes through the lower catchment zones. In such a fragile and tectonically active area where slope failure is a common phenomenon, the need for a landslide susceptibility map has become very imperative. The following parameters, namely, slope, aspect, curvature, drainage, geology, proximity to the fault, distance from the roads, rainfall, and land use were integrated into the GIS platform to delineate landslide susceptibility zones based on the Weighted Index Overlay method. SRTM DEM was used to extract the landslide causative factors like slope, aspect, and curvature. The land cover was generated from Landsat 9 satellite data based on supervised classification by the Maximum Likelihood Method. The landslide susceptibility map classified the study area into low, moderate, high, and very high susceptible zones. About 1.04% of the total area falls under low susceptibility, 49.12% of the area falls under moderate risk zones, 49.37% of the total area falls under the high susceptible zone and the rest 0.5% falls under very high–risk zone. Since a huge portion falls under high–moderate risk zones, it is important to plan developmental activities in the region based on the susceptibility map.

Landslide Risk Assessment in Joshimath and Adjoining Region, District Chamoli (Uttarakhand)

Situated in the abode of Himalaya, lying at an altitude of approximately 1800 m the hilly town of Joshimath (30°33′1.9872"N latitude, 79°33′57.4704"E longitude) is located in the administrative district of Chamoli in the state of Uttarakhand. The region has a historical record of sinking, toe–erosion, and subsidence issues. However, the situation worsened in January 2023 when unexpected cracks appeared in the town. The appearance of cracks followed a distinct arcuate path in the east–west direction and then extended southwards. The newly developed cracks were mainly seen inthe Singhdhar and Marwari areas.However, this was unexpected as such signatures of slides had not been reported from the west side of the town earlier. The need for a landslide susceptibility map has become very imperative in a geologically sensitive town like Joshimath. Landslide susceptibility of an area is an essential component during the study of any landslide assessment. Hence an attempt has been made to prepare

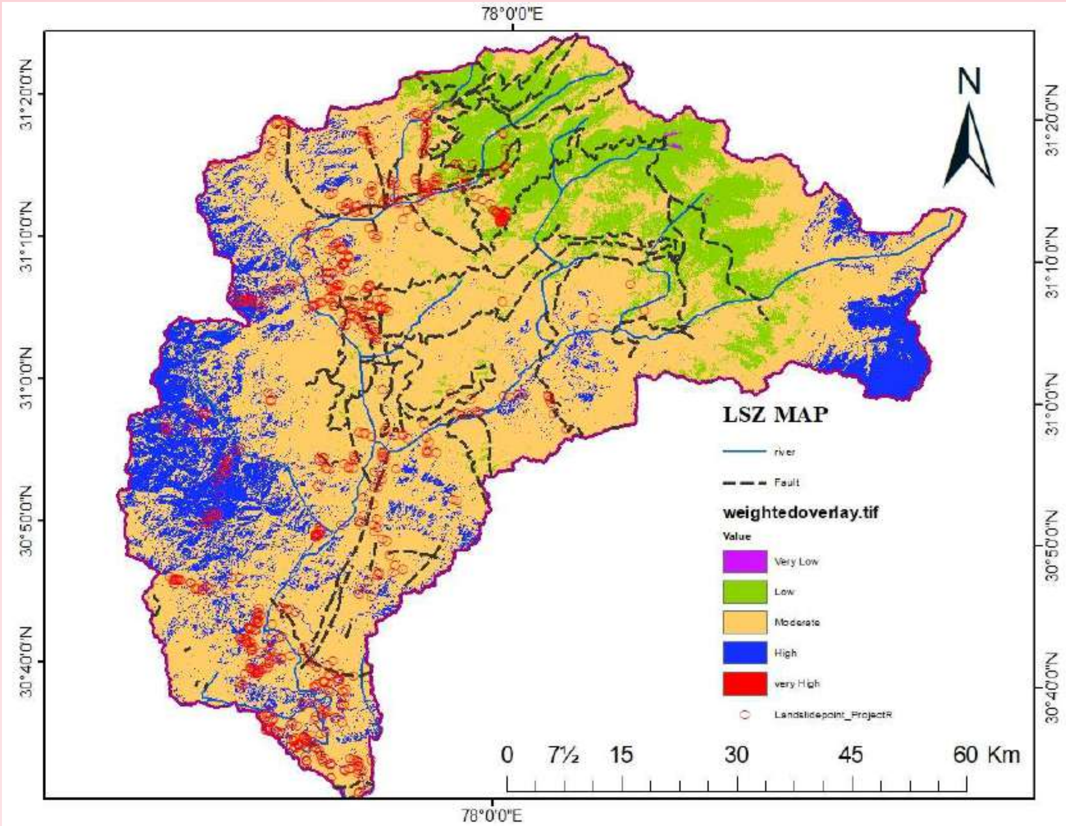


Fig. 50: Landslides mapped in the Tons Catchment (partly falling in Chakrata, Uttarakhand) with Landslide Risk Assessment using multiple parametric studies and Weighted Overlay Method.

a susceptibility map of the region. The susceptibility map has been prepared for the area from Badrinath at the top to Birahi, downstream of Pipalkoti. The following parameters namely slope, aspect, geology, soil, proximity to the faults, distance from road, rainfall, and land use were integrated into the GIS platform to delineate landslide susceptibility zones based on the weighted index overlay method. A 30m × 30m resolution SRTM DEM was used to extract the landslide causative factors like slope, and aspect. The land cover was generated from Landsat 9 satellite data based on supervised classification by the maximum likelihood method in Arc GIS 10.8.2.

It is crucial to understand that over time, the susceptibility of a region can change due to increasing developmental activities. Therefore, regular revisions of these maps from time to time are vital. In areas like Joshimath, where geological and environmental factors make landslides a significant concern, up-to-date landslide susceptibility maps prove to be a handy tool for disaster preparedness, and land use planning to minimize landslide-related risks.

The resultant landslide susceptibility map has been classified into four susceptible zones. The study reveals that a total of 1.50% area falls in the low-risk zone, m 34.66% in the moderate zone, 62% area falls under the high zone, and 1.82% in the very high zone. Most of the very high landslide zones are located in the Central Crystallines of the Higher Himalaya in the vicinity of the Main Central Thrust, and the mapped faults. Anthropogenic activities like slope cutting for road construction along National Highway-7 are influencing the landslides. This is correlatable with Landuse/Landcover mapping. Almost 30% falls under a 10–30° slope angle, which also falls under a very high susceptible zone. The majority of the slope falls under the high susceptible zone. This shows that slope angle plays an important role in causing landslides. This is seen in high-resolution LiDAR data. A total of 53% falls under the E-NE direction, which is conformable with the slide direction. The validation curve with Area Under Curve (AUC) shows an accuracy of 96% (Figs. 51–53).

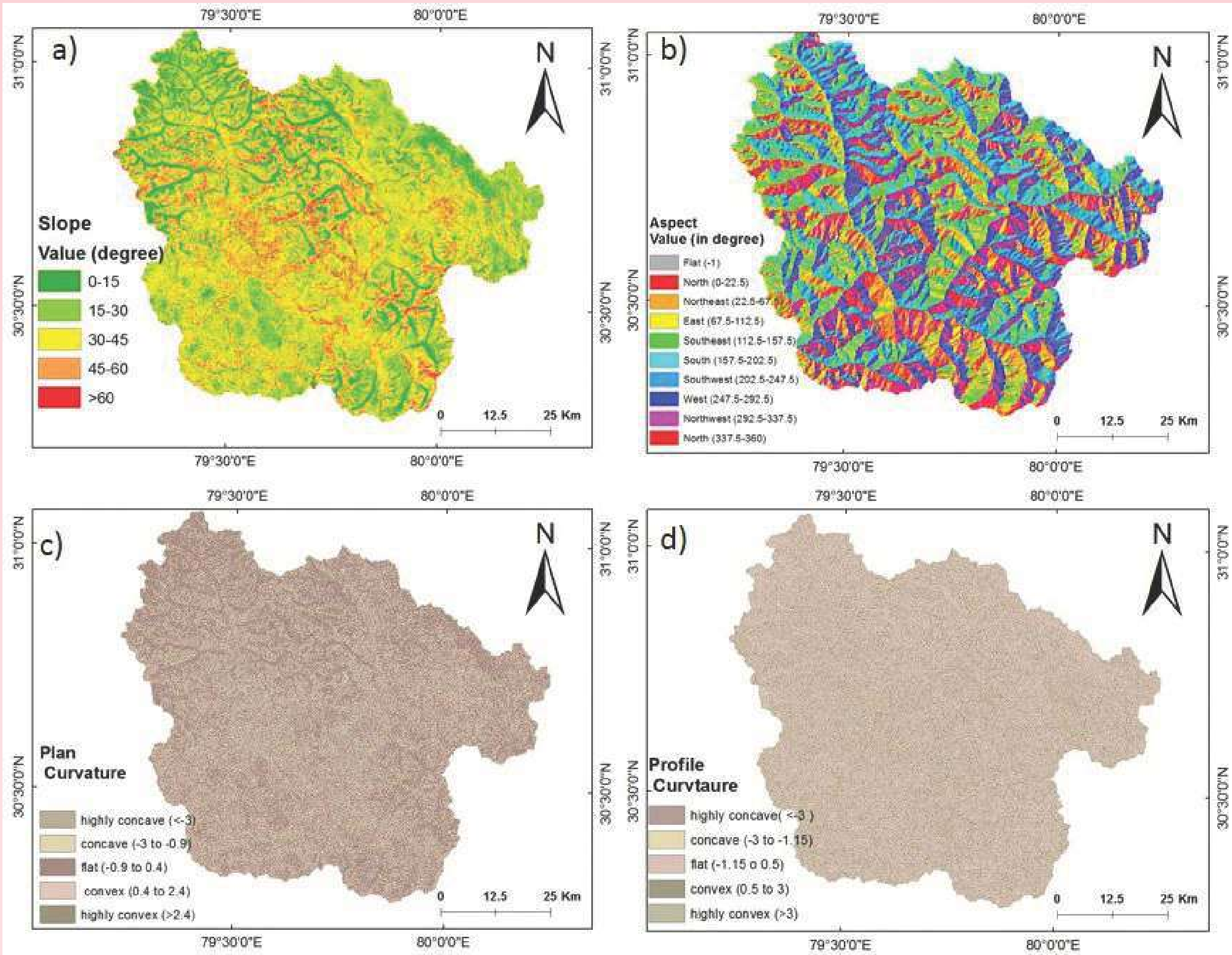


Fig. 51: Thematic layers a. Slope map, b. Aspect map c. Plan Curvature and d. Profile curvature.

Geotechnical Investigation around Rudraprayag and Karnaprayag

Geotechnical parameters of debris samples collected between Rudraprayag and Karnaprayag regions along the National Highway-7, in Uttarakhand state, are assessed for further debris slope stability investigation. Geotechnical characterization of Debris materials shows that soils are mostly coarse sand size ranging from 58.64 to 83.8 %, which belongs to the SM (silty sand) group, whether, some locations are in SP (Poorly graded sand) –SC (Clayey Sand), SW (Well graded Sand),-SC (Clayey Sand), and SP (Poorly graded Sand) –SM (silty sand) groups of soil. The maximum dry density and optimum moisture content of the soils vary from 2.04 to 1.94 g/cm3, and 11 to 13.5% respectively. Here well-graded and coarse material gives higher dry density and lower moisture content. Densities have variations in the range from 2.04 to 1.94 g/cm3. The soils are of firm-stiff consistency based on the unconfined compressive strength of the soil. Cohesive values range from 27.1 to 64.7 which implies most of the locations have soft to medium soil, and the friction angle varies from 29.3° to 52.2° Permeability of the examined soil samples is in the range of 10^{-9} to 10^{-14} and thus classified as low-permeable soil.

Fracture Toughness Determination

The stability of buildings and foundation designs constructed on or within rock masses depends on highly intricate and critical rock fracturing processes. Rock fractures are primarily characterized by parameters associated with fracture toughness and stress intensity factors. This study aims to explore Mode I, Mode II, and mixed Mode (I+II) fracture toughness of semi-circular bend (SCB) samples using the acoustic emission (AE) monitoring technique. Three different types of rocks, namely khondalite, limestone, and basalt, have been selected to examine the fracturing process from particular locations in India. The experimental results of fracture toughness for different rock types indicate that

ACTIVITIES

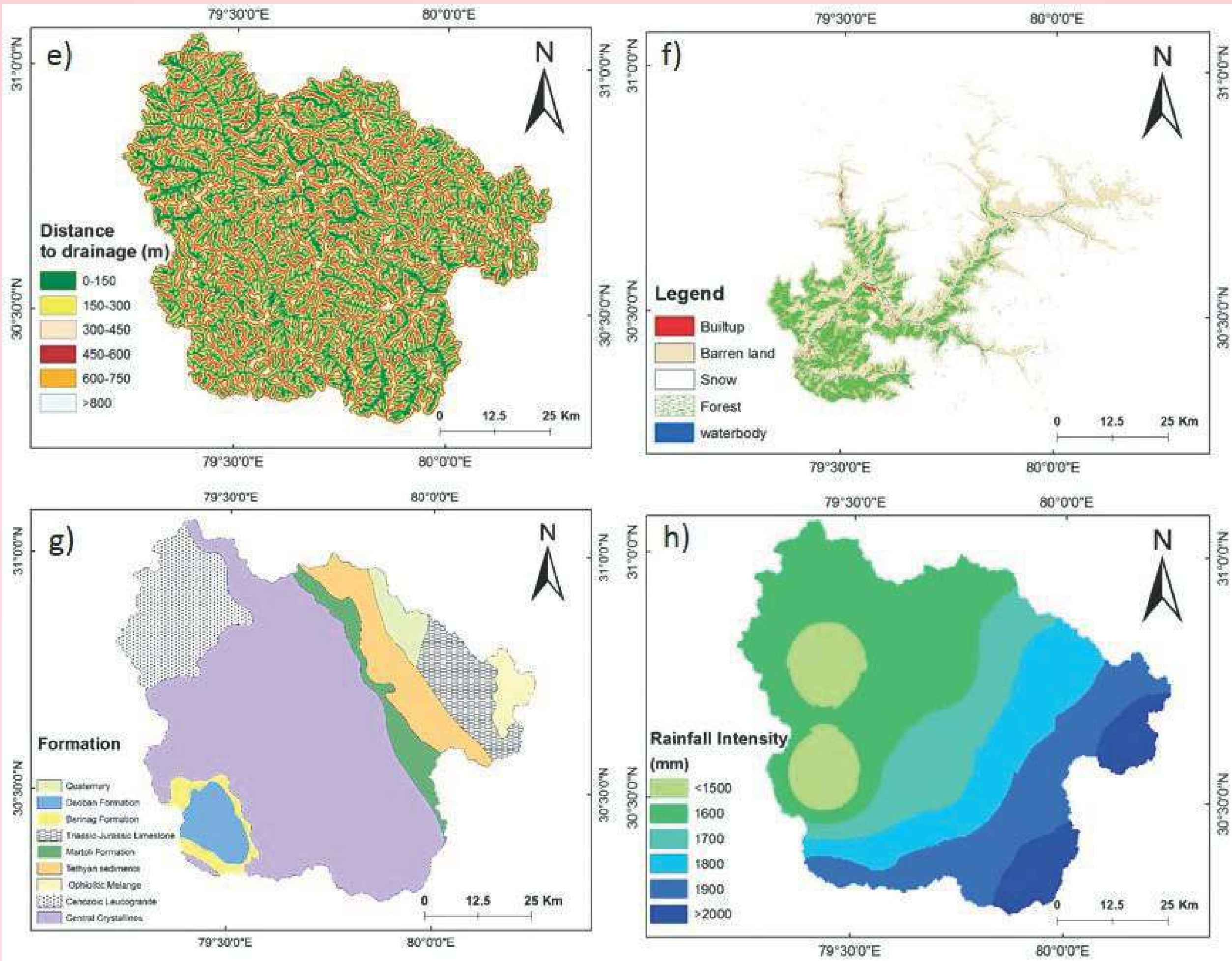


Fig. 52: Thematic layers (*e*) Lithology, (*f*) Distance to drainage, (*g*) Distance to road, (*h*) Distance to fault.

Mode I fracture toughness gradually decreases as the notch angles increase. However, Mode II fracture toughness rises significantly as notch angles increase, reaching a threshold value of $\beta = 45°$, beyond which there is a sudden decline in Mode II fracture toughness with increasing notch angles in all rock types. The AE (Acoustic emission) results, such as AE counts and AE energy reveal four distinct stages of fracture propagation in various modes during the compression process until the rock collapses.

Activity: 6A

Glacial dynamics, glacier hydrology, mountain meteorology, and related hazard

(Kalachand Sain, Manish Mehta, Vinit Kumar (on Lien), Sameer Tiwari, Amit Kumar, Rakesh Bhambri, Pankaj Chauhan & Jairam Singh Yadav)

Status of Glacier Surface Changes in Doda and Suru River basins; Past and current status, priorities and prospects

The annual mass balance of Pensilungpa Glacier for seven years shows a negative trend with an average rate of specific balance of ~−0.57 m w.e. and annual mean mass balance of ~−5.7 x10^6 m^3 w.e. The resulting ~31.47 x10^6 m^3 w.e. cumulative volume loss. Whereas the depression of equilibrium-line altitude (ELA) was ~27 m between 2016 and 2023, and the present ELA is located at 5242 m asl (Fig. 54).

Furthermore, the study focuses on the geomorphological, morphological, and glacier lake dynamics around the Durung-Drung (DDG) and Pensilungpa (PG) glaciers in Zanskar Himalaya, Ladakh. It identifies evidence of five stages of glacier advancement through preserved lateral moraines, showcasing approximately 21 phases of recessional moraines for DDG and about 9 phases for PG. Maximum advancement extents indicate negative mass balances, reaching ~8 km and ~9 km for DDG and PG, respectively, suggesting similarities with the Last Glacial Maximum (LGM) in the Himalaya and Tibet

ACTIVITIES

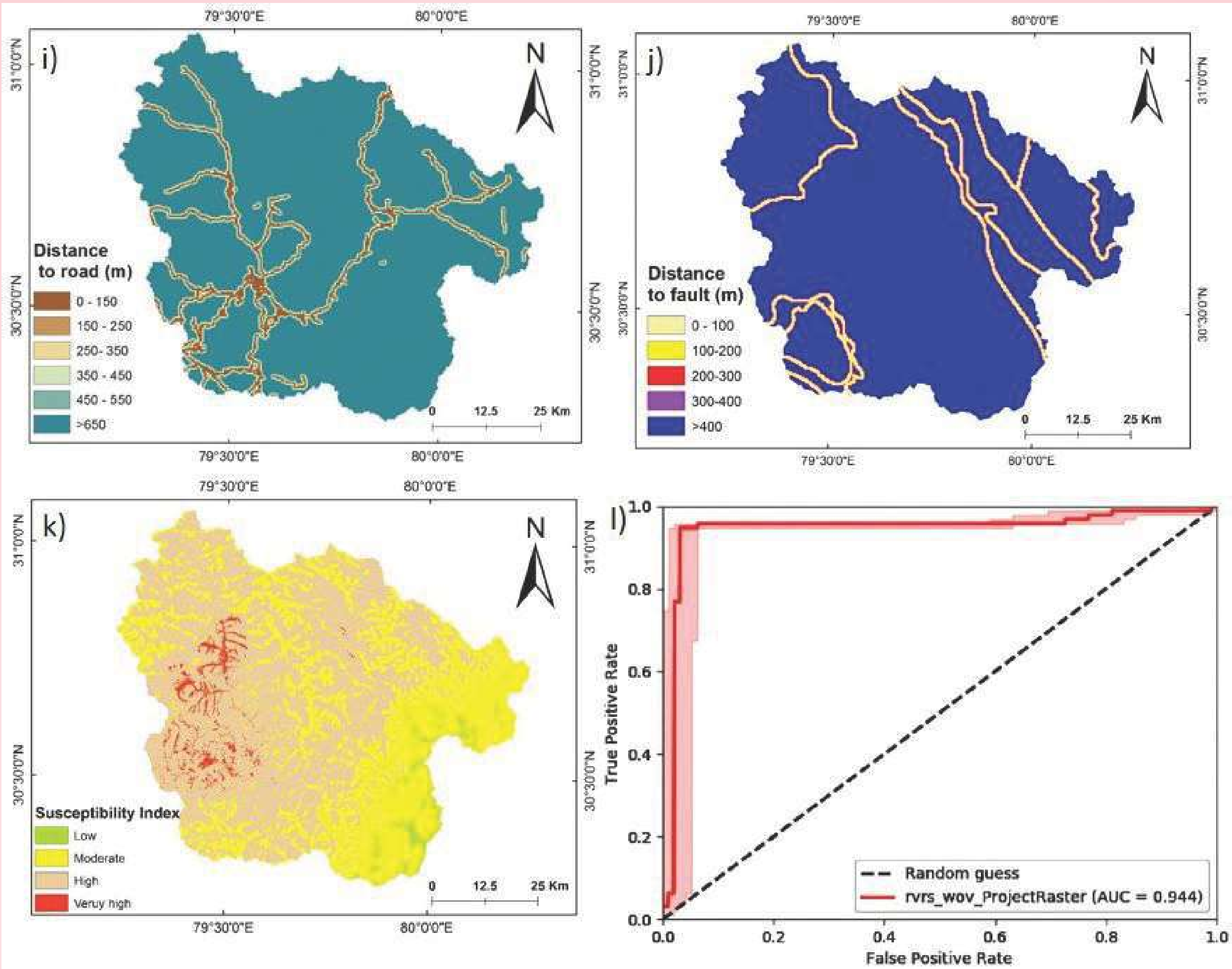


Fig. 53: Thematic layers (*i*) Rainfall map, (*j*) Land cover map, (*k*) Landslide Susceptibility Map (LSM) and (*l*) Area under Curve (AUC).

(Fig. 55). The oldest lateral moraines observed thickness measures ~350 m for DDG and ~170 m for PG. Additionally, seven peri-glacial lakes near the Pensila Pass and two proglacial lakes near the front of DDG were studied. In a field study between 2015 and 2023, these lakes exhibited an increase in area and volume. Peri-glacial lake dimensions showed a marginal rise of about 6.5% in surface area and around 7% in water volume, highlighting their dependence on non-glacial water sources. The expansion of the proglacial lake near DDG was notable, with approximately a 164% increase in area and 190% in water volume between 2004 and 2023. These substantial increments underscore intensified glacial melt processes, emphasizing the vulnerability of the region's glacial dynamics to climate change. Field observations from 2015 to 2023 reveal a recession of ~165.5 ±95.2 meters with an average rate of 20.68 ±12 meters per year for DDG and a loss of ~80 ±35 meters with an average rate of 10 ±4.4 meters per year for PG. These findings signify a concerning acceleration in glacial melt, potentially influenced by ongoing climate change factors.

The result shows that the Durung-Drung Glacier (DDG) receded ~−624 ± 547 m with an average rate of −12 ± 11 m a^{-1} between 1971 and 2019. The frontal part of the DDG is broad (~2 km wide), which shows wide discrepancies in its retreat. Compared to DDG, the small and narrow snout of the Pensilungpa Glacier (PG) retreated −270.5 ± 27.5 m (1971 to 2019), with an average rate of −5.6 ± 0.57 m a^{-1}. Similarly, the four years (2015–2019) of field observations suggest that the retreat rate of PG and DDG is −6.7 ± 3 and −18 ± 15 m a^{-1}, and the rate of modeled glacier mass loss is −0.29 ± 0.3 and −0.3 ± 0.3 m w.e. a^{-1}, respectively. Furthermore, the ELA of the DDG and PG between 1971 and 2019 increased by ~59 ± 38 and ~23 ± 19 m, respectively.

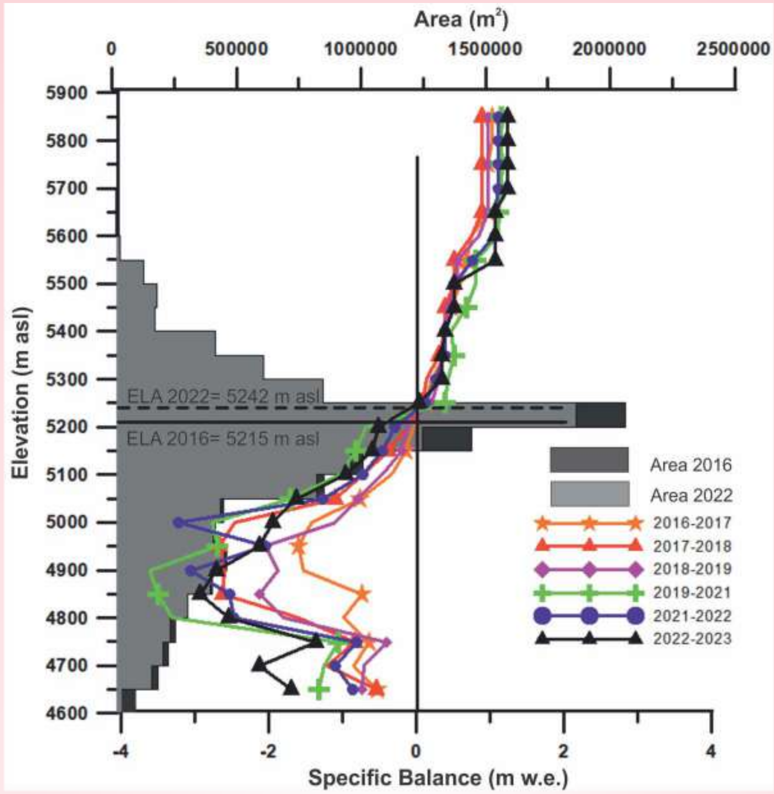


Fig. 54: Specific mass balance gradient vs elevation (2016/17 to 2018/19). The area distribution of PG is derived from field measurements (stakes and pits). Between elevation 4800 and 5000 m a.s.l. The glacier experienced high ablation (less debris cover) compared to lower areas (4670 to 4800 m a.s.l.; thick debris cover).

Flash floods and its cascading tumult: An example from Teesta River valley, Eastern Himalaya, Sikkim

Rapid melting of snow/ice and heavy rainfall have resulted in the formation and expansion of moraine-dammed lakes, creating a potential danger from glacial lake outburst floods (GLOFs). Around 9:30 –10 PM on 3rd September 2023, the South Lhonak Lake, a glacial lake in the upper reaches of Sikkim Himalaya, burst its banks following a cloudburst in the catchment area of Lachung River. The water, with all the debris it picked up along the way, rammed into the dam, causing parts of it to give way. This led to massive flooding downstream (Fig. 56). This catastrophic event changed the landscape in many parts of the upper reaches of Sikkim, making the whole region more fragile and vulnerable.

Monitoring of Himalayan Glaciers and associated hazards

Conducted an extensive review of the hazards in the high mountains of Uttarakhand, emphasizing the area's vulnerability to natural disasters such as flash floods, landslides, and glacial lake outburst floods (GLOFs). The Uttarakhand region's rugged terrain, steep slopes, and varied altitudes contribute to its susceptibility to these hazards. Our review included several case studies, such as the 2002 avalanche near Gangotri Temple, the devastating floods in 2013 affecting the Mandakini, Bhagirathi, and Alaknanda valleys, and the 2017 debris flow at the foreland of the Gangotri Glacier. These case studies highlighted the complex interaction between natural processes and their catastrophic outcomes. The consequences of these events on the local communities, biodiversity, and the economy have also been explored. Furthermore, the "Map the Neighborhood in Uttarakhand" (MANU) project has been examined. This project was initiated by the Department of Science and Technology (DST) following the 2013 disaster. This project involved collaboration among multiple institutions and featured a mobile app for on-site data collection, subsequently uploaded to ISRO's Bhuvan Geoportal. The collected data encompassed GPS coordinates, local geology, and details of landslides and other damages, with around 2,340 ground observations recorded in the Bhagirathi Valley. The present study concluded with a call for more thorough investigations into these events to support future planning and hazard reduction. It highlights the need for enhanced understanding, preparedness, and mitigation strategies

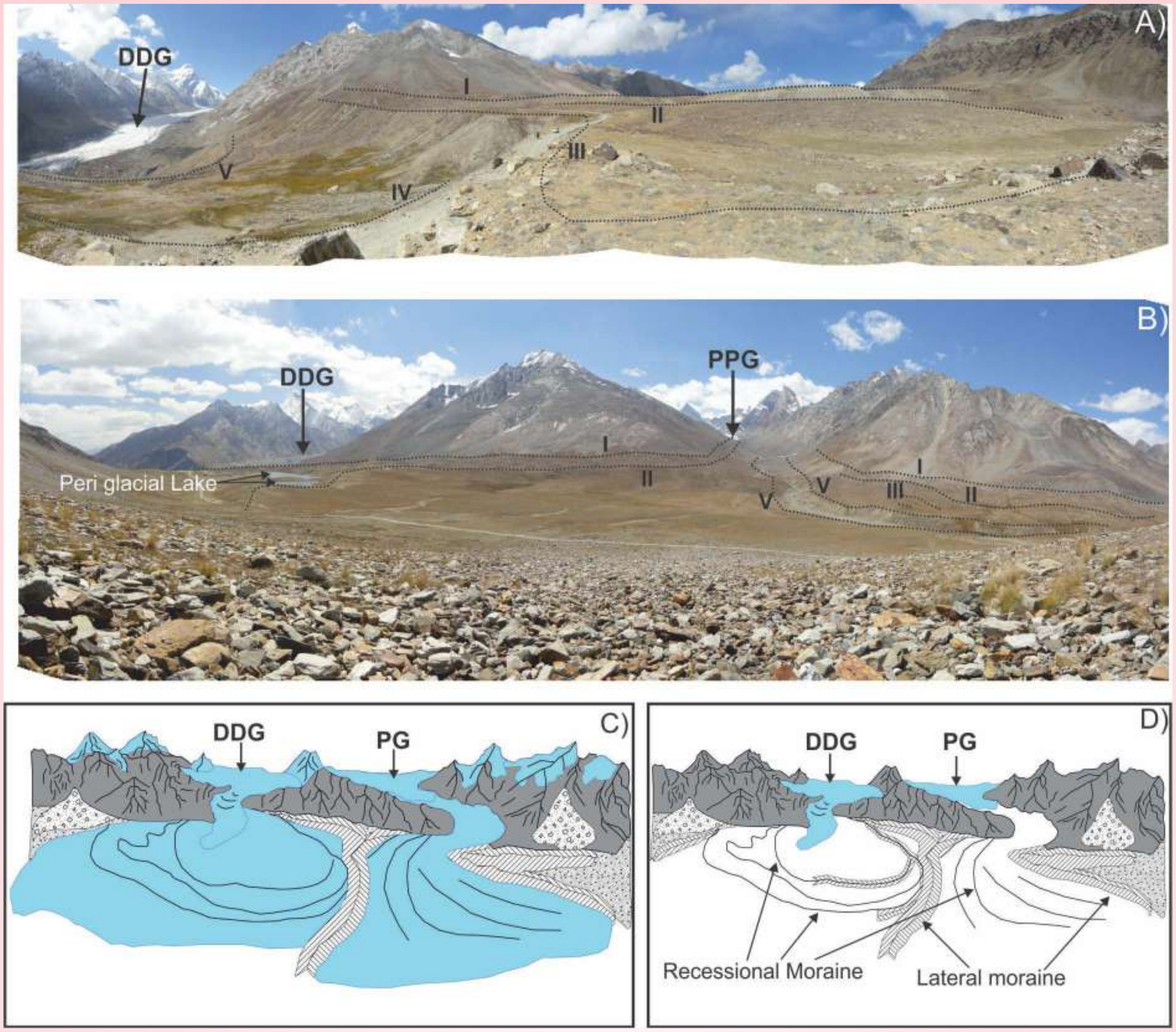


Fig. 55: A comprehensive view of the Pensi La area, showcasing the geographical division between the Suru and Doda basins by the Pensi La pass. The image also reveals the extensive lateral moraines, marked as A and B, formed by the Durung Drung and Pensilungpa glaciers, respectively. Additionally, diagrammatic sketches (C and D) illustrate the glaciation and deglaciation conditions around Pensi La, providing insights into the historical dynamics of the region's glacial landscape.

to reduce the impact of high mountain hazards in the Himalayan region. The evolution of supraglacial lakes (SGLs) in the Himalayan and Karakoram regions was analyzed over 30 years from 1990 to 2020. This research is crucial as it offers a consistent, accurate decadal inventory of SGLs, which are dynamic and sensitive to climate change, making them crucial indicators of glacier health and potential water resources or hazards. The Google Earth Engine platform and Landsat imagery were used to map SGLs. The Normalized Difference Water Index (NDWI) and band ratios were also used to distinguish water bodies from non-water areas, complemented by manual corrections to address misclassifications. The region was divided into four sub-regions: Karakoram (KK), Western Himalaya (WH), Central Himalaya (CH), and Eastern Himalaya (EH), each characterized by distinct glacier features. The study revealed a 61% increase in the total area of SGLs over the three decades, with the most notable growth occurring in the last decade (2010–2020). The Central Himalaya region, especially around Everest, observed the most significant rise. Conversely, the Eastern Himalaya region experienced a reduction in SGL area, as some lakes transformed into proglacial lakes. The overall increase in SGLs was attributed to factors such as higher mass loss, slower glacier surface velocities, and increased rainfall, particularly in the Central Himalaya.

Monitoring the Rishiganga–Dhauliganga basins

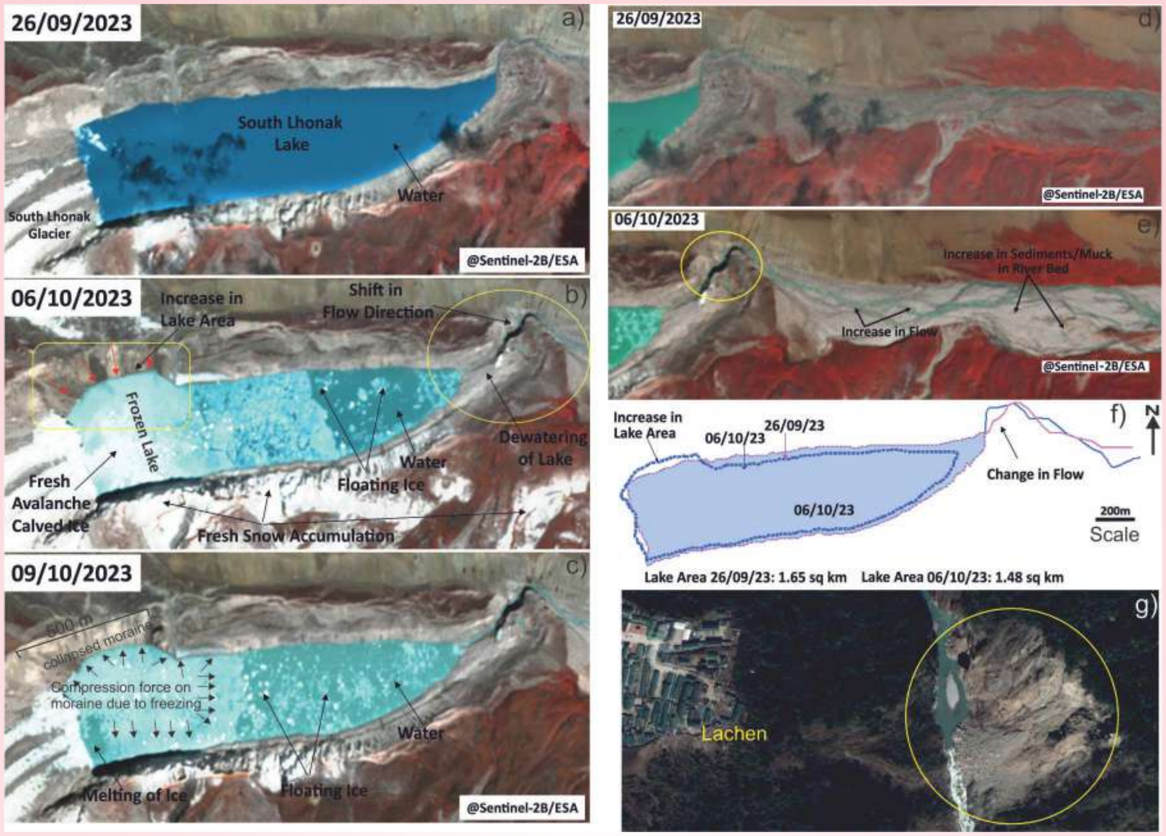


Fig. 56: Sentinel-2B time series annotated satellite images showing the status of South Lhonak Lake (a) pre-event (26th September 2023), (b&c) post-event (06th & 09th October 2023), (d) flow conditions downstream frontal moraine and river morphology before the event (26th September 2023), (e) associated changes in flow and morphology post event (09th October 2023), (f) comparative map showing pre and post event changes and (g) A substantial landslide occurrence in Lachen at an elevation of 2481 m asl (N27° 42′56”-E 88° 33′57”), leading to partial obstruction of the Teesta River.

since the region experienced a catastrophic flash flood on 7th February 2021 during which the Rishiganga and Tapovan hydroelectric projects were severely affected and ~200 people were feared dead. In the 12 months post-event, 7.0 ± 1.5 Mm^3 (67.2%) of the deposit volume was removed along a 30-km-long (Dhauliganga downstream) domain and the median erosion rate was 2.3 ± 1.1 $m\ a^{-1}$.

Most sediment was removed by pre-monsoon and Monsoon River flows, which conveyed bedload waves traveling at 0.1–0.3 km day^{-1} and sustained order-of-magnitude increases in suspended sediment concentrations as far as 85 km from the event source (Fig. 57-58). The transportation of bedload is a major factor that destabilizes the slope due to toe-erosion.

Other studies based on the physical observations and satellite-based information during the period April 23 to March 2024 have indicated that the meltwater stream from the Gangotri Glacier originates near the left lateral moraine, flowing across the snout of the glacier (Goumukh) before moving downward. During the end of January and February, surface water in the Bhagirathi River near the snout was found in a frozen state, while some water was flowing below the frozen layer after the debris flow event in 2017. The debris cover (sublimation of surface ice), orientation, and microclimatic conditions (temperature, wind, and rain) of the two glaciers control the isotope signatures of the glacier surface ice in the Himalayan region, indicating heterogeneity and complexity in the isotopic compositions (Fig. 59).

The studies estimating the contribution of different components to the streamflow downstream using generalized values of stable isotopes (glacier ice, snow) are complicated, as several glaciers contribute to the total runoff in large basins. The stable isotopes of streamflow indicate the contribution of snow and ice melt during early ablation (May-June), rainfall and ice melt during the ISM (July-August), and ice melt during late ablation (September-October). The contribution of snow-glacier melt and rainfall for the ablation season (June-October) was 89% and 11%, respectively. The

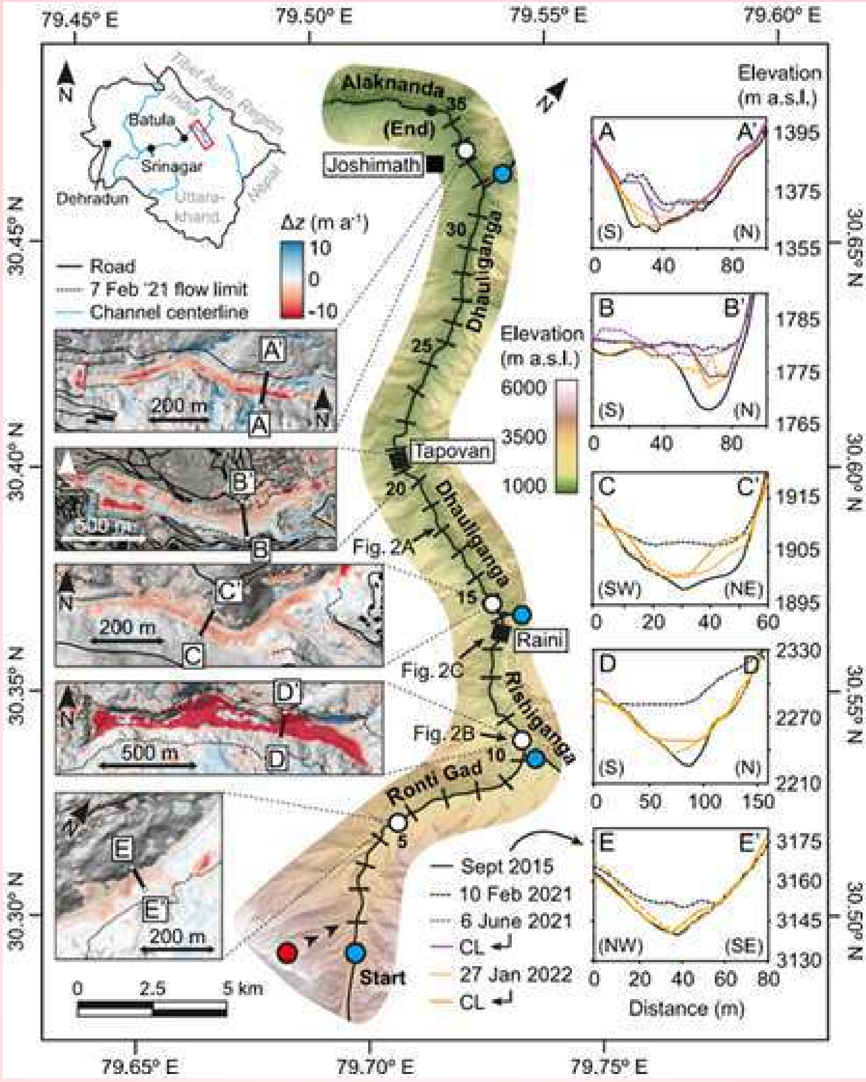


Fig. 57: Shows the study domain with river names labeled, and breakpoints supporting geomorphological analysis. The red circle and the arrows show the source location and travel direction of the rock–ice avalanche. The left panels show spatially distributed vertical change (Δz) from satellite DEM differencing (10 February 2021–27 January 2022). The right panels show cross-channel surface profiles from satellite and CL DEMs.

Fig. 58: Post-event field photographs of the flow path. (A) New debris-flow deposits (B) Remobilizing flood deposits in the Rishiganga (C) Perched deposits on the Rishiganga.

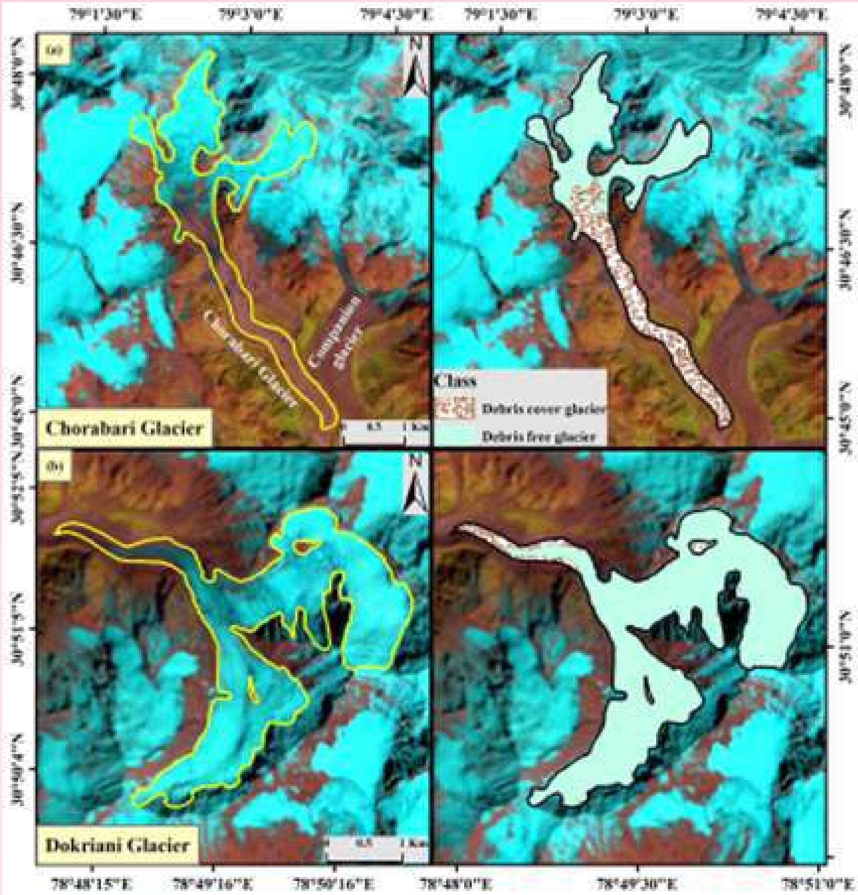


Fig. 59: Landsat 8 images for the classification of debris-covered ice and debris-free ice over Chorabari (a) and Dokriani (b) glaciers.

separation of the hydrograph is complex, site and time-specific, which needs attention.

Supraglacial geomorphology of Companion Glacier, central Himalaya: evolution, controls and consequences

As per the MSI image of 2020, the total area of the Companion Glacier is 2.08 ±0.1 km^2. In 2001, the total area of the glacier was 2.11 ± 0.1 km^2. Thus, the glacier area has only slightly reduced by −0.03 ±0.1 km^2 (−1.3% ± 2.8%) in the last 19 years. The glacier's ablation zone varies in width between ~200 and ~600 m and is characterized by heavy debris cover. The total debris cover on the glacier was 59.4% (1.25 ±0.1 km^2) in 2001, which increased to 63.2% (1.31 ±0.1 km^2) in 2020, showing a growth of 4.9% ±2.8% (0.3% ±0.1% a^{-1}). These results show that the changes in area and debris cover are trivial and are within the range of associated uncertainties. Notably, almost the entire ablation zone of the glacier is debris-covered (Fig. 60) leaving a limited scope for increasing the debris cover further up the glacier. The length of the glacier was 4.6 km in 2020, and snout fluctuation analysis reveals a very low retreat of only 70.6 ±33.1 m during 2001–2020, which translates into an annual retreat of 2.7 ±1.7 m a^{-1}.

The Surface Ice Velocity (SIV) is computed using two approaches: a) zonal SIV, where the mean of all the pixels in each of the 100 m altitude bands (categorized here from Zone-I to Zone-V) is computed, and b) along the central flow line (CFL): where the mean of every 50 m distance from the snout to the up glacier is computed. Zonal results reveal that almost the entire ablation zone is moving at very low rates (Fig. 61). Zone-I (5.8 ± 2.1 m a^{-1} in 2019/20) and Zone-II (5.8 ± 2.1 m a^{-1} in 2019/20) moved at similar and the slowest rate, but an acceleration of ~34% and ~15%, respectively, is observed in these zones. Zone-III has slowed down (by ~5%) and moved at a rate of 7.6 ± 2.1 m a^{-1} in 2019/20. Zone-IV moved at an almost similar rate of 10.1 ± 3.4 m a^{-1} during 2000/01 and 10.0 ±2.1 m a^{-1} during 2019/20 showing almost no change in velocity. A notable acceleration (by ~76%) in SIV from 7.3 ± 3.4 to 12.9 ± 2.1 m a^{-1} occurred in Zone-V, which became the fastest-

Fig. 60: Debris cover characteristics of the Companion Glacier observed during the fieldwork in October 2020. The debris is very thick (~2–3 m) over lower reaches [Zone-I through Zone-III; Panels (A–E)]. The debris thickness keeps decreasing, increasing the distance from the snout in the glacier's direction. Panels (F–H) show a clear transition from huge to relatively fine debris. Upper portions [Panels (I–J)] have fine and comparatively thin debris (<40 cm).

moving zone of the glacier (Fig. 61A). The average SIV of all five zones was 7.0 ± 3.4 m/during 2000–01, which increased (by 21%) to 8.5 ± 2.1 m a^{-1} during 2019/20. The average SIV along the CFL during 2000/01 (10.1 ±3.4) and 2019/20 (11.8 ± 2.1) is comparatively higher than zonal, but it also confirms an acceleration (by ~16%). The SIV of Zone-I increased (by 61%) from 4.9 ± 3.4 to 7.9 ± 2.1 m a^{-1} and that of Zone-II (by ~80%) increased from 4.0 ± 3.4 to 7.2 ± 2.1 m a^{-1}. Zone-III decelerated (by ~8%) from 10.2 ± 3.4 to 9.3 ± 2.1 m a^{-1} whereas Zone-IV, in the case of CFL, showed deceleration (by ~12%) from 14.6 ± 3.4 to 12.8 ± 2.1 m a^{-1}. SIV increases dramatically (by 58%) over Zone-V, from 11.8 ± 3.4 to 18.6 ± 2.1 m a^{-1}, similar to Zonal

Resource and power potential assessment of the Badrinath geothermal field northwest Himalaya, India

Many countries are harnessing geothermal energy for electricity generation and direct utilization, but India has yet to join this group. One of the reasons for this is a lack of information about the potential of geothermal fields and the latest technologies. Geothermal energy has vast potential, and its utilization in many forms in the Indian Himalaya, where more than 100 geothermal fields are actively available. These geothermal fields can meet the area's daily energy requirements (direct or electricity) of human settlements in the cold region. This study aims to estimate the geothermal power potential of the Badrinath geothermal field, northwest Himalaya, which is one of the best possible sites to utilize geothermal energy in direct or indirect form. Therefore, accurately and scientifically assessing geothermal resource potential is necessary; the volumetric method and Monte Carlo simulation is an ideal solution to quantitatively measure the distribution of geothermal power potential through probability distributions. In this study, Monte Carlo Simulation was introduced based on the volumetric method, considering the uncertainty of geothermal resource distribution parameters, and the triangular, constant distribution model was used to simulate the input parameters of the Badrinath geothermal field. The power potential (MWt) and (MWe) values for 25, 35, and 50 years for three identified anomalies in terms of P10, P50, and P90 values are estimated. The maximum thermal power and electrical potential are calculated as

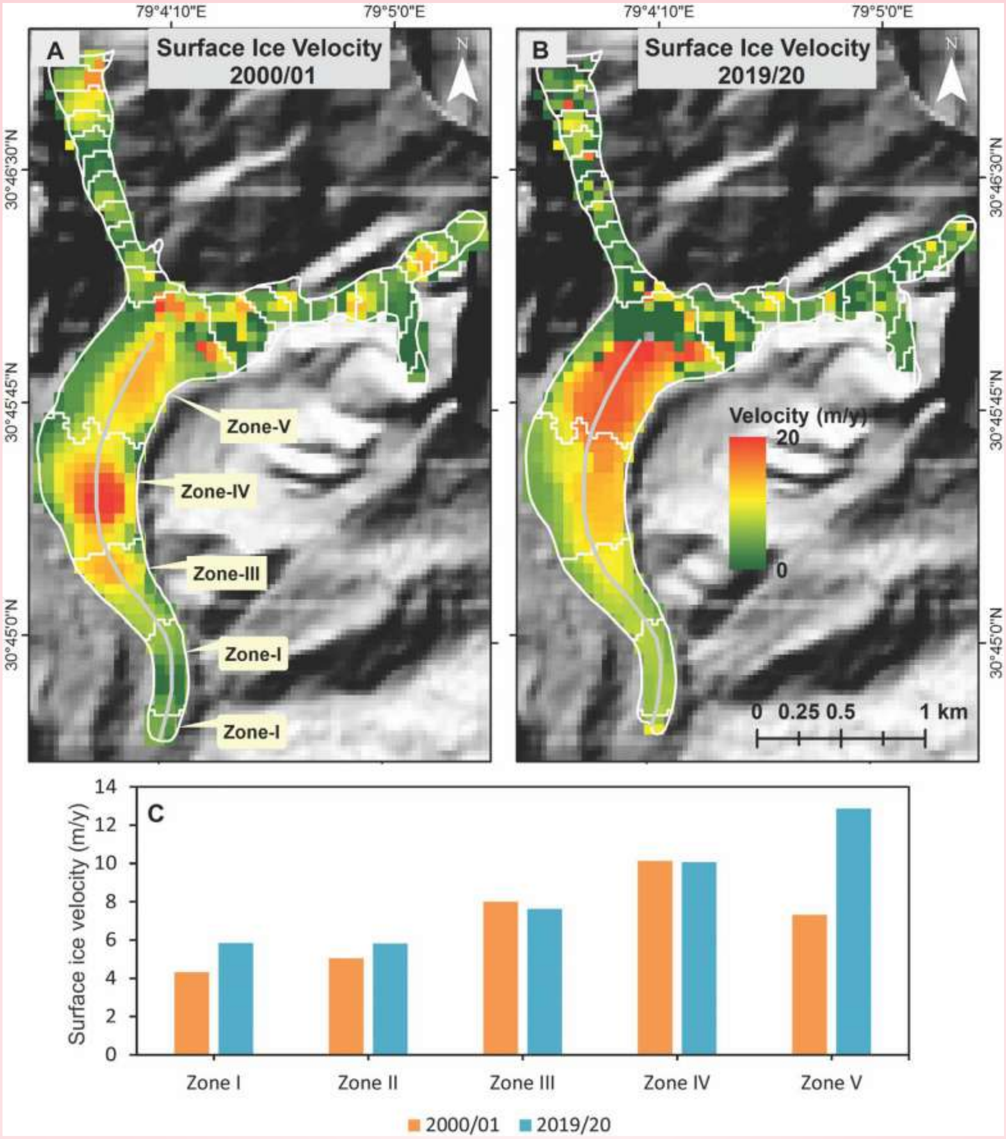


Fig. 61: The average zonal Surface ice velocity (SIV) of the Companion Glacier. Panel (A) shows the spatial distribution of SIV for 2000/01 deduced from correlating repeat Enhanced Thematic Mapper Plus (ETM+) images. Panel (B) shows the spatial distribution of SIV for 2019/20 deduced from correlating MultiSpectral Instrument (MSI) images. Panel (C) shows the average zonal SIV for the years 2000/01 and 2019/20. Notice a decrease in SIV over Zone-III and an increase over Zone-V. Zone-IV, with no change in SIV, became sandwiched between slow-moving Zone-III and fast-moving Zone-V, which led to changes in glacier morphology.

39MWt and 3.0 MWe from the study area. Another important aim of this study is to examine the technical possibilities of establishing the first pilot project of a district heating system at the Government guesthouse based on the potential geothermal resource. Based on the results, a heating system for a government guest house using the available geothermal fluid is discussed. The calculations were made for the building's heat load and energy balance with the present scenario. In this area, the outside temperature is as low as -10 °C in the winter. The main issue is to design a suitable heating system where a heat exchanger can transfer the heat between the geothermal spring and a radiator. After that, hot water will be circulated to the guest house in a conventional steel piping system through the heat exchanger. Electrical circulation pumps will be used to supply the water from the spring to the heat exchanger, for that there is issue of electricity in the area. Geochemical analyses of water samples suggest that the spring water is suitable for heating and will not create any problems for the heat exchanger.

The Alaknanda Valley is entirely known for the existence of geothermal springs at Badrinath town. It has been well reputed since long back for its sacredness and has thus become a place of pilgrimage. South of the main Badrinath spring, with a water temperature of 27 °C and five lit/min discharge. Presently, there is only one geothermal spring at Badrinath, which is situated on the right banks of the Alaknanda River at an altitude of 3089 m. asl. It emerges through the overburden of morainic material, and the point of emergence is covered by a dome-like shape and other permanent structures around it. The spring water has been diverted to different Kunds through artificial channels for the bathing of pilgrims. The water from this spring is hot (55.6 C) and tasteless. It has a sulfurous smell, and intermittent gas bubbles can also seen associated with this spring. Water discharge from this spring is about 400 lit/min. Spring deposit (carbonate) is also seen at places, especially when the water falls into Tapta Kund. No ferruginous staining is seen near the hot spring (Figs. 62-63). About 50 m. downstream of the main geothermal spring is another lukewarm water spring with a surface temperature of 20 °C. This spring's actual mode of occurrence is unknown because the area around it is covered with permanent constructions. The water is colorless and slightly sour. It is used for bathing purposes and washing clothes. The discharge of the spring is about 190 liters/min.

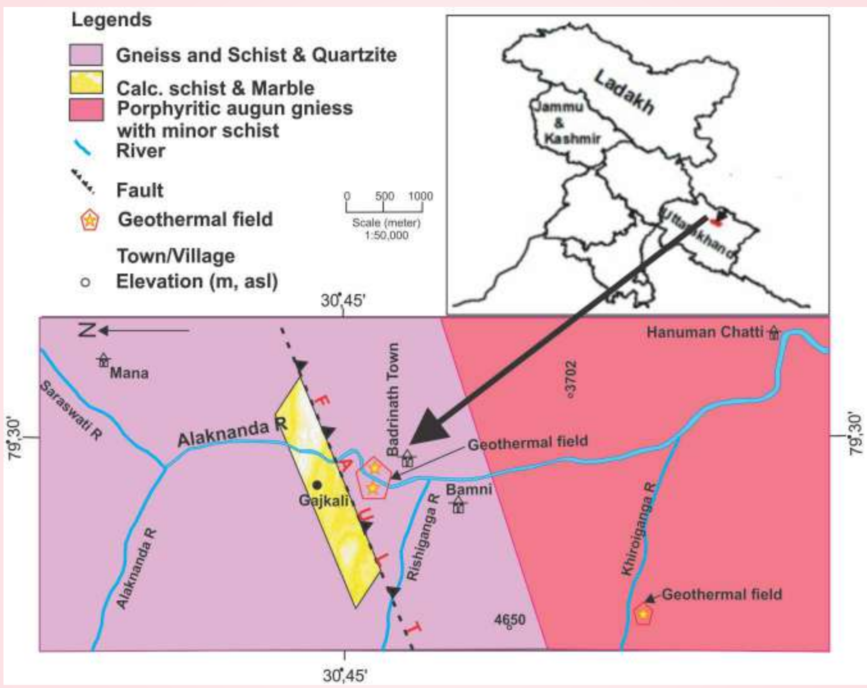


Fig. 62: Geological map of the study area with the location of the Badrinath geothermal field.

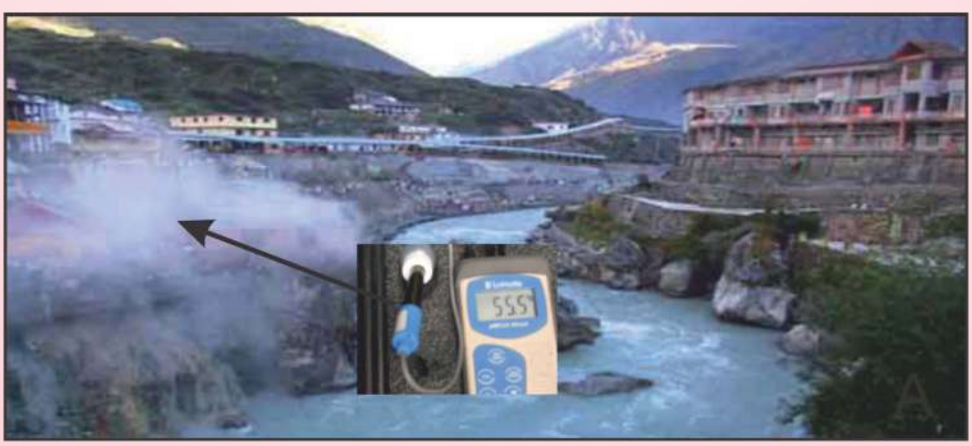


Fig.63: Surface manifestation of Badrinath Geothermal field.

The objective of the present study is to estimate the potential of geothermal resources of the Badrinath geothermal field using the volumetric method and Monte Carlo simulation and to demonstrate how the geothermal water can be used for space heating in the Garhwal northwest Himalaya. The outcome of the volumetric assessment of the Badrinath geothermal field is very feasible. Briefly, this geothermal field can produce at least 3 MWe (electricity) and 39 MWt (Thermal power) after the successful drilling of geothermal wells in the future. Therefore, this is a suitable site to demonstrate the geothermal house heating system to a government guesthouse, Garhwal Mandal Vikas Nigam undertaking, by the Government of Uttarakhand. The dominant radicals present in the water are of ($Na-HCO_3$) type.

Activity: 6B

Himalayan Fluvial System & Groundwaters

(Santosh Kumar Rai and Rouf Ahmad Shah)

Denudation of the silicate rocks in Himalayan catchments is recognized as a major process exerting significant control on the CO_2 consumption to the atmosphere. It regulates the climate on longer time scales under greenhouse conditions. Isotopic studies ($^{87}Sr/^{86}Sr$, εNd & δ^7Li, etc.) on the bed sediments and core samples have helped in decoding the control of active tectonics on the erosion and sedimentary budget of the Teesta River basin. Samples shown in pink color (Fig. 64) have $^{87}Sr/^{86}Sr$ ratios similar to that of the Lesser Himalaya (LH) end-members, but ε_{Nd} compositions are inclined towards the Higher Himalayan Crystalline (HHC) units. Also, the expected isotopic compositions for a mixture of LH: HHC in 50:50, 60:40, and 70:30

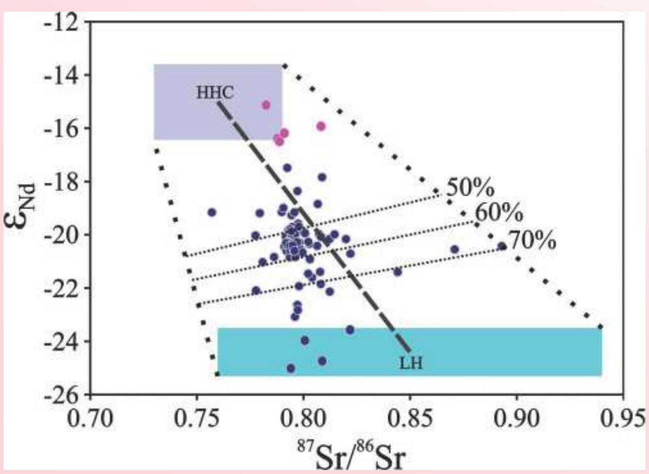


Fig. 64: Two isotope plots ($^{87}Sr/^{86}Sr$ and ε_{Nd}) of the samples in the silicate fractions of the samples along with the possible end-members to the Siliguri core site.

ratios are shown (dotted lines). Results (Fig. 64) show that the majority of the sediments cluster towards the LH values, averaging for ~56 ± 10%.

Lithium isotopic values (δ^7Li) were used to evaluate the response of chemical weathering in tectonically active regions. Oxygen and Hydrogen isotopes measured in Doon groundwater show their plausible recharge sources in the Lesser Himalayan zone around 2000 meters. The work on the Karst Aquifers and their hydraulic linkages have revealed that the Doon Groundwater has a recharging height of 2±0.5 Km. Such information is useful on the counts of water availability and Groundwater for Sustainable Development.

Multiple approaches (stable water isotopes, major ions, and discharge) were used to provide detailed insights into the recharge mechanism and the processes contributing the solute chemistry of groundwater (available as springs) in karst settings of the Lesser Himalayan sequence (hosting suit of extensive karstic rocks) in the Doon Valley This study suggests that fluctuating and variable flow pattern (0.11 to 1.4 $m^3 s^{-1}$) of the springs is connected with different levels of subsurface karst heterogeneity; however, seasonal changes in their flow primarily corresponds to the variable rainfall patterns (rainy and dry periods) at their respective recharge areas. The study reveals that karst springs are alkaline (pH: 7–8.3), moderate-to-highly mineralized (EC:100 to 1092μScm^{-1}], with relatively higher partial pressure pCO_2 (–2.7 to –1.8 atm.), having the potential to scale. The study further suggests that preferential flows through carbonates (enriched with gypsum pockets) enhance the precipitation-dissolution along the flow paths and contribute major dissolved solutes, which eventually shape hybrid water facies ($Ca-Mg-HCO_3$ & $Mg-HCO_3-SO_4$). Furthermore, $\delta^{18}O$ (or δ^2H)-precipitation is preserved in the karst springs in terms of varying isotopic characteristics, however, the lower slope (5.5 ±0.39) and lower intercept (5.3 ±2.4) of $\delta^{18}O$–δ^2H regression lines of karst springs than global and local meteoric water lines, indicates the evaporative effect of recharging water. This study supports significant recharge between July and September and hints at the mixing of recharge waters from different flow paths between recharge elevations of 1900 and 2600 meters above sea level (m, asl). Field surveys were also conducted in the Chakrata and Kashmir regions to understand the geohydrology of the region and to prepare the spring inventories of these Himalayan regions.

ACTIVITIES

Activity: 7

Quantification of strain accumulation/release rate along Main Himalayan Thrust (MHT) at different time scales

(R. Jayangondaperumal, Koushik Sen, P.K.R. Gautam, Rajesh S., Vikas Adlakha, Rajeeb Lochan Mishra, Shubam Bose and Mahesh Kapawar)

Quantification of Strain Accumulation rate in Kumaun Central Himalaya

Geodetic data from WIHG Network and published literature are used in the study of the evolution of tectonic landscapes and deformation along the major faults in the south-eastern Kumaun and western Nepal Himalayas. The ITRF velocity indicates secular plate motion toward the northeast, with a velocity ranging from 37.67 to 67.98 mm/yr. The direction of motion varies from 28.83° to 52.76°. The velocity fixed with respect to the IISC falls within the range of 0.71 to 19.26 mm/yr with a clockwise motion from northwest to northeast, which reflects the crustal deformation in the region. To decipher the behavior of local deformation in the study area, the velocity is estimated with a fixed **MUNS**. Here, the clockwise motion of the velocity field and non-linear pattern of deformation with velocity ranges from 0.5 to 14.79 mm/yr are observed. A portion of the central Almora Nappe shows a higher deformation rate of 28.66 mm/yr, which may be due to active local faults/thrusts. The west and southwest motions indicate oblique-slip movements along the frontal thrusts of the Kumaun central Himalaya.

Seismicity data of magnitudes 2.1 to 5.5 plotted against the period 2007 to March 2020 shows maximum seismicity along the MCT, some along the MBT, and a few earthquakes along the HFT; shallow depth earthquake of magnitude 4.0 occurred in 2020 is evidence of tectonic activity along the frontal part of the Himalaya.

Quantification of Strain Accumulation rate along the Karakoram Fault

GPS measurements along the Karakoram fault suggest that the fault in the Nubra Valley (K2 segment of the northern Karakoram fault, NKF) is inactive while that in the Bangong Chaxikang region (the southern Karakoram fault, SKF), slips at a rate of 1.6–3.2 mm/year. Further, the modeling of GPS measurements indicates a locking depth of ~12–15 km for the southern Karakoram fault and probably confirms strain accumulation for several centuries.

The ML technique has also been implemented over the data from permanent and campaign-mode GPS stations, located on the Tibetan plateau and its environs for forecasting the crustal velocity. The ML predictive models are considerably reliable for estimating geodetic velocity vectors.

Studies on seasonal positional anomalies using GPS data

The nonlinear changes in the estimation of GPS coordinates in three components, mainly because of the elastic deformation of Earth's surface produced by seasonal hydrological movements, have been studied at different locations in the frontal, Sub, and Lesser Himalayan regions. Figure 65 shows the seasonal positional anomalies consisting of both annual and semi-annual components in all three N-S, E-W, and UP-Down components from the Dehradun station. The linear changes in the positional anomalies are removed through linear regression, and the model values (slope) represent the interseismic station velocity components.

These oscillating behaviors of the immediate crust have been modeled as a linear combination of harmonic functions with constant slopes, and their amplitudes have been quantified through the extraction of individual coefficients. The stations situated at the frontal part and across the Ganga Tear, particularly at Haridwar and Biharigarh, show nearly equal rates of steady subsidence and uplift of -7.90 ± 0.22 mm/a and 7.64 ± 0.63 respectively. Apart from the steady component, there exists a periodic uplift rate at the mountain front station BIHA -which is situated at the frontal part of Siwalik Hills and the footwall of HFT. Here, the periodic uplift rate is predominantly determined by the annual seasonal component (6.57 ± 0.60 mm/a) compared to its semi-annual component (2.5 ± 0.6 mm/a). However, for the case of non-mountain frontal station HARI situated at the footwall of HFT, where a steady rate of subsidence has been observed, the annual and semi-annual vertical loading of the immediate crust is nearly similar (3.26 ± 0.25 and 3.64 ± 0.24 mm/a). But here, the steady state subsidence is modulated by the annual seasonal subsidence happening in the EW component (i.e., along the strike of the HFT) rather than the annual and semi-annual vertical components. Thus, the level of hydrological loading or unloading in the frontal Himalayas is higher owing to the water storage and extraction from the thick alluvium. However, their characteristic nature of loading at the frontal part of the mountain and non-mountainous regions is different.

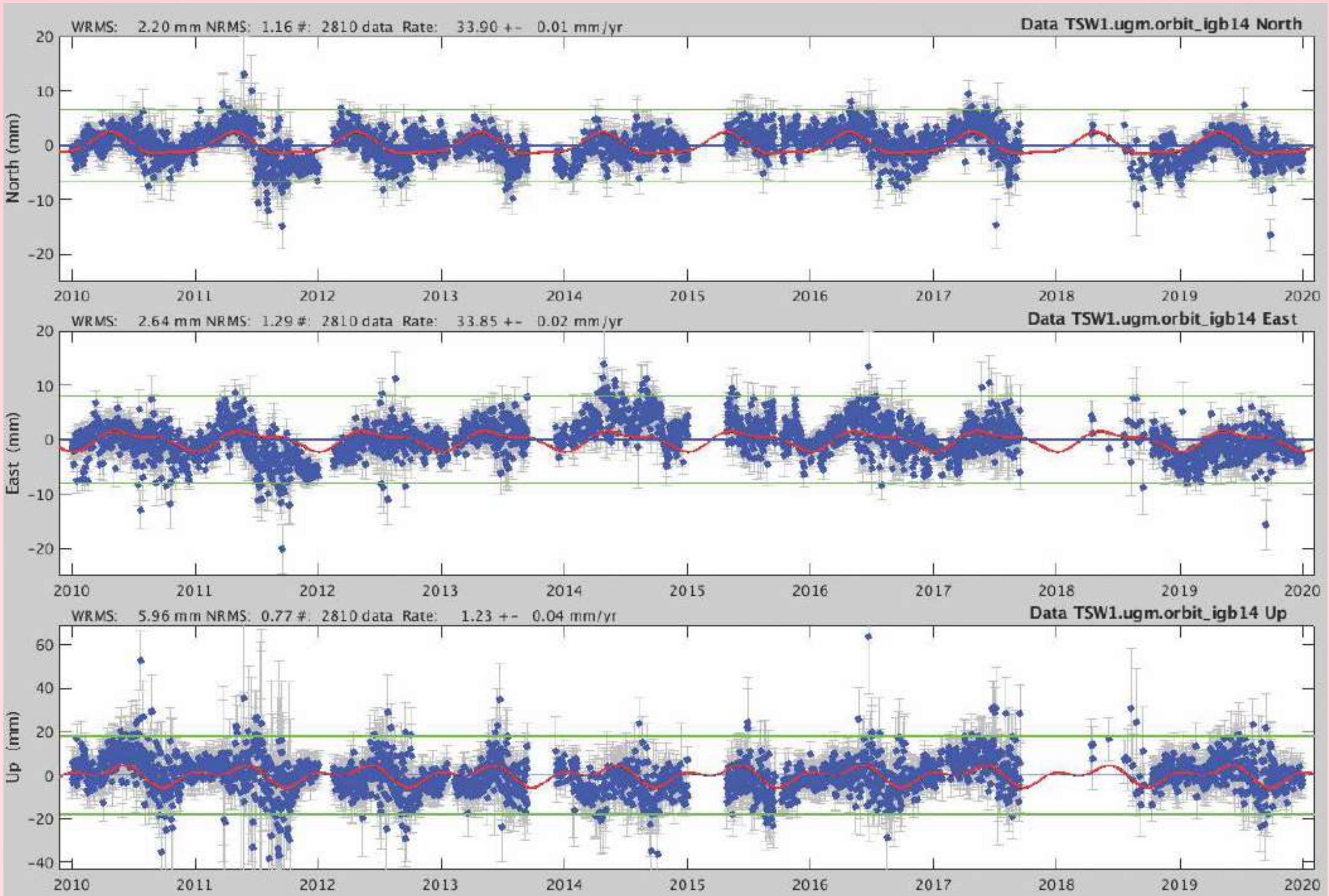


Fig. 65: Shows the seasonal positional anomalies from the Dehradun station (Details see text).

Inter-seismic and Post-seismic surface strain-rate changes caused by the 25th April 2015 (Mw 7.8) Nepal earthquake

The Mw 7.8 Gorkha, Nepal earthquake occurred on 25 April 2015 in the central Himalaya. The event was produced by the rupture on the MHT and its consequent southeasterly propagation was a textbook case to study the characteristic nature of inter-seismic and post-seismic deformation and strain-rate distribution. Considering the continuity of major plate boundary faults in the Garhwal-Kumaun and the Nepal Himalaya, the crustal deformation and surface strain rates associated with the Mw 7.8 event are quite relevant; particularly, the style of inter-seismic deformation and the post-seismic relaxation of the crust. Initial results obtained from the processing of 72 CORS stations with 42 stations from the NEGAR network are presented here.The inter-seismic second-invariant strain rate clearly shows a pattern of high strain rate (~100 nstrain/a) along the MCT zone and also at the location of Mw 7.8 Gorkha (Nepal) earthquake in the high compressional strain-rate zone. The post-seismic strain-rate distribution is high towards the southeastern part of the Mw 7.8 event. The study also shows that the crustal relaxation process was almost completed within five years after the 2015 Mw 7.8 Nepal earthquake, but the rapid relaxation of the crust with an exponential fall in the offsets happened within five to six months and thereby underwent significant strain adjustments within the crust.

Land Gravity data processing

As a part of processing land gravity data an absolute gravity base station has been developed in WIHG along with nine more such base stations between Sahranpur and Mussoorie. The raw instrumental data has been processed and applied various initial reduction procedures including instrumental corrections like static drift and for the tide. The WIHG base station's absolute value has been tied with respect to the Survey of India (SOI) absolute base station near the Hage Observatory, Dehradun.The acquired land gravity data along the Sahranpur-Institute of Technology Management (ITM) and Sahranpur-Zeropoint/ Mussoorie profiles have been processed for absolute base station correction, atmospheric correction, free-air correction, datum correction, and Bullard-B correction. The Bouguer anomaly along these profiles is also generated. It is observed that the free-air anomaly and the topography along these profiles have a one-to-one correlation, while the Bouguer anomaly is negative at higher altitudes towards north of the Main Boundary Thrust.

Geometry of the MHT, quantification of strain release and seismic hazard in the Eastern Himalaya

The easternmost Himalaya near the 96°E longitude shows a sharp ~90° orogenic bend known as the Eastern Himalayan Syntaxis (Fig. 66). A complicated configuration of the region and related space problems, combined with extreme vigorous erosion and surface

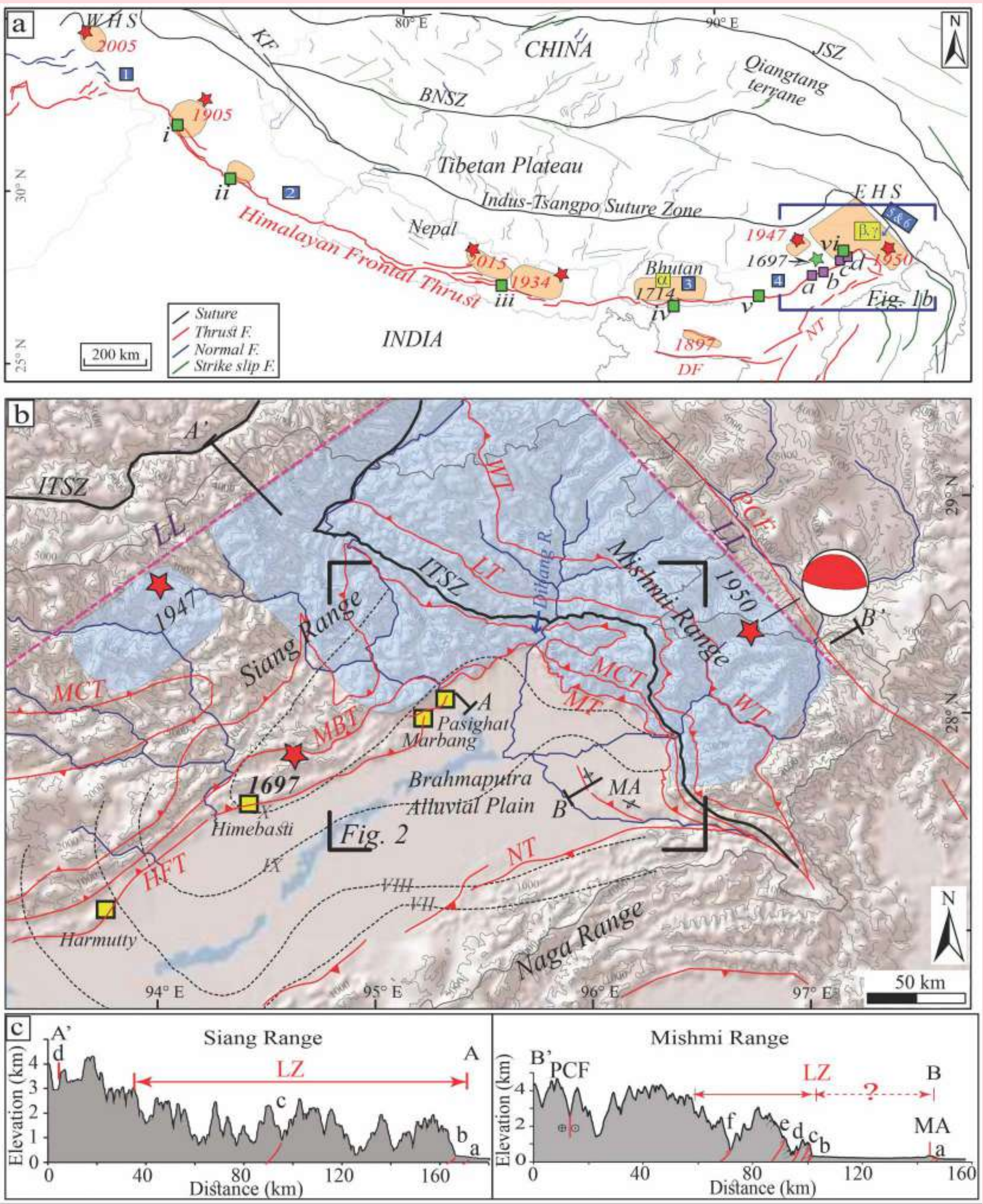


Fig. 66: (a) Regional tectonic map of the Himalaya and Tibetan Plateau showing the major tectonic structures. Solid orange polygons represent rupture zones of historical and instrumentally recorded earthquakes in the Himalaya adapted from previous studies. Red stars denote the epicenters of historical earthquakes along the Himalayan arc. Green star is the epicenter of the historical 1697 Sadiya earthquake.

processes makes it difficult to understand the strain release pattern, slip rate on the participating thrust/s, and the seismic potential of the geological structures.

To understand the deformation pattern in the region, Fission-Track (U-Th)/He, luminescence, and radiocarbon dating methods were used on deformed landforms in the frontal Siang and Mishmi ranges of the Eastern Himalayan Syntaxis. The fault slip rates were obtained for the late quaternary period. The Holocene rates range over 7.5 ± 0.2 mm/yr in the northern segment, 1 ± 0.1 to 10.1 ± 1.5 mm/yr in the central segment, and 8 ± 0.5 mm/yr in the southern segment of the Mishmi Thrust, whereas the Late Pleistocene rates are of the order of 1 ± 0.1 mm/yr in the central segment and 0.9 ± 0.1 mm/yr in the southern segment of the Mishmi range. The obtained Late Pleistocene rates are lower than the Holocene rates but are consistent with exhumation rates reported earlier from the northern segment.

Holocene fault slip rates of the range ~2–9.1 mm/yr across the Manabhum Anticline suggest foreland strain partitioning due to the widening of the fold-thrust belt and the locked zone (Fig. 67). A widening of the locking width implies an increase in the seismic potential of the region. It is suggested that the Manabhum Thrust is possibly a proto-thrust or a footwall imbrication of the Mishmi Thrust. Contrastingly, a lesser Holocene fault slip rate of 2.3 ± 0.3 mm/yr obtained from the eastern Siang range along the Main Boundary Thrust indicates considerable strain partitioning in the hinterland. Results demonstrate that in tectonically active regions, representative rates of rock uplift inferred from incised bedrock should be integrated over at least one complete seismic and inter-seismic cycle.

The 3D theromo-kinematic model Pecube has been applied to the newly generated thermochronological data, revealing the MHT's geometry for the Lohit Valley region of the easternmost Himalayas. The MHT forms a 28° ramp with two 8° flat components in this region, as shown in figure 68.

Successive 1344 CE and 1505 CE earthquakes in the western part of the central Seismic gap, Kumaun Himalaya

Findings suggest that two great (Mw ≥ 8.0) earthquakes may have occurred in rapid succession at the western part of the Central seismic gap in the Kumaun Himalaya during the Late Medieval period (Fig. 69).

Radiocarbon dating of deformed stratigraphic units that are modeled using the OxCal software program constrain the timing of the events to 1317–1391 CE and 1447–1572 CE, which is coincident with historical earthquakes in 1344 CE and 1505 CE (Fig. 70). With over 500 years of quiescence since the last great earthquake in the Central Seismic Gap, it is possible that another devastating rupture could be imminent.

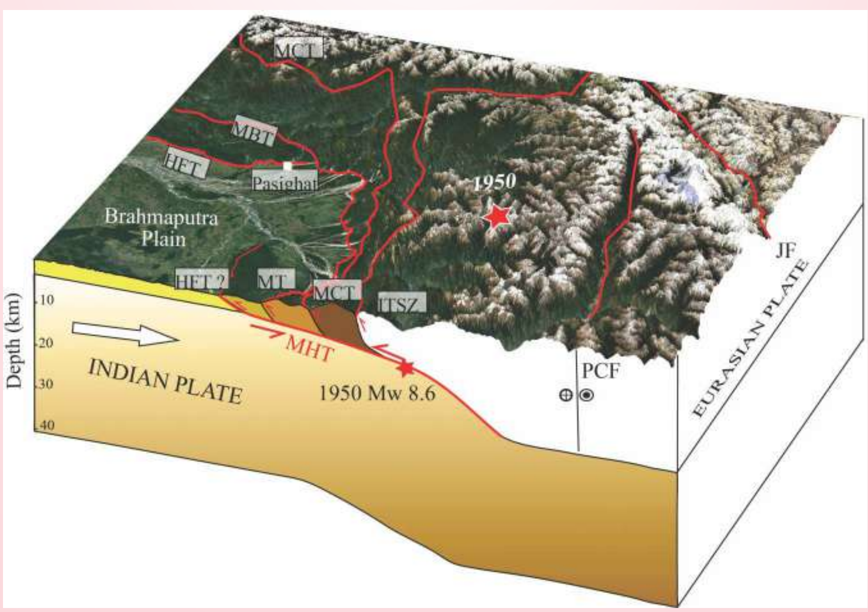


Fig. 67: A simplified block diagram showing a narrow and wide fold-thrust belt of the Mishmi and Siang ranges respectively in the Eastern Himalayan Syntaxis (Singh et al., 2024). HFT: Himalayan Frontal Thrust, MCT: Main Central Thrust, MT: Mishmi Thrust, ITSZ: Indus-Tsangpo Suture Zone, PCF: Po-Chu Fault, JF: Jiali Fault.

ACTIVITIES

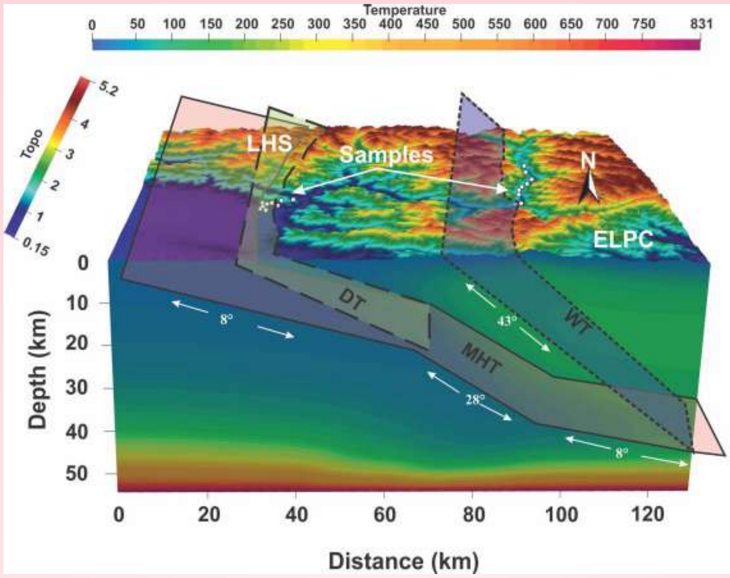


Fig. 68: The geometry of the MHT as revealed using a 3D theromo-kinematic Pecube model for the litho units of the Lohit Valley region of the easternmost Himalaya. DT: Demwe Thrust; WT: Walong Thrust; MHT: Main Himalayan Thrust. Arrows indicate the exhumation paths of the rocks along the thrust sheets. Red dots indicate the sample locations for the generated thermochon FT and (U-Th)/He data.

Structural and thermochronological studies

Characterization of tectonic scenario and the evolution of strain regimes across the Main Central thrust Zone and the Himalayan Metamorphic core, Garhwal Himalaya, India. Evaluation of shortening estimates and delineating deformation mechanisms prevalent during the tectonic episodes across the Main Boundary thrust (MBT) zone, Garhwal Himalaya, India. Delineating recent stress states across the major litho-tectonic discontinuities in the Garhwal Himalaya.29 new Apatite and 29 new Zircon Fission Track (AFT & ZFT) Data have been generated along the Uttarkashi-Gangotri-Gomukh transect of NW Himalaya. The AFT ages range from 0.7±0.1 to 5.4±1.3 Ma, while the ZFT ages range from 3.8±0.2 to 12.1±0.5 Ma, which provides the exhumation history since Middle-to-Late Miocene. The youngest AFT ages within the Vaikrita Thrust zone in the region suggest that the rocks in this zone cooled rapidly, probably due to the re-activation of the VT. 13 New samples along Gangotri Glacier have been collected to constrain the role of glaciation over millennial-scale exhumation rates. Mineral Separation of all samples has been completed. 07 samples for A He and 05 samples for ZHe analysis have been sent for analysis to the University of Michigan. Thermal neutron irradiation was carried out at the Oregon State University nuclear reactor for AFT and ZFT analysis. The Fission Track Counting work is under process.

Structural and Rock magnetism and studies

Field-based geological studies were carried out in and around the Yamuna River valley along the Silkyara-Barkot transect. The purpose of this field program was to characterize the detailed geology, deformation episodes, and structures transecting and deforming the lithologies at diverse scales across the Ramgarh Thrust. Regional scale shear zones, faults, and thrusts, along with their effects on the exposed lithologies, were identified and delineated. Structural data pertaining to foliations, lineations, fault planes, and their respective slip lines and fold and warp axes were collected in the course of the fieldwork. Oriented samples were collected in order to characterize the deformation conditions that prevailed during penetrative aseismic creep and evaluation of shortening estimates across the Ramgarh Thrust. This fieldwork was primarily directed at determining the role (if any) of the regional-scale structures in the recent Silkyara-Barkot tunnel collapse and was a consultancy project provided by Uttarakhand State Council for Science & Technology (UCOST).

Two field works were undertaken within the Ganga-Yamuna River valleys, as well as along and across the Mohand Anticline. The studies will help understand the evolution of fault damage zones, structural analysis, identification and preliminary sampling of new sections for possible rock magnetic and magneto-stratigraphic studies, and the long-term interseismic deformation

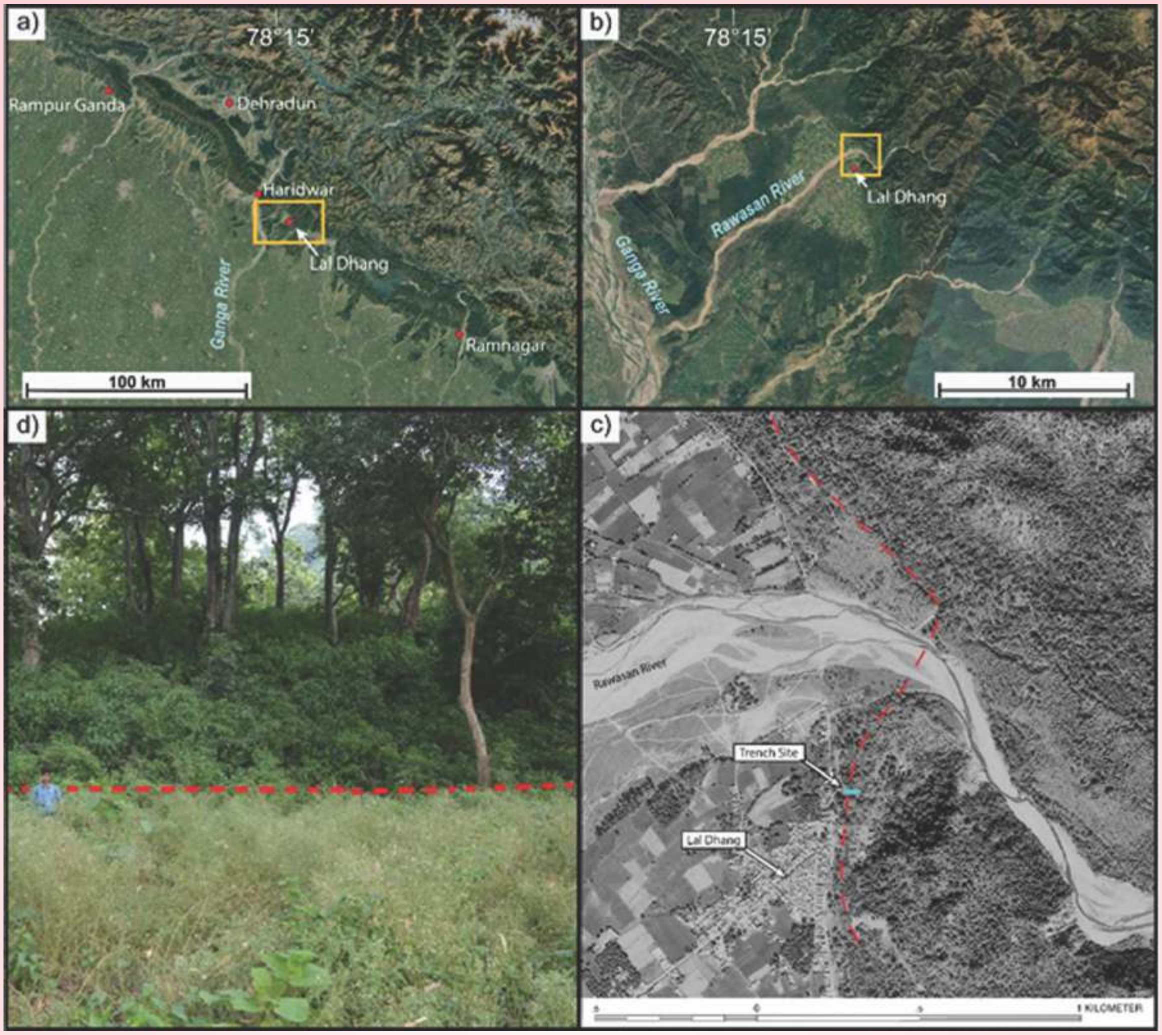


Fig. 69: The Himalayan Frontal Thrust Fault (HFT) at the site of Lal Dhang.Photograph of the ~10-m-high fault scarp viewed toward the east. The Red, dashed line shows the approximate base of the scarp. The person for scale (1.5 m) is positioned several meters in front of the scarp base.

preserved by geomorphic landforms within the Yamuna and Ganga River valleys. The geomorphic landforms preserved between the Yamuna and Ganga River valleys in the Himachal and Uttarakhand Himalaya, India, were sampled for charcoal and OSL. The fieldwork is expected to yield new estimates on geological convergence in the region. The results will address the gap in the available incipient data and complement the research undertaken in the region almost two decades ago.

Characterization of tectonic scenario and the evolution of strain regimes across the Main Central thrust Zone and the Himalayan Metamorphic core, Garhwal Himalaya, India. Evaluation of shortening estimates and delineating deformation mechanisms prevalent during the tectonic episodes across the Main Boundary thrust (MBT) zone, Garhwal Himalaya, India. Delineating recent stress states across the major litho-tectonic discontinuities in the Garhwal Himalaya.

Field-based geological studies were carried out in and around the Yamuna River valley along the Silkyara–Barkot transect. The purpose of this field program was to characterize the detailed geology, deformation episodes, and structures transecting and deforming the lithologies at diverse scales across the Ramgarh Thrust. Regional scale shear zones, faults, and thrusts, along with their effects on the exposed lithologies, were identified and delineated. Structural data pertaining to foliations, lineations, fault planes, and their respective slip lines and fold and warp axes were collected in the course of the fieldwork. Oriented samples were

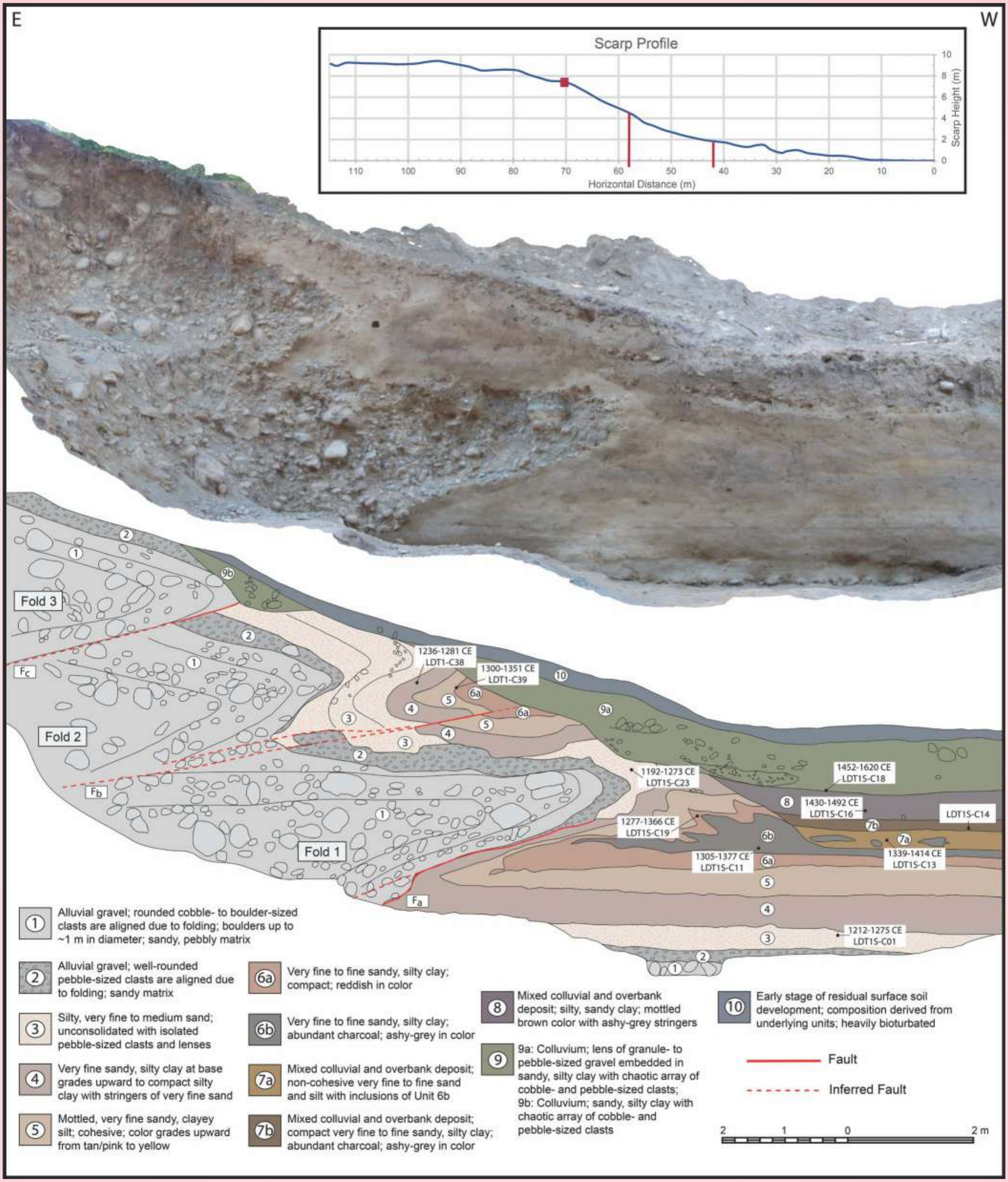


Fig. 70: Photomosaic and trench log of the south wall exposure in the paleoseismic trench at Lal Dhang. Two-sigma probability distribution calendar date ranges for deposition of the stratigraphic units (modeled with OxCal) are shown. A topographic profile of the scarp is shown above (2× V.E.) with vertical red lines delimiting the extent of the trench log and a red box marking the approximate location of a test pit excavated higher on the scarp.

collected in order to characterize the deformation conditions that prevailed during penetrative aseismic creep and evaluation of shortening estimates across the Ramgarh Thrust. This fieldwork was primarily directed at determining the role (if any) of the regional-scale structures in the recent Silkyara-Barkot tunnel collapse and was a consultancy project provided by UCOST.

A field visit of 11 days was carried out at the Upshi-Lato transect of Indus Molasse, Ladakh Himalaya, specifically to establish the magnetic chron by assigning ages to this sedimentary unit (magnetostratigraphy study). During this field visit, a total of 90 oriented sandstone, siltstone, and mudstone samples were collected from 20 sites, and structural information (bedding attitudes) was also gathered at each site for later paleomagnetic data curation. Another field visit of 7 days was performed in Mohand Rao and adjacent areas for collecting Siwalik rocks for rock magnetism study to understand and deduce the provenance, sedimentary environment, and overall depositional history of the Siwaliks and particularly the Siwaliks of the Dehradun Sub-basin.

SPONSORED PROJECTS

MoES Sponsored Project

High-resolution mapping of crust and upper mantle structure across the northwest

(Devajit Hazarika and Naresh Kumar)

Himalaya and Ladakh-Karakoram zone with special emphasis on the seismotectonic of the Shyok Suture zone and adjoining region

Sequential H-k staking analysis has been applied to analyze receiver functions at 12 stations located in the western part of the Indo-Gangetic Plain. One of the best ways to study crustal composition is the estimation of the ratio of velocity of *P* and *S* waves (*Vp/Vs*) of bulk crust which is primarily sensitive to mineral composition and is an important parameter for characterizing the physical properties of the crust. The H-*k* stacking of the receiver function (Zhu and Kanamori, 2000) is widely used for the estimation of average thickness and Vp/Vs of crust. This method works well in the case of a simple crust but it poses challenges in the presence of a thick surface sedimentary layer due to complexity originated by reverberations and requires consideration of the effect of sediments. The low-velocity sediments cause a delay of arrivals from deeper converters leading to incorrect mapping of crustal thickness, if not accounted for. Hence, an upgraded technique known as the sequential H–*k* stacking technique (Yeck et al., 2013) has been used for stations located over the sedimentary basin of western IGP (Punjab and Haryana Plain). In this approach, first, the H-k stacking of high-frequency RFs is performed to constrain sedimentary thickness and Vp/Vs ratio. Then, a second modified H-k stack is performed with lower-frequency RFs using the sediment results as a priori information to estimate the depth of Moho discontinuity and Vp/Vs ratio. Sequential *H–k* stacking analysis has been initiated at 12 stations in the IGP. The modeled crustal thickness gradually increases from ~29 km to ~45 km from south to north in the Haryana plains. In contrast, the crustal thickness in the Punjab plains gradually becomes shallow to about 40.9 km at Gurdaspur station near the HFT. The crustal Vp/Vs ratio for all stations high very high due to the presence of soft sediments at the top ~400-700 m of the surface. Such sediments reduce the efficiency in the transmission of shear waves, leading to lower shear-wave velocities and finally contributing to the high Vp/Vs values. The work is under progress at other stations of the NW Himalaya. In order to carryout a passive seismological study to investigate subsurface structure, a seismological network comprising 5 broadband seismological stations has been established in the Shyok Suture Zone (Nubra Valley, Leh-Ladakh).

MoES Sponsored Project

Multi-Parametric Geophysical Observatory, Ghuttu Garhwal Himalaya for Earthquake Precursory Research

(Naresh Kumar, Gautam Rawat, Devajit Hazarika and P.K.R. Gautam)

Assessment of gravity time series for noise analysis and normal mode studies

The superconducting gravimeter provides the highest accurate gravity measurements using an unparalleled cryogenic temperature environment. It is very useful for geodynamic studies, tidal modes, and related applications. It is also denoted as a long-period seismometer. A study on gravity data has been presented from the Observatory Superconducting Gravimeter (OSG-051) located at MPGO Ghuttu in the Garhwal Himalaya, India. Ambient noise observed at this site is compared with other worldwide SGs and computed seismic noise magnitude for the OSG-051. Instrumental noise has been observed at frequencies ranging from ~0.0239 to ~0.03207 Hz in the form of parasitic mode for the lower and upper sensors of SG, whose quality factor has been estimated in different modes of oscillations (Fig. 71). The signal is enhanced at noise reduction below 2.0 mHz using local barometric pressure data and modeled tidal effect of the site. Other seismic noise factors are discussed through data analysis of OSG-051. OSG-051 and trillium 240 Broad Band Seismometer data are analyzed and compared in the seismic normal mode frequency band. Several observations have been made regarding noise sources that affect the gravity data in the seismic normal mode's frequency band. Residual gravity data after removal of atmospheric pressure, tidal, and co-seismic effects, respond very well to long-period seismometers than any conventional seismometer. This characteristic and low noise level of the MPGO Ghuttu site makes it a suitable station for long-period earth wave studies. The gravity data obtained after different corrections has multiple useful applications.

Assessment of Radon Transportation in the tectonically active zone of the Himalaya

The inert gas Radon is present as the radioactive daughter particle of Uranium/Thorium, with more

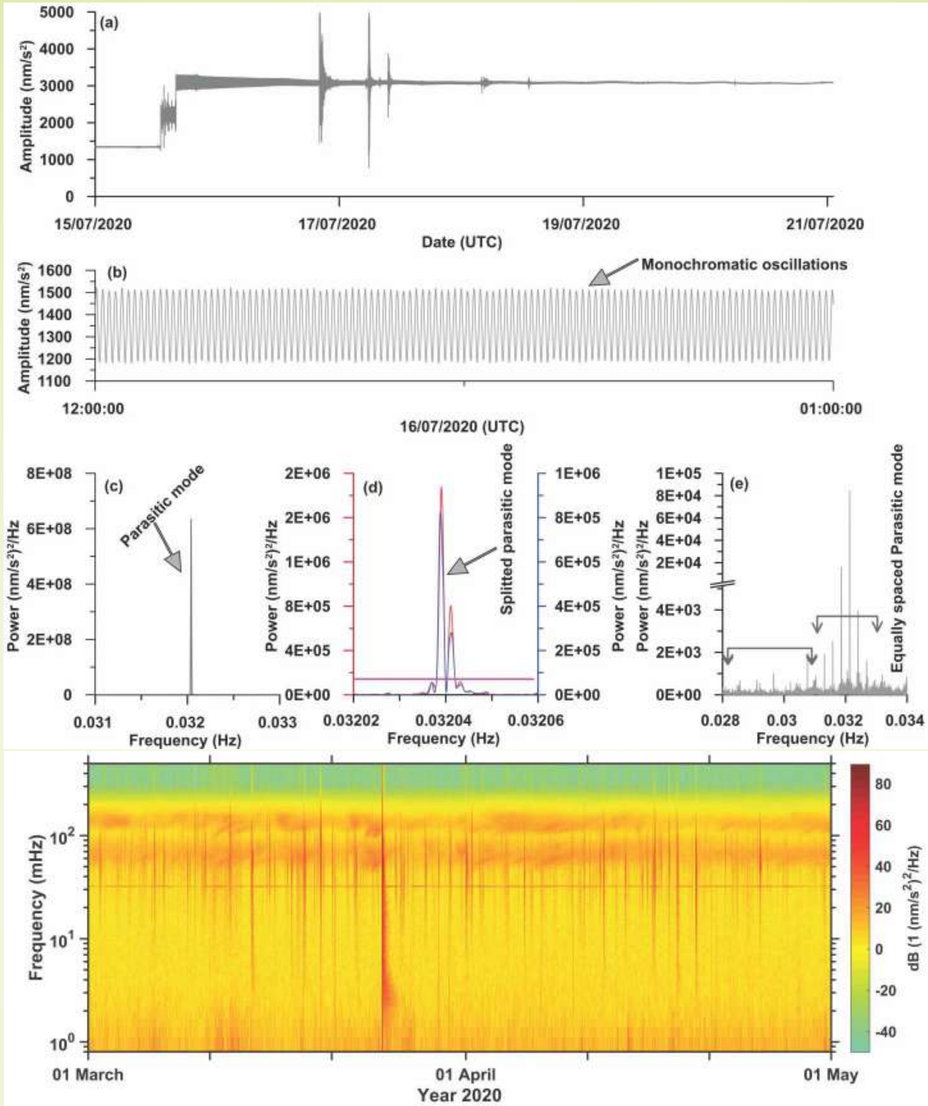


Fig. 71: 3D S-wave velocity variations along two vertical cross-sections (parallel and perpendicular to the Himalayan arc), and earthquakes are projected on cross-sections with a lateral extent of 0.2° to both sides of the vertical slices. Increasing size and colour scale indicate the magnitude of the earthquakes.

concentration through geotectonic processes and mobility/solubility in water. Its ^{222}Rn isotope has the longest life (half-life period 3.92 days) with multiple geohazard applications. The tectonically active zone, namely the Ghuttu region, which is located within the Himalayan seismic belt (Fig. 72), was studied to decipher its impact on soil gas ^{222}Rn concentrations. A soil gas ^{222}Rn study was performed in the soil at a depth of 30 cm, and it varied from 426 ± 156 Bq m^{-3} to 24,057 ± 1110 Bq m^{-3} with an average of 5356.5 ± 1634.6 Bq m^{-3}. At 60 cm depth below the soil surface, the concentration varied from 1130 ± 416 Bq m^{-3} to 30,236 ± 1350 Bq m^{-3} with an average of 8928.5 ± 2039.5 Bq m^{-3}. These concentrations vary in soil from ~3.4 % to 437.3 % as the depth moves from 30 cm to 60 cm. The variation in uranium content also shows anomalies, and higher values of uranium content in the soil affect the radon concentration in the study area. The average soil gas ^{222}Rn concentration in the Ghuttu window was found to be higher than that in its surrounding region (Fig. 72). This is likely due to transportation from daughter products of uranium. ^{222}Rn mass exhalation rate measurements were also carried out, and a weak correlation with the soil gas ^{222}Rn concentration was observed. A significant variation in the mass exhalation rate was noticed in tectonically active areas. This study is vital to understanding the behavior of radon and uranium in tectonic regions.

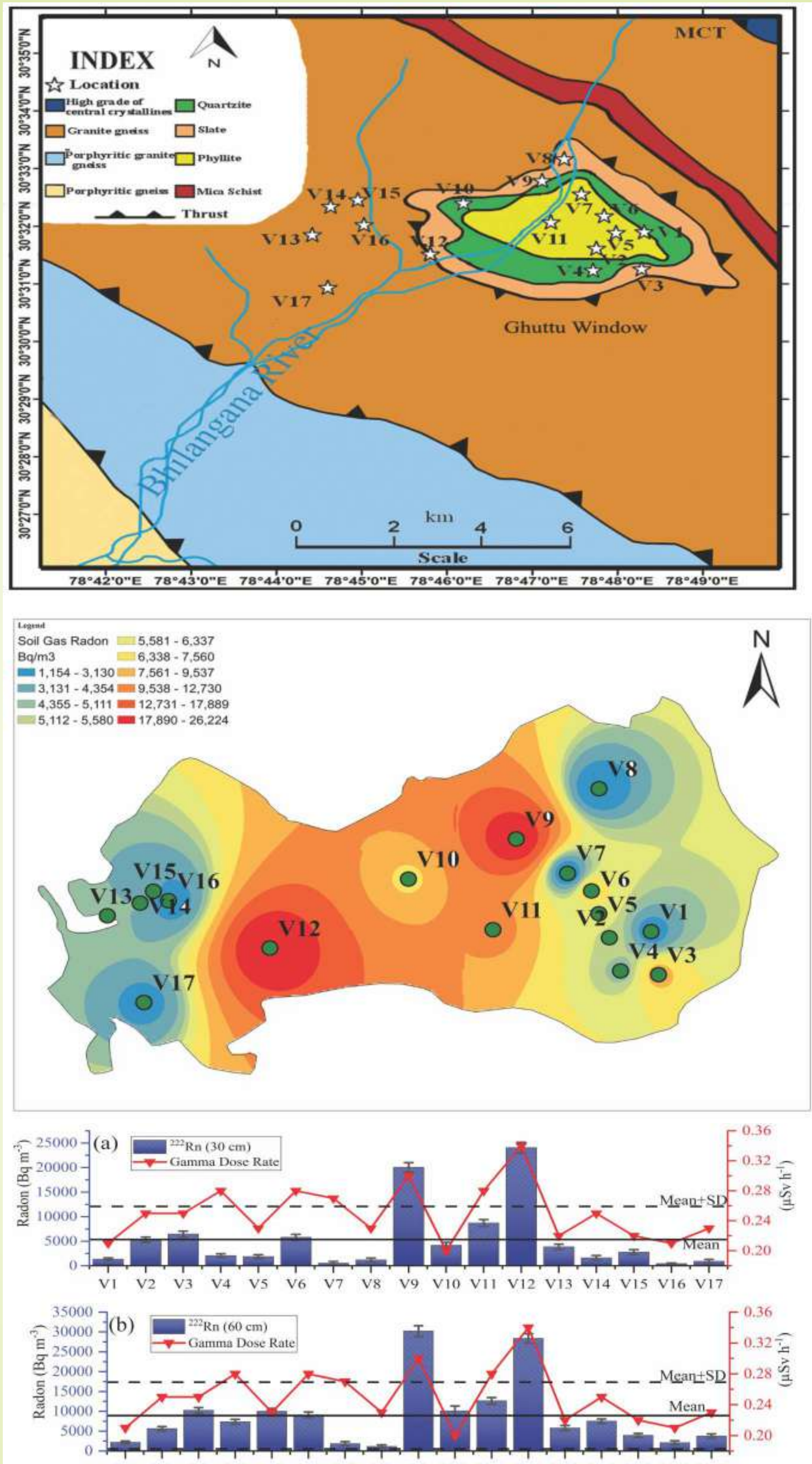


Fig. 72: 3D S-wave velocity variations along two vertical cross-sections (parallel and perpendicular to the Himalayan arc), and earthquakes are projected on cross-sections with a lateral extent of 0.2° to both sides of the vertical slices. Increasing size and colour scale indicate the magnitude of the earthquakes.

SERB Sponsored Project

Advancement of the attenuation tomography scheme from inversion of strong motion data: A tool for seismic hazard evaluation

(Parveen Kumar)

The analysis carried out in this project produces (i) a six-layered, spatially-averaged Q model and (ii) a three-dimensional attenuation model for the Himachal Himalaya, India. Using acceleration data recorded in the Himachal Himalaya, this work quantifies the attenuation characteristics in the form of shear-wave quality factor (Q_β). The low Q_β values (ranging from 10 to 60) depict a fluid or partial melt material starting from a depth of ~11 km. This fluid or partial melt zone identified in the study region closely resembles the intra-crustal high conductive layer identified by other researchers in its adjacent area. The present work is one of the initial works in which the intra-crustal high conductive layer is identified in the Himachal Himalaya based on attenuation characteristics. A frequency-dependent shear wave attenuation ($Q_\beta(f)$) model of the form $Q_o f^n$ is also proposed for six different layers of 5km thickness each (Fig. 73). The obtained $Q_\beta(f)$ model directly reflects the region's seismic hazard as it describes the level of heterogeneity and tectonic activity in the present study region.

MoES Sponsored Project

Comparative study of weathered/ soil profiles developed on Granitic and Basaltic rocks of Higher and Lesser Himalaya in Garhwal region: Implication on climate-tectonic interaction

(Anil Kumar, Pradeep Srivastava, R. Islam and Sohan Kumar)

A multitude of coupled physical, chemical, and biological factors govern weathering and despite the importance of rock weathering in controlling global biogeochemical cycles of elements, soil formation, shaping the landforms, and regulation of the climate via sequestration of atmospheric CO_2, weathering processes, rates and microbial feedback in the tectonically active Himalaya are largely unexplored.

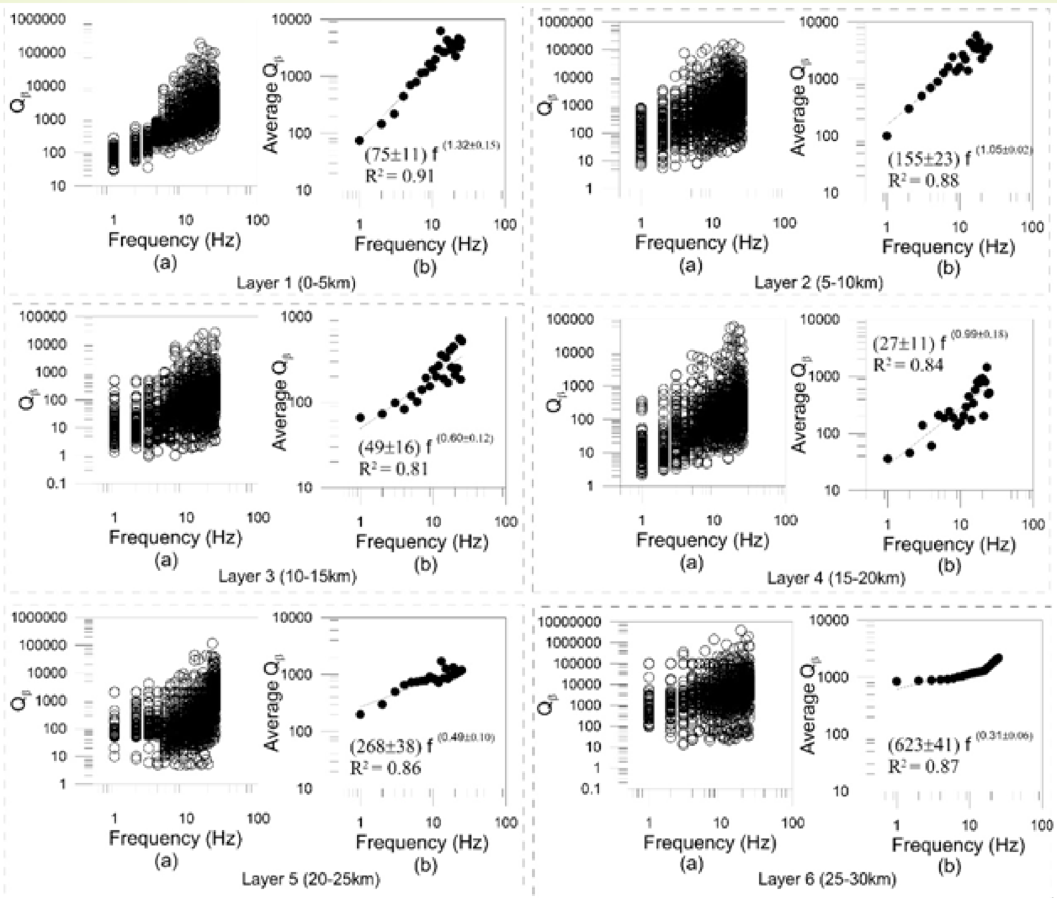


Fig. 73: The frequency-dependent quality factor (Q) relationship of six different layers in the Himachal Himalaya. (a) The Q values obtained for the small blocks, and (b) the average Q value at different frequencies. R^2 represents the coefficient of determination.

The present study complied: (i) the influence of tectonic on physical and chemical weathering of two contrasting rock types (gneisses and metabasalts) both in Higher and Lesser Himalaya; (ii) the evolution of weathering profiles through time using U-series isotopes in Higher and Lesser Himalaya; and (iii) the role of microbes in weathering.

Lithological, climatic, and tectonic impressions have been observed on the geochemical and chronological properties of the weathering profiles. In-situ weathering rates of metabasalt (40.6 mm/ka) are very high in the granite rocks (24 mm/ka) under similar climatic conditions (humid) and tectonically stable regions of the Garhwal Lesser Himalaya. Metabasalt, containing a higher fraction of ferromagnesian minerals, is more susceptible to weathering than granite, containing silicate minerals. In tectonically active regions adjacent to a strike-slip fault, the in-situ weathering rates of metabasalt are even higher (123 mm/ka), almost three-fold of the metabasalt rocks under similar climatic settings but stable tectonic scenarios. Brittle structures increase the fracture density in the rock mass increasing the surface area and allowing the atmospheric agents to work on a larger surface area and percolation to deep down the surface through the dense fracture system.

Climate has a conspicuous role in weathering and weathering rates vary temporally as well as spatially corresponding to the climatic variability. Coinciding with the fact that chemical weathering processes accelerate in a warm and wet environment, very high weathering rates are recorded during the warm and wet period in the recent past. For example, the bulk of the granitic weathering profile from the humid Lesser Himalaya was produced during Marine Isotope Stage (MIS) 5, the warmest and wettest period in the recent past and the weathering rate during the period was ~450 mm/ka, almost 19 times of the average weathering rate (24 mm/ka) across the profile. Other profiles also witness similar variations. Spatially, the climate varies from humid in the Lesser Himalaya to semi-arid in the Higher Himalaya. Weathering responses to climatic variation as well. Weathering profiles are thinner in Higher Himalaya owing to low vegetation cover and lesser chemical alteration. Despite very thin weathering profiles, the weathering rates in Higher Himalayan Weathering profile is 47 mm/ka and the maximum weathering record is preserved up to 62 ka, the times of glacial retreat in Himalaya. The earlier record is missing due to extensive glacial erosion before 60 ka and the weathering products started preserving once the glaciers retreated.

Microbes play a significant role in weathering. Microbes have diverse metabolic pathways which require specific ionic or elemental fluxes to metabolize. Some of the required ions are readily available from a weathered soil/ rock mass; however, for elements such as Fe and K, microbes adhere to the surfaces of some minerals and disintegrate them. Metagenomics, community physiological profiling, and elemental and mineralogical analysis in a granite weathering profile from Lesser Himalaya provided information about the microbe-rock interaction that caused the dissolution of biotite and feldspar from the rock and secondary calcium carbonate precipitation in the soil micro-environment in the saprock zone. The secondary precipitation decreased upward in the profile and, with limited nutrient availability in the regolith zone, resident microbes helped the disintegration of quartz, K-feldspar minerals for nutrients, and sequestered soil CO_2.

Given the anticipated increase in global temperature in the near future, a rise in weathering rates is expected. In addition to chemical weathering, resident carbon-sequestering microbes can be harnessed or mimicked to regulate global temperature via the sequestration of atmospheric CO_2. On the applied side, microbes that dissolve K-feldspar or solubilize silica in the regolith can promote plant growth and sustainable agricultural practices to manage excessive weathering events, thereby fine-tuning biogeochemical cycles.

Uttarakhand State Disaster Management Authority (USDMA) Sponsored project

LiDAR Survey of Joshimath (Data Acquisition and Modeling)

(Swapnamita C. Vaideswaran and Param K. R. Gautam)

In light of the land subsidence/landslide events of January 2023, it was crucial to obtain a high-resolution topographic map of the region covering the entire town of Joshimath and surrounding regions. The requirement was at least a 1 m contour map and Digital Elevation Model (DEM) for mapping the Joshimath town, and hence to plan rehabilitation and town planning. The requirement was to plan the non-existent sewer connections and drainage systems inside the town. Since Joshimath lies on a steep slope, with quite dense concrete built-up, along with some parts densely forested, the Airborne-LiDAR technique seemed to be the most suitable and viable option for mapping the area. As per the initiative of the Uttarakhand State Disaster Management Authority, WIHG, Dehradun carried out the airborne LiDAR-derived high-resolution map and digital elevation models of 100 sq km of

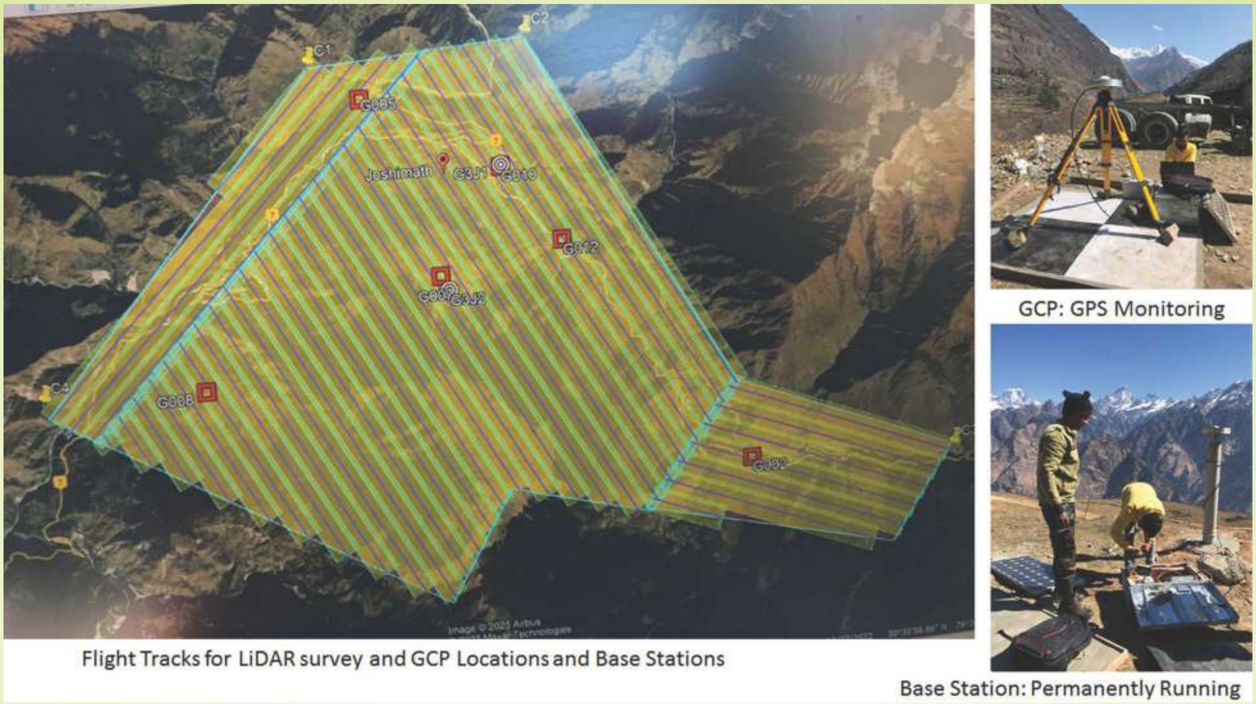


Fig. 74: LiDAR coverage and locations of Ground Control Points (GCPs) for the Joshimath topographic mapping. The two Base Stations at NTPC Helipad, Ravigram and Auli.

Joshimath and the surrounding regions for landslide mitigation and management purposes (Fig. 74). The deliverables from the LiDAR survey were (i) the generation of high-resolution LiDAR data including raw data, Classified (ground, building, vegetation), and geo-referenced point cloud, (ii) Images (raw data and ortho-rectified images, 5 cm GSD, geo-referenced in tiff format), (iii) Digital Terrain and Surface Model (DTM and DSM) with 25 cm x 25 cm grid, tif format, georeferenced, (iv) Contours with contour interval 10 cm (or higher as requested), georeferenced, in ArcGIS Database and (v) One set of deliverables in ITRF14 Ref. Frame, and WGS84 heights. Another set in ITRF14, orthometric (msl) heights

Acquisition of LiDAR Data and observations

The ground team established Ground Control Points (GCPs) by constructing slabs at several locations, with two pillar base stations, around the survey area (Fig. 74). Despite bad weather conditions, the airborne data was collected from 26 to 27 February 2023. One of the most important requirements for the generation of the LiDAR-derived topographic map is that the reference system had to be on an Orthometric Projection (with elevation reference on mean sea level). The Survey of India Type-B benchmarks close to Joshimath were required. Thereafter, the GPS monitoring in 6 GCP locations and two base stations was done by taking measurements in each GCP point for 8 hours. The team also started the search for Survey of India benchmarks (BM) inside the survey area and close to the survey area, east, west, north, and south. LiDAR data was processed keeping in mind, a corrected and generated geoid model, especially for Joshimath. The data was classified as Bare Earth, that is the DEM, which was the most important requirement for the rehabilitation, the DSM, and vegetation in three height layers. The built-up was classified as a separate layer.

The processed LiDAR data provides important insights into the situation in Joshimath. The paleo-landslide scar is visible and shows as the active scarp and crown of the present zone of subsidence. The aspect map and the slope map show that the crown of the landslide has moved upward. Manohar Bagh and Singdhar are the scarp regions, with Marwari as the west flank, and the Upper Bazar, along the Nau Ganga Nala as the east flank. Sunil region in the scarp of the landslide shows double ridges and is the surface of rupture. There is slumping on the toe region on both flanks, which is dumped on the Alaknanda River by the Nau Ganga and even at Marwari near the bridge. All these are suggestive of the situation in Joshimath as that of a deep-seated landslide, with slow, continuous, movement over long periods.

SERB Sponsored project

Development of an enhanced landslide detection model from remote sensing imagery through deep learning

(Naveen Chandra)

The project is focused on developing a deep learning–based landslide detection model from remote sensing images that will be realized through the following: (i) Data set preparation and configuration, (ii) Development and implementation of the deep learning–based feature extraction models, (iii) Qualitative and quantitative evaluation, and (iv) Dissemination of the results to the governmental authorities for the intended application. Therefore, to address the aforementioned objectives an improved YOLOv8 (nano (n), small (s), and medium (m)) network was introduced incorporating popular attention modules, specifically CBAM (convolutional block attention module), and ECA (efficient channel attention) aimed at enhancing landslide detection accuracy from satellite images. Figure 75, represents the architecture of the proposed network. The experiments are conducted using the open source landslide detection databases. Standard evaluation metrics, including precision, recall, F-score, and mean average precision (mAP), are used for quantitative analysis. Among the variants tested, YOLOv8n+ CBAM demonstrates the most promising performance (mAP=78%). This study underscores the model's efficacy in facilitating inventory preparation and precise landslide mapping for disaster recovery and response efforts, thereby supporting early prediction models.

SERB sponsored project

Early Landslide Monitoring of the Kondoi Village, Chakrata Block: with special emphasis on slope vulnerability investigation and suggestive measures

(Swapnamita C. Vaideswaran)

The study region is the Kondoi Village located in Chakrata block of Dehradun, Uttarakhand. Lakha Mandal, an old Hindu temple complex on the Yamuna River's banks, is about 14 kilometers away from Kandi (near Kondoi Bandur). Lakha Mandal is located in the Yamunotri Valley along the road of Char Dham Yatra. Travelers and pilgrims frequently take the Kondoi route from Lakha Mandal to Chakrata. Before choosing Kandi (Kondoi) as the suggested study area, a number of vulnerable and existing sites in the Chakrata region were visited and evaluated. With a few outliers in the Mandhali Formations, the majority of the landslides in Chakrata occur in the country rocks that comprise the Chakrata and Rautgara formations. Many road sections exhibit anthropogenically generated landslides, primarily as a result of building activities. The approach road between Kunen and Amraha villages is crucial in terms of the number of landslides caused by road cutting since a significant portion of the road section is built along the unstable and steep slopes where landslides are common during the monsoon.

The Kondoi village experiences landslides that result from both natural and human-caused causes. About 200 people live in the settlement, which contains about 28 dwellings. Over a few hundred meters,

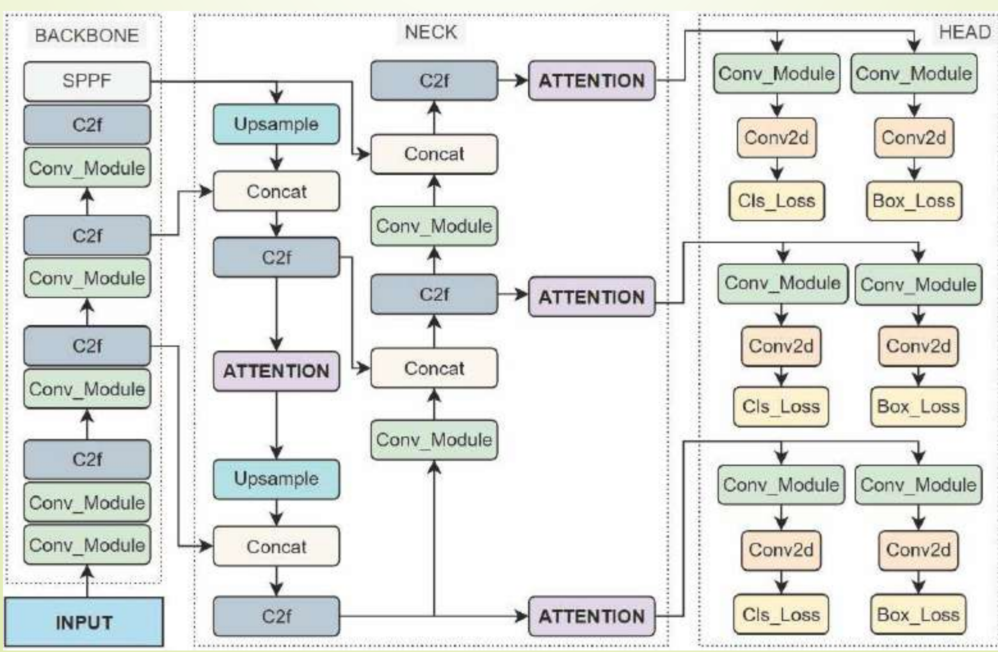


Fig. 75: Proposed YOLOv8+attention model for landslide event detection.

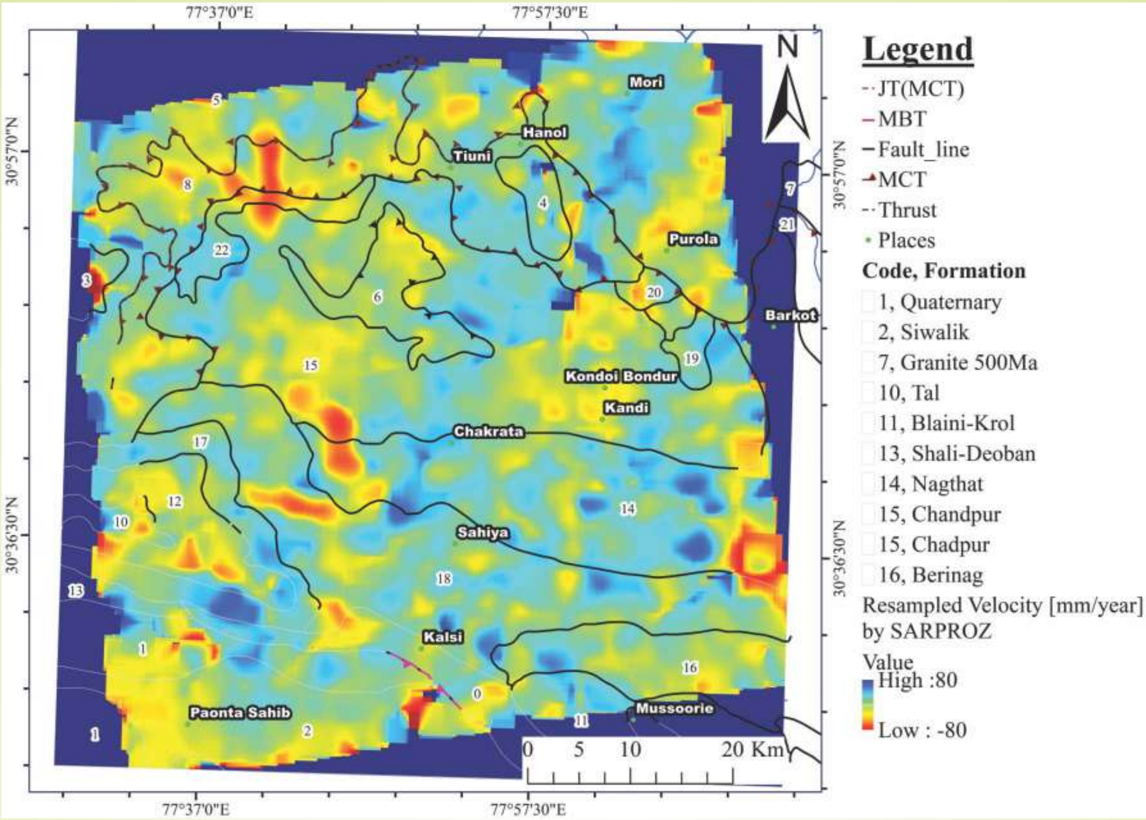


Fig. 76: InSAR analysis shows control of lithology, thrust systems and anthropogenic activities in the region around the project site in Chakata.

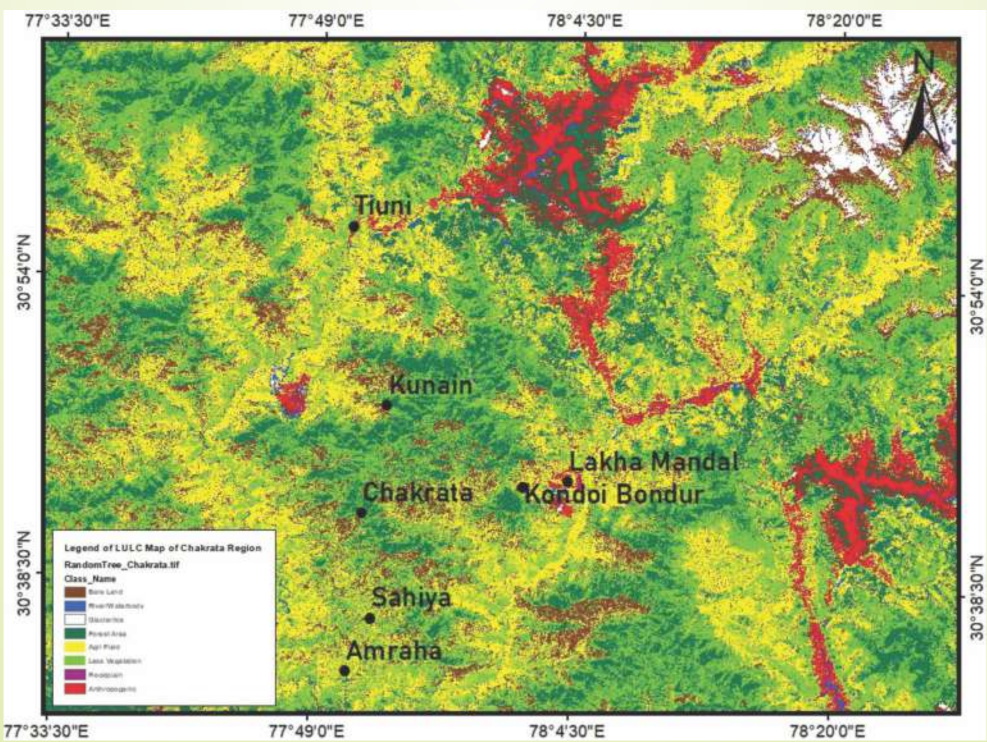


Fig. 77: Land Use and Land Cover (LULC) map generated around the project site in Kandi (near Kondoi Bandur), Yamuna Catchment (Uttarakhand).

SPONSORED PROJECTS

landslides have been caused by road construction. There are some fractures visible upslope of the main scar, and these could potentially slide during the monsoon. The whole slope of the village is at risk. Some of the houses show the development of cracks. There are fractures along the entire 150–200 m slope from top to bottom, making a significant slide possible.

A network of instruments measuring the displacements as a wholesome component for a Landslide Early Warning System (LEWS) is to be installed on the slopes of the village. It's clear that the combination of natural factors such as geology and tectonic activity, along with anthropogenic factors like road construction, contribute to the high susceptibility of landslides. The generated map shows that deformation in this region coincides with changes in lithology, association with faults, and also anthropogenic controls. The creation of a landslide susceptibility map is indeed crucial. It can help in predicting areas of potential risk and aid in planning and implementing preventive measures. For this land cover maps were required and have been generated from Sentinel 2 satellite data through a supervised classification using the maximum likelihood method (Fig. 76). The susceptibility map generated (Fig. 77) in the project classifies areas into five categories based on their susceptibility: Very Low (1.04% of the area), Low (16.07%), Moderate (46.12%), High (36.37%), and Very High (0.5%). Approximately 30% of the area, which falls under the very high-level zones, has a slope angle of 10–30°. A summary of the susceptibility zones, given that a significant portion (approximately 82.19%) of the area falls under moderate to high-risk zones. These zones are primarily located in the Central Crystalline of the Higher Himalayas, near the Main Central Thrust and mapped faults. The moderate to low-level zones display varying vegetation density.

SERB sponsored project

Post-LGM precipitation and temperature variability in western Himalaya

(Som Dutt and Anil Kumar)

Field surveys have been accomplished during the reporting period which was focused on the collection of sediment samples from various natural lakes in Himachal Pradesh. Two sediment cores of length 243 cm and 133 cm were retrieved from the Khajjiar Lake. The core samples were recovered from the area where anthropogenic activity was minimal. A 40 cm long core was recovered from Chakund Lake, Himachal Pradesh which is located at an altitude of 2948 m. above mean sea level. A paleolake at Shyaso, Sutlej Valley was also sampled and 58 samples were collected.

Khajjiar Lake

The Khajjiar Lake is a small lake situated at an altitude of 1900m in Chamba district of Himachal Pradesh. The lake has an area of 4500 m2 and a total catchment of 6km^2. Geologically, the area is mainly comprised of Silurian rock sales, schist, and conglomerate. These rocks are underlain by granite, gneiss, and conglomerate. The strata is conventionally known as Dalhousie Granite forming part of Dhauladhar Granite. The area is influenced by two moisture mechanisms, the Indian summer monsoon (ISM) and mid-latitude westerlies. The ISM contributes more than 70% of the average annual precipitation in the region. Snowfall occurs during winter. One core of Khajjiar Lake was sliced at every 1cm interval in the Sedimentology laboratory at the Wadia Institute of Himalayan Geology, Dehradun. The subsamples were air-dried at room temperature and processed for various laboratory analyses such as grain size characteristics, magnetic susceptibility, Total organic carbon, and Stable Oxygen and Carbon isotopes. The samples of one core of ~243 samples are under process for analysis.

The grain size and total organic carbon analysis of 120 samples at 2cm resolution had been done. Results indicate that the sediment from the Khajjiar Lake is dominated by silt-sized grains. Based on sediment size characteristics, the Khajjiar time series can be categorized into three different zones, Zone 1: Between 243 and 130 cm, sediments are dominated by silt size fractions, and within the silt fraction, coarse and medium sand concentration is high, and fine silt is less (Fig. 78). This can be interpreted as high energy transport linked with high water discharge from the catchment related to the strengthened Indian summer monsoon. Zone 2: At 130 cm, sand-sized grain concentration increased drastically to more than 20 percent and silt size decreased. This can be seen as the very high energy transport linked with the very high precipitation in the region. This phase continued till 90cm. Zone 3: After 90 cm to the top of the core, and again decreased fine silt fraction increased gradually. This can be referred to as decreasing high energy transport and decreased strength of ISM and less precipitation in the region. Based on visual investigation, similar zoning can also be done with organic content in the core. Zone 1 is dark-colored and can be interpreted as having high organic content in the sediment. Intense ISM gave rise to the high vegetation productivity in the catchment. In Zone 2, organic content is less and less vegetation input in the lake from the catchment, and Zone 3 has organic content

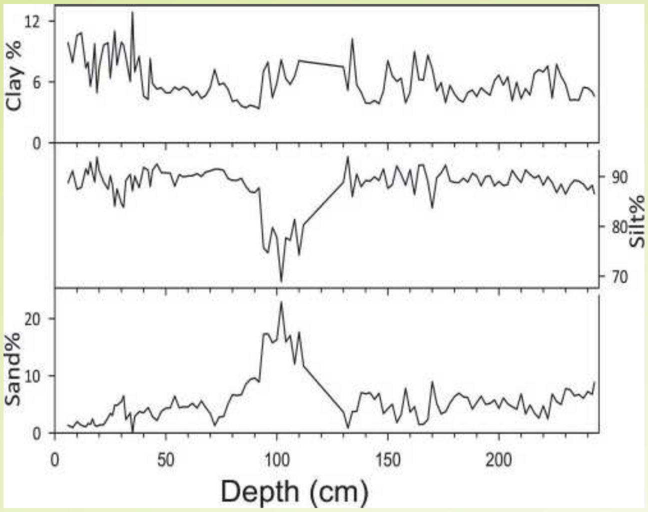


Fig. 78: Grain size characteristics for sediment samples from the Khajjiar Lake, Himachal Pradesh.

higher than Zone 2 but less than Zone 1. Bulk Magnetic susceptibility measurements of all 243 samples are under process.

MoES Sponsored Project

Tectono-thermal evolution of the Lohit Batholith along Dibang and Lohit Valleys, India using Fission Track and (U-Th)/He Thermochronology

(Vikas Adlakha and Koushik Sen)

A new low-temperature thermochronological record from the Lohit Valley, Eastern Himalaya, has been obtained across the major tectonic boundaries. The ZHe cooling ages range from 6.94±1.17 to 12.51±2.84 Ma, while AHe ages vary between 1.73±0.15 and 3.56±0.42 Ma. The ZHe cooling ages suggest that the Mishmi Crystallines exposed at the southwestern mountain front are the slowest exhuming domain since ~12 Ma. The Z He ages are youngest in the Demwe Thrust zone, a contact between the frontal low-grade metamorphic rocks of Mishmi Crystalline and high-grade gneissic rocks of the Mayodia Group. The rapid exhumation in the Demwe Thrust zone obtained from the ZHe cooling ages suggests an out-of-sequence thrusting at ~7 Ma. The QTQt thermal history modeling of the co-genetic pairs of ZHe and AHe cooling ages of the northeastern most Lohit Plutonic Complex suggests that the exhumation rates in this region were as high as ~3.7 mm/yr during the Pliocene-Quaternary. These high exhumation rates are in good correlation with the local topographic relief, hill slopes, and channel steepness, which suggests the establishment of the present-day topography of the Lohit Valley region latest by Pliocene-Quaternary. Variation in exhumation rates does not correlate with the present-day precipitation pattern. Tectonics appears to be the prime driver of the exhumation rates of the Lohit Valley region of the easternmost Himalaya. In addition, the 3D Thermo-kinematic model Pecube has been applied to the newly generated dataset, and the geometry of the MHT has been constrained for this Himalayas region. The geometry of the MHT is revealed for the Lohit Valley region, NE India, using inverse thermochronology 3D Pecube modeling. MHT forms a 28° ramp with two 8° flat components in this region.

SERB Sponsored Project

Paleoclimate, paleoenvironmental and biostratigraphy reconstruction in light of India-Asia collision and global bio-events of Surma Group, Neogene sediments of the Naga Hills, Indo-Myanmar Range

(Kapesa Lokho and M. Prakasam)

The project emphasized investigating past environmental changes in the Naga Hills region. This critical area holds clues in understanding the impact of the India-Asia collision on regional climate and global bio-events during the Neogene period (roughly 23-2.6 million years ago). The project is focused on (i) investigating the Foraminiferal biostratigraphy of the Surma Group of the Neogene sediments in the Naga Hills, (ii) documentation of the paleoclimatic and paleoenvironmental history of the Neogene and (iii) understanding the paleo-biogeography and tectonic evolution in light of India-Asia collision.

A field survey was conducted to collect rock samples for paleontological and geochemical analyses from the Surma Group of the Naga Hills in the Northeast Himalaya (Fig. 79). A systematic close-sampling strategy was engaged to gather a comprehensive set of rocks. These samples are currently undergoing processing at the Wadia Institute of Himalayan Geology for multi-proxy analysis. This analysis will help us understand fossil content and geochemical composition, and ultimately, reconstruct past environmental conditions in the region.

A total of 80 samples were processed for foraminifera recovery, while 6 samples underwent processing for nannofossils. Additionally, 27 samples were analyzed for total organic carbon (TOC) content. In the present investigations, calcareous nannofossils have been discovered within the studied section. Further processing of rock samples for microfossil recovery is going on. The recovered fossils are currently undergoing identification and interpretation using microscopic studies.

Fig. 79: Field photograph of a representative outcrop within the Surma Group succession, highlighting the specific location from which rock samples were collected for microfossil and geochemical analysis.

SERB Sponsored Project

Origin and evolution of Lesser Himalayan mafic magmatism, northwest India: constrains from new whole-rock, zircon U-Pb age and Sr-Nd isotope geochemistry of mafic rocks

(M. Rajanikanata Singh)

The preliminary geological fieldwork has been carried out in the Uttarakhand as well as the Rampur areas of the Himachal Himalaya. The granitic-gneiss and mafic igneous rocks intruded into metasedimentary rocks (quartzite/phyllite/slate) and the contact between them was identified. A variety of mafic magmatic rocks, primarily massive, vesicular, dark green to greyish types, were found in the field intercalated with metasedimentary rocks and collected for petrological, geochemical, and geochronological studies. Petrographic studies and major element XRF data indicate that dolerites, gabbros, vesicular basalts, andesites, and amphibolites are the most commonly identified rock types. Trace+REE, Zircon U-Pb, and Sr-Nd isotopic analysis are in progress.

UCOST Sponsored project

Black carbon personal exposure levels in different polluted micro-environments: A case study from Himalayan foothills

(*Chhavi Pandey*)

Investigations have been carried out on the extent of exposure to black carbon (BC) air pollution in different micro-environments located in the Himalayan foothills, namely in the Dehradun and Haridwar districts of Uttarakhand. BC aerosols, which are short-lived climatic forcing agents resulting from incomplete biomass and fossil fuel combustion, have a substantial influence on both the environment and human health. This study highlights the significance of regional research for a thorough understanding by focusing on the location-based variability of BC caused by various pollution sources, atmospheric conditions, and regional topography.

Rapid industrialization and increased vehicular emissions have made Dehradun one of the world's most polluted cities. This study conducted multiple monitoring campaigns using portable devices to measure BC exposure in various locations, such as city centers, transit routes, schools, and dwellings. This research emphasizes personal exposure evaluations, which give more precise data for the management of air quality. This is in line with typical studies, which rely on stationary monitoring.

The collected data revealed significant fluctuations in BC concentrations. In Rajpur, concentrations ranged from 9.109 µg/m^3 to 22.859 µg/m^3, influenced by traffic and residential emissions. The concentrations in the Hathibarkala region varied from 8.374 µg/m^3 to 13.378 µg/m^3, and the Dehradun Railway Station area exhibited a wide range from 14.453 µg/m^3 to 32.740 µg/m^3 due to transportation activities. Uttarakhand State Council for Science & Technology (UCOST), Dehradun showed a stable range from 10.424 µg/m^3 to 11.667 µg/m^3, while the Rispana area ranged from 25.450 µg/m^3 to 42.310 µg/m^3. During the Diwali festival, levels soared to 43.276 µg/m^3. The mobile eBC monitoring of the Haridwar area ranged from 1.20 µg/m^3 to 102.55 µg/m^3, and fixed monitoring showed variations from 1.31 µg/m^3 to 61.31 µg/m^3, particularly during festivals. These findings emphasize the necessity of implementing focused interventions and evidence-based policies to effectively address air quality issues and safeguard public health. As of March 31, 2024, the project has completed its duration.

SERB Sponsored Project

Flood Prediction Monitoring and Management using, Water Battery and IoT based Early Warning System in Tosacho city, Japan

(Pankaj Chauhan)

The increased frequency of disasters has stressed the state governments beyond their collective capacities to respond. According to the IPCC report, such situations will be more frequent in the future, due to a decline in seasonal rainfall, coupled with the increase in extreme precipitation in pockets during monsoon season. This will put more and more lives and properties at risk. On the other hand, the Sendai Framework for Disaster Risk Reduction (SFDRR) stresses on reduction of life loss and economic losses in disasters by 2030 by adopting various risk reduction measures at both national and local levels.

Introducing Water Battery and early warning dissemination

In recent technology, IoT (Internet of Things), AI (Artificial Intelligence) and ML (Machine Learning) are worldwide emerging fields. The IoT is an escalating discipline with multiple potentials and diverse opportunities for growth and development. In this context, to reduce risk during disasters, a smart early warning system is needed in the rugged and tough Himalayan terrain. Water Battery and early warning System (WBEWS) were tested and demonstrated at Keio University, JAPAN. The experiment was carried out in the pond of Keio University premises along with Mr. Kishimoto from Teijin Pvt. Ltd., and Project mentor Prof. Rajib Shaw and masters/ PhD students of the lab, under the SERB International Research Experience (*SIRE*) program 2023-24.

Initially, the technology of the warning system was demonstrated and tested in this Powerless Low-Cost Smart Early Warning System (PLCSEWS) in Japan. The PLCSEWS can be deployed to monitor glacier lakes, glacier tributaries, reservoirs, dams, canals, etc. The powerless system could be most effective for the Himalayan regions, where there is no source of power in the complex rugged, and tough terrain to monitor the hydro-climatic data. The preliminary findings show that, with the addition of some field observations, including meteorological and hydrological information, a new development in smart flood early warning system could be a remarkable initiative and experiment for the reduction of the risk and enhance disaster resilience in the Himalayan region and flood-prone hotspots worldwide. It overcomes the prevailing literacy and digital divides in society by simplifying flood warning dissemination through light signals, thus minimizing communication barriers and supporting quick action by the local community. Further, by using a combination of these at different heights, the dissemination system can be easily contextualized to local conditions.

These are batteries that can generate electricity when soaked with water (or any type of H_2O). It is a low-cost solution for providing timely early warning to the surrounding residents, particularly in rural areas where systematic early warning is not installed. The mechanism is simple (Fig. 80); when the water level rises, pre-set batteries are soaked at the risky level of the river water table, and it generates electricity (and turns on the emergency evacuation signal lights). Water batteries were installed at the site and setup the overflow risk is high for the residents, and it was equipped with an emergency light to begin with. Further advancement with data transmission systems can be installed as well and interconnected with IoT systems.

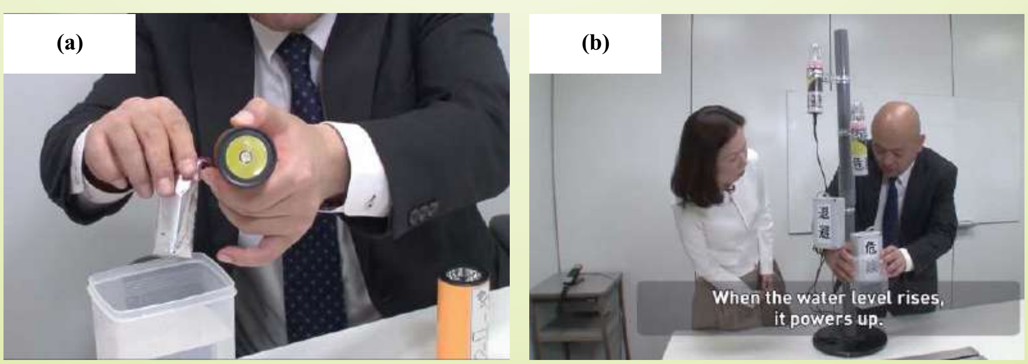


Fig. 80: (a) Water Battery, (b) Functioning of Water Battery.

RESEARCH PUBLICATIONS

Papers Published

1. Absar, N., Kalam, T.D.A., Raza, M.Q., Ashok, M. & Islam, R. 2024: Redox conditions of Early Cambrian Ocean as deciphered from multi-proxy geochemical and isotopic studies of Proto-Tethys carbonaceous sediments from Outer Lesser Himalaya, India. Journal of Earth System Science, 133, 26. https://doi.org/10.1007/s12040-023-02233-8

2. Ahuja, V., Pandey, C.P., Joshi, L.K., Nandan, H. & Pathak, P.P. 2024: Extreme value analysis of precipitation and temperature over Jammu & Kashmir and Ladakh in western Himalaya, India. MAUSAM, 75(1), 149-180.

3. Ahuja, V., Pandey, C.P., Joshi, L.K., Nandan, H. & Pathak, P.P. 2023: Statistical modelling of century-long precipitation and temperature extremes in Himachal Pradesh, India: generalized extreme value approach and return level estimation. Indian Journal of Physics, 98, 2653–2664.

4. Akiner, M.E., Chauhan, P. & Singh, S.K. 2024: Evaluation of Surface Water Quality in the Betwa River Basin through the Water Quality Index Model and Multivariate Statistical Techniques. Environmental Science and Pollution Research, 31, 18871–18886.

5. Alam, M., Kaulina, T.V., Varma, R.R. & Ahmad, T. 2024: Zircon U–Pb geochronology, Nd isotopes and geochemistry of mafic granulites from the Central Indian Tectonic Zone: isotopic constraints on Proterozoic crustal evolution. Geological Society Special Publication, 537, 333-358. https://doi.org/10.1144/SP537-2022-135.

6. Amarjeet, Sharma, V., Pandey, C., Gupta, A. & Chakraborty, A. 2023: Study of moisture flux over Uttarakhand State: signature of cloud bursts. Climate Dynamics, 61, 5349–5366.

7. Babu, V., Bhan, U., Devaraju, J. & Rai, S.K. 2023: Dashboard Design to Analyze Chemical Weathering of Clastic Sediments. Journal of the Geological Society of India, 99(6), 809-819.

8. Babu, V.G., Kumar, N.,Verma, S.K. & Pal, S.K. 2023: An updated earthquake catalogue and seismic regimes in the Northwest Himalaya: seismic periodicity associated with strong earthquakes. Journal of Earth System Science, 132, 173(1-20).

9. Babu, V., Devaraju, J., Rai, S.K. & Bhan, U. 2023: Utilizing Geochemical Analysis for Provenance Determination in Sedimentary Systems. Research Journal of Chemistry and Environment, 27(7), 126-132.https://doi.org/10.25303/2707rjce1260132

10. Bandyopadhyay S., Sinha S., Kumar A., Srivastava, P. & Jana, NC. 2023. Late Holocene river dynamics and sedimentation in the Lower Ganga plains, India. Geological Journal, 58 (4), 1564-1586. https://doi.org/10.1002/gj.4678

11. Basumatary, P., Borah, D., Chauhan, H., Prakash, T. & Gogoi, B. 2024: Mineralogy and geochemistry of trachytic rocks from the Lichi Volcanics, Eastern Himalaya: insights into the Kerguelen mantle plume activity in the Eastern Himalayan Region. Acta Geochim, 43,180-197.

12. Bhambri, R., Schmidt, S., Chand, P., Nüsser, M., Haritashya, U., Sain, K., Tiwari, S.K. & Yadav, J.S. 2023: Heterogeneity in glacier thinning and slowdown of ice movement in the Garhwal Himalaya, India. Science of the Total Environment, 875, 162625.

13. Bhandari, A., Flynn, L.J. & Lokho K. 2023: Discovery of Parapelomys (Murinae) from the Siwalik Group of Mohand, NW Himalaya: palaeobiogeography implications. Journal of the Palaeontological Society of India, 68(2), 147-153.

14. Bhat, I.M., Chauhan, H. & Ahmad, T. 2024: Tectono-magmatic evolution of the Ladakh and Karakoram, Trans-Himalaya, Northwest India. Proceedings of the Indian National Science Academy, 90(1), 1-9.

15. Bhat, I.M., Chauhan, H., Ahmad, T., Tanaka, T., Bickle, M., Asahara, Y., Chapman, H. & Dar, R.A. 2024: –Fate of an oceanic plate in the Neo-Tethys intra-oceanic subduction system: Evidence from elemental and Rb/SrSm/Nd isotopic systematics. Gondwana Research, 125, 266-283.

16. Bisht, P. 2023: Sensitive response of glaciers to changing climate in the YanktiKuti valley, Kumaon Himalaya, India, between 1990 and 2021. Environmental Monitoring and Assessment, 195(9), 1024.

17. Biswas, M. & Sain, K. 2023: Surin-Mastgarh Anticline in NW Himalaya from 2D seismic data, and its Implication on Geotectonics and Hydrocarbon Exploration. Journal of Asian Earth Sciences, 257, 105840.

18. Bohra, A., Laskar, A.H., Mehta, M., Anoop, A. & Pandey A.K. 2024: Late Quaternary palaeoclimatic records from the Indian Himalaya and Ganga foreland basin: Assessment on current understanding and future prospective. Quaternary Science Advances, 13, 100152.

19. Chanu, N.M., Kumar, N., Babu, V.G. Kumar, A., Mukhopadhyay, S. & Kumar, A. 2023: Shear-Wave velocity Models in and around North-East India by modelling Rayleigh wave Group velocity Dispersion Data. Journal Earth System Science, 132, 170(1-16).

20. Choudhary, D., Jukar, A.M., Patnaik, R., Singh, N.A., Singh, N.P. & Sharma, K.M. 2023. The first report of cf. Zygolophodon (Mammalia, Proboscidea, Mammutidae) from the Upper Miocene of Kutch, India. Journal of Vertebrate Paleontology, 42(4), 1-5. https://doi.org/10.1080/02724634.2023.2197959

21. Chauhan, P., Sharma, J., Bhardwaj, P., Mehta, M., Shah, R.A., Singh, O. & Sain, K. 2023: Comparative analysis of discharge and sediment flux from two contiguous glacierized basins of Central Himalaya, India. Environmental Monitoring & Assessment, 195(6), 729.

22. Chauhan, H., Pandit, D., Ahmad, T., Giri, R.K. & Pandey, A.C. 2023: Formation of manganoan ilmenite in Archean tonalite-trondhjemite-granodiorite (TTG) gneisses inferred from re-equilibration of biotite and Fe-Ti oxide assemblage: a case study from the Aravalli Craton, northwest India. Neues Jahrbuch fur Mineralogie, Abhandlungen (J. Min. Geochem.), 198(2), 171-190. https://doi.org/10.1127/njma/2023/0371

23. Coggon, R.M., Sylvan, J.B., Estes, Prakasam, M. et al. 2024: Site U1557. South Atlantic Transect. Proceedings of the International Ocean Discovery Program, 390/393: College Station, TX. https://doi.org/10.14379/iodp.proc.390393.105.2024.

24. Coggon, R.M., Teagle, D.A.H., Sylvan, J.B., Prakasam, M. et al. 2024: Expedition 390/ 393 methods. South Atlantic Transect. Proceedings of the International Ocean Discovery Program, 390/393, College Station, TX. https://doi.org/10.14379/iodp.proc.390393.102.

25. Daniels, R.L., Niemi, T.M., Jayangondaperumal, R., Aravind, A., Rautela, P., Pandey, A. & Murphy, L.D. 2023: Late Medieval seismicity on the Himalayan Frontal Thrust Fault at Lal Dhang, Uttarakhand, India. Tectonophysics, 864, 229934. https://doi.org/10.1016/j.tecto.2023.229934

26. Das, A., Hazarika, D., Kundu, A., Kumar, N. & Yadav, D.K. 2024: Sedimentary structures of the western part of the Indo-Gangetic Plain and Siwalik Himalaya inferred from receiver function inversion. Geophysical Journal International, 236(3), 1424–1438.

27. Das, S., Rai, S.K., Rahaman, W., Singhal, S., Panda, S. & Sarangi, S. 2023: Decoding the control of active tectonics on the sedimentary budget of a Himalayan River basin: Insights from Sr and Nd isotopic compositions ($^{87}Sr/^{86}Sr$, εNd) of bed. Geochemistry, 83 (4), 126027.

28. Datta, A., Luirei, K. & Mehta, M. 2024: Slope instabilities and evolution of tectonic geomorphology along the strike of the Main Boundary Thrust zone in the western Himalaya, India. Natural Hazard Research, 4, 118-133.

29. Dey, A., Sen, K. & Mamtani, M.A. 2023: Lattice preferred orientation of quartz in granitic gneisses from Tso Morari Crystalline Complex, Eastern Ladakh, trans-Himalaya: evaluating effect of Dauphiné twin in dynamic recrystallization during exhumation. Geological Magazine, 160(8), 1556-1577.

30. Dey, A., Sen, K., Sen, A. & Choudhary, S. 2023: Omphacite breakdown, symplectite formation and carbonate metasomatism in a retrograded continental eclogite: Implications for the exhumation of the Tso Morari Crystalline Complex (Trans-Himalaya, NW India). Physics and Chemistry of the Earth, Parts A/B/C, 131, 103453.

31. Dhamodharan, S., Gautam, R. & Bagri, D.S. 2023: Deep electrical resistivity imaging of crustal structures along the Satluj River valley, northwest Himalaya, India. Tectonophysics, 869, 230096. doi:10.1016/j.tecto.2023.230096

32. Garg, P.K, Mehta, M., Shukla, A., Chauhan, P., Kesarwani, K. & Mukherjee, S. 2023: Supraglacial geomorphology of Companion Glacier, central Himalaya: evolution, controls and

consequences. Front. Earth Science, 11, 1219755. doi: 10.3389/ feart.2023. 1219755.

33. Gautam, R., Kapil, M., Dhamodharan, S., Dadhich, H., Chingtham, P., Sain, K. & Mishra, O.P. 2023: Geoelectrical Charactersiation of the junction of seismically active Delhi Hardwar Ridge and Delhi Sargodha Ridge. Scientific Reports, 13,1, doi: 10.1038/s41598-023-42722-w

34. Goswami, A., Sarangi, S., Mohanty, S.P., Patil, D.J., Sarkar, A., Ray, J.S., Das, S., Mohanty, D., Ahmad, S.M., Pradhan, R.M. & Barik, A. 2023: Negative δ^{13}C carb excursions within early part of the Lomagundi event recorded in the Paleoproterozoic sedimentary carbonates, Aravalli Supergroup, Rajasthan India: Chemostratigraphy and basin evolution. Precambrian Research, 399, 107240. https://doi.org/10.1016/j.precamres.2023.10724

35. Gupta, A.K., Mandal, P., Sain, K., Haldar, C. & Paul, A. 2024: 1-D Shear wave velocity structure beneath North India using surface wave dispersion study. Journal of Earth System Science, 133 (17), 1-16.

36. Gupta, A.K., Mandal, P., Srinagesh, D., Tiwari, A, Sain, K. & Paul, A. 2023: One-dimensional regional shear velocity structure from joint inversion of fundamental mode group velocity dispersion measurements of Love and Rayleigh waves: application to the Uttarakhand Himalaya. Acta Geophysica, 71, 2619-2632. https://doi.org/10.1002/esp.5869.

37. Gupta, A.K., Mandal, P., & Sain, K. 2023: Modelling of earthquake source parameters and scaling relations in the Uttarakhand Himalayan region, India. Journal of Earth System Science,132(73), 1-11.

38. Gupta, V., Kaur, R., Kumar, S., Ram, B.K. & Tanton, R.S. 2023: Regional-scale landslide susceptibility assessment for the hilly state of Himachal Pradesh, NW Himalaya, India. Current Science, 125(12), 1369-1380. DOI:10.18520/cs/v125/i12/1369-1380

39. Jain, A.K., Mukul, M., Pant, N.C. Mukherjee, P.K., Singh, P., Singh, T., Rajendran, C.P., Pebam, J., Singh, P., Deshmukh, G.G. & Dixit, R. 2024: Tectonics of the Northwestern, Sikkim and Eastern Himalaya. Proceeding in Indian National Science Academy, 90, 266-280.

40. Kaur, S., Yadav, J.S., Bhambri, R., Sain, K. & Tiwari, S.K. 2023: Assessment of geothermal potential of Kumaun Himalaya: A perspective for harnessing green energy. Renewable Energy, 212, 940-952.

41. Kanyan, N.K., Kumar, N., Rana, S., Kumar, N. & Singh, A.K. 2023: Origin and Tectonic Implications of I-type Granites, North Delhi Fold Belt, NW, India: Insights from Whole Rock Geochemistry and Mineral Compositions. Journal of the Geological Society of India, 99(12), 1641-1658. https://doi.org/10.1007/s12594-023-2521-8

42. Kharya, A., Rai, S.R., Sachan, H.K., Manish, K. & Vikas, K. 2023: Origin of exotic blocks in Himalaya: a case study from Zildat ophiolitic mélange, Indus suture zone, Ladakh, India. Carbonates and Evaporites, 38, 11.

43. Konar, S., Mukherjee, B. & Sain K. 2024: Machine learning assisted gas hydrate saturation proxy: A case study from KG basin, India. Himalayan Geology, 45(1), 89-107.

44. Kothyari, G.C., Pant, P.D., Kotlia, B.S., Mehta, M., Joshi, H., Chauhan, D.S., Dumka, R.K., Luirei, K., Joshi, M., Tamta, B.K. Joshi, A., Taloor, A.K., Chauhan, G. & Rawat, S. 2023: Geoheritage Sites in Kumaun Himalaya of Uttarakhand, India. Geoheritage, 15(3), 104. https://doi.org/10.1007/s12371-023-00834-9.

45. Kothyari, G.C., Dumka, R.K., Luirei, K., Kandregula. R.S., Taloor. A.K., Malik. K., Joshia, A., Patidara, A.K. & Bhana, U. 2024: Estimation of active surface deformation using PSInSAR technique of the Central Himalayan region. Geocarto International, 39(1), 2302415.

46. Kothyari, G.C., Pant, P.D., Kotlia, B.S., Mehta, M., Joshi, H., Chauhan, D., Dumka, R.K., Luirei, K., Joshi, M., Tamta, B.K., Joshi, A., Chauhan, G.V. & Rawat, S. 2023: Geological and Geoheritage sites in Kumaun Himalaya of Uttarakhand, India. Geoheritage, 15, 104.

47. Kumar, J., Kumar, P.C. & Sain, K. 2023: Appraisal of reservoir porosity using a machine learning approach: A study from the Eocene-Miocene interval of the Upper Assam Basin, NE India. Geological Journal, 58(11), 4181-4193.

48. Kumar, J., Kumar, P.C. & Sain, K. 2023: Delineation of Oil-Water-Contact within Tipam reservoir: A study from Upper Assam Basin, NE India. Geological Journal, 58(11), 4004-4014.

RESEARCH PUBLICATIONS

49. Kumar, N., Haldar, C. & Sain, K. 2023: Seismological evidence for intra-crustal low velocity and thick mantle transition zones in the north-west Himalaya. Journal of Earth System Science, 132, DOI:10.1007/s12040-023-02109-x

50. Kumar, N., Rana, S. & Singh, A.K. 2023: High concentration of cobalt in the Ajabgarh rocks of Delhi Supergroup, Southwest Haryana, India. Current Science, 125(4), 428-435. https://doi.org/10.18520/cs/v125/i4/428-435

51. Kumar, P.C. & Sain, K. 2023. Machine Learning elucidates the anatomy of buried carbonate reef from seismic refection data. Artificial Intelligence in Geosciences, 4, 59-67.

52. Kumar, P.C., Kumar, J. & Sain, K. 2024: Cenozoic tectonic subsidence in the Upper Assam Basin: A case study from NE India. Geosystems and Geoenvironment, 3(1), 100223.

53. Kumar, P.C., Sain, K. & Omosanya, K.O. 2023: Growth and Kinematics of strike-slip faults: A case study from the Dibrugarh field, Upper Assam foreland basin, NE India. Journal of Marine and Petroleum Geology, 153, 106291, 1-16.

54. Kumar, P.C., Sain, K. & Omosanya, K.O.L. 2023: Geometry and Kinematics of strike-slip faults in the Dibrugarh field of the Upper Assam foreland basin, NE India. Marine and Petroleum Geology, 153, 10629. https://doi.org/10.1016/j.marpetgeo.2023.106291

55. Kumar, P.C., Kumar, J. & Sain, K. 2023. Subsurface fluid flow: A case study from the Indo-Gangetic peripheral foreland basin. Results in Geophysical Sciences, 14, 100057, 1-12.

56. Kundu, A. Hazarika, D., Hajra, S. & Yadav, D.K. 2023: Imaging the crustal structure at the northeast corner of the indenting Indian Plate in the Eastern Himalayan Syntaxis. Geophysical Journal International, 2352(2), 1035-1048.

57. Liu, H., Mukherjee, B., Zuo, Y., Roy, P., Wu, Z., Sun, W., Zheng, L., Pan, C. & Lin, J. 2023: Fractal dimension used as a proxy to understand the spatial distribution for carlin-type gold deposits. Ore Geology Reviews, 158, 105534.

58. Lokho, K., Aitchison, J.C., Kumar, A., Zhou, R., Prakasam, M. & Raju, D.S.N. 2023: Middle Miocene final demise of remnants of an eastern Neotethyan seaway, Naga Hills, Indo-Myanmar Range. Marine Micropaleontology, 181, 102243.

59. Lokho, K., José Francisco Carrasco, J.F. Biswal, S., Whiso, K. & Bhandari, A. 2023: First Report of Eocene Echinoids from the Sylhet Limestone, Mikir Hills of Assam, India: Paleontological, Paleogeography and paleoenvironmental significance. Journal of the Paleontological Society of India, 68(2), 188-198.

60. Luirei, K., Lokho, K., Zimik, H.V., Rino, V., Chahong, N., Tiwari, S.K., Angkang, M., Khangrah, N., Richa, H.O., Neikha, K. & Thong, G.T. 2023: Stable hydrogen and oxygen isotope investigation of the saline and hyperalkaline springs in parts of the Inner Fold Belt and Ophiolite Complex of Manipur and Nagaland, India. Himalayan Geology, 44(2), 9-14.

61. Luirei, K., Mehta, M., Iqbal, A., Nazir, S. & Kothyari, G.C. 2023: Factors influencing the slope instability of the Mussoorie-Bhitarli area, Garhwal Himalaya. Geosciences Journal, 27(3), 337-350.

62. Mishra, S.R., Chakraborty, P.P., Das, K., Saha, S., Shibata, T., Mohanty, S.P. & Tripathi, S.C. 2024: Tracking provenance shift in the Cretaceous-Paleogene sedimentary succession of the Garhwal foreland basin, NW Himalaya using sediment geochemistry and U-Pb detrital zircon geochronology. Journal of Asian Earth Sciences, 264, 106067, 1-21.

63. Modi, P., Hower, J.C., Giri, R.K., Rahi, I.C., Siddiqui, M.A., Rajak, P.K. & Jamal, A. 2024: Recovery of rare earth elements from coal samples from the Sohagpur coalfield, Madhya Pradesh, India. International Journal of Coal Preparation and Utilization, 44(2), 219-239.

64. Mohanty, A., Gahalaut, V.K., Chowdhury, S., Bansal, A.K., Gautam, P. & Catherine, J. 2024: Geodetic constraints on slip rate on the Karakoram fault and its role in the Himalayan arc deformation. Earth and Planetry Science Letters, 626, 118512.

65. Monika, Sandeep, Kumar, P., Devi, S. & Joshi, A. 2023: Modeling of 1991 Uttarkashi and 2011 Indo–Nepal earthquakes using the modified semi-empirical technique by integrating site-specific Quality factor. Journal of Earth System Science 132, 189, 1-17.

66. Mukherjee, B., Gautam, P.K. & Sain, K. 2024: Machine learning assisted crustal velocity proxy: A case study over the Tibetan Plateau and its surroundings. Journal of Asian Earth Sciences, 263, 106004.

67. Mukherjee, B. & Sain, K. 2023: Semi-automated Rock Layer Recognition from Borehole Log Data Using Combined Wavelet and Fourier Transform: A Case Study in the KG basin. India. Journal of the Geological Society of India, 99, 1659-1670.

68. Nayak, R., Pal, D., Chinnasamy, S.S., Satyanarayanan, M., Kumar, S., Dash, J., Sethy, P.C. & Mohan, A. 2023: Influences of subduction derived fluids and melt in the genesis of Nidar ophiolite peridotites, Ladakh Himalaya, India: Evidence from mineralogy, PGE and Nd isotopic compositions. Geochemistry, 83(4), 126022.

69. Nirmal, B., Mohan, K., Tripati, A., Christensen, B.A., Mortyn, P.G., De Vleeschouwer, D., Prakasam, M. & Saravanan, K. 2023: Agulhas leakage extension and its influences on South Atlantic surface water hydrography during the Pleistocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 615, 111447.

70. Penserini, B.D., Morell, K.D., Codilean, A.T., Fülöp, R-H., Wilcken, K.M., Yanites, B.J., Kumar, A., Fan, S. & Mearce, T. 2024: Magnitude and timing of transient incision resulting from large-scale drainage capture, Satluj River, Northwest Himalaya. Earth Surface Processes and Landforms, 49(1), 334-353.

71. Perumalsamy, C., Anand, V. & Nagarajan, R. 2024: Petrogenesis of S-type Ladakh granite and mafic microgranular enclaves in the southern margin of Ladakh batholith: An evidence of crust-mantle interaction during the collision between Indian and Eurasian plates. Island Arc, 33(1), e12520.

72. Ram, B.K., Shawez, M., Gupta, V. & Gautam, R. 2024: Ground subsidence in Dar village (Darma valley), Pithoragarh district, Kumaun Himalaya, India: A Himalayan disaster in waiting. Journal of Earth System Science, 133, 34. https://doi.org/10.1007/s12040-023-02244-5

73. Ram, B.K. & Gupta, V. 2024: Physico-mechanical characterization of Higher Himalayan granite under the thermal treatments of different heating–cooling conditions. Acta Geotechnica, 19, 2841-2854. https://doi.org/10.1007/s11440-023-02224-5

74. Rana, A.S., Kunmar, P., Mehta, M. & Kumar, V. 2023: Glacier retreat, dynamics and bed overdeepenings of Parkachik Glacier, Ladakh Himalaya, India. Annals of Glaciology, https://doi.org/10.1017/aog.2023.50.

75. Rastogi, T., Singh, J., Singh, N., Chauhan, P., Yadav, R.R. & Pandey, B. 2023: Temperature variability over Dokriani glacier region, Western Himalaya, India. Quaternary International, 664, 33–41. https://doi.org/10.1016/j.quaint.2023.05.013

76. Rawat, G., Kapil, M., Dhamodharan, S., Dadhich, H., Chingtham, P., Sain, K., Mishra, O.P. 2023: Geoelectrci Charactersiation of the junction of seismically active Delhi Hardwar Ridge and Delhi Sargodha Ridge. Scientific Reports, doi: 10.1038/s41598-023-42722-w

77. Sagwal, S., Kumar, A., Sharma, P.C., Srivastava, P., Agarwal, S. & Bhushan, R. 2023: Late Holocene hydrological variability from NW Himalaya and southwestern Tibetan Plateau: Paleo-salinity records from Pangong Tso. The Holocene, 33(7), 842-859.

78. Sagwal, S., Sengupta, D., Kumar, A., Dutt, S., Srivastava, P., Agnihotri, R., Gahlaud, S.K.S., Jena, P.S., Shivam, A. & Bhushan, R. 2023: Late Holocene wildfire record from the Stagmo peat section, Leh valley, NW Himalaya. The Holocene, 33(6), 685-694.

79. Sahu, R., Ramsankaran, R., Bhambri, R., Verma, P. & Chand, P. 2023: Evolution of Supraglacial Lakes from 1990 to 2020 in the Himalaya–Karakoram Region Using Cloud-Based Google Earth Engine Platform. Journal of the Indian Society of Remote Sensing, 51, 2379-2390. https://doi.org/10.1007/s12524-023-01773-2

80. Sehgal, R.K., Singh, A.P., Singh, N.P., Gilbert, C.C., Patel, B.A. & Patnaik, R. 2023: First report of rodents from the Miocene Siwalik locality of Dunera, Pathankot District, Punjab, India. Palaeontologia Electronica, 26(3), a49. https://doi.org/10.26879/1308

81. Sen, A., Phukon, P., Sen, K., Bose, S. & Srivastava, H.B. 2024: Exhumation mechanisms of the Himalayan metamorphic core in the Bhagirathi Valley, NW India: Insights from an integrated structural and metamorphic analysis. Journal of Structural Geology, 179, 105043.

82. Sengupta, D., Dutt, S., Daly, B.D.K. & Panda, S. 2024: Development of Geopark for Protecting Karst Region of Nongkhlieh Area, Meghalaya. Geoheritage, 16(1), 6.

83. Sharma, A., Kumar, D., Paul, A. & Teotia, S.S. 2023: Simulation of strong ground motions of 1991 Uttarkashi (M 7) and 1999 Chamoli (M 6.6) earthquakes using modified hybrid technique. Acta Geophysica, 71, 2573-2602.

84. Sharma, A., Kumar, D., Paul, A. & Teotia, S.S. 2024: Evaluation of seismic hazard in the central seismic gap region of Himalaya based on site effects and simulated accelerograms. Acta Geophysica. doi.org/10.1007/s11600-023-01268-1.

85. Sharma, A., Kumar, D., Paul, A. & Teotia, S.S. 2024: Simulation of strong ground motions from 2016 Kumamoto (Mw 7.1), Japan, earthquake using modified hybrid technique. Arabian Journal of Geosciences, 17, 55, 1-21.

86. Singh, A., Deep, A., Pandey, C. & Nandan, H. 2023: Comparative study of gaseous pollutants for major cities in foothills of Garhwal Himalaya of Uttarakhand. MAUSAM, 74(1), 57-72.

87. Singh, A., Pandey, C.P., Nandan, H. & Semwal. P. 2023: Variation of AIRS-Retrieved CO_2 over Uttarakhand, India, During 2010–2017. Journal of the Indian Society of Remote Sensing, 51, 1553–1564.

88. Singh, A.P., Pandey, S., Sehgal, R.K. & Singh, N.P. 2024: Fluvial ichnofossil assemblage from the Miocene Siwalik succession of Pathankot District, Punjab, India: Palaeoenvironmental interpretation. Journal of Earth System Science, 133, 1-19. https://doi.org/10.1007/s12040-023-02223-w .

89. Singh, D., Karan, K., Singh, S.K., Chauhan, P. & Berndtsson, R. 2023: Fusing Morphometric Characteristics with Extreme Precipitation Indices for Identifying the Most Vulnerable Sub-basin at Risk of Flooding. Journal of Hydro-environment Research, 50, 44-56.

90. Singh, I., Jayangondaperumal, R., Pandey, A., Rao, S.P., Mishra, R.L., Morthekai, P., Jagtap, S., Srivastava, P., Kumar, P. & Chopra, S. 2023: Late Quaternary deformation, strain partitioning, and fold-thrust belt widening in the Eastern Himalayan Syntaxis, India. Tectonophysics , 871. https://doi.org/10.1016/j.tecto.2023.230193

91. Singh, N.L., Akhtar, S., Singh, A.K., Bingh, B.P., Saikia, A. & Jeelani, S.H. 2023 Petrogenesis and tectonic implications of the Late Cretaceous to Paleogene calc-alkaline volcanic rocks, Ladakh Himalaya. Journal of Asian Earth Sciences, 253, 105700. doi.org/10.1016/ j.jseaes.2023.105700

92. Singh, P. & Patel, R.C. 2024: Mio-Pliocene exhumation of the hinterland and sediments provenance of the Neogene strata from Kumaun Himalaya of northwest India: Insights from detrital fission-track thermochronology. Geological Journal, 59(1), 29-45.

93. Singh, P., Chaudhary, S.K., Sandhu, M., Singh, R.P. & Sagwal, A. 2024: Mio-Pliocene tectonic activity along the Main Boundary Thrust and exhumation of the Amritpur Granite Body, Kumaun region, northwestern Himalaya. Himalayan Geology, 45(1), 123 -137.

94. Singh, S., Prakash, D., Kharya, A. & Sachan, H.K. 2023: Metamorphic evolution of the UHT granulites from Mandikota, Eastern Ghats Mobile Belt, India: Constraints from phase equilibria modelling, fluid inclusions and monazite U-Th-total Pb geochronology. Precambrian Research, 390, 107042.

95. Thakkar, M.G., Chauhan, G., Padder, A.H., Parcha, S.K., Sharma, S., Thakur, V.C. & Dorjay, C.P. 2023: Geoheritage Merits of the Zanskar Range of the Kashmir Himalaya: a Field Geology Museum from Precambrian to Present. Geoheritage, 15(2), 75. https://doi.org/10.1007/s12371-023-00842-9.

96. Tiwari, A., Kumar, P., Sain, K. & Paul, A. 2023: Possible implication of recent Doti-Nepal earthquake (M 6.3) for seismicity monitoring in the Central Himalaya. Himalayan Geology, 44 (2), 57-63.

97. Tiwari, A., Paul, A., Sain, K., Singh, R. & Upadhyay, R. 2023: Depth-dependent seismic anomalies and potential asperity linked to fluid-driven crustal structure in Garhwal region, NW Himalaya. Tectonophysics, 862, 229975.

98. Tiwari, S.K., Sain, K., Kaur, S., Yadav, J.S. & Baiswar, A. 2023: Degassed versus Consumed Flux of CO2 from the Third Pole. Journal of the Geological Society of India, 99(9), 1305-1308.

99. Vandana, Dadhich, H.K., Mittal, H. & Mishra, O.P. 2023: Ground motion prediction equation for NW Himalaya and its surrounding region. Quaternary Science Advances, 13(3), 100136. https://doi.org/10.1016/j.qsa.2023.100136

100. Venugopal, A., Tripathy, G.R., Goswami, V., Ghosh, S.K. & Singh, D. 2023: Oceanic Redox State During the Early Cambrian: Insights from Mo-S Isotopes and Geochemistry of Himalayan Shales. Geochemistry, Geophysics, Geosystems, 24(12), e2023GC011182. https://doi.org/10.1029/2023GC011182

101. Verma, A., Kumar, A., Tiwari, S.K., Bhambri, R., Sain, K., Rai, S.K. & Patidar, P. 2023: Heterogeneity in glacio-hydrological processes and estimation of different components in streamflow from central Himalayan glaciers. Journal of Hydrology: Regional Studies, 49, 101495.

102. Verma, A., Sain, K. & Kumar, A. 2023: Environmental Changes in Antarctica Using a Shallow Ice Core from Dronning Maud Land (DML), East Antarctica. Environmental Processes, 10(2), 22.

103. Verma, S.K., Kumar, N., Hazarika, D., Paul, A., Yadav, D.K. & Pal, S.K. 2023: Shear wave crustal velocity structure in the Garhwal-Kumaon Himalaya based on noise cross-correlation of Rayleigh wave. Tectonophysics, 866, 230047, 1-18. doi:https://doi.org/10.1016/ j.tecto.2023.230047

104. Verma, S.K., Kumar, N. & Pal, S.K. 2023: Noise analysis of the observatory superconducting gravimeter in the normal mode frequency range using gravity data of Ghuttu, Garhwal Himalaya, India. Journal of Asian Earth Sciences, 10, 100165, 1-15.

105. Yadav, J., Khyalia, B., Kumar, N., Panghal, A., Singh, P.P., Devi, S., Kataria, N., Singh, P. & Dalal, R. 2023: Assessment of natural radioactivity in soil and water in the upper Himalayas region along the Manali–Leh highway, India. Journal of Radioanalytical and Nuclear Chemistry, 333, 3075-3086.

106. Yadav, P.K., Singha, D.K. & Sain, K. 2023: Rock Physics Modelling for Estimation of Gas Hydrate Saturation Using NGHP-02 Well Data in the Krishna–Godavari Basin. Pure and Applied Geophysics, 180(8), 2999-3018. https://doi.org/10.1007/s00024-023-03322-x

107. Westoby, M.J., Dunning, S.A., Carrivick, J.L., Coulthard, T.J., Sain, K., Kumar, A., Berthier, E., Haritashya, U.K., Shean, D.E., Azam, M.F., Upadhyay, K., Koppes, M., Harley, R., McCourt, Sh. & Dan, H. 2023: Rapid fluvial remobilization of sediments deposited by the Chamoli disaster, Indian Himalaya. Geology, 51(10), 924-928.

Non-SCI / Book Chapter

108. Kumar, R., Devrani, R., Pundir, S., Lone, I.U., Adlakha, V., Sathunuri, K., Deshmukh, B. & Kumar, A. 2023. Soil Loss Rates in Trans Himalayan Region: Case Study of Shyok Suture Zone, Ladakh, India. Edited chapter, 243-263. *In:* Singh, V.B., Madhav, S. , Pant, N.C. & Shekhar, R. (eds.), Weathering and Erosion Processes in the Natural Environment.

109. Jouanne, F., Mugnier, J.L., Vassallo, R., Munawar, N., Ahmed, A., Awan, A.A., Malik, M.A. & Jayangondaperumal, R. 2023: Recent and Present Deformation of the Western Himalaya. Edited Chapter, 193-216. *In:* CATTIN, Rodolphe & EPARD, Jean-Luc, (eds.), Himalaya: Dynamics of a Giant 3: Current activity of the Himalayan Range, © ISTE Ltd. DOI: https://doi.org/10.1002/9781394228683.

110. Pappachen, J.P., Hamdan, H.A.M., Sathiyaseelan, R., Darya, A.M., Shanableh, A. & Leblouba, M. 2024: Ionospheric anomalies associated with the Mw 6.0 and 6.4 South Iran Twin earthquakes from GPS and Ionosonde Observations. Edited Chapter, 275-278. *In:* Recent Research on Geotechnical Engineering, Remote Sensing, Geophysics and Earthquake Seismology. DOI: 10.1007/978-3-031-48715-6_59.

111. Das, S., Sandeep, Devi, S., Mittal, H., Kumar, P. & Monika 2023: Spatial Distribution of Stress Orientation by Inversion of Focal Mechanism Solutions Using MSATSI: A Case Study Across Japan Trench in the 'Proceeding of 17th symposium on earthquake engineering at IITR, 4, 243-256.

112. Kumar, P., Sandeep & Monika 2024: Estimation and Validation of arias intensity relation using the 1991 Uttarkashi and 1999 Chamoli earthquakes data. Edited Chapter, 15-23. *In:* 'Recent Developments in Earthquake Seismology. DOI: 10.1007/978-3-031-47538-2_2.

113. Kumar, S., Kumar, P., Kaushik, S., Sundriyal, Y.P. & Gupta, V. 2023: Spatial prediction of earthquake-induced landslide susceptible zones-A case study from Indian Himalaya. *In:* Geohazards: Analysis, Modelling and Forecasting, 9, 125-135.

114. Bhambri, R., Mehta, M., Tiwari, S.K., Yadav, J.S. & Sain, K. 2024: High Mountain Hazards in Uttarakhand. Springer (book chapter).

115. Hajra, S. & Hazarika, D. 2023: Stress Dissipation in the North-West Himalaya: What We Learnt from Post-seismic Stress Changes. Advances in Natural and Technological Hazards Research, 25-37. https://doi.org/10.1007/978-981-99-3955-8.

State-of-the-Art Reports:

116. Ansari, T.A., Saha, S. & Kumar, A. 2024: A preliminary report on the landslides and land subsidence across the Solan District, Himachal Pradesh during the monsoon season 2023. Submitted to Department of Revenue (DM Cell) Government of Himachal Pradesh, no. Rev (DMC) (F) 11-09/2021-LM, Department of Revenue (DM Cell) Government of state of Himachal Pradesh.

117. Sekar, K.C., Mondal, K., Padalia, H., Singh, G. & Kumar, A. 2024: Joint Committee Report in the matter of original Application No. 720/2023 on the news item appearing in Current Science dated 25.10.2023 entitled “Need to declare the Higher Himalaya an eco-sensitive zone”, submitted before Hon'ble National Green Tribunal (Principal Bench).

Field Guide

118. Ahmad, T. & Jayangondaperumal, R. 2023: Pre-meet field transect across the Mohand Anticline, Uttarakhand Sub Himalaya and Field Transect across the Outer-Garhwal Lesser Himalaya, Uttarakhand. Field Guidebook, DFG, 1-28.

RESEARCH PUBLICATIONS

SEMINAR/SYMPOSIA/WORKSHOP ORGANIZED

The 7^{th} National Geo-Research Scholar's Meet-2023

The 7^{th} National Geo-Research Scholar's Meet was held at Wadia Institute of Himalayan Geology, Dehradun from September 12 to 14, 2023. Following the inauguration ceremony, there were 4 technical sessions in which eminent speakers (18 resource persons) from the geoscientific fraternity of the country delivered their talks to educate the young researchers. In total 70 research scholars from around the country participated in the program and showcased their research through poster and oral presentations. To enhance the geological field-based knowledge of the research scholars, a post-conference field visit to the Main Boundary Thrust (MBT) section in the Dehradun-Mussoorie region was carried out on September 15, 2023. Such training remained helpful to the young researchers in understanding several geodynamic processes combined with the lecture series by eminent scientists.

The Chief Guest Honourable, Lt. Gen. Gurmit Singh and other distinguished guests of the inaugural ceremony, Prof. A.K. Jain, Prof. Sunil Bajpai, and Padma Shri Dr. V.C. Thakur emphasized the importance of geoscientific studies on the Himalaya and adjoining regions. In the welcome address, Prof. A.K. Jain, Prof. Sunil Bajpai, and Padma Shri Dr. V.C. Thakur enlightened the importance and recent advances in geosciences. Dr. R. Jayangondaperumal gave the vote of thanks. The abstract volume and the excursion guides were released during the meeting.

On the day-1, during the technical session-I, Dr. V.C. Thakur and Prof. A.K. Jain highlighted the importance of collisional tectonics that gave birth to the Himalayas and associated mountain-building processes. Dr. A.K. Singh elaborated on the magmatic episodes that caused the movement of the Indian plate during pre- and post-Himalayan formation. Further, Prof. Sunil Bajpai and Dr. N.K. Meena lectured on the evolution and extinction of dinosaurs with respect to the Indian sub-continent and the prevailing paleoecology in the NW and central Himalayas. Technical session-II was devoted to the Geo-research scholar's talk, in which the scholars were allowed for a 2-minutes talk on their research. In technical session-III, eminent geoscientists delivered their lectures on climate, tectonics, geo-hazards, and interpretation of subsurface geo-resources. The technical session-IV was again devoted to the Geo-research scholar's talk, in which the scholars were allowed for a 2-minute talk on their research. The day ended with a poster session followed by a cultural event. On day-2 similar technical sessions were carried out in which eminent scientists from different parts of the country like Dr. Pankaj Kumar, Dr. R.

Inaugural ceremony of the 7^{th} Geo-Research scholar's meet, 2023

Jayangondaperumal, Dr. Rakesh Bhambri, Dr. Rajesh Sharma, Dr. Naresh Kumar, and Prof. Vikram Gupta delivered their lectures on geochemical and geochronological methods, mineral exploration, geospatial techniques and mitigations of geo-hazards. The day ended with a poster session and valedictory function. To encourage and motivate young minds, awards were presented to the best posters.

A post-conference field visit to the Main Boundary Thrust (MBT) section in the Dehradun-Mussoorie region was carried out on the third day of the event. In the field, experts showcased the students' thrust exposures and important geological outcrops which are important for geoscientific investigations.

Group photographs of participants of the 7th NGRSM

A one-day workshop on "Himalayan Hazards: Way Forward (HHWF-2023)

Wadia Institute of Himalayan Geology (WIHG), Dehradun, organized a one-day Workshop on November 24, 2023. This Workshop, "*Himalayan Hazards: Way Forward*", under the framework: Mountain Specific Hazards and their Management, was a curtain-raiser Pre-Congress of the 6th World Congress on Disaster Management (WCDM), organized by the Government of Uttarakhand in collaboration with Disaster Management Initiatives and Convergence Society (DMICS), Uttarakhand State Disaster Management Authority (USDMA), and Uttarakhand State Council for Science & Technology (UCOST) from November 28 to December 01, 2023, with the overarching theme of "*Strengthening Climate Action and Disaster Resilience*", having the specific focus on '*Mountain Ecosystems and Communities*'.

The Workshop was attended by more than 350 dignitaries from different departments from all over India and abroad. The participation of diverse groups, representing the scientific community, Institutions, administrative departments including decision makers and political forums, public works, irrigation, industries like hydropower projects, research scholars, heads of schools and colleges, social workers, and media. The whole workshop was telecast live on YouTube (https://youtu.be/b5hANKrP1so). The Workshop was sponsored entirely by the Science and Engineering Research Board, SERB-DST, Govt. of India, and by National Thermal Power Corporation (NTPC), Govt. of India. The Convenors of the workshop were Dr. Swapnamita Vaideswaran and Dr. Naresh Kumar, Scientists, WIHG.

The Workshop was focused on deliberations through plenary talks and display of posters on the following sub-themes: (i) Landslide Management for Sustainable Development, (ii) Glacier Hazards and Plausible Mitigation, (iii) Seismic Risks and Advances in Earthquake Science, and (iv) Mountain Fluvial Extremes and Risk-Management.

The presentations by experts from within and outside India spoke on the above themes, which provided implications in comprehending several factors influenced by the natural processes, climate changes, changed geomorphic features, land degradation, and anthropogenic activities, development of early warning systems against geohazards and suggest the way forward for mountains ecosystem risk management and mitigation. WIHG played a unique role in this workshop bringing world-class experts together in building disaster-resilient, and climate-adaptable brain-storming discussions for secure living in the Himalaya and adjoining regions.

Inaugural session of the workshop

Group photo of the experts present in the workshop

Participants of the workshop

A Special Session on "Joshimath Disaster: A Geoscience Outlook"

A Special Session on Joshimath was organized at Graphic Era University, Dehradun by Wadia Institute of Himalayan Geology, Dehradun, as part of the Special Feature Event on November 29, 2024, in the 6th World Congress of Disaster Management (WCDM). The Session was chaired by Dr. Prasun Jana, DDG, Geological Survey of India, Govt. of India, along with B. Ramesh Amalanathan, Principal, St. George's College, Mussoorie and Dr. Shantanu Sarkar, Director, Uttarakhand Landslide Mitigation and Management Centre, Govt. of Uttarakhand as Co-Chairs. The session was aimed to bring different communities, from schools and the public to the discussion forum on the Joshimath land movements and to enlighten them about the scientific investigations and the results in understanding the Joshimath slides. Dr. Swapnamita Vaideswaran and

A glimpse of the special session on "Joshimath Disaster: A Geoscience Outlook" the team from WIHG convened the Session. The participants included school students from St. George's College, Mussoorie, and the Oasis, Dehradun along with persons from Community Radio, faculties from schools and colleges, officers from different organizations in India, and many Indian and Foreign delegates. The panelists Drs. Kalachand Sain, Naresh Kumar, P.K.R. Gautam, Swapnamita Vaideswaran, and Vinit Kumar discussed different issues related to the Joshimath Disaster and results obtained from geological and geophysical investigations.

The 2nd Edition SERB-DFG sponsored Indo-German Young Researcher-2023 meet on Geodynamics and Climate Science of Himalaya Region

The 2nd Indo-German Week of the Young Researcher, organized jointly by the SERB (Science and Engineering Research Board) and DFG (Deutsche Forschungsgemeinschaft), was hosted by the Wadia Institute of Himalayan Geology (WIHG), Dehradun during November 25 on December 2023. The Himalayan orogen has been a source of inspiration for generations of geoscientists, but many scientific questions and challenges remain. Prof. R. Jayangondaperumal and Prof. Talat Ahmad convened the meeting. It brought together young and senior researchers from various scientific disciplines, working in German and Indian Scientific Institutions, covering a wide range of research topics investigating India's geologic, geomorphologic, and climatic evolution with a particular focus on the Himalayan region. The latest research presented at the meeting generated extensive discussions and interdisciplinary exchange and sparked ideas for collaborative future projects. The meeting commenced with a special lecture by Dr. Akhilesh Gupta, Secretary of SERB and Senior Adviser at DST (Department of Science and Technology). Dr. Gupta outlined India's Climate Research Agenda for 2030 and beyond, shedding light on significant discoveries by the Indian scientific community in various domains of Climate Science and Adaptation. These included Monsoon, Climate Modelling, Aerosol-Climate Interactions, Hydrology & Cryosphere, Extreme Events, Oceanic Sciences, Urban Climate, Carbon Cycle, and Sector-specific Climate Services. Additionally, Dr. Gupta emphasized existing gaps in climate research and proposed futuristic avenues to bridge these gaps. The significant findings and directions for future research have been subdivided into five major themes summarised in this brief note.

Photograph featuring both young and senior researchers,as well as representatives from the DFG and SERB at WIHG, Dehradun

Theme 1: Provenance and sediment flux

Sediments and sedimentary rocks represent material sourced from rocks that have once been present at the Earth's surface but have been lost due to erosion. Considering that sediments and sedimentary rocks cover more than two-thirds of the Earth's surface, these represent an invaluable archive to understand the evolution of our planet. Sedimentary studies presented at the meeting cover many state-of-the-art analytical techniques and novel developments applied to understand geologic processes from 1.8 billion years ago. Prof. Bodo Bookhagen (University of Potsdam) delivered a keynote lecture and presented a synopsis of the long-term work on capturing recent sediment fluxes in the Himalayas.

Theme 2: Geodynamics, climate, and landscape evolution in the Himalaya

The evolution of the Himalayas at different spatiotemporal scales was discussed in this theme. The session started with the keynote address by Prof. Talat Ahmad, who summarized the extensive geochemical investigations of the mafic and felsic rocks of northwest Himalaya, shedding light on their petrogenetic history.

Finally, the thermodynamic constraints related to the textural and mineralogical evolution of high-grade metamorphic rocks were discussed, where the role of equilibration volume in the formation of complex microstructures, such as double coronal structures around alumina silicate minerals, was presented. The participants discussed and introduced novel concepts that aim to bridge the gap between thermodynamic constraints and petrochronological modeling, facilitating a more precise understanding of the tectonic-metamorphic evolution of the Himalayan orogeny.

Prof. Peter van der Beek from the University of Potsdam presented a keynote lecture exploring potential connections between atmospheric CO_2 and the lithosphere. Prof. Van Der Beek discussed the role of silicate weathering and organic carbon storage in the Himalayas, examining their impacts on glaciation, mountain belt erosion, and relief.

Theme 3: Geo-Hazards in the Himalaya and plausible mitigation steps

Over the past two decades, numerous paleo-seismic studies have been undertaken in the Himalayas to deduce information about the timing, size, rupture extent, return period, and mechanics of faulting associated with large to great surface rupturing earthquakes along the Himalayan Frontal Thrust (HFT) or Main Frontal Thrust System. During the meeting, a keynote lecture was delivered by Prof. R. Jayagondaperumal (Scientist-F, WIHG, Dehradun) and presented on the various aspects of paleoseismic studies in the Himalaya, focusing on the role of the HFT in Himalayan seismicity. The speaker emphasized the necessity of developing a calendar recording the paleo-earthquake history of the Himalayan region for academic research and varied future purposes. Such efforts could unveil seismic gaps and have practical applications in providing input parameters for Seismic Hazard Assessment, potentially impacting the safety of the Himalayan foothills. Dr. Rasmus Thiede from Kiel University presented a keynote lecture on millennial-scale fault slip rates and the associated structural architecture in the Western Himalayas.

Two keynote talks (Delivered by Dr. Kalachand Sain, Director, WIHG, Dehradun, and Prof. T. N. Singh, Director, IIT Patna) focussed on the numerical modeling of the landslides and mitigating natural hazards. He proposed that mitigation efforts could involve designing appropriate buildings and developing Integrated Early Warning Systems (IEWS). This would include deploying web-based sensors in the field, real-time data transmission to the laboratories, processing and analyzing data using advanced algorithms, and disseminating information through an alert system before potential tragedies occur. The benefits of the use of Artificial Intelligence, with the help of high-resolution sensor data, to mitigate natural hazards were also discussed.

Theme 4: Field Excursions

Three field excursions were conducted as part of the workshop: (i) Transect across the Mohand Anticline/Monocline and exposure of the Main Frontal thrust (MFT), (ii) Visit the Tehri Dam and the transect across the Outer Lesser Himalaya in Uttarakhand, (iii) Visit to the exposure of the Main Boundary thrust (MBT).

Theme 5: Brainstorming sessions

After the scientific sessions and talks by the representatives of the funding agencies, the participants engaged in a brainstorming session to deliberate on the major thrust areas of research and the future direction.

AWARDS AND HONOURS

- Dr. M. Rajanikanata Singh received International Young Scientist Award 2023 (Silver medal and certificate) for paper presentation at the 6th International Scientist Congress, 8-9, May 2023 organised by the International Science Community Association in collaboration with Graphic Era Deemed to be University, Dehradun.
- Dr. Kalachand Sain received the "Excellence in Research Award" from the Dehradun International Science & Technology Festival.
- Dr. Pankaj Chauhan was awarded by SERB International Research Experience (*SIRE*) fellowship for the year 2023-24.
- Dr. Parveen Kumar received the award of SERB International Research Scheme 2023-2024.
- Dr. Kalachand Sain received the Best Paper Award-2023 from WIHG, Dehradun.

VISITS ABROAD

- Dr. Kapesa Lokho attended the INQUA Congress held during July 14-20, 2023 at Sapienza University of Rome, Italy.
- Dr. Rakesh Bhambri visited Heidelberg University, Germany, from June 06 to July 02, 2023 and delivered lectures on Himalayan Cryosphere Hazards to master students of Heidelberg University.
- Dr. Pankaj Chauhan Visited Japan under the SERB International Research Experience (*SIRE*) fellowship program from September 11, 2023 to March 11, 2024.
- Dr. Parveen Kumar visited the Department of Earth Sciences, University of Oregon, Eugene, Oregon, USA as a Visiting Scholar from September to December 2023.

PH.D. THESES

Sl. No.	Name of Student	Supervisor	Title of the Theses	University	Awarded/ Submitted
1.	Dhirendra Yadav	Dr. Naresh Kumar Prof. Sanjit K. Pal	Subsurface structure and seismotectonic investigation of Kinnaur Himalaya: Constraint from waveform modelling of seismological data	IIT (ISM), Dhanbad	Awarded March, 2023
2.	Anil Tiwari	Dr. Ajay Paul Dr. Rajeev Upadhyay	Source mechanisms of earthquakes in Kumaon-Garhwal region, NW Himalaya, India, and its seismotectonic implications	Kumaon University, Nainital	Awarded April, 2023
3.	John P. Pappachen	Dr. Rajesh Sathiyaseelan Prof. Sanjit K. Pal	Crustal deformation studies in the Garhwal-Kumaun Himalaya, Northwest India: An investigation on the kinematics of plate boundary faults using Geodetic measurements	IIT (ISM), Dhanbad	Awarded June, 2023
4.	Monika	Dr. Parveen Kumar Dr. Sandeep	Attenuation studies of Uttarakhand Himalaya and its implication in strong motion simulation	BHU, Varanasi	Awarded July, 2023
5.	Varsha Rawat	Dr. Suman Lata Srivastava	Centennial scale variations in the Indian summer monsoon: A multi-proxy record using deposits of Bedni and Deoriatal, Garhwal Himalaya	Kumaun University, Nainital	Awarded Sept., 2023
6.	Vaishali Shukla	Dr. Naresh Kumar Prof. C.C. Pant	Seismogenesis of the Garhwal Himalaya and its correlation with earthquake precursory signatures: Constraint from recent seismicity and earthquake source characteristic	Kumaun University, Nainital	Awarded Sept., 2023
7.	Sakshi Maurya	Dr. Santosh K Rai Prof. Sushanta Sarangi	Late Holocene climatic reconstruction from Higher Himalaya, Ladakh	IIT (ISM), Dhanbad	Awarded Oct., 2023
8.	Ambar Solanki	Dr.Vikram Gupta Dr. S.S. Bhakuri Prof. M. Joshi	Slope stability assessment with reference to morphotectonics, Kali valley, Kumaun Himalaya	BHU, Varanasi	Awarded Dec., 2023
9.	Aravind Anil	Prof. R. Jayangondaperumal	Neo Tectonics of Surin Mastgarh Anticline (SMA) along Chenab, Munavar Tawi, and Chakki River Basins, Jammu and Kashmir, NW-Himalaya, India	Kumaun University, Nainital	Awarded Jan., 2024
10.	Manas M.	Dr. Barun K. Mukherjee Prof. R. Dubey	Genetic facets of Ophiolite-Melange of Indus-Tsangpo Suture Zone, Western Ladakh Himalaya, India	IIT (ISM), Dhanbad	Awarded Jan., 2024
11.	Nongmaithem Menaka Chanu	Dr. Naresh Kumar Prof. Sagarika Mukhopadhyay	3D Tomographic modeling for NE India using surface wave	IIT, Roorkee	Awarded March, 2024

Sl. No.	Name of Student	Supervisor	Title of the Theses	University	Awarded/ Submitted
12.	Sanjay Kumar Verma	Dr. Naresh Kumar Prof. Sanjit K. Pal	Earth structure from free oscillations and seismic tomography: Spatial temporal anomalies of seismic wave speeds	IIT (ISM), Dhanbad	Submitted Nov., 2023
13.	Abhishek Pratap Singh	Dr. R.K. Sehgal Dr. N. Premjit Singh	Reconstruction of biostratigraphy and palaeoecology of the Siwalik succession exposed around Nurpur (District Kangra, Himachal Pradesh) and Dunera (District Pathankot, Punjab), India	AcSIR, (WIHG)	Submitted Jan., 2024
14.	Alosree Dey	Dr. Koushik Sen	Evaluating metamorphism and strain regime during continental subduction and exhumation of the Tso Morari Crystalline Complex, NW Himalaya	AcSIR (WIHG)	Submitted Jan., 2024
15.	Monika Chaubey	Dr. A.K. Singh	Geochemistry and Geodynamic implication of Mafic-Ultramafic rocks of the Ophiolites in the Indo-Myanmar Orogenic Belt, NE India	BHU, Varanasi	Submitted Feb., 2024

PARTICIPATIONS IN SEMINAR/ SYMPOSIA/ MEETINGS/ TRAINING

- A Conclave on "Urbanization and Development in Fragile Mountain Ecosystems" in Nainital, Uttarakhand, from April 4 to 6, 2023, organized by Urban Development Directorate, Uttarakhand

  Participant:Pankaj Chauhan

- Executive Council meeting of the Palaeontological Society of India on April 19, 2023 (Virtual mode)

  Participant: Kapesa Lokho

- Brainstorming Session on "Climate Change Impact and Adaptation in the Water Sector in India" at the National Institute of Hydrology, Roorkee on April 28, 2023

  Participant: Amit Kumar

- 7th Conference on Science & Geopolitics of ARCITIC AND ANTARCTIC SaGAA 7, entitled "The Future of Arctic Ice, An Indo-Pacific Connect" held at India International Centre, New Delhi, during April 27-28, 2023 (Sponsored by MoES, New Delhi)

  Participants: Amit Kumar, and Pankaj Chauhan

- 7th Annual Convention "Advances in Earthquake Science (AES-2023)" of Indian Society of Earthquake Science (ISES) at Kashmir, Jammu & Kashmir (UT), during May 25-27, 2023

  Participants: Naresh Kumar, D.K. Yadav, and Chinmay Halder

- Executive Council meeting of the Palaeontological Society of India on August 05, 2023 (Visual mode)

  Participant: Kapesa Lokho

- 7th National Geo-Research Scholar's Meet-2023 held at WIHG, Dehradun during September 12-14, 2023

  Participants: All WIHG Scientists and Research Scholars

- Akhil Bhartiya Rajbhasha Sammellan held at Pune on September 14, 2023

  Participant: Suman Lata Srivastava

- The 19th Centre Geological Programming Board (CGPB) Committee-IX (Geoscientific Investigation) meeting held on September 26, 2023 (Online)

  Participant: Kapesa Lokho

- Hands-on training in "Material Diagnostics and Analytical Techniques" organized by Uttarakhand Science Education & Research Centre (USERC) during October 05-11, 2023

  Participants: Anil Kumar and Saurabh Singhal

- The Pre-Conference workshop of the 6th World Congress on Disaster Management (WCDM) on October 13, 2023, organized by Uttarakhand State Disaster Management Authority (USDMA), Dehradun at Hotel Pacific, Dehradun

  Participants: Swapnamita Vaideswaran, Santosh Rai, Devajit Hazarika, and Amit Kumar

- The 4th Dehradun International Science and Technology Festival (DISTF-2023) held at DIT University, Dehradun during October 27-29, 2023

  Participant: Jitender Kumar

- National workshop on "Geodynamics in Himalaya & Disaster management" and Annual Convention of Geological Society of India at Central University of Himachal Pradesh Dharamshala during November 6-8. 2023

  Participant: Naresh Kumar, Kapesa Lokho, Devajit Hazarika, Swapnamita Vaideswaran, N.K. Meena and Naveen Chandra

- One-day workshop on "Himalayan Hazards: Way Forward (HHWF-2023)" held at WIHG, Dehradun on November 24, 2023

  Participants: All the scientists of WIHG, Dehradun

- The Consultation Workshop on "Mainstreaming resilience for water security in Uttarakhand" held on November 18, 2023, at Uttarakhand State Irrigation Department, Dehradun

  Participants: Santosh K Rai and Rauf A Shah

- Webinar on "Heritage in the Asia-Pacific: Nature, Culture and the World Heritage Convention" organized by WII-C2C at Wildlife Institute of India, Dehradun on December 18, 2023

  Participant: Kapesa Lokho

- Quarterly Hindi workshop on "Climate Change in the Present Scenario", organized at WIHG, Dehradun on December 18, 2023

  Participant: N.K. Meena

- IEEE India Geoscience and Remote Sensing Symposium (InGARSS) held at International Institute of Information Technology Bangalore during December 10-13, 2023

  Participant: Naveen Chandra

- Executive Council meeting of the Palaeontological Society of India on February 19, 2024 (Virtual mode)

  Participant: Kapesa Lokho

- GRO-GTP Geothermal Training Programme in Iceland for 6 months from May to November 2023

  Participant: Sameer K. Tiwari

- 60th Annual Convention of Indian Geophysical Union, held at Department of Marine Geology and Geophysics, Cochin University of Science and Technology, Kochi, Kerala during November 22-24, 2023

  Participants: Suman Konar, Kurakula Kalyani, Bappa Mukherjee, and Kalachand Sain

DISTINGUISHED LECTURES DELIVERED IN THE INSTITUTE

Sl. No.	Date	Speaker	Event & Topic
1.	May 11, 2023	Prof. Annpurna Nautiyal, Vice Chancellor, H.N.B. Garhwal University, Srinagar	National Technology Day "India's G20 Presidency and how technology can be used for confronting climate change and education"
2.	May 29, 2023	Isabella Marino Criminology and Criminal Justice Department, University of East Tennessee State	Women Harassment Prevention Committee of WIHG "Women trafficking in this world, concerns and awareness for such issues"
3.	June 05, 2023	Shri Satya Prakash Sharma Former Administrator and Academic Advisor Govt. of Delhi	World Environment Day "Indian thought on Environment Protection"
4.	June 30, 2023	Padma Bhushan Dr. Anil Prakash Joshi Founder-HESCO	Foundation Day "Economy and Ecology: Steps together"
5.	Sept. 15, 2023	डॉ. चन्द्रमोहन नौटियाल रिटा. वैज्ञानिक (बीरबल साहनी पुराविज्ञानी संस्थान)	हिंदी पखवाडा "चन्द्रमा तथा सूरज की ओर भारत की उडान"
6.	Sept. 20, 2023	श्री देवेन्द्र मेवाडी वरिष्ठ विज्ञान साहित्यकार	हिंदी पखवाडा "हिन्दी में विज्ञान लेखन की परंपरा और प्रयोग"
7.	Sept. 22, 2023	श्रीमती शांति अमोली बिंजोला लोकसंस्कृति लेखिका	हिंदी पखवाडा "लोकगीत तथा लोकाचार"
8.	Sept. 26, 2023	पद्म श्री श्रीमती बसंती बिष्ट विश्वप्रसिद्ध जागर गायिका	जागर का सामाजिक महत्व
9.	Sept. 29, 2023	डॉ. हरेन्द्र सिंह बिष्ट, सी.एस.आई.आर. भारतीय पेट्रोलियम संस्थान, देहरादून	हिन्दी पखवाडा समापन समारोह
10.	Oct. 05, 2023	Dr. Paritosh Singh DBS College, Dehradun	Swachhta Pakhwada (Swachhta hi Seva) Lecture "Mahatma Gandhi and Sociology of cleanliness (Role of the cleanliness in social change)"
11.	Oct. 31, 2023	Prof. T.N. Singh Director, Indian Institute of Technology (IIT) Patna	J.B. Auden Memorial Lecture "Rockfall: Prediction and its Remedial Measures in High Hill" Vigilance
12.	Nov. 03, 2023	Shri Satya Prakash Sharma Former Administrative and Vigilance Officer, Govt. of Delhi	Awareness Week "Vigilance and Corruption"
13.	Nov. 10, 2023	Dr. Shishir Prasad Uttarakhand Ayurved University, Dehradun	8th Ayurveda Day Lecture Global Outreach and Clinical Applications of Marma Chikitsa for Pain Management
14.	March 12, 2024	Padma Shri Smt. Basanti Bisht	International Women's Day "The situations of women in remote areas and villages"

LECTURES DELIVERED/ INVITED TALKS BY INSTITUTE SCIENTISTS

Name of Institute Scientist	Programe Organizer/Venue/ Institute	Date	Topic/ Title of lecture
M. Rajanikanta Singh	6th International Young Scientist Congress 2023, which was held on May 8 and 9, 2023, organised by the International Community Science Association in collaboration with Graphic Era Deemed to be University, Dehradun	May 08, 2023	Petrogenesis of Proterozoic volcanic rocks from the Northwestern Himalaya: A probable example of interaction between plume and sub continental lithospheric mantle
R. Jayangonda-perumal	Dept. of Geology, Kashmir University	May 25, 2023	Detachment folding, growth mechanism and seismic potential in the Jammu Sub-Himalaya
Devajit Hazarika	CSIR-Northeast Institute of Science and Technology, Jorhat Assam on the occasion of Assam Earthquake Day	July 04, 2023	Great earthquakes of the North-East India
Parveen Kumar	FRI Deemed University, Dehradun	July 10, 2023	Natural Hazards and Disasters
B.K. Mukherjee	ONGC GEOPIC	July 17, 2023	Hydrocarbon in recycled crust
Kapesa Lokho	The INQUA Congressheld during 14-20 July, 2023 at Sapienza University of Rome, Italy	July 14, 2023	Sea-level changes and the closure of Neo -Tethys seaway during the Middle Miocene in the Naga Hills, Indo-Myanmar Range
Rakesh Bhambri	7th National Geo-Research Scholars Meet on Geosciences: Emerging Methods, at WIHG, Dehradun	Sep. 13, 2023	Assessment of Himalayan Glaciers and Associated Hazards Using Geospatial Techniques
Naresh Kumar	7th National Geo-Research Scholars Meet on Geosciences: Emerging Methods, at WIHG, Dehradun	Sept. 12, 2023	Geophysical Tools and Techniques: Study of Geodynamics and natural Hazards in the Himalayan Region
Vikas	7th National Geo-Research Scholars Meet on Geosciences: Emerging Methods, at WIHG, Dehradun	Sept. 12, 2023	Understanding Orogenic Exhumation using Thermochronology
M. Rajanikanta Singh	7th National Geo-Research Scholars Meet on Geosciences: Emerging Methods, at WIHG, Dehradun	Sept. 13, 2023	Orally and through posters entitled "Zircon separation from the northwest Himalayan mafic rocks: a potential method for U-Pb dating
Rakesh Bhambri	International Conference on Himalayan Environment in Changing Climate Scenario. University of Ladakh, Leh, 19-23 September 2023	Sept. 20, 2023	Assessment of Himalayan Glaciers and Associated Hazards

Swapnamita Vaideswaran	International Conference on Himalayan Environment in Changing Climate Scenario. University of Ladakh, Leh, Sept. 19-23, 2023	Sept. 20, 2023	The Joshimath Crisis: interpreting the ground signatures and the causes.
Pankaj Chauhan	Keio University, Japan	Oct. 12, 2023	Glacier of the Himalaya and related hazards
P.C. Kumar	Workshop on “AI & ML in Earth System Science” held at BHU Varanasi during Oct. 16-17, 2023	Oct. 16, 2023	Basic Concepts of AI/ML: Motivations and Fundamentals
Jitender Kumar	Workshop on “AI & ML in Earth System Science” held at BHU Varanasi during Oct. 16-17, 2023	Oct. 16, 2023	A peep into the subsurface through ML approach
Bappa Mukherjee	Workshop on “AI & ML in Earth System Science” held at BHU Varanasi	Oct. 16, 2023	ML & DL assisted geoscientific data interpretation
Santosh K. Rai	The Young Scientists Online Seminar on Climatic Change and Earth Systems, on November 2, 2023, Kathmandu, Nepal	Nov. 2, 2023	Denudation process and Material transfer in Himalayan River Systems
Devajit Hazarika	National workshop on Geodynamics in Himalaya & Disaster Management held during Nov. 6–8, 2023 at Central University of Himachal Pradesh, Dhramshala, Himachal Pradesh	Nov. 6, 2023	Imaging the crustal structure at the northeast corner of the indenting Indian Plate
M. Rajanikanta Singh	National workshop on Geodynamics in Himalaya & Disaster Management held during Nov. 6–8, 2023 at Central University of Himachal Pradesh, Dhramshala, Himachal Pradesh	Nov. 6, 2023	Implications for Paleoproterozoic arc magmatism: Geochemistry of tholiitic dykes from the Banjar Formation, Himachal Himalaya
Kapesa Lokho	National workshop on Geodynamics in Himalaya & Disaster Management held during Nov. 6–8, 2023 at Central University of Himachal Pradesh, Dhramshala, Himachal Pradesh.	Nov. 7, 2023	First Report of Eocene Echinoids from the Sylhet Limestone, Mikir Hills of Assam, India: Paleontological, Paleogeography and paleoenvironmental significance.
Naveen Chandra	National workshop on Geodynamics in Himalaya & Disaster Management held during Nov. 6–8, 2023 at Central University of Himachal Pradesh, Dhramshala, Himachal Pradesh.	Nov. 7, 2023	Automated Extraction of Landslides in the Himalayan Region Using Satellite Imagery-Based on YOLO Algorithms.

Swapnamita Vaideswaran	Pre-Conference of the 6thWCDM, Doon University, Dehradun	Nov. 07, 2023	Dima Hasao to Joshimath - Disasters & Development: Addressing the concerns and reimaging strategies
Pinky Bisht	The 14th Symposium on Polar Science, NIPR, Tokyo (online)	Nov. 15, 2023	Late Quaternary glaciation and its implications in the Yankti Kuti valley, Uttarakhand, India
Pankaj Chauhan	Keio University, Japan	Nov. 15, 2023	Early Warning System Vs Hazards
Anil Kumar	An International; workshop on DFG week of Young Researcher 2023 held at Wadia Institute of Himalayan Geology, Dehradun during Nov. 27 - Dec. 1, 2023	Nov. 27, 2023	Paleoflood records from the Himalaya
Rakesh Bhambri	The Indo-German Young Scholar Meet, organized by DST and DFG, held at the Wadia Institute of Himalayan Geology,	Nov. 28, 2023	Assessment of Himalayan Glaciers and Associated Hazards Using Ground and Space Observations
Swapnamita Vaideswaran	6th World Congress on Disaster Management, held at Graphic Era University, Dehradun	Nov. 29, 2023	What is happening in Joshimath?
Naresh Kumar	6th World Congress on Disaster Management, held at Graphic Era University, Dehradun	Nov. 29, 2023	How is the shaking around Joshimath?
Devajit Hazarika	6th World Congress on Disaster Management, held at Graphic Era University, Dehradun	Nov. 29, 2023	Earthquakes scenario in northeast India: An appraisal on seismogenesis and subsurface structure
Vandana	6th World Congress on Disaster Management, 28th Nov.-1st Dec., 2023, Dehradun, India	Nov. 29, 2023	Assimilation of seismic attenuation model of NW Himalaya region and its earthquake risk potential
Naveen Chandra	6th World Congress on Disaster Management, 28th Nov. -1st Dec., 2023, Dehradun, India	Nov. 29, 2023	Landslide Information Extraction in Multiple Satellite Datasets Based on YOLO-NAS model.
Naveen Chandra	IEEE India Geoscience and Remote Sensing Symposium (InGARSS) held at International Institute of Information Technology Bangalore during Dec. 10-13, 2023.	Dec. 12, 2023	Attention-Based YOLOv5 Model for Enhancing Landslide Detection in Remote Sensing Imagery

Swapnamita Vaideswaran	Technical Workshop on Landslide Treatment and Erosion Control Works in Hills, Uttarakhand Forest Resource Management Project, Govt. of Uttarakhand	Dec. 15-16, 2023	The deep-seated, slow-moving landslide of Joshimath: interpreting the ground signatures and the causes
B.K. Mukherjee	India International Science Festival (IISF) outreach held at WIHG, Dehradun	Dec. 18, 2023	Himalaya past & present
Pankaj Chauhan	Keio University, Japan	Jan. 17, 2024	Overview of the Himalaya glaciers and impact of the climate change, A case study from Kumaun Himalaya
Swapnamita Vaideswaran	National Workshop on Landslide Treatment and Erosion Control Works in Project for Natural Disaster Management in Forest Areas in Uttarakhand, Govt. of Uttarakhand	Feb. 01, 2024	Considering the unexpected during management of a disaster: the deep-seated landslide of Joshimath
Rakesh Bhambri	The International Geomorphological Society Conference (Virtual mode)	March 02, 2024	Monitoring of Himalayan Glaciers and Associated Hazards Using Ground and Space Observations
A.K. Singh	Two weeks Refreshers Course in Earth Sciences organized by University of Jammu, Srinagar	March 06, 2024	Remnants of ancient oceanic lithosphere in the eastern margin of Indian plate: origin, evolution and emplacements
Naresh Kumar	8th Annual Convention on “Advances in Earthquake Science (AES-2024)”, held at CSIR-CBRI, Roorkee	March 28, 2024	An overview of central Himalayan seismicity: Implications for seismic hazard and Joshimath subsidence

MEMBERSHIP

Naresh Kumar	Executive Committee Member:	Indian Geophysical Union (IGU)
Manish Mehta	Member: Expert Member:	28th Regional Coordination Committee (RCC) meeting of National Institute of Hydrology (Nominated) Steering Committee for "Monitoring of Glaciers" in NIH, Roorkee
Pinkey Bisht	Member:	• The Association of Quaternary Researchers (AoQR), India • American Geophysical Union (AGU) • Stratigraphy and Chronology (SACCOM)
Sameer Tiwari	Member:	Life Time member of UNESCO-GTP, Iceland
Som Dutt	Member:	Life membership of Vijnana Bharti
Anil Kumar	Member:	• Joint Committee in the matter of original Application No. 720/2023 on the news item appearing in Current Science dated 25.10.2023 titled "Need to declare the Higher Himalaya an eco-sensitive zone", submitted before Hon'ble National Green Tribunal (Principal Bench). • 3rd FIGA held at WIHG • A committee member for finalizing the technical specification for the Instrumentation andanalytical facilities required for establishing the Polar Luminescence Laboratory at the National Centre for Polar and Ocean Research (NCPOR), Goa
Naveen Chandra	Annual Member:	• Geoscienceand Remote Sensing Society (GRASS), 23 November, 2023 • Institute of Electrical and Electronics Engineers (IEEE), 23 November 2023
Jitender Kumar	Active Member:	Society of Exploration Geophysicists
Vandana	Member:	• Life time member of Indian Society of Earthquake Science (ISES) • Life time member of Himalayan Geology

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section brought out the (i) 'Himalayan Geology' volumes 44(2) 2023 and 45(1) 2024; (ii) Annual Report of the Institute for the year 2022-23 (bi-lingual); (iii) Hindi magazine 'Ashmika' volume 29 (2023); (iv) Booklet on 6th WCDM Pre-Congress Workshop on Himalayan Hazards: Way Forward (HHWF-2023) and Publicity brochure etc.

The section was also involved in the dissemination of the publications to individuals, institutions, lifetime subscribers, book agencies, national libraries, and indexing agencies, under an exchange program, and maintaining the sale and accounts of publications. Apart from this, works pertaining to the printing of publicity brochures, etc., are also taken up.

Himalayan Geology (journal) website http://www.himgeology.com is functioning along with an online manuscript submission facility under this section. All information regarding the journal including contents and abstracts is updated from time to time on the website. Online access to the current published volume to the online subscribers and lifetime members (those who have been given the choice to obtain the volumes in soft copy through online access/email) also has been provided. At present, 182 lifetime subscribers receive the journal through online access/email. The journal is indexed in UGC CARE, Scopus, Web of Science (SCIE), Thomson Reuters/Clarivate Analytics (US), Elsevier (Netherlands), and Indian Citation Index (India) regularly etc. The current impact factor of the journal is 1.2 (Source: Clarivate Analytics).

The section also provides the facility & technical support services of A0 size scanning and printing to the scientists, research scholars, and other staff of the Institute. During this period, more than 150 maps and posters were printed for display in laboratories, workshops/seminars and exhibitions, etc. and 100 maps/sheets were scanned.

LIBRARY

Wadia Institute of Himalayan Geology library has an excellent collection of books, monographs, journals, e-books, etc., on mountain building and geological and geophysical aspects of the Himalayas. It has a unique position with its collection. Also, the collection and services offered make it one of the country's best libraries in earth sciences. The scientists, researchers, project staff, and students fully utilize the Library while publishing their research work in reputed peer-reviewed journals. Specialists and professionals nationwide also visit our library to consult thematic and rare collections.

The Library has more than 6882 selected e-books from different publishers and learned societies on the thrust areas of the research in the Institute.

Acquisition of Documents: The Library has paid and subscribed to 58 International and 2 Indian Journals, and 10 magazines have also subscribed to this year. A total of 38 reference books have been added. In addition to this, a total number of 73 books have been purchased for the Hindi Collections.

National Knowledge Resource Consortium (NKRC): The Library is a member of NKRC and continues to receive the support of Consortia towards online access to Elsevier's "Earth and Planetary Science collection", Wiley's "Earth, Space & Environmental Sciences"; Springer "Earth and Environmental Science and Chemistry" collections. In addition to this, WIHG Library has access to the IEEE, Web of Science, Elsevier-Scopus, Wiley & Blackwell, and iThenticate (Plagiarism Detection Software) publications. Apart from our subscriptions, all these publishers contribute online access to more than four hundred journals' titles. Grammarly, Knimbus, E-Journals, E-books, and Pro-Quest databases (Dissertations and Theses, Science and Technology, E-Books) were also purchased during this period.

Reprography facility: The library serves as a central repository for the institute's demand. This facility is being extended to the scientific and administrative sections of the institute. And 85000 (approx.) pages were copied during the reporting year.

Computer Facility: The library has a hub of computers for users to access e-books, e-journals, and other e-resources, either subscribed to by WIHG Library or available through NKRC. This facility was also extended to the students and summer trainees. The hub is also being used to conduct several tests to recruit the administrative and technical staff of the institute.

The WIHG library provides the following services to support Scientific, Technical, and Administrative work: (i) Reprographic Services, (ii) Reference and Consultation Services, (iii) Electronic information resource access, (iv) Document Delivery Services, (v) CD-ROM Database, (vi) CAS and SDI, (vii) Printing of Article, (viii) Scanning of Document, (ix) Plagiarism Check, and (x) Circulation Service. The Institute Library organized a training program in the Committee Room in collaboration with the Clarivate-Proquest Database. The training theme was Nurturing the Research Ecosystem with Clarivate-Proquest Database. The training program deals with improving research output using the Proquest database. This training gave a practical demonstration of the Proquest database. The WIHG participants benefitted from this training. The training was coordinated by Dr. Balram, Librarian WIHG Dehradun.

S.P. NAUTIYAL MUSEUM

The Museum of the Institute continued to attract a large number of students and the general public from across the country. The visitors showed keen interest in rocks, minerals, and fossil specimens displayed in museum galleries. The models of the extinct mammals received a special attraction. The museum of the Institute is receiving more and more publicity and its name can be found on various social media platforms such as www.tripadvisor.in; www.dehraduntourism.in; www.myholidayhappiness.com and many others. In the previous year, IFS probationers, Forest Rangers, Navy Officers, Army personnel, etc. visited the museum. Visitors from foreign countries such as Germany, Australia, England, Nepal, and Sri Lanka also visited the museum.

This year museum organized several outdoor exhibitions including:

- 4th Dehradun International Science and Technology Festival (DISTF-2023) during October, 27- 29, 2023 at DIT University, Dehradun
- India International Trade Fair (IITF) held at Pragati Maidan, New Delhi during November 14- 27, 2023.
- 6th World Congress on Disaster Management (WCDM) held at Graphic Era University, Dehradun from November 28 to December 01, 2023.
- One Day Outreach Program at WIHG, Dehradun as a part of India International Science Festival (IISF-2023) organized on December 18, 2023.
- Rise in India Mega Exhibition at Ghaziabad, Uttar Pradesh during December 21- 23, 2023.
- India International Science Festival (IISF) 2023, 'Science and Technology Public Outreach in Amrit Kaal' at Faridabad, Haryana, January 17-20, 2024.
- 18th Uttarakhand State Science and Technology Congress (USSTC), Haldwani, Nainital (Uttarakhand) during February 8-9, 2024.
- Vasant Utsav at Rajbhavan, Dehradun during March 01-03, 2024.

Shri Kiren Rijiju, Union Cabinet Minister, Prof. Abhay Karandikar, Secretary, DST, Prof. Ashutosh Sharma, Former Secretary, DST and Shri S. Somanath, Chairman ISRO visited WIHG exhibition stall in the IISF-2023 held at Faridabad during January 17-20, 2024.

TECHNICAL SERVICES

Analytical Services

The number of samples analyzed by various instruments is listed below

Laboratory/Instruments	Number of samples analyzed		
	WIHG Users	Outside Users	Total
Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Lab	Newly Installed in January 2024	-	-
Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA- MC-ICP-MS) Lab	252	34	286
Stable Isotope Lab	603	22	625
Luminescence Dating (TL/OSL) Lab	70	63	133
Fission Track Lab	79	20	89
Mineral Separation Lab	162	30	192
Sample Preparation Lab			
Slide preparation	814	370	1184
Sample powdering	658	436	1094
XRD Lab	231	18	249
X-Ray Fluorescene Spectrometer (XRF) Lab	566	628	1194
Laser Micro Raman Spectrometer (LMRS) & Fluid Inclusion Lab	23	2	25
Rock magnetic & Palaeomagnetism Lab	106	48	154
Dendrochronology Lab	85 Tree cores	0	85 Tree cores
Micropaleontology Lab	350	0	350
Laser Particle Size Analyzer (LPSA) Lab	345	1	346
Sedimentology Lab	83	9	92
Vibratory Sieve Shaker	85	5	90
Clay Slide Preparation	14	0	14
Palynology Lab	65	0	65
Laser Water Isotope Analyzer (LWIA) Lab	200	100	300
Water Chemistry Lab (Ion-Chromatograph)	200	100	300
Total Organic Carbon Lab	615	32	647

Photography Section

WIHG Photography section plays a crucial role in documenting the various functions and activities organized by the institute. With approximately 6300 photographs and videos taken during the reporting year 2023-2024, the photography section covers a wide range of events, from foundational celebrations like Foundation Day and Founders Day to national observances like National Science Day, National Technology Day, Independence Day and Republic Day, as well as cultural events, such as Women's day, Udbhav, Scientific activities including conferences, Seminars / Symposia and also superannuation parties for institute events. The high-resolution DSLR camera used ensures that the images captured are of excellent quality, which is essential for their use on the institute's web pages and in various reports. Additionally, the around 283 snaps taken of rocks and fossils in the museum add another dimension to the documentation efforts, showcasing the scientific and educational aspects of the institute's work. The majority of scientists have cameras issued permanently to them for use in the field and laboratory, while the remaining scientists form a project, and research scholars are provided cameras from a pool as and when they require it.

Drawing Section

The Drawing Section provides the cartographic needs of the Scientists of the Institute for in-house as well as sponsored project works. During the Year, the section has provided fourteen geological maps/structural maps/ geomorphological maps/seismicity diagrams for the scientists and research scholars of the Institute. Besides, the tracing of two topographic sheets/aerial photo maps was carried out along with the preparation of the four geological columns. The section has also provided name labels and thematic captions during different activities and functions of the Institute.

Sample Preparation Laboratory

The Sample Preparation Lab of WIHG, Dehradun prepares samples for high-end geochemical, structural, sedimentological, and geotechnical investigations, at par with international standards. Presently, ordinary and EPMA thin-section slides are being prepared in this facility. Mineral Separation and slide preparation work for the geochronological and thermochronological investigation is an integrated component of this facility. The lab also performs the powdering of rock samples for XRF, ICPMS, and OSL investigations. The Lab is equipped with Buehler, Struers make rock cutting and polishing machines. In addition, the lab also has Frantz Magnetic Barrier Separation, Fritsch Jaw Crusher and Disk Mill, Holman Wilfley Table, and Automatic Polishing machine. This high-end facility is being used by researchers of various R&D institutes and universities all across India.

Computer and Networking Section

WIHG Computer & Networking Section takes care of all the computational requirements of the Institute to facilitate important research work free of any IT-related worries. Post-COVID pandemic, the role and responsibilities of the Computer Section have increased manifold. The pandemic changed the way meetings, seminars, interviews, etc. are conducted, and ever since many of the important meetings, seminars, workshops, interviews, etc., have been conducted online or in hybrid mode. The employees of the Computer Section work tirelessly to not only organize these events seamlessly but also to provide uninterrupted IT services to the whole Institute.

Wadia Institute has been organizing Distinguished Lectures by Eminent Scientists/Professors around the year. Many of these lectures have been conducted online (or in hybrid mode) and the WIHG Computer Section has been instrumental in the successful conducting of these lectures by providing all-round support for the same. Even during offline events, requisite arrangements as per the requirement are made for the success of the events.

As per the instructions from the S&T Ministry, the Cyber Jagrookta Diwas (CJD) is being organized on the first Wednesday of every month to create awareness about the latest cyber threats and cyber hygiene for the prevention of cyber crimes. Lectures and presentations have been given not only to the Institute employees and research scholars but efforts have also been made towards educating the security guards, gardeners, and housekeeping staff so that they can also be made fully aware of these threats and safeguard against any loss arising from it.

The Computer Section caters to the computational requirements of the whole Institute i.e., scientists and all the other employees of the Institute. It manages various servers which have been installed and configured in-house by the Computer Section. All the servers are working on a secure Linux environment and using the latest Open Source Technology. The different types of servers being used are DNS, Mail, Web, Application, etc. The Institute is connected with the National Knowledge Network through a high-speed 1 Gbps link. For uninterrupted internet connectivity, a standby internet bandwidth leased line connectivity link has also been taken. The section has not only maintained a virus and spyware-free environment by adopting centralized anti-virus and anti-spyware solutions but has also been adopting the latest preventive security measures in this regard.

Apart from the above, the WIHG Computer Section also:

- Caters to the hardware troubleshooting and maintenance requirement of the whole Institute and along with the same, support is also being provided for the different softwares being used in the Institute and also for other facilities like data backup, data retrieval, etc.
- Uses the latest networking technologies for excellent speed and reliability of all the network-related services which are the need of the hour.
- Maintains and upgrades the network as per the requirement. The network is not limited to the office but the same has been extended to the WIHG residential colony, Guest House, WIHG Students cum transit hostel and has recently been extended to the remaining staff quarters also so that all employees and students can have 24x7 connectivity.
- Provides a VPN facility to facilitate the access of Institute resources securely over the public network.
- Maintains the different web portals hosted by the Institute viz., Institute website, Institute publication portal, WAICS (Wadia Analytical Laboratory Instrument Facility and Consultancy Advisory Services) portal.

For the optimum utilization of the hardware resources, Virtualization has been used. Apart from this, extensive use of open source softwares has been done by the section on different computers, workstations, and servers thereby saving considerable financial resources that may have been spent in purchasing other commercial paid softwares and solutions.

The Computer Section has been playing a very important role in all the fields, where IT services are utilized. It maintains and manages the high-speed fiber connectivity of the various blocks/buildings; connectivity of the sophisticated scientific instruments installed in the Institute to carry out the research work; connectivity and operation of the different high-end workstations; installation and configuration of the scientific and general softwares; the CCTVs installed in the Institute for the overall security, etc., the services are being provided by the WIHG Computer Section.

CELEBRATIONS

National Technology Day

National Technology Day was celebrated on May 12, 2023. On this day, the Institute observed an open day by keeping its Museum and laboratories for students and the general public. On this occasion, a popular lecture was delivered by Prof. Annpurna Nautiyal, Vice Chancellor, H. N. B. Garhwal University, Srinagar, on the topic “India's G20 Presidency and how technology can be used for confronting climate change and education”. A large number of students from different schools, colleges, the general public, Institute staff, and invited guests attended the talk.

National Technology Day lecture by Prof. Annpurna Nautiyal

8th International Yoga Day

The 9th International Yoga Day was celebrated on June 21, 2023, in the Institute. Each year, International Yoga Day centers around a particular theme that highlights a specific aspect of yoga, emphasizing its significance and influence on society. The theme for International Yoga Day 2023 was "Yoga for Vasudhaiva Kutumbakam”. All the WIHG employees and research students participated in International Yoga Day under the directive and guidance of Ms. Pooja Devi, Assistant Professor Department of Yogic Science, Govt. PG College Dakpathar, Dehradun.

Employees and research scholars of the Institutes practicing Yoga on the International Yoga Day

Foundation Day

The 55th Foundation Day of the Institute was celebrated in the Institute on June 30, 2023. Padma Bhushan Dr. Anil Prakash Joshi, Founder of Himalayan Environmental Studies and Conservation Organization (HESCO), was the Chief Guest and he delivered the

Felicitation of the Padma Bhushan Dr. Anil Prakash Joshi during the Foundation Day program

Foundation Day Lecture on the topic “Economy and Ecology: Steps together”. The occasion was also marked by the distribution of awards by the Chief Guest for the best research paper published by the Institute scientists as well as to the best workers in the various categories of the Institute. The 'Best Paper Award' was given to Dr. Ayushi Baiswar, Dr.Jairam Singh Yadav, Dr. Kalachand Sain, Dr. Rakesh Bhambri, Dr. Arjun Pandey, and Dr. Sameer K. Tiwari for their joint paper on "Emission of greenhouse gases due to anthropogenic activities: an environmental assessment from paddy rice fields.” published in Environmental Science and Pollution Research journal. The 'Best Workers Awards' for the Institute employees were given to Smt. Shalini Rawat and Sh. Prateek Negi for the good work carried out by them during the year.

Independence Day

The Institute celebrated Independence Day on August 15, 2023. On this occasion, Dr. Kalachand Sain, Director, unfurled the National Flag and delivered a formal address. To mark the occasion, several sports and fun competitions as well as a cultural program were organized for the Institute employees and their family and prizes were distributed to the winners.

Independent Day-2023 celebration

Himalaya Diwas

Like previous years, the Institute celebrated "HIMALAYA DIWAS-2023" on September 09, 2023. Padma Bhushan Dr. Anil Prakash Joshi, Founder of Himalayan Environmental Studies and Conservation Organization (HESCO) was the Chief Guest, and Prof. (Dr) Durgesh Pant, Director General of Uttarakhand State Council for Science & Technology (UCOST), Dehradun was the Guest of Honour in the event. The event was jointly organized by WIHG, Dehradun with Himalayan Environmental Studies and Conservation Organization (HESCO) and Uttarakhand State Council for Science & Technology (UCOST), Dehradun. There were panel discussions on two topics: (i) Climate Change & Himalayas – challenges & opportunities and (ii) Developing Disaster Resilient Mountain Ecosystem.

Moments of Himalaya Diwas

Science of Nature

Wadia Institute of Himalayan Geology, Dehradun organized a "Science of Nature" program on September 29, 2023. Shri Vishvajit Sahay, Additional Secretary and Financial Adviser, Department of Science and Technology (DST), New Delhi was the Chief Guest of the program. Padma Bhushan Dr. Anil P. Joshi delivered the overview and background of the "Science of Nature" program. Professor Durgesh Pant, Director General, UCOST, Dehradun discussed on “Nature Park Initiative by Government”. Several expert comments and suggestions were received from renowned dignitaries

like Dr. Ram Sharma, Vice-Chancellor, University of Petroleum and Energy Studies (UPES), Dehradun; Dr. Harender Singh Bisht, Director, IIP, Dehradun; Dr. M. Madhu, Director, ICAR-Indian Institute of Soil & Water Conservation, Dehradun; Dr. Ashish Pandey, IIT Roorkee.

Moments during the program "Science of Nature"

Founder's Day

The Institute celebrated its Founder's Day, the 140th birth anniversary of Prof. D. N. Wadia- (1883-1969), on October 23, 2023. On this occasion, a floral tribute was paid by the Institute staff.

Founder's Day Celebration

Swachhta Abhiyan (Swachhta Hi Seva)

The Institute observed the Swachhta Hi Seva campaign under the Swachch Bharat Mission at WIHG, Dehradun in two phases. The first phase was observed during September 15-30, 2023. In this phase, various activities were carried out, such as cleaning of rooms, laboratories, and other workplaces by the Institute employees.

The second phase was observed during October 02-31, 2023. In this phase, several activities were conducted. The employees and researchers of the Institute observed the program "Shramdaan" for mass

Moments during the Swachhta Hi Seva campaign cleaning activity in the Institute campus on October 01, 2023. On October 02, the employees of the Institute took a pledge on “Swachhta” before cleaning the campus and the residential colony of the Institute. The Institute organized an essay competition on the topic “Swachhta hi Seva” and a slogan competition on “The role of Collective cleanliness in the formation of a developed nation” on October 04, 2023.

An invited talk on the topic “Mahatma Gandhi and Sociology of Cleanliness; the Role of Cleanliness in Social Change” was delivered by Dr. Paritosh Singh, Head, Department of Sociology, DBS College, Dehradun on October 05, 2023. “Sapling plantation” was another significant event conducted by the Employees of the Institute. Another lecture on the topic “E-waste: Why and How?” was delivered by Dr. Gautam Rawat, Scientist, where he educated about the details of e-waste and its disposal.

A “Zero Plastic: Green Campus" Jagruktta rally was conducted in the office campus and residential colony of the Institute as well as in the nearby areas of the GMS Road, Dehradun. All employees and research scholars participated in the rally. The “Swachhta hi seva” Campaign and awareness program were also conducted in different schools and colleges by the Institute scientists.

Vigilance Week

Vigilance Awareness Week-2023 was observed at WIHG Dehradun from October 30–November 05, 2023. In this connection, an Integrity pledge has been taken by the employees of the Institute followed by a lecture by Director WIHG on the topic “Corruption and it's preventive measures” on October 30, 2023. During November 1-2, 2023, the Wadia Institute of Himalayan Geology, Dehradun conducted a series of programs in conjunction with Vigilance Awareness Week (2023).

Scientific and staff, as well as students of the Institute, took part in a quiz and slogan competition on vigilance and corruption. On November 3, 2023, Shri Satya Prakash Sharma, Former Administrative and Vigilance Officer, Government of Delhi, delivered a lecture on the Vigilance-2023 theme “Say no to corruption; commit to the Nation”. Scientists from WIHG delivered talks on Vigilance Awareness and took pledges with the faculties and staff of different schools and colleges.

Moments during the vigilance week program at WIHG, Dehradun

Republic Day

The 75th Republic Day was celebrated in the Institute on 26 January 2024. On this occasion, Dr. Kalachand Sain, Director, unfurled the National Flag and delivered a formal address to the Institute employees and research scholars. To mark the occasion, various sports activities, craft exhibitions, and competitions were organized for the employees and their children. Prizes were distributed to the winners of various events. A cultural event 'Udbhav' was performed mainly by the research scholars.

Republic day celebration on January 2024

National Science Day

The National Science Day was observed on February 28, 2024. The theme of Science Day was “Indigenous Technologies for Viksit Bharat”. On this day, the WIHG museum and other laboratories were kept open for the general public and students of schools and colleges. A large number of students and teachers visited the museum and other laboratories. On this occasion, A Science Quiz Competition was organized for the staff members and research scholars of the Institute.

National Science Day celebration at WIHG, Dehradun

International Women's Day

International Women's Day is a significant event that is celebrated globally on March 08, every year. It is a day to celebrate the social, economic, cultural, and political achievements of women and to advocate for gender equality. This significant event was celebrated at WIHG, Dehradun on March 12, 2024. This year the theme of the International Women's Day was "Inspire Inclusion”. The event was started with a welcome address by Dr. Kalachand Sain, Director of WIHG Dehradun. He motivated all the women employees during his welcome address. Padma Shri Smt. Basanti Bisht was the chief guest on the occasion. She delivered a talk on the situation of women in remote areas and villages. She emphasized how to overcome the struggles faced by women in day-to-day life. Her words of wisdom were thought-provoking, truly inspiring, and highly benefitted the scientists, researchers, and staff of the Institute. Some of the scientists of the Institute also delivered lectures on various topics making the event successful.

Moments of the International Woman Day

DISTINGUISHED VISITORS TO THE INSTITUTE

1. Prof. Annpurna Nautiyal, Vice Chancellor, H. N. B. Garhwal University, Srinagar
2. Shri Satya Prakash Sharma, Ex-Administrator and Academic Advisor, Government of Delhi
3. Lt Gen VK Mishra, Commandant of the Indian Military Academy (IMA)
4. Prof. (Dr.) Durgesh Pant, Director General, UCOST, Dehradun
5. Padma Bhushan Dr. Anil Prakash Joshi, Founder-HESCO
6. Dr. Harender Singh Bisht, Director, Indian Institute of Petroleum, Dehradun
7. Shri Vishvajit Sahay, Additional Secretary & Financial Adviser, DST, GoI
8. Prof. T. N. Singh, Director, IIT Patna

STATUS OF IMPLEMENTATION OF HINDI

The WIHG strictly adheres to & complies with the policy and guidelines as formulated by the Rajbhasha Vibhag, Home Ministry, GoI and regularly submits its quarterly, half-yearly& annual progress reports to Rajbhasha Vibhag and DST. The Institute also submits its half-yearly and annual progress reports to NARAKAS, Dehradun in the desired formats. The Official Language Implementation Committee (OLIC) under the chairmanship of the Director, WIHG is monitoring the implementation of Hindi in the Institute & it also reviews the draft of various Hindi reports before their submission to the aforementioned ministries. The committee monitors & formulates plans for the progressive use of Official Language in the office. The committee takes cognizance of the progress in the Hindi implementation through its regularly organized quarterly meetings.

The Official Language Implementation Committee of WIHG regularly organizes quarterly workshops to promote the use of the Official Language through the organization of interactive lecture series of prominent Speakers/Scientists & also through various Hindi typing workshops.

The Institute under the banner of OLIC organized Hindi Pakhwara from 14 Sep to 29 September 2023 in the Institute. This year's opening ceremony of the Hindi Pakhwara was organized in Pune on 14 September 2023 at an All India Level as per the directives from Rajbhasa Vibhag, Home Ministry. The representatives from the Institute attended the opening event held in Pune.

Thereafter various competitions/events were organized in the Institute from September 15, 2023, onwards.First, the Invited Lecture by Dr. Chandra Mohan Nautiyal, retired-Scientist BSIP, Lucknow was organized. Thereafter essay & slogan writing competitions were also organized for the school students & Institute's employees. During the *Pakhwara* many renowned personalities & well-known speakers of Dehradun i.e. Padma Shri Smt. Basanti Bisht; Smt Shanti Amoli Binjola & Sh. Devendra Mewari Jee was invited for their talks on the issues of cultural & social importance in the Institute. The institute's employees also delivered popular talks on various science-related topics. Various other competitions like photography competitions, story competitions, *antyakshri,*etc. were also organized during the duration of Hindi *Pakhwara*.

In the closing ceremony of the *Pakhwara*, Dr. Harendra Singh Bisht, Director, IIP-Dehradun was the chief guest of the closing ceremony of the *Pakhwara*. In his remark, he emphasized the role of the official language in the dissemination of scientific knowledge in a very lucid manner. The Pakhwara Celebrations concluded after prize distribution from the chief guest.

This year we published the 28th issue of the Annual Hindi Magazine "*Ashmika*". Authors from various organizations, scholars, and employees of the Institute contributed their articles pertaining to various disciplines of science, literature, poetry, stories & philosophy in the magazine. The articles published in the magazines are very informative and well-appreciated by the readers. It is attempted to receive many more popular science articles in Hindi. Due to the extensive & collaborative works of the editorial board of *Ashmika*, this edition of "*Ashmika 2023*" received third prize amongst all AI's of DST in the First All India Scientific & Technical Official Language Symposium held at ARCI, Hyderabad under the patronage of DST, GoI.

MISCELLANEOUS ITEMS

1. Reservation/Concessions for SC/ST employees

The government's orders on reservations for SC/ST/ OBCs are followed in recruitment to posts in various categories.

2. Monitoring of personnel matters

Monitoring of personnel matters relating to employees of the Institute is done through various Committees appointed by the Director/Governing Body from time to time.

3. Mechanism for redressal of grievances

The Grievance Redressal Committee (GRC) consisting of five Seniors Scientists/officers, is operational in this Institute. During the reporting period, a total of four grievances were received. Two of them were related to recruitment, one was related to harassment, and the other one was related to Natural Disasters. Among the four grievances, three were received from the DST portal (DOSAT) and the other one was received through the Prime Minister's Office (PMO). The grievances of the applicants against the post advertised, selection, harassment, and natural disaster were resolved and disposed of by looking into the relevant documents.

4. Welfare measures

The Institute has various welfare measures for the benefit of its employees. Various advances like House Building Advance, Conveyance Advance, Festival Advance, etc. are given to the employees. There is a salary Earner's Cooperative Society run by the Institute employees that provides loans to its members as and when required. The Institute also runs a canteen for the welfare of the employees and students. As a welfare measure, the Institute is providing recreational facilities to its employees.

5. Mechanism for redressal of complaints of sexual harassment of women employees at workplaces

An Internal Complaints Committee (ICC) was constituted to safeguard the women employees and to enquire into the complaints of sexual harassment of women employees at workplaces in the Institute. The Committee consists of one presiding officer from outside the Institute and four members from the Institute. As far as ICC is concerned, one case is sub-judice and another is continuing.

6. Status of Vigilance Cases

No vigilance case is pending in the year 2023-2024.

7. Information on the RTI cases

The details of information on the RTI cases during the year 2023-24 are as under:

Details	Opening balance as on 01.04. 2023	Received during the year 2023-2024	Number of cases transferred to other public authorities	Decisions where requests/ appeals were rejected	Decisions where requests/ appeals were accepted
Requests for information	02	38 (All disposed off)	0	0	0
First appeals	1	7	0	7	0

8. Sanctioned Staff strength (category wise)

Group/ Category	Scientific	Technical	Administ-rative	Ancillary	Total
A	60	-	1	-	61
B	-	2	14	-	16
C	-	52	22	35	109
Total	**60**	**54**	**37**	**35**	**186**

9. Sanctioned and released budget grant for the year 2023-2024

Plan	:	Rs. 4456.00 Lakhs
Non- Plan	:	NIL
Total	:	Rs. 4456.00 Lakhs

STAFF OF THE INSTITUTE

Scientific Staff:

1.	Dr. Kalachand Sain	Director
2.	Dr. Vikram Gupta	Scientist 'G' (On lien)
3.	Dr. Ajay Paul	Scientist 'F' (Retired on 30.09.2023)
4.	Dr. R.Jayangondaperumal	Scientist 'F'
5.	Dr. A.K.Singh	Scientist 'F' (On lien)
6.	Dr. K.S. Luirei	Scientist 'F'
7.	Dr. (Mrs) Kapesa Lokho	Scientist 'F'
8.	Dr. R.K. Sehgal	Scientist 'E'
9.	Dr. Santosh Kumar Rai	Scientist 'E'
10.	Dr. Jayendra Singh	Scientist 'E'
11.	Dr. B.K. Mukherjee	Scientist 'E'
12.	Dr. Naresh Kumar	Scientist 'E'
13.	Dr. Gautam Rawat	Scientist 'E'
14.	Dr. Devajit Hazarika	Scientist 'E'
15.	Dr. Kaushik Sen	Scientist 'E'
16.	Dr. Satyajeet Singh Thakur	Scientist 'E'
17.	Dr. Narendra Kumar Meena	Scientist 'E'
18.	Dr. Param Kirti Rao Gautam	Scientist 'E'
19.	Dr. Dilip Kumar Yadav	Scientist 'E'
20.	Dr. Manish Mehta	Scientist 'E'
21.	Dr. Rajesh S.	Scientist 'D'
22.	Dr. (Mrs) Swapnamita Choudhuri	Scientist 'D'
23.	Dr. Vikas	Scientist 'D'
24.	Dr. Som Dutt	Scientist 'D'
25.	Dr. Anil Kumar	Scientist 'D'
26.	Sh. Saurabh Singhal	Scientist 'D'
27.	Dr. Narendra Kumar	Scientist 'D'
28.	Dr. Parveen Kumar	Scientist 'D'
29.	Dr. Vinit Kumar	Scientist 'D' (On lien)
30.	Dr. Aditya Kharya	Scientist 'D'
31.	Dr. (Ms) Suman Lata Srivastava	Scientist 'D'
32.	Dr. (Mrs) Chhavi Pant Pandey	Scientist 'D'
33.	Dr. Sameer Kumar Tiwari	Scientist 'D'
34.	Dr. Paramjeet Singh	Scientist 'C'
35.	Dr. Sudipta Sarkar	Scientist 'C'
36.	Dr. Pinkey Bisht	Scientist 'C'
37.	Dr. Rakesh Bhambari	Scientist 'C'
38.	Dr. Amit Kumar	Scientist 'C'
39.	Dr. C. Perumalsamy	Scientist 'C'
40.	Dr. Pratap Chandra Sethy	Scientist 'C'
41.	Dr. Hiredya Chauhan	Scientist 'C'
42.	Dr. Vandana	Scientist 'C'
43.	Dr. Rouf Ahmad Sah	Scientist 'C'
44.	Dr. Pankaj Chauhan	Scientist 'C'
45.	Dr. Priyadarshi Chinmoy Kumar	Scientist 'C'
46.	Dr. M. Prakasam	Scientist 'B'
47.	Dr. Mutum Rajnikanta Singh	Scientist 'B'
48.	Dr. Chinmay Haldar	Scientist 'B'
49.	Dr. Subhojit Saha	Scientist 'B'
50.	Dr. Jairam Singh Yadav	Scientist 'B'
51.	Dr. Subham Bose	Scientist 'B'
52.	Dr. Naveen Chandra	Scientist 'B'
53.	Dr. N. Premjit Singh	Scientist 'B'
54.	Dr. Tariq Anwar Ansari	Scientist 'B'
55.	Dr. Bappa Mukherjee	Scientist 'B'
56.	Dr. Rajeeb Lochan Mishra	Scientist 'B'
57.	Dr. Mahesh Ramrao Kapawar	Scientist 'B'
58.	Dr. Kunda Badhe	Scientist 'B'
59.	Dr. Jitender Kumar	Scientist 'B'
60.	Dr. Pramod Kumar Rajak	Scientist 'B'

Technical Staff

1.	Shri Sanjeev Kumar Dabral	Sr. Technical Officer
2.	Shri Rakesh Kumar	Sr. Technical Officer
3.	Shri N.K. Juyal	Sr. Technical Officer
4.	Shri C.B. Sharma	Executive Engineer
5.	Shri T.K. Ahuja	Technical Officer
6.	Shri S.S. Bhandari	Technical Officer
7.	Shri Rambir Kaushik	Technical Officer
8.	Shri Bharat Singh Rana	Technical Officer
9.	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
10.	Dr. Balram	Librarian
11.	Shri R.M. Sharma	Sr. Lab. Technician
12.	Mrs. Sarita	Sr. Tech. Assistant
13.	Shri Rakesh Kumar	Sr. Tech. Assistant
14.	Mrs. Sakshi Maurya Chaudhary	Sr. Tech. Assistant
15.	Mrs. Disha Vishnoi	Sr. Tech. Assistant
16.	Shri Vipin Chauhan	Technical Assistant
17.	Shri Deepak Kumar	Technical Assistant
18.	Shri Akash Khati	Technical Assistant
19.	Shri Pramod Kumar	Technical Assistant
20.	Shri Rahul Lodh	Lab Assistant
21.	Shri Nain Das	Lab Assistant (Retired on 31.03.2024)
22.	Shri Prateek Negi	Artist-cum-Modeller

23.	Shri Nand Ram	Elect/cum/Pump.Optr.
24.	Shri Tarun Jain	Draftsman
25.	Shri Pankaj Semwal	Draftsman
26.	Shri Anil Singh	Draftsman
27.	Shri Santu Das	Section Cutter
28.	Shri Puneet Kumar	Section Cutter
29.	Shri Amit Bhandari	Junior Photographer
30.	Shri Hari Singh Chauhan	F.C.L.A.
31.	Shri Ravi Lal	F.C.L.A. (Retired on 31.03.2024)
32.	Shri Preetam Singh	F.C.L.A.
33.	Shri Sanjeev Kumar	F.C.L.A.
34.	Shri Deepak Tiwari	F.C.L.A.
35.	Shri Ajay Kumar Upadhaya	F.C.L.A.
36.	Ms. Sangeeta Bora	F.C.L.A.
37.	Mrs. Anjali	F.C.L.A.
38.	Shri Ajay Kumar	F.C.L.A.
39.	Shri Vipin Kumar Aditya	F.C.L.A.
40.	Shri Nitesh Kumar	F.C.L.A.
41.	Shri Abhishek Kumar	F.C.L.A.
42.	Shri Sandeep Singh	F.C.L.A.
43.	Shri Ajit Kumar	F.C.L.A.
44.	Shri Narender Manral	Field Attendant
45.	Shri Aakash Sharma	Field Attendant
46.	Shri Ashish Singh	Field Attendant
47.	Shri Aakash Saini	Field Attendant

Administrative Staff

1.	Shri Pankaj Kumar Verma	Registrar
2.	Shri S.K. Srivastava	Admin. Officer
3.	Shri Manas Kumar Biswas	Store & Purchase Officer
4.	Shri Rahul Sharma	Asstt. Fin. & Acc. Officer
5.	Mrs. Prabha Kharbanda	Accountant (Retired on 31.01.2024)
6.	Shri Ankit Rawat	Sr. Personal Asstt.
7.	Mrs. Rajvinder Kaur Nagpal	Stenographer, Gr. II (Retired on 31.08.2023)
8.	Mrs. Shalini Rawat	Stenographer, Gr. II
9.	Mrs. Neelam Chabak	Assistant
10.	Mrs. Seema Juyal	Assistant
11.	Mrs. Suman Nanda	Assistant
12.	Shri Kulwant Singh Manral	Assistant
13.	Shri Yashpal Singh Bisht	Jr. Hindi Translator
14.	Shri Vijai Ram Bhatt	Upper Division Clerk
15.	Shri Girish Chander Singh	Upper Division Clerk
16.	Shri Rajeev Yadav	Upper Division Clerk
17.	Shri Amardeep Kumar	Upper Division Clerk
18.	Shri Dhanveer Singh	Upper Division Clerk
19.	Mrs. Megha Sharma	Upper Division Clerk
20.	Mrs. Surbhi	Upper Division Clerk
21.	Shri Deepak Jakhmola	Upper Division Clerk
22.	Shri Dinesh Kumar Singh	Upper Division Clerk
23.	Mrs. Rachna	Upper Division Clerk
24.	Mrs. Richa Kukreja	Stenographer, Gr. III
25.	Mrs. Pushpa Barthwal	Lower Division Clerk
26.	Shri Amit Kumar	Lower Division Clerk
27.	Shri Pintu Kumar	Lower Division Clerk
28.	Shri Naved Khan	Lower Division Clerk
29.	Shri Vishesh Kumar Gautam	Lower Division Clerk
30.	Ms. Saba	Lower Division Clerk
31.	Shri Manjeet Rana	Lower Division Clerk

Ancillary Staff

1.	Shri Manmohan	Driver
2.	Shri Vikkee Tomar	Driver
3.	Shri Bhupendra Kumar	Driver
4.	Shri Rajesh Yadav	Driver
5.	Shri Pradeep Shah	Driver
6.	Mrs. Deveshawari Rawat	M.T.S. (Retired on 30.09.2023)
7.	Shri S.K. Gupta	M.T.S.
8.	Shri Surendra Singh	M.T.S.
9.	Shri Satya Narayan	M.T.S.
10.	Shri Rohlu Ram	M.T.S.
11.	Shri H.S. Manral	M.T.S.
12.	Shri G.D. Sharma	M.T.S.
13.	Shri Dinesh Parsad Saklani	M.T.S.
14.	Shri Pritam	M.T.S.
15.	Shri Ramesh Chand Rana	M.T.S.
16.	Shri Ashish Rana	M.T.S.
17.	Shri Sunil Kumar	M.T.S.
18.	Shri Harish Kumar Verma	M.T.S.
19.	Shri Kamlesh Singh	M.T.S.
20.	Shri Rajkiran Singh	M.T.S.
21.	Shri Abdul Basit	M.T.S.
22.	Shri Yogender Saklani	M.T.S.
23.	Ms. Deepti Pandey	M.T.S.
24.	Mrs. Sakshi Chauhan	M.T.S.

Contractual Staff

1.	Shri Rezaw Uddin Chaudhary	Driver
2.	Sh. Vijay Singh	Driver
3.	Shri Rudra Chettri	M.T.S.
4.	Shri Laxman Singh Bhandari	M.T.S.
5.	Shri Kalidas	M.T.S.
6.	Shri Ummed Singh	M.T.S.

MEMBERS OF THE GOVERNING BODY/RESEARCH ADVISORY COMMITTEE/FINANCE COMMITTEE/BUILDING COMMITTEE

Governing Body

Sl.	Name	Address	Status
1.	Prof. Talat Ahmad	Vice-Chancellor, University of Kashmir Hazratbal, Srinagar, Jammu & Kashmir-190006	Chairman
2.	Dr. Srivari Chandrasekhar	Secretary to the Government of India Department of Science and Technology, Technology Bhawan, New Mehrauli Road, New Delhi- 110 016	Member
3.	Prof. Shakil Ahmad Romshoo	Vice-Chancellor, Islamic University of Science & Technology, 1-University Avenue, Awantipora, Pulwama Jammu and Kashmir-192122	Member
4.	Shri Vishvajit Sahay	Additional Secretary & Financial Adviser, Department of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016	Member
5.	Dr. O.P. Mishra	Scientist 'G', Ministry of Earth Sciences, Government of India, Prithvi Bhavan, Opp. India Habitat Centre, Lodhi Road, New Delhi- 110003	Member
6.	Prof. M. Jayananda	Head, Centre for Earth and Space Sciences, University of Hyderabad P.O. Central University, Gachibowli, Hyderabad-500 046 (Telangana)	Member
7.	Prof. Pulak Sengupta	Professor, Department of Geological Sciences Jadavpur University, 188, Raja Subodh Chandra Mallick Road, Poddar Nagar, Jadavpur, Kolkata-700032,WB	Member
8.	Prof. N.V. Chalapathi Rao	Professor, Department of Geology Banaras Hindu University (BHU) Ajagara, Varanasi-221005, UP	Member
9.	Prof. Anupam Chattopadhyay	Department of Geology 34 Chhatru Marg, University of Delhi (North Campus) Delhi-110007	Member
10.	Prof. Saibal Gupta	Professor & Head, Deptt. of Geology & Geophysics, Indian Institute of Technology, Kharagpur Kharagpur -721302, WB	Member
11.	Prof. S.C. Patel	Professor, Department of Earth Sciences Indian Institute of Technology-Bombay Powai, Mumbai-400076, Maharashtra	Member
12.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun-248001	Member Secretary
13.	Sh. Pankaj Kumar Verma	Registrar, Wadia Institute of Himalayan Geology, Dehradun- 248001	Non-Member Asstt. Secretary

Research Advisory Committee

Sl.	Name	Address	Status
1.	Dr. Shailesh Nayak	Director, National Institute of Advanced Studies, Indian Institute of Science campus, Bengaluru -560012	Chairman
2.	Prof. T. N. Singh	Director, Indian Institute of Technology, Patna, Bihta, Patna-801106 (Bihar)	Member
3.	Prof. D.C. Srivastava	Emeritus Professor, Department of Earth Sciences, Indian Institute of Technology-Roorkee, Roorkee-247667, Uttarakhand	Member
4.	Shri Rajesh Kumar Srivastava	Director, Oil and Natural Gas Corporation Limited, 5, Nelson Mendela Road, Vasant Kunj, New Delhi-110070	Member
5.	Dr. Rasik Ravindra	608, Lalleshwari Apart Sector 21D, Faridabad-121001	Member
6.	Prof. Rajesh K. Srivastava	Professor & Former Head, Department of Geology,Banaras Hindu University, Varanasi- 221005, UP	Member
7.	Dr. Binita Phartiyal	Scientist 'E' Birbal Sahni Institute of Palaeoscience, 53, University Road, Lucknow- 226007, UP	Member
8.	Dr. Prakash Chauhan	Director, Indian Institute of Remote Sensing, 4, Kalidas Road, Dehradun- 248001, Uttarakhand	Member
9.	Dr. O.P. Mishra	Scientist 'G' and Head, NCS, Ministry of Earth Sciences, Government of India, Prithvi Bhavan, Opp. India Habitat Centre, Lodhi Road, New Delhi-110003	Member
10.	Dr. Prasun Jana	Deputy Director General, Geological Survey of India, Dehradun-248001	Member
11.	Prof. Kusala Rajendran	Centre of Earth Sciences, Indian Institute of Science, Bengaluru-560012	Member
12.	Prof. L.S. Chamyal	Head, Department of Geology, Faculty of Science, The M.S. University of Baroda Vadodara-390002, Gujarat	Member
13.	Prof. Santanu Banerjee	Department of Earth Sciences Indian Institute of Technology-Bombay Powai, Mumbai-400076, Maharashtra	Member
14.	Dr. V. Balaram	Scientist 'G' (Retd.), SCIR-NGRI, Hyderabad, Consultant IUAC, Delhi	Member
15.	Prof. Devesh K. Sinha	Oceanography and Marine Geology, Department of Geology, Delhi University, Delhi- 110007	Member
16.	Prof. Saibal Gupta	Professor & Head, Department of Geology & Geophysics, Indian Institute of Technology-Kharagpur Kharagpur-721302, West Bengal	Member
17.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun- 248001	Member
18.	Dr. R. Jayangondaperumal	Scientist 'F', Wadia Institute of Himalayan Geology, Dehradun- 248001	Member Secretary

Finance Committee

Sl.	Name	Address	Status
1.	Shri Vishvajit Sahay	Additional Secretary & Financial Adviser Department of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi- 110 016	Chairman
2.	Prof. Anupam Chattopadhyay	Department of Geology, 34 Chhatra Marg, University of Delhi (North Campus) Delhi- 110 007	Member
3.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun-248001	Member
4.	Shri Pankaj Kumar Verma	Registrar, Wadia Institute of Himalayan Geology, Dehradun-248 001	Member
5.	Shri Rahul Sharma	Assistant Finance & Accounts Officer, Wadia Institute of Himalayan Geology, Dehradun 248 001	Member Secretary

Building Committee

Sl.	Name	Address	Status
1.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun-248001	Chairman
2.	Shri Vishvajit Sahay or his nominee	Additional Secretary & Financial Adviser Department of Science & Technology Technology Bhavan, New Mehrauli Road, New Delhi-110016	Member
3.	Representative of Survey of India	Hathibarkala, Dehradun	Member
4.	Chief Engineer or his/ her nominee	CPWD, Dehradun- 248001	Member
5.	Sh. Ashish Kumar Singh	SE (Civil), Tel Bhawan, Oil & Natural Gas Corporation, Dehradun-248001	Member
6.	Dr. R. Jayangondaperumal	Scientist-'F', Wadia Institute of Himalayan Geology, Dehradun-248001	Member
7.	Sh. Rajesh Kumar	Sr. Principal Scientist, Head ASD, CSIR- Indian Institute of Petroleum Haridwar Road, Dehradun-248005	Member
8.	Sh. Pankaj Kumar Verma	Registrar, Wadia Institute of Himalayan Geology, Dehradun-248001	Member
9.	Shri C.B. Sharma	Executive Engineer, Wadia Institute of Himalayan Geology, Dehradun-248001	Member Secretary

STATEMENT OF ACCOUNTS

KRA & Co.
CHARTERED ACCOUNTANTS

AUDITOR'S REPORT ON CONSOLIDATED FINANCIAL STATEMENTS

The Members of Governing Body,
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun
Uttarakhand

We have audited the accompanying Consolidated Financial Statements of **WADIA INSTITUTE OF HIMALAYAN GEOLOGY, 33, GMS Road, Dehradun** for the year ended March 31st, 2024 which comprises Balance Sheet, Income and Expenditure Account, Receipt and Payment Account and summary of significant accounting policies.

Society's management is responsible for the preparation of these Financial Statements in accordance with law. This responsibility includes the design, implementation and maintenance of internal control relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatement, whether due to fraud or error.

Our responsibility is to express an opinion on these financial statements based on our audit. We conducted our audit in accordance with the Standards on Auditing issued by the Institute of Chartered Accountants of India. Those Standards require that we comply with ethical requirements and plan and perform the audit to obtain reasonable assurance about whether the financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the Society's preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances. An audit also includes evaluating the appropriateness of accounting policies used and the reasonableness of the accounting estimates made by management, as well as evaluating the overall presentation of the financial statements.

: Floor, Shri Raj Complex, Opp. Nagri Bus Stand, Kathua (J&K) 184 101 Visit us at : www.kra.co.in
Phone : 01922-233567, 236667, 236767 • Fax : 01922-236767 • E-mail : ajay.kraindia@gmail.com

AUDITOR'S REPORT

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

In our opinion and to the best of our information and according to the explanations given to us, the financial statements give the information required by the Act in all material respects and give a true and fair view in conformity with the accounting principles generally accepted in India subject to our comments given in Annexure-"1":

a) in the case of the Balance Sheet, of the state of affairs of the Society as at March 31st, 2024;
b) in the case of the Income and Expenditure Account of the surplus for the year ended on that date; and
c) in the case of the Receipt and Payment Account, of the cash flows for the year ended on that date.

FOR KRA & CO
CHARTERED ACCOUNTANTS

CA AJAY KUMAR
FCA
FRN: 020266N
M.NO: 503015

Date: 2nd Aug, 2024
Place: Dehradun

UDIN:- 24503015BJZWTX4028

Action Taken Report on observations of the Chartered Accountant- Annexure-1 to the Consolidated Financial Statement of Audit Report (F.Y. 2023-24)

SI. No.	Comments/Observations by Chartered Accountants	Replies and Action taken by the Institute
1	It was observed that there were long outstanding balance in Earmarked / Endowment Fund. The management is suggested to settle the balances with the concerned ministry/department.	Most of the balance have been reconciled with funding agencies and balances will be settled in due course.
2	During the audit it was observed that in few cases field contingency expenditure incurred by employees during the field visit are made in non-digital form. It is suggested to make payments in digital form so to ensure the transparency in the transaction.	The necessary instructions will be issued in this regards and compliance of the audit observation will be shown in the next audit.
3	The actuary valuation has not been obtained by the Institute to book the Liability on accounts of Retirement Benefit.	Noted for future compliance.
4	It was observed that the institute has not opened bank account with State Bank of India as required by the provisions of FCRA account. Hence, all the transactions and returns pertaining to FCRA are pending.	Noted for strict compliance. It is to be intimated that there has been no foreign transaction during the period under Audit.
5	The physical verification of Fixed Assets and Library for the financial year 2023-24 has not been undertaken. The reason for not complying with the rule laid down in GFR regarding physical verification of Assets may be specified.	Physical verification for the year 2022-23 has already been completed. Action with regard to the physical verification for the year 2023-2024 is in progress and report will be submitted to the next audit.
	FOR K R A & CO **CHARTERED ACCOUNTANTS** KRA & CO. CA INDIA FRN:020266N KATHUA Chartered Accountants **CA AJAY KUMAR** **FCA**	**(Rahul Sharma)** **AF & AO** **(Pankaj Kumar Verma)** **Registrar** **(Dr. Kalachand Sain)** **Director**

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31st MARCH 2024)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	80,28,25,623	68,39,86,424
Reserves and Surplus	2	-	-
Earmaked/ Endowment Fund	3	33,96,395	32,07,880
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	76,53,632	13,01,49,469
TOTAL		**81,38,75,650**	**81,73,43,773**
ASSETS			
Fixed Assets	8	37,96,98,636	39,49,12,712
Investments from Earmaked/		-	-
Endowment Funds	9	1,16,089	1,09,706
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	43,40,60,925	42,23,21,355
TOTAL		**81,38,75,650**	**81,73,43,773**
Significant Accounting Policies	37		
Contingent Liabilities and Notes on Accounts	38		

AUDITOR'S REPORT
"As per our separate report of even date"

FOR KRA & CO.
CHARTERED ACCOUNTANTS

CA AJAY KUMAR
(F.C.A)

(RAHUL SHARMA)
A F & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 2nd August, 2024
Place : Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31st MARCH 2024

(Amt in Rs...)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12	-	-
	Grants/ Subsidies	13	45,95,28,063	39,09,62,940
	Fees/Subscription	14	-	-
	Income from Investments	15	11,31,316	9,79,376
	Income from Royalty, Publication etc.	16	1,45,430	1,16,540
	Interest earned	17	1,27,78,059	1,13,84,114
	Other Income	18	1,05,47,054	80,86,162
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**48,41,29,922**	**41,15,29,133**
B	**EXPENDITURE**			
	Establishment Expenses	20	23,22,66,228	45,94,51,879
	Other Research & Administrative Expenses	21	8,25,63,317	9,58,83,522
	Grant Refunded	22	22,55,347.00	-
	Interest/ Bank Charges	23	43,39,776	44,49,113
	Depreciation Account	8	6,63,30,606	6,66,53,157
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	(33,757)	(40,466)
	(Profit)/ Loss on sale of Assets	36	-	14,45,341
	TOTAL (B)		**38,77,21,517**	**62,78,42,546**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		9,64,08,405	(21,63,13,413)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	SURPLUS /(DEFICIT) CARRIED TO CAPITAL FUND		**9,64,08,405**	**(21,63,13,413)**

AUDITOR'S REPORT
"As per our separate report of even date"

FOR KRA & CO.
CHARTERED ACCOUNTANTS

KRA & CO. CA INDIA FRN:020266N KATHUA Chartered Accountants

CA AJAY KUMAR
(F.C.A)

(RAHUL SHARMA)
A.F & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 2nd August, 2024
Place: Dehradun

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2024)

(Amt in Rs…)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	21,79,83,393	31,55,09,620
Grants - in - Aids	26	51,51,28,063	45,09,62,940
Grants - in - Aids/Other Receipts (Ear Marked)	27	1,11,91,761	12,00,000
Loan & Advances	28	22,12,38,342	41,63,48,510
Loan & Advances (Ear Marked)	31	-	-
Fees/Subscription	14	-	-
Income from Investments	15	11,31,316	9,79,376
Income from Royalty, Publication etc.	16	1,45,430	1,16,540
Interest earned	17	1,27,78,059	1,39,86,021
Other Income	18	1,05,47,054	80,86,162
Investment (L/C Margin Money)	34	-	-
TOTAL		**99,01,43,419**	**1,20,71,89,170**
PAYMENTS			
Establishment Expenses	20	23,22,66,228	45,94,51,879
Other Administrative Expenses	21	8,25,63,317	9,58,83,522
Grant Refunded	22	1,60,83,800	-
Interest/ Bank Charges	23	43,39,776	44,49,113
Loans & Advances	29	36,67,19,661	32,82,23,028
Loans & Advances (Ear Marked)	32	6,383	-
Investment (L/C Margin Money)	35	-	-
Fixed Assets	36	5,11,16,530	10,03,80,058
Ear Marked Fund Expenses	33	1,10,03,246	8,18,177
Grant - in - Aid (Ear Marked) Refunded	30	-	-
Closing Balance	25	22,60,44,479	21,79,83,393
TOTAL		**99,01,43,419**	**1,20,71,89,170**

AUDITOR'S REPORT
"As per our separate report of even date"

FOR KRA & CO.
CHARTERED ACCOUNTANTS

KRA & CO, CA INDIA, FRN:020266N, KATHUA, Chartered Accountants

CA AJAY KUMAR
(F.C.A)

(RAHUL SHARMA)
AF & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 2nd August, 2024
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2024

SCHEDULE – 37: SIGNIFICANT ACCOUNTING POLICIES

1. ACOUNTING CONVENTION

The financial statements are prepared on the basis of historical cost convention, unless otherwise stated and on the cash method of accounting except interest accrued on fixed deposit.

2. INVESTMENTS

Investments classifieds as "long term investments" are carried at cost.

3. FIXED ASSETS

a) Fixed Assets are stated at net book value as recommended in the "Uniform Accounting Format" of financial statements for the Central Autonomous Bodies as made compulsory by the Ministry of Finance w.e.f. 01.04.2001.
b) Additions to fixed assets are taken at cost of acquisition, inclusive of freight, duties and taxes, incidental and direct expenses related to acquisition.

4. DEPRECIATION

a) Depreciation is provided on Written down Value method as per rates specified in the Income Tax Act, 1961.

b) When an asset is discarded or sold or deleted, the original cost is deducted from the gross block, the W.D.V. is deducted from the W.D.V. block and accumulated depreciation on the asset upto the date of deletion is deducted from accumulated depreciation of the respective block.

c) In respect of addition to/ deduction from fixed assets during the year, depreciation is considered on full yearly basis.

KRA & CO.
INDIA
FRN:020266N
KATHUA
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

5. MISCELLANEOUS EXPENDITURE

Deferred revenue expenditure, if any, will be written off over a period of 5 years from the year it is incurred.

6. ACCOUNTING FOR SALES & SERVICES

The consultancy services provided by the institute is accounted for on net service basis.

7. GOVERNMENT GRANTS / SUBSIDIES

a) Government grants of the nature of contribution towards Capital Cost are directly credited to Corpus Fund and Other Revenue cost are transferred to Income & Expenditure account and the surplus or deficit after deducting all the expenses is transferred to Capital / Corpus fund.

b) Grants towards Earmarked / Endowment Funds are directly transferred to the respective fund account.

c) Government grants / subsidy are accounted on realization basis.

(Rahul Sharma)
A.F. & A.O

(Pankaj Kumar Verma)
Registrar

(Dr. Kalachand Sain)
Director

Date : 2nd **August, 2024**
Place: Dehradun

KRA & CO.
CA INDIA
FRN:020266N
KATHUA
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2024

SCHEDULE – 38: CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS

1. CONTINGENT LIABILITIES

(Amount in Rs.)

a)	Claims against the Entity not acknowledged as debts		- Nil -
b)	In respect of		
	i)	Bank Guarantees given by /on behalf of the Entity	- Nil -
	ii)	Letter of credit opened by Bank on behalf of the entity	-Nil-
	iii)	Bills discounted with banks	- Nil -
c)	Disputed demands in respect of		
	i)	Income –tax (TDS)	- Nil -
	ii)	Sales tax	- Nil -
	iii)	Municipal Taxes	- Nil -
d)	In respect of claims from parties for non-execution of orders, but contested by the Entity		- Nil -

2. CAPITAL COMMITMENTS

Estimated Value of contracts remaining to be executed on capital account and not provided for (net of advances)		
a)	Construction of Building	- Nil -
b)	Other Assets	-Nil -

3. LEASE OBLIGATIONS

Future obligations for rentals under finance lease arrangements for plant and machinery amount to Rs. Nil	- Nil -

4. CURRENTS ASSETS, LOANS AND ADVANCES

In the opinion of the Institute, the current assets, loans and advances have a value on realization in the ordinary course of business, equal at least to the aggregate amount shown in the Balance Sheet.

5. TAXATION

In view of there being no taxable income of the Institute under income tax Act, 1961, no provision for Income Tax has been considered necessary

KRA & CO. FRN:020298N KATHUA Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

6. FOREIGN CURRENCY TRANSACTIONS

a)	Value of Imports Calculated on C.I.F basis:		
	i)	Purchase of finished goods	- Nil -
	ii)	Raw Materials & Components (including in transit)	- Nil -
	iii)	Capital goods	- Nil -
	iv)	Stores, Spares and Consumables	- Nil -
b)	Expenditure in foreign currency		
	i)	Travel (for attending Seminar/Conference abroad)	- Nil -
	ii)	Remittances and Interest payment to Financial Institutions / Banks in Foreign Currency	- Nil -
	iii)	Other expenditure	
		Commission on Sales	- Nil -
		Legal and Professional Expenses	- Nil -
		Miscellaneous Expenses	- Nil -
c)	Earnings		
	i)	Value of Exports on FOB basis	- Nil -
	ii)	Grants for Projects	- Nil -

7. The payments to auditors during the F.Y. 2023 -24 is as follows:

Remuneration to auditors		
i)	As Auditors	1,97,650/-
	Taxation matters	- Nil -
	For Management Services	- Nil -
	For Certification	- Nil -
ii)	Others	- Nil -

8. Separate Financial Statements have been prepared for:

a) Wadia Institute of Himalayan Geology.
b) Contributory/ General Provident Fund.
c) Pension Fund.
d) Consolidated financial statement of projects sponsored by other Agencies.
e) Individual financial statements of Projects sponsored by other agencies.

9. Corresponding figures for the previous year have been regrouped / rearranged, wherever necessary.

10. Annexed Schedules & Annexures are an integral part of the Balance Sheet as on 31st March, 2024, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2024.

(Rahul Sharma)	**(Pankaj Kumar Verma)**	**(Dr. Kalachand Sain)**
A.F. & A.O	**Registrar**	**Director**

Date : 2nd August, 2024
Place: Dehradun

KRA & CO. CA INDIA FRN:020266N KATHUA Chartered Accountants

वाडिया हिमालय भूविज्ञान संस्थान
WADIA INSTITUTE OF HIMALAYAN GEOLOGY

सदस्यता/Membership No.
LTSS-..........................

हिमालयन जियोलॉजी
HIMALAYAN GEOLOGY

आजीवन ग्राहक सदस्यता हेतु पंजीकरण प्रपत्र
Registration form for Life Time Subscriber membership

केवल व्यक्तिगत उपयोग हेत/for individuals use only

1. मैं "हिमालयन जियोलॉजी" का आजीवन ग्राहक बनना चाहता हूँ।
   I would like to become a Life Time Subscriber for "Himalayan Geology".

2. आजीवन सब्सक्रिप्शन शुल्क की राशि निदेशक, वाडिया हिमालय भूविज्ञान संस्थान के पक्ष में ऑनलाइन भुगतान विवरण/ड्राफ्ट/चैक के साथ निम्नलिखित के लिए संलग्न है।
   The Life Time subscription fee with online payment details/Draft/Cheque in favour of Director, Wadia Institute of Himalayan Geology is enclosed herewith for the following:

   Type of subscription (Tick [✓] which is applicable): ☐ Print copy ☐ Soft copy by online access/email

   - ❑ Fee for Print copy : Rs. 7500.00 (India) US$ 750.00 (Foreign)
   - ❑ Fee for Soft copy : Rs. 4000.00 (India) US$ 250.00 (Foreign)

   नाम/Name: ....

   पता/Address:...

   ....

   ....

   ईमेल/Email: ....

   मोबाइल/Mobile: ....

मैं प्रमाणित करता हूँ कि यह सदस्यता केवल मेरे निजी प्रयोग के लिए है तथा यह प्रिंट/साफ्ट–सदस्य प्रति, प्रकाशन होने से कम से कम दो वर्ष की अवधि तक किसी पुस्तकालय या वाचनालय को उपलब्ध नहीं करवाई जाएगी।

I certify that the subscription is for my personal use only and that print/soft subscriptions will not be released to libraries or reading rooms for at least 2 years after publication.

***हस्ताक्षर* / Signature**

आफॅर (सीमित अवधि के लिए) : नये पंजीकृत आजीवन ग्राहकों को "हिमालयन जियोलॉजी" के पुराने प्रिंट वोल्यूमों का एक मुफ्त सैट (1971 से 2012 तक, उपलब्धता के आधार पर) उपलब्ध कराया जाएगा (डाक शुल्क ग्राहक द्वारा वहन किया जाएगा)।

Offer (for a limited period) : A free set of old print volumes (1971 to 2012, subject to availability) of "Himalayan Geology" will be provided to the newly registered Life Time Subscribers (Postage to be borne by the Subscriber).

कार्यालय उपयोग हेतु ***/For office use***
रसीद सं./Receipt No.:......................दिनांक/Dated:................................राशि/Amt. Rs........................
जारी मौजूदा वोल्यूम /Issue Current Vol. No.:...

Editorial Office, Himalayan Geology (Journal)
Publication Division, Wadia Institute of Himalayan Geology,
33 Gen. Mahadeo Singh Road, Dehradun - 248001 (India) ; Phone : +91-135-2525430;
Web: http://www.himgeology.com; Email: himgeol@wihg.res.in, himgeology.com@gmail.com

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN
PUBLICATIONS AVAILABLE FOR SALE

HIMALAYAN GEOLOGY

(These volumes are the Proceedings of the Annual Seminars on Himalayan Geology organizsed by the Institute)

		(in Rs)	(in US $)
Volume 1	(1971)	130.00	26.00
Volume 2*	(1972)	50.00	
Volume 3*	(1973)	70.00	
Volume 4*	(1974)	115.00	50.00
Volume 5	(1975)	90.00	50.00
Volume 6	(1976)	110.00	50.00
Volume 7	(1977)	110.00	50.00
Volume 8(1)	(1978)	180.00	50.00
Volume 8(2)	(1978)	150.00	45.00
Volume 9(1)	(1979)	125.00	35.00
Volume 9(2)	(1979)	140.00	45.00
Volume 10	(1980)	160.00	35.00
Volume 11	(1981)	300.00	60.00
Volume 12	(1982)	235.00	47.00
Volume 13*	(1989)	1000.00	100.00
Volume 14* (in Hindi)	(1993)	600.00	-
Volume 15*	(1994)	750.00	

(Available from M/s Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, Bombay, Kolkata)

Volume 16*	(1999)	1000.00	100.00

Journal of Himalayan Geology

(A bi-annual Journal : published from 1990 to 1995)

Annual Subscription	(in Rs)	(in US $)
Institutional	500.00	50.00
Individual	100.00	25.00

Volume 1 (1990) to Volume 6 (1995)*

HIMALAYAN GEOLOGY

(A bi-annual Journal incorporating Journal of Himalayan Geology)

Annual Subscription:	(in Rs)	(in US $)
Institutional	500.00	50.00
Individual	100.00	25.00

Volume 17 (1996)*

HIMALAYAN GEOLOGY

Revised Annual Subscription (w.e.f. 1997):	(in Rs)	(in US$)
Institutional	750.00	50.00
Individual (incl. postage)	100.00	25.00

Volume 18 (1997) to Volume 26 (2005)*

Volume 27 (2006) to Volume 32 (2011)*

Volume 33 (2012)

Volume 34 (2013) to Volume 36 (2016)*

Volume 37 (2015) to Volume 38 (2017)

Volume 39 (2018) to Volume 43 (2022)

Revised Annual Subscription (w.e.f. 2018):	(in Rs)	(in US$)
Institutional	2000.00	150.00
Individual (incl. postage)	600.00	50.00

Volume 44 (2023) to Volume 45 (2024)

Revised Annual Subscription (w.e.f. 2023):	(in Rs)	(in US$)
Institutional	3000.00	225.00
Individual (incl. postage)	1000.00	100.00

OTHER PUBLICATIONS

Geology of Kumaun Lesser Himalaya, 1980 (by K.S. Valdiya)	Rs. 180.00 US $ 50.00
Geology of Indus Suture Zone of Ladakh, 1983 (by V.C.Thakur & K.K. Sharma)	Rs. 205.00 US $ 40.00
Bibliography on Himalayan Geology, 1975-85	Rs. 100.00 US $ 30.00
Geological Map of Western Himalaya, 1992 (by V.C. Thakur & B.S. Rawat)	Rs. 200.00 US $ 15.00
Excursion Guide :The Siwalik Foreland Basin (Dehra Dun-Nahan Sector), (WIHG Spl. Publ. 1,1991) (by Rohtash Kumar and Others)	Rs. 45.00 US $ 8.00
Excursion Guide : The Himalayan Foreland Basin (Jammu -Kalakot-Udhampur Sector) (WIHG Spl Publ. 2, 1999) (by A.C. Nanda & Kishor Kumar)	Rs. 180.00 US $ 15.00
Glacier Lake Inventory of Uttarakhand (by Rakesh Bhambri et al. 2015)	Rs. 500.00 US $ 50.00
Siwalik Mammalian Faunas of the Himalayan Foothills With reference to biochronology, linkages and migration (by Avinash C. Nanda, 2015)	Rs. 1200.00 US $ 100.00
Lithostratigraphy, Biostratigraphy and Palaeogeography of the Eastern Karakoram, India (by K.P. Juyal, 2018)	Rs. 600.00 US $ 50.00

Note: 'Journal of Himalayan Geology' & 'Himalayan Geology' have been merged and are being published as Himalayan Geology' after 1996.
*** Out of Stock**

Life Time Subscription of Himalayan Geology (Individuals only)
Fee for Print copy : India: 7500.00 Abroad: US$ 750.00
Fee for Soft copy : India: 4000.00 Abroad: US$ 250.00

Trade Discount (In India only)
1-10 copies: 10%, 11-15 copies: 15% and >15 copies: 20%

Offer (for a limited period): A free set of old print volumes (1971 to 2012, subject to availability) of 'Himalayan Geology' will be provided to the new registered Life Time Subscribers (Postage to be borne by the subscriber).

Publications: *may be purchased from Publication & Documentation Section and Draft/Cheque may be drawn in the name of The Director, Wadia Institute of Himalayan Geology, 33- General Mahadeo Singh Road, Dehra Dun – 248 001*

Phone: 0135-2525430 Fax: (91) 0135-625212 Website: http://www.himgeology.com E-mail: himgeol@wihg.res.in

Wadia Institute of Himalayan Geology
(An Autonomous Institute of Dept. of Science & Technology, Govt. of India)
33, General Mahadeo Singh Road, Dehradun-248001 (INDIA)