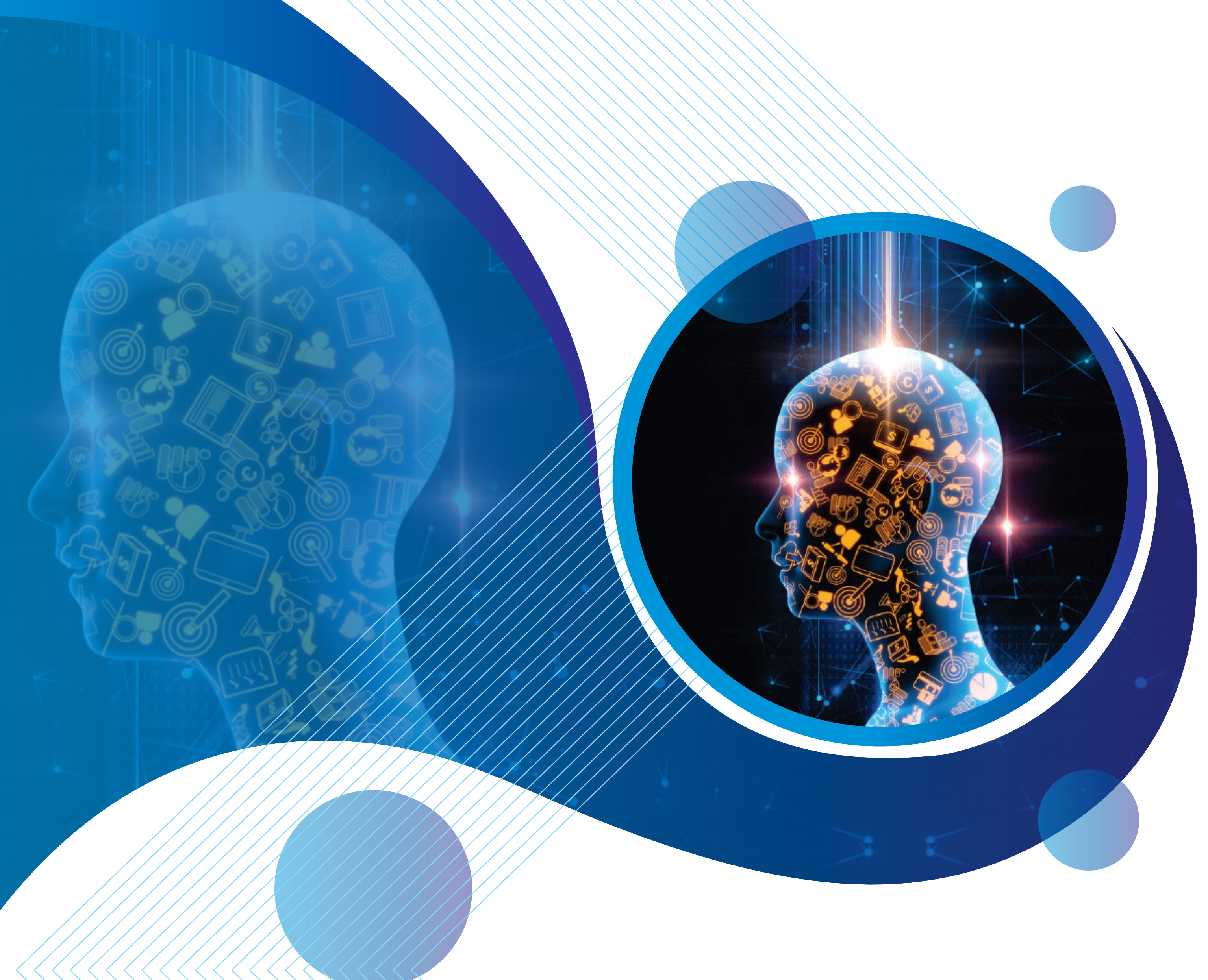
ANNUAL REPORT 2021-22



WADIA INSTITUTE OF HIMALAYAN GEOLOGY DEHRADUN

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

ANNUAL REPORT 2021-22

WADIA INSTITUTE OF HIMALAYAN GEOLOGY

(An Autonomous Institute of Department of Science & Technology, Government of India)
33, General Mahadeo Singh Road, Dehra Dun - 248 001
EPABX : 0135-2525100; Fax : 0135-2625212
Email : dir.off@wihg.res.in; Web : http://www.wihg.res.in

Contact :

The Director,
Wadia Institute of Himalayan Geology
33, General Mahadeo Singh Road, Dehra Dun - 248 001
Phone : 0135-2525103, Fax : 0135-2625212 / 2525200
Email : director@wihg.res.in
Web: http://www.wihg.res.in

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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

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D.C. Srivastava
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Rasik Ravindra
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Binita Phartiyal
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V. Balaram
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Saibal Gupta
Kalachand Sain
Vikram Gupta

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

DIRECTOR

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
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- 7: Quantification of strain accumulation/release rate along MHT at different time scales

UNITS ANCILLARY TO RESEARCH

- TCPME
- Publication & Documentation
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- 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) at Dehradun is an autonomous research Institute of the Department of Science & Technology, Govt. of India, which came into being in 1968. It has been pursuing basic research to unravel the orogeny of majestic Himalaya and to provide an improved understanding of seismogenesis, geodynamics, climate-tectonic interaction, biotic evolution, ores/minerals forming processes, glacial dynamics, fluvial system, geo-hazards (landslides, flash floods, avalanches, earthquakes), geo-resources (minerals, ore bodies, hydrocarbons, cold/hot springs), anthropogenic impact, etc. towards the well-being of the population and safe-guarding the properties and structures in the Himalaya and adjoining areas.

The research activities to understand the mountain building processes and shed light on the above themes are based on observations 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, remote sensing, etc.

The institute is equipped with sophisticated analytical facilities like LA-MC-ICP-MS, Stable Isotope Mass Spectrometer, EPMA, ICP-MS, XRF, SEM, XRD, Raman Spectrometer, TL/OSL, Magnetic Susceptibility meter, etc., run by competent scientists and technicians. It has state-of-the-art geophysical data acquisition, processing, modeling, and interpretation laboratories coupled with the AI/ML Centre of Excellence for Geosciences data. The analytical and laboratory facilities are being utilized by the scientists of WIHG as well as researchers from state and central universities, other institutes, and organizations. It has as many as 75 Broad Band Seismographs and 25 Acceleragraphs spread over Himachal Pradesh, Uttarakhand, Punjab, Haryana, and Arunachal Pradesh states, and Jammu & Kashmir and Ladakh Union Territories. Around 20 GPS instruments are installed in Himachal Pradesh and Uttarakhand states, and Jammu & Kashmir and Ladakh Union Territories.

The Institute has been nurturing a unique set up to perceive changes in subsurface properties that may lead to earthquake precursory study in the Himalayan region by hoisting and monitoring an integrated 'Multi-Parametric Geophysical Observatory (MPGO)' at Ghuttu in Tehri district of Uttarakhand. The institute also provides consultancy services for engineering projects, drinking & ground water surveys, natural hazards, road and rail alignments in the Himalaya and adjoining regions.

The institute serves as a National Centre of excellence in Himalayan Geoscience Education and Research; provides summer/winter training to over 100 students; produces an average of 10 Ph.Ds. as trained man power and publishes over 120 research papers in peer-reviewed journals every year; collaborates with Universities, Industries and other Institutes on Himalayan Geosciences; maintains a modern Geological Museum decorated with varieties of rocks, minerals, and fossils of the Himalaya for Education; conducts outreach programs for Science Education and Geo-hazards awareness; organizes illustrious Award Lectures and National/International Seminars, etc.

During the glorious journey, a few scientists have brought accolades with the Padma Awards, many researchers with the National Geosciences Awards, Academy Fellowships, and Young Scientists Awards. The vision of WIHG is “Questing for Himalayan Seismogenesis, Geodynamics, Geo-Hazards, Climate Variability, and Geo-Resources through Geoscientific study to fulfill the Societal Needs and pursue Basic Sciences”.

The Institute is structured into seven major R&D Activities (mentioned below) to focus on the multidisciplinary mission mode project entitled “Characterization and Assessment of Surface and Subsurface Processes in Himalaya (CAP Himalaya): Implications on Geodynamics, Sesimogenesis, Bio-

Events, Paleo-climates, Natural Hazards and Natural resources for Sustainable Development".

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

An executive summary of the significant contributions in each of the activities is highlighted below along with other activities of the Institute.

Geodynamics of Indo-Eurasian collisional zone - Crustal evolution, carbon sequestration and mineralization

- Geochemical and Geochronological studies carried out in the Siang Window (SW) of Arunachal Himalaya reveal that the major magmatic event in the core of the SW is coeval with the Rajmahal-Sylhet-Mikir-Shillong flood basalts of eastern and northeastern India and the Comei-Bunbury Large Igneous Province of SE Tibet and SW Australia. These events are related to the breakup of eastern Gondwana and the outbreak of the Kerguelen plume.

- The Tidding-Mayodia ophiolites exposed along the Lohit and Dibang river valleys in the eastern Himalaya consist of depleted harzburgite and dunite with lesser amounts of mafic rocks (gabbro intrusives, mafic dykes) and carbonates. The geochemical study suggests that the Tidding-Mayodia ophiolites have formed from the entrapment of depleted Normal-Mid Oceanic Ridge Basalt (N-MORB) mantle in the mantle wedge of an intra-oceanic subduction zone.

- Newly obtained U-Pb zircon geochronological ages in a combination with available zircon ages of the Jutogh Thrust sheet range (between 550.0 Ma and 2750.0 Ma), with two main peaks (~825.0 Ma and ~910.0 Ma), envisages that the Higher Himalayan Crystalline Sequence was meta-sedimentary and was deposited in an active margin set-up during the Neoproterozoic period.

- The partial melting model indicates that the Mandi-Kathindi mafic rocks were generated at a depth corresponding to 3-4 GPa by partial melting ranging from 5% to 20% from the mantle plume. All the basalts and dykes from the Mandi-Kathindi section did erupt/intrude in an intracontinental rift setting based on geochemical discrimination

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

- Quartz-calcite veins of the ophiolitic mélange in the Indus Suture Zone preserve a diversity of fluid activity in the late stages of ophiolitic mélange formation. The microstructures of quartz and calcite veins indicate deformation temperatures between 200°C and 400°C. The $\delta^{13}C$ and $\delta^{18}O$ values of calcite veins from the ophiolitic melanges are within the mixing hyperbolas of marine and primitive-mantle fields in the mixing model.

- The Sr and Pb isotopic study of calcite veins from the Zildat Ophiolitic Melange (ZOM) revealed a mid-ocean ridge basalt (MORB) fluid source of vein formation that was radiogenically enriched by metasomatism in a supra subduction zone.

- The microthermometry fluid pressure-temperature estimation of veins from the studied sections suggests that the maximum depth of emplacement of veining fluid was about 24.5MPa (corresponding to ~ 2.5 km) at 336°C. The vein-forming fluids (calcareous and siliceous) were introduced into the fractures that developed in the host as a result of deformation.

- Ladakh granites are fractionated S-type granite with syn-collisional affinity. They are also enriched in Rb, Ba, U, Th, and Pb and depleted in Ti, P, Zr, Hf, Nb, and Ta indicating a middle-upper continental crust affinity, with evolved continental crustal signature of high $(Sr^{87}/Sr^{86})_I$ = 0.698-0.719 and a large negative $\varepsilon Nd_{t=0}$ values of (-12.3) to (-4.2). The study shows that they were sourced from two different heterogeneous crustal components of the source of radiogenic heat melting likely the medium to high-grade metasedimentary rocks (supra crustal rocks) of mature middle-upper crustal rocks melting and the Greater Himalayan crystalline rocks (metagranite).

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

- High-quality, three-dimensional (3D) seismic reflection data have been used to investigate the structural growth and evolution of faults within a geologically complex region in the Upper Assam Basin, NE India which is bounded by fold-and-thrust orogenic belts.

- Seismic textural responses have been studied in detail using 3D seismic data to decode the depositional environment of the Oligocene-Miocene subsurface sedimentary successions in the Upper Assam Basin of NE India.

- Different seismic experiments using an open source database have been performed to improve a detailed understanding of seismic interpretation techniques and their applications.

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

- About 800 micro-earthquakes ($1.0 \leq M \leq 4.5$) recorded by 12 stations of Kinnaur Himalaya from 2008 to 2012 are relocated and obtained 1D velocity structure that show the division of the upper 35 km thick crust into 8 layers with variable Vp/Vs values. The 5-25 km depth range is marked as a seismogenic zone.

- The computations of source parameters of 75 earthquakes of the Kinnaur Himalaya show the ranges of source parameters e.g. seismic moment (2.73×10^{11} – 3.44×10^{14} N-m), stress drop (0.03–13 bar), source radius (0.3–0.9 km), and radiated energy (5.64×10^{02}–1.19×10^{08} J).

- The detailed crustal structure has been imaged by surface wave tomography from Bangal Basian to the Bangong Suture zone showing a variation of crustal thickness ranging from ~35 km to 70 km and imaged the sedimentary cover in the Bengal Basin and Indo-Gangetic as well as Brahmaputra Basin.

- A seismotectonic study in the Eastern Himalayan Syntaxis reveals micro-seismicity up to ~40 km depth. The Mishmi, Lohit, and Tidding faults are characterized as steeply dipping thrust faults accommodating large crustal shortening whereas the Walong fault is characterized as a strike-slip fault that facilitates rotational tectonics.

- The seismic anisotropy and gravity lineament studies in the Kumaon Himalaya reveal that predominant NE-SW and NW-SE oriented crustal anisotropy originates due to the combined effect of stress-aligned micro-cracks due to regional tectonic stress and local geological features.

- Detected low-stress drop earthquakes (~0.06-64.36 bar) in the Ladakh-Karakoram zone caused by the possible presence of aseismic creeping patches in the Karakoram Fault. A partial stress drop mechanism is proposed for low-stress drop in the forearc region.

- Magnetotelluric imaging was carried out around

Delhi NCR (Budaun-Moradabad profile). The bottom resistive part represents the Precambrian basement and the resistivity section of TM polarisation shows a break in the resistive basement where recent Moradabad earthquake (strike-slip) occurred.

Seismicity and seismic hazard assessment in the Himalaya

- The study of source zones of the present, as well as past earthquakes along the Himalayan seismic gaps, reveals that the moderate earthquakes occurring on the ramp section of the flat-ramp geometry of the MHT has more possibility of reaching to the frontal Himalaya.
- Receiver function imaging beneath the Doda-Kishtwar region reveals that the crustal thickness varies from 47 km to 58 km from south to north and detected a mid-crustal low-velocity zone suggesting the presence of fluid/partial melt. The MHT is inferred at a depth range of ~21-26 km.
- Site amplification study for the seismically active Garhwal Himalayan region shows a low attenuation quality factor (Qo) value (<200) and a high degree of frequency (n) value (>0.8) for the Garhwal Himalaya. A regional quality factor relationship of form, $Q_\beta(f) = (102 \pm 3.9)f^{(1.0\pm0.1)}$ is established for the region.
- A seismic anisotropy study using SKS/SKKS splitting analysis in the mantle beneath NW Himalaya covering the Delhi–Hardwar Ridge (DHR) reveals anisotropy directions parallel to the strike of the DHR. Wide variations of delay times suggest a complex source of anisotropy.
- Seismicity and source parameter estimations of local earthquakes in the Siang Valley, Arunachal Himalaya show that the region is seismically active up to ~50 km. The source parameters (e.g. stress drop: 0.5-114.5 bars, seismic moment: 2.30E +11 Nm to 6.86E+16 Nm, and source radius: 116-1392m) and scaling relations have been estimated for the first time.

Biotic evolution with reference to Indo-Eurasian collision – evidences for global events

- A new mammalian faunal assemblage representing ruminants (Tragulids) was revealed from the late Oligocene Kargil Formation of the Ladakh Molasse Group. These fossils were attributed to *Nalameryx savage*
- A new genus and species of fossil tree shrew were identified from the Lower Siwalik (middle Miocene) succession of the Ramnagar area, (Jammuand Kashmir). The new fossil discovery is very significant as it represents fossil tree shrews and hedgehogs which are very poorly known from the Siwaliks. The new tree shrew was named as *Sivatupaia ramnagarensis,* and the present locality now represents the oldest record of fossil tupaiids in the Siwaliks and extends their time range in the region by ~2.5- 4 million years.
- A new assemblage of microvertebrate and arthropod faunas has been reported for the first time from the Nurpur region of Himachal Pradesh. The present assemblage consists of rodents such as *Karnimata* cf. *K. darwini* and Murinae indet; reptiles such as Crocodylia indet, 'Colubrinae' indet or 'Natricinae' indet.; fishes such as Cyprinidae indet. and Perciformes indet.; and crab *Sartoriana* indet.
- The spatial–temporal heterogeneity in a small post-glacial lake of the Lahaul Himalaya and its influence on paleoclimate reconstruction is explored. The depocenter of the lake (CC) received ~ 2.5 times higher average sedimentation compared to the shore margin (CPT).

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

- Variation in lake levels and hydrology over the Trans-Himalaya and Tibetan Plateau is reconstructed by studying the deltaic sequences of the Pangong Tso. Three phased lake level changes are observed during the past 3 ka.
- Oxygen isotope records from the Mawmluh cave, Meghalaya suggests a pronounced weakening of the Indian summer monsoon in northeastern India from 4.25 kyr BP that lasted till 4.0 kyr BP, and linked with the cold-arid 4.2 kyr BP global event.
- The chronology of moraines shows glacial advances in the Yankti Kuti valley, upper Kali Ganga catchment of the Kumaon Himalaya,

during 52.8±3 – 50.4±3 ka (MIS 3), ~36.4±1.8 to34.5±2.2 ka (late MIS 3), followed by its termination that continued until ~ (~30.3±2 ka). The second glacial advance took place during ~22.2±1.1–21.4±1.2 (global last glacial maximum), one re-advance/standstill occurred following MIS 2 at 16.1±0.1 ka (late-glacial) and ~4.4±0.4–4.2±0.1 ka (Mid-Holocene) in the Central Himalaya.

- Sedimentological facies analysis from Mesoproterozoic (~1.6 Ga) Rautgara Formation, Lesser Himalaya, identified the presence of mixed (wave-tide) energy estuarine depositional setting. A total of five facies associations have been identified i.e., i) tidally influenced fluvial, ii) wave dominated shoreface-foreshore, iii) Tidal flat iv) tidal channel and v) Intertidal tidal channel-bar complex.

Ecology and climate dynamics of the Himalaya-Cenozoic to present

- Two major wet and warm (1839-1890 AD and 1929-1959) and two arid (1890-1929 AD and 1959-2003 AD) phases of the climate were observed in Renuka Lake. It has also been observed that the relationship between El Niño–Southern Oscillation (ENSO) and the Indian summer monsoon (ISM) was weakened and the influence of the Indian Ocean Dipole (IOD) increased theIndian summer monsoon rainfall.
- The grain-size data, generated from Laser Particle Size Analyzer (LPSA), corroborates the lithology of the peat section, from Chamoli, Central Garhwal Himalaya. The results suggest both low and high-energy conditions down the core.
- From the OSL age dating, it appears that the paleoclimatic reconstruction of around 6000 years old sedimentary sequence could be possible from the peat section, Chamoli, Central Garhwal Himalaya.
- Ring-width chronology was prepared using *A. pindrow* trees growing in Din Gad valley, Dokriani glacier region, Uttarakhand. The reconstruction of the 247 years (AD 1769-2015) records revealed maximum mass loss and mass gain during AD 1887-1917, 1793-1823, and, AD 1827-1857, 1925-1955, and 1968-1998, respectively.

Geological and geomorphic controls on landslide for risk assessment and zonation in the Himalaya

- A regional scale landslide susceptibility mapping of the state of Himachal Pradesh has been carried out to indicate landslide hotspots. An inventory of 2034 active landslides was prepared by identifying landslides on high-resolution satellite images.
- The landslide is one of the major modifying agents of landforms of the Main Boundary Thrust (MBT) zone in the Kosi River valley. The instability of the slope resulted from repeated splitting of the sheared and deformed rocks due to movements along the thrust planes.
- The tectonically induced lake has been reported from the Champawat area in the outer Lesser Himalaya of Kumaon. The lake originated before 17 ka and the water drains out after 13 ka, it resulted from tectonic activity along a system of normal faults.
- Permanent Scatterer Interferometry (PSI) time-series analysis in Chakrata Block and adjoining areas reveals very less active landslides that are localized at some places like Amraha and Kunain which are mostly of anthropogenic origin. Geological formations and subsurface processes seem to control the Kunain major slide in Chakrata. The scatterer points, where a slope movement can be mapped, show a cumulative displacement up to 200 mm, with a velocity of ~100 mm/year.
- The Chakrata town area is a relatively stable land surface. On a regional scale, the slow land movements are seen to be accelerated in the post-monsoon times, which shows even up to 100 mm/year displacements at points where coherence could be obtained.

Glacial dynamics, glacier hydrology, mountain meteorology and related hazard

- The glacier study of the Zanskar Himalaya, Ladakh shows that the cumulative net balance of the Pensilungpa glacier (PG) was ~ (-)8.1 x10^6 m^3 in 2019-2021 (02 years) with a specific balance of (-) 1.12 m we. However, the equilibrium-line altitude (ELA) of the glacier is located at 5232 m asl, while the Accumulated Area Ratio (AAR) of the glacier is about 0.43.

- The meltwater discharge of the Parkachik stream for the periods of September and October (2 months) between 2017 and 2021 has been estimated. The volume of water discharged from the glacier was estimated to be 31 x10^6 m^3 (43 days) in 2017, 26.49 x10^6 m^3 (42 days) in 2018, 54.40 x10^6 m^3 (51 days) in 2019 and it was 36.06 x10^6 m^3 (49 days) in 2021.
- The investigation in the Tapoban Geothermal field (Uttarakhand) reports the presence of ~874.35 x 10^{11} KJ geothermal heat energy. The energy estimated for the binary power plant is ~1.02 MWe and 0.71 MWe for 20 years and 30 years, respectively
- The devastating Chamoli disaster of February 07, 2021, has been studied in a multidisciplinary approach. The satellite imagery, numerical modeling, and field evidence reveal that ~27 × 10^6 cubic meters of rock-ice mass collapsed from the steep north face of Ronti Peak. A sequence of precursory signals of main failure/detachment was found in seismological data preceded by a dynamic nucleation phase. The rock-ice avalanche appears to have been initiated by seismic precursors which were continuously active for 2:30 h before the main detachment.
- In-situ glacier melt consisting of suspended sediment concentration has been investigated in detail over the acquired data from streams of Pindari and Kafni glaciers in the central Himalayan valley using the Artificial Neural Network approach and Multi-Linear Regression analysis.

Hydrogeology-Himalayan Fluvial System and Groundwaters

- Rock weathering in the Ganga-Brahmaputra River catchments has significant control on the CO_2 level in the atmosphere and hence influences the climate on longer time scales under greenhouse conditions.
- Geochemical and isotopic study in the Teesta River system infers the role of Sulfuric Acid in continental weathering, Riverine Strontium fluxes, and Hydrological Processes in the Basin. The role of H_2SO_4 in the continental weathering process is also inferred from the stable isotope measurements conducted on Doon groundwater and Rivers.
- It is evident from experiments that [Sulfate] in Teesta is higher (92±47 µM) than regional rainwater (~5 µM). It implies that ~Half of the Cations from H_2SO_4-mediated weathering. At outflow, the CO_2 uptake (Sil. ~4.9x10^5 moles/km^2/y) and release H_2SO_4-Carb (~3.9x10^5 moles/km^2/y) rates are nearly in balance.
- The dissolved Sr and ^{87}Sr flux to the Bay of Bengal (Brahmaputra River) 1×10^7 moles/yr and 7.1×10^5 moles/yr, respectively. It contributes to 0.03% of the global riverine supply to the oceans.

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

- Paleoseismological investigations in the frontal Mishmi Range (MR) of the EHS show evidence of the surface rupture of the 1950 earthquake along a fault scarp at Kamlang Nagar in the MR of Arunachal Himalaya.
- Middle-to-Late Miocene exhumation history along the Uttarkashi-Gangotri-Gomukh transect of the NW Himalaya has been studied through a total of 29 new Apatite and 29 new Zircon Fission Track (AFT & ZFT) data. The youngest AFT ages obtained from the rocks within the Vaikrita Thrust zone suggest that the rocks in this zone cooled rapidly, probably due to the re-activation of the Vaikrita Thrust.
- Based on GPS velocities the estimated surface shortening rate across the Garhwal Himalaya is 16 ± 0.8 mm/a. The linear surface shortening rates between the Higher and the Lesser, Lesser and the Sub and Sub and the Gangetic plains across the Garhwal region are also estimated as 7.38 ± 0.24 mm/a, 2.40 ± 0.02 mm/a, and 1.26 ± 0.02 mm/a respectively. The overall linear surface shortening rate estimated across the Kumaun Himalaya is 17.62 ± 4.6 mm/a.

- Correlation of interseismic strain rate with topography suggests that along the low strain rate corridors in the Garhwal-Kumaun Himalaya; particularly, in the Lesser Himalaya the strain rate changes are out-of-phase with the topography. This indicates that the strain transfer process from the high compressional Main Central Thrust zone to the frontal part of the Himalaya is primarily regulated by the structural complexities involved with the sub-surface Lesser Himalayan duplex system.

Academic Pursuits

The scientist and research scholars of WIHG have published a total of 112 research papers in peer-reviewed journals of national and international repute during 2021-2022. A total of 12 research scholars received their Ph.D. degrees while 4 more researchers submitted their Ph.D. theses during the reporting period. The institute provided laboratory facilities/analytical services to various organizations, and academic institutions, particularly to young researchers. Library facilities are provided not only to the institute researchers but also to the students/researchers coming from different organizations/Universities. The scientists of the Institute provided Summer and Winter Training (both offline and online), leading to Dissertations of more than 272 Master's students. The museum of WIHG is visited by several Indian and foreign visitors. The Institute has successfully organized the 5th National Geo-Research Scholars Meet (NGRSM) through webinar during 22-23 July 2021 intending to encourage young researchers and students for improving their research interests, providing them a platform to share their research work, receive feedback from the peers and refine their ideas.

The 42nd Annual Convention and Exhibition of the Association of Exploration Geophysicists (AEG) was successfully organized (in virtual mode) by WIHG jointly with the AEG during December 01-03, 2021 with a special theme on “Himalayan Geology and Exploration Geophysics” with reference to Natural Hazards, Minerals, and Hydrocarbon Exploration. The convention was started with a one-day workshop on “*Artificial Intelligence for Advanced Interpretation of 3D Seismic Data*” and “*New Frontiers in Hydrocarbon Exploration*” coordinated by WIHG and GEOPIC, ONGC, Dehradun.

The Institute published a biannual SCI journal “Himalayan Geology” (impact factor: 1.293). The Institute also published a Hindi Magazine 'Ashmika' during 2021-2022. The AcSIR (Academy of Scientific & Innovative Research) at WIHG aims to disseminate advanced knowledge in the field of Geosciences through teaching and research by WIHG scientists with extensive work experience. Emphasis is given to emerging areas and interdisciplinary research in earth sciences for the benefit of Geo-Sciences society, and the intellectual and academic welfare of the people. About 60 students have enrolled in the Ph.D. program under AcSIR since its inception in 2021.

Institute scientists received several prestigious awards and honours on various platforms. Dr. Kalachand Sain received the J.C. Bose National Fellowship (2021) from SERB-DST, GoI as well as the National Award for Excellence in Geosciences (2021) from the Ministry of Earth Sciences (MoES), New Delhi. Dr. P.C. Kumar was awarded with the Associateship (2021) of the Indian Academy of Sciences, Bangalore. He was also awarded with the NASI-Young Scientist Platinum Jubilee Award (2021). Dr. Anil Kumar was conferred with the Dr. J. G. Negi Young Scientist Award (2021) of the Indian Geophysical Union (IGU). Dr. Sameer Tiwari received the prestigious N. N. Chatterjee Award (2021) from the Geological Society of India. The WIHG was adjudged with the Best Stall Award (2021) at the Rise in Uttar Pradesh mega Exhibition. Besides these, Miss Shiva Kalyani received the Anni Talwani Memorial Travel Grant from IGU.

Other Highlights

Several eminent dignitaries visited WIHG. Dr. Shekhar C. Mande, Secretary, DSIR and Director General, Council of Scientific & Industrial Research, New Delhi delivered the S.P. Nautiyal Memorial Lecture held on June 17, 2021, at WIHG, Dehradun. Former Chief Minister of Uttarakhand Shri Trivendra Singh Rawat visited WIHG, Dehradun on September 13, 2021. Mr. Vishal Shastri, Executive Director-Head of GEOPIC, ONGC, Dehradun delivered the Founders Day Lecture on the topic “Energy Scenario and Indian Hydrocarbon Sector”. The 'W. D. West Memorial Lecture'- 2021 was delivered by Prof.

Ashutosh Sharma, Former Secretary to the GoI, Dept. of Science and Technology, New Delhi in November 2021. His Excellency Mr. Gudni Bragason, Ambassador of Iceland to WIHG, Dehradun on November 12, 2021. Mr. Shrikant N. Chitnis, Executive Director and HoI- KDMIPE, ONGC, Dehradun delivered the New Year talk on the topic "*Hydrocarbon Exploration Gamut: Advances and Challenges*". His Excellency Mr. Hans Jacob Frydenlund, Ambassador of Norway to India visited WIHG on March 25, 2022.

The Institute observed national days of importance with great enthusiasm and various government programs like Swachch Bharat Abhiyan etc. in an utmost manner. The Institute followed the Rajbhasa guidelines. The Hindi Pakhwara was celebrated from 14 Sep to 28 September 2021. Various steps were taken to promote the use of Hindi in routine work as well as in Scientific Research publications. General official orders, circulars, notices, etc. were issued in the bilingual form to promote the use of Hindi. As a part of celebrating **'Azadi ka Amrit Mahotsav'**, the institute organized several talks by eminent scientists and professors, which are being continued till date to complete 75 Lectures.

Kalachand Sain
Director

ACTIVITIES

Activity:1A

Geodynamics of Indo-Eurasian collisional zone - Crustal evolution, carbon sequestration and mineralization

(A.K. Singh, Barun K. Mukherjee, Paramjeet Singh, Pratap Chandra Sethy and M. Rajanikanta Singh)

Magmatism in the Siang Window of Eastern Himalayan Syntaxis, Northeast India

The magmatic rocks have been investigated using new zircon U–Pb ages of mafic rocks (gabbro and andesite) along with whole-rock geochemistry of mafic and felsic suite of rocks from the Siang Window, Eastern Himalayan Syntaxis (Fig. 1). The new data define the timing of the emplacement of magmatism in the Siang Window in context to the tectonic evolution of the Eastern Himalayan Syntaxis.

Field observations along with the mineralogical and geochemical characteristics of the studied mafic-intermediate-felsic rocks suggest their co-magmatic linkage that was generated in an extensional tectonic environment. Incompatible trace elements and low concentrations of Large-Ion Lithophile Elements (LILE) and Rare Earth Elements (REE) behavior reflect both the enriched nature of the mafic rocks and the limited influence of crustal contamination in their genesis. Partial melting and fractional crystallization processes have played a major role during the genesis of the felsic volcanic rocks of the Siang window.

The zircon U-Pb ages estimated by Laser Ablation - Inductively Coupled Plasma - Mass Spectrometry (LA-ICP-MS) suggest that the mafic plutonic rock was emplaced ~121.18±1 Ma and intermediate volcanic rock was emplaced ~135.48±0.50 Ma during the early Cretaceous period (Fig. 2). The new ages are consistent with earlier reported zircon U-Pb ages (130.7±1.8 to 133.0±1.9 Ma) of felsic volcanic rocks from the present study area.

The obtained zircon U-Pb ages from the present study show that both the mafic plutonic and felsic volcanic rocks of the study area are coeval with the Cona igneous province of southeast Tibet and the Bunbury basalt of southwestern Australia. It was reported that Sangxiu A-type granite rocks are dated as ~133 Ma, and the associated Sangxiu basalts can also be compared to those of the Kerguelen basalts. This mafic-felsic suite was interpreted to be the consequence of interactions between the Kerguelen hotspot and the northeastern margin of the Greater Indian lithosphere. Both units are believed to have formed simultaneously, during the initial breakup of southwest Australia and Greater India. Since the studied rocks are found to have been emplaced in a continental extensional environment and their U-Pb zircon ages (~121–135 Ma) are similar to those of the Comei-Bunbury Large Igneous Province (LIP) of ~ 132 Ma. The geochemical characteristics have been investigated to evaluate the correlation of the studied rocks with this LIP magmatism. Combining all our geochemical and geochronological evidence as well as previous studies, it is proposed that the magmatic rocks of the Siang Window are related to the Kerguelen plume activities of the early Cretaceous. A generalized plate tectonic reconstruction of the Gondwana supercontinent at 132 Ma, shows the studied rocks as part of the Comei–Bunbury LIP (Fig. 2).

The new field observations, mineralogical and geochemical characteristics in conjunction with the U-Pb isotopic database suggest that the major magmatic event in the core of the Siang Window of the eastern Himalaya is coeval with the Rajmahal-Sylhet-Mikir-Shillong flood basalts of eastern and northeastern India and the Comei-Bunbury Large Igneous Province of southeastern Tibet and southwest Australia (Fig. 3). These events are related to the breakup of eastern Gondwana and outbreak of the Kerguelen plume.

Tectono-magmatic evolution of the Tidding-Mayodia ophiolites, eastern Himalaya, northeast India

The Tethyan ophiolites exposed along curvilinear suture zones in the Alpine-Himalayan orogenic system are highly diverse in terms of their structural and petrological features and emplacement mechanisms. The Tethyan ophiolite suite of rocks of the E–W trending Indus-Tsangpo Suture Zone turn sharply southwestward at the eastern Himalayan syntaxis, offset northward by the Sagaing Fault. The Tidding-Mayodia ophiolites exposed along the Lohit and Dibang river valleys in the eastern Himalaya that have been considered as the extension of the Indus-Tsangpo Suture Zone ophiolites, are revisited to review their petrogenetic-tectonic origin. The ophiolites consist of depleted harzburgite and dunite with lesser amounts of mafic rocks (gabbro intrusives, mafic dykes) and

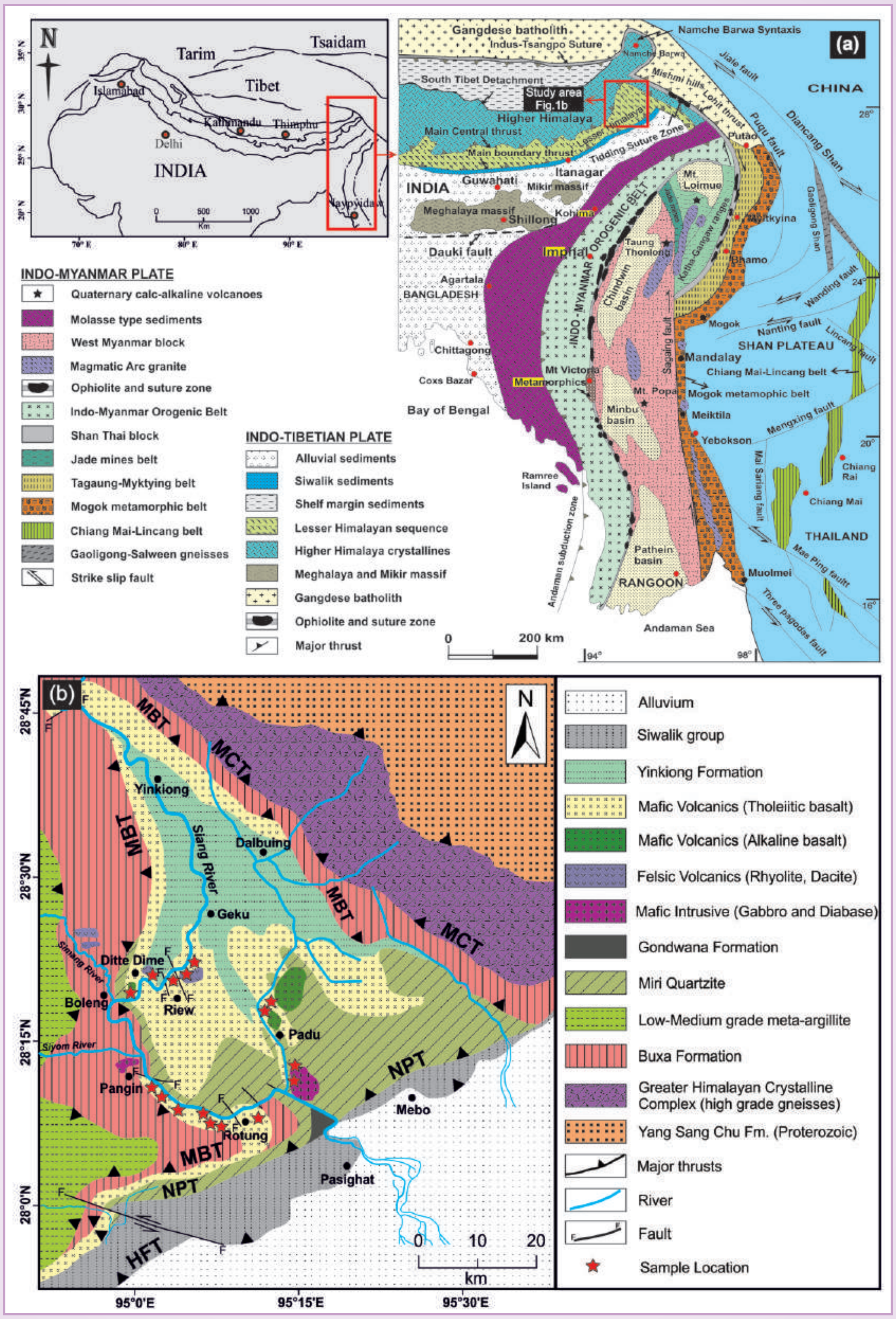

Fig. 1 : (a) Geological map of eastern Himalaya, Indo-Myanmar Orogenic Belt, northern and central Myanmar, and adjacent areas. (b) Geological map of Siang window. HFT – Himalayan Frontal Thrust; NPT – North Pasighat Thrust; MBT – Main Boundary Thrust; MCT – Main Central Thrust.

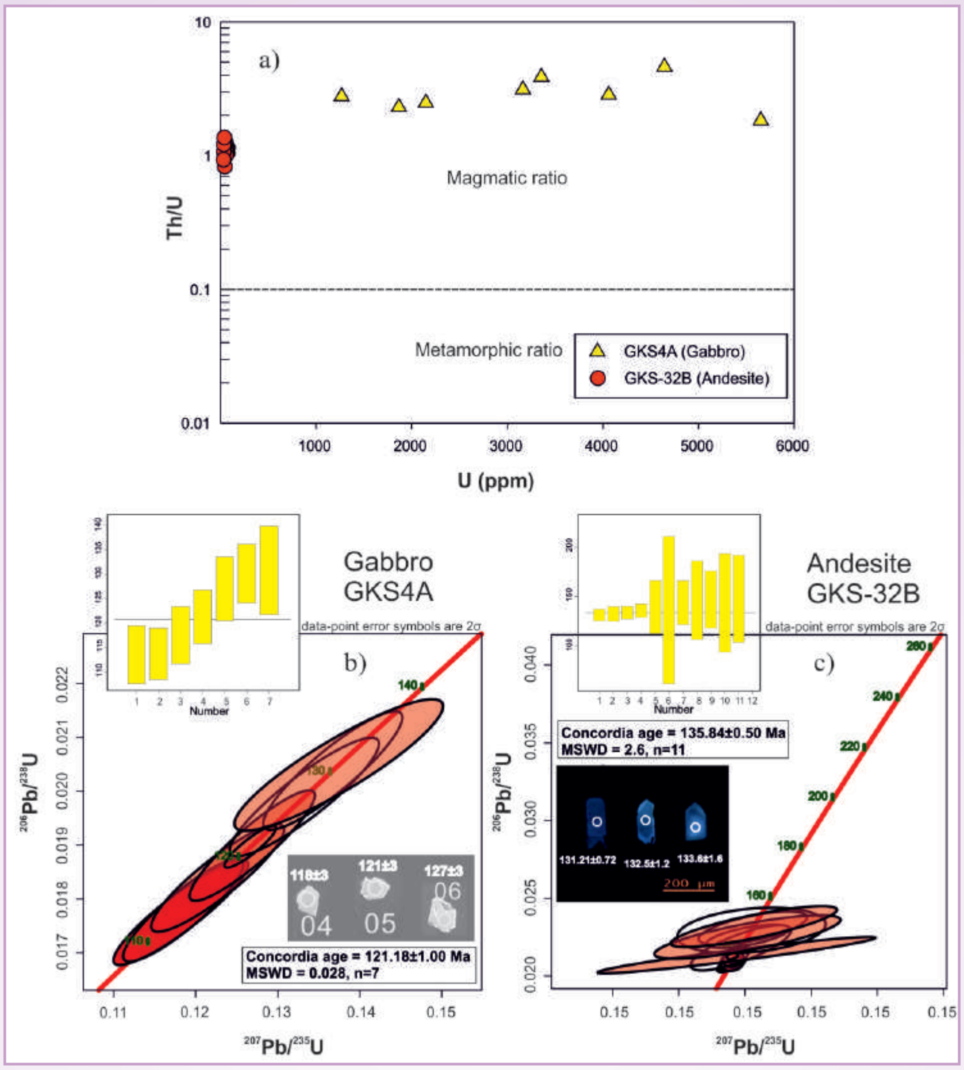

Fig. 2 : (a) U vs. Th/U plot shows that all the analyzed zircons from gabbro and andesite are plotted in the magmatic zircon field (b) U-Pb Concordia diagram of zircons grains from gabbro (sample GKS8A) and (c) Andesite (sample GKS32B). Their respective weighted mean $^{206}Pb/^{238}U$ age plots are also shown.

carbonates. The serpentinized peridotites consist of antigorite, lizardite, olivine, Cr-spinel, and bastite with minor sulfide minerals. From Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) studies, sulfide minerals were observed to be associated mainly with magnetites. The main sulfide mineral is pentlandite with minor millerite that exists as inclusions inside the pentlandite grains. Elemental mapping of these sulfides shows that they are mainly Ni-(Co-)-bearing sulfides. The olivines are highly forsteritic (Fo = 95–96) while the Cr-spinels show distinct Cr-magnetite rims with a chromite core (Cr# = ~93). The serpentinized peridotites have whole-rock compositions of SiO_2<47 wt% and high MgO (>36.37 wt.%) and low Al_2O_3 (<1.21 wt.%), CaO (<0.82 wt.%), indicating the depleted nature of the parent rocks. Highly fractionated Light Rare Earth Elements (LREEs) as compared to Heavy Rare Earth Elements (HREEs) [(La/Yb)N = 2.62–13.22], and REE and Cr spinel chemistry modeling suggests that the studied peridotites have formed from ~22% partial melting of a depleted spinel lherzolite source which later underwent interactions with a high-temperature silicate melt that caused enrichment in LREE and Cr of spinels. The parental melt compositions of Cr spinel yield their formation during arc tectonism (Al_2O_3melt = 6.28–7.65 wt.%, FeO/MgO = 1.00–1.33). Furthermore, Mn and Zn concentrations in spinels, the occurrence of Cr

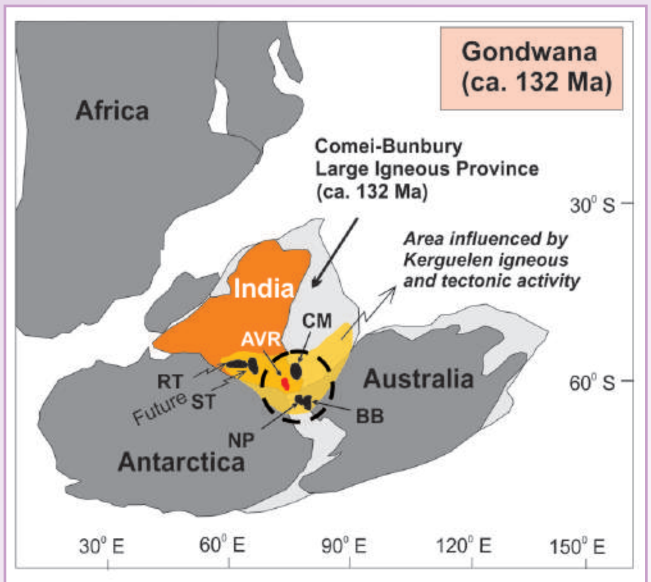

Fig. 3 : Generalized plate tectonic reconstruction of Gondwana at 132 Ma, showing the magmatic rocks of Eastern Himalaya is a part of the Comei-Bunburuy Large Igneous Province (LIP). Locations of Sylhet traps (ST), Rajmahal Traps (RT), Naturaliste Plateau (NP), Bunbury Basalt (BB), and Comei LIP (CM) are shown.

magnetite rim in Cr-spinels, the presence of secondary olivine with higher Fo (~98), and the occurrence of low-temperature re-equilibrated sulfide minerals, indicate that the rocks were subject to low-temperature metamorphism. Based on this evidence, combined with data from previous studies, a tectonic model has been proposed for the genesis of the studied ophiolites. This model shows that the ophiolites have formed from the entrapment of depleted Normal-Mid Oceanic Ridge Basalt (N-MORB) mantle in the mantle wedge of an intra-oceanic subduction zone. During the nascent forearc regime, this mantle wedge underwent interactions with high-temperature melts, which caused changes in their chemistry. Moreover, the rocks underwent interactions with low-temperature fluids in the mature forearc, which caused the formation of sulfides and metamorphosed these rocks.

Geochemistry and U-Pb (zircon) Geochronology of Jutogh Thrust sheet of Himachal Pradesh, India

During the late-Oligo-early-Miocene periods, the crumpled part of the Higher Himalayan Crystalline Sequence (HHCS) was thrust over the Lesser Himalaya Sequence (LHS) along the MCT in the south direction. The far-traveled thrust sheets (i.e. southern extension of the HHCS) thrust over the LHS zone are known as the Jutogh Thrust sheet in the eastern Himachal Pradesh, Lansdown-Almora- Baijnath-Askot klippen in the Kumaun-Garhwal region (Fig. 4). The metapelites and granitic gneisses of the Jutogh Thrust sheet are enriched with moderate to high SiO_2, Al_2O_3, Na_2O, K_2O, rare earth elements (REEs), and depletion in mafic elements. The A/CNK ($Al_2O_3/CaO+Na_2O+K_2O$) ratio range ≥ 1, indicates the peraluminous nature, calc-alkaline series, and S-types granitoids. The high values of Rb and Th as compared to Nb and negative Ba anomaly also suggest the crustal dominance of source material. The distinct enrichment of LILE of Rb, Th, K, Ba, Pb and strong depletion in high-field-strength elements (HFSE) of Zr, Nb, and Ti results in high incompatible elements/HFSE ratios, which suggests that source derived from many intra-crustal tectonic environments. All samples are well-fractionated REEs pattern [(La/Yb)N = 6.06-17.37)] and characterised by moderately flat enriched [(La/Sm)N = 2.31-4.71)] of light rare earth elements (LREEs). The negative Eu anomalies (Eu/Eu*= 0.18 to 0.71), suggest the plagioclase fractionation from the sourced magma and origin of gneisses through the high temperature (~800˚C).

The zircon U-Pb ages of granite range between 883.0 ± 15.0 Ma and 1260.0 ± 10.0 Ma, with only one consistent peak of ~929.0 Ma (Fig. 5a). It confirms that the northern edge of the Indian plate collided with the microcontinent and in contemporaneous process, the upper crust underwent partial melting, and magma generated during the process has intruded in an extensional tectonic set-up of the northern edge (i.e., the presently known as Jutogh and Vaikrita thrust sheets) of the Indian plate during the Neoproterozoic periods. The available zircon U-Pb age of the Jutogh Thrust sheet ranges between 550.0 Ma and 2750.0 Ma, with two main peaks of ~825.0 Ma and ~910.0 Ma (Fig. 5a), which reveals that the Higher Himalayan Sequence was meta-sedimentary and was deposited in an active margin set-up during the Neoproterozoic period. The magmatic nature of zircons and two peaks reveal episodic magmatic processes that took place during the Neoproterozoic periods (Fig. 5b).

Geological field observations and geochemical characteristics along the Mandi-Kataula-Bajaura-Toss section of Himachal Pradesh, NW India

In NW-Himalaya, the Mandi-Kataula-Bajaura-Toss section of Himachal Pradesh covers all the litho-tectonic units of the Himalayan fold-thrust belt (Fig. 6). It comprises (i) the Lesser Himalayan Sequence (LHS), which includes Shali and Rampur groups, and (ii) low to

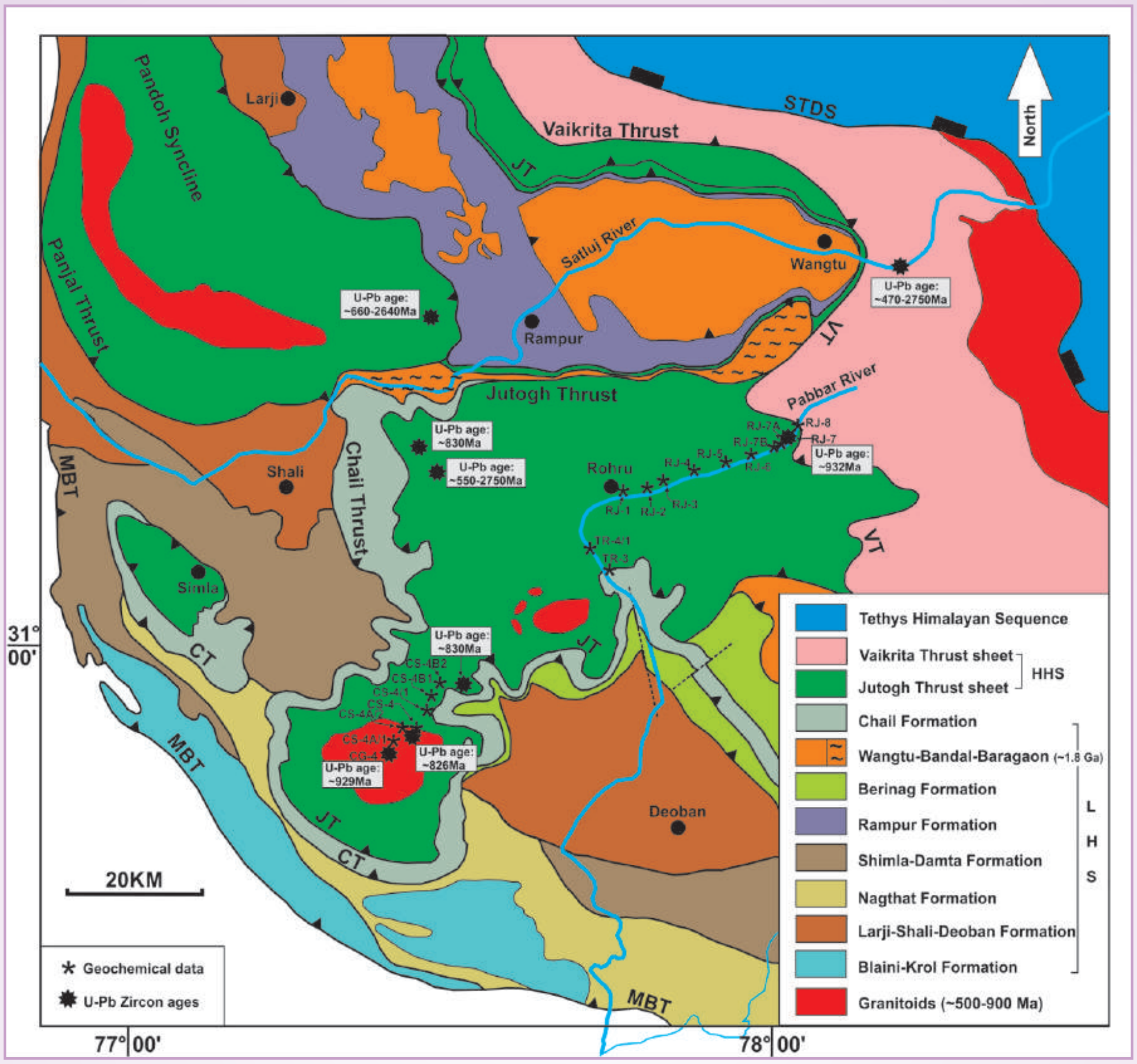

Fig. 4: Geology and tectonics map of the Himachal Himalaya. MBT: Main Boundary Thrust; CT: Chail Thrust; JT: Jutogh Thrust; PT/MCT: Panjal Thrust/Main Central Thrust; VT: Vaikrita Thrust and STDS: South Tibetan Detachment System.

medium grade metamorphic of the Lesser Himalayan Crystallines, which includes the Kulu thrust sheet of the Himachal Himalaya. The meta-sedimentary sequence of the LHS in the south of the low to medium-grade metamorphic of the synclinal structure (also known as Pandoh Syncline) (Fig. 7) and Kulu-Rampur window in the north exposed along the Mandi-Kataula-Bajaura-Toss section. Based on field observations, the deformation behaviors, shear-sense indicators near major thrusts, and the grade of metamorphism of the Pandoh syncline of the Himachal Pradesh, NW-Himalaya have been identified.This study suggests that the southern and northern limbs of the Pandoh Syncline reached up to garnet-grade of metamorphism and the core part remains low-grade metamorphism (i.e. biotite grade). In both limbs of the synclinal structure, the garnet crystal size varies from 0.5 mm to 5 mm along the above-mentioned section (Figs. 7-8).

Geochemically, the investigated rocks have the characteristics of peraluminous, calc-alkaline to shoshonitic granitoids. Similarly, the petrography and geochemical studies of the Tosh granite, Himachal Pradesh have been carried out to understand its origin and explore the genetic relationship with the neighbouring granitic complex and have been classified as (a) tourmaline bearing and (b) garnet-bearing granite. Geochemically, they have the characteristics of

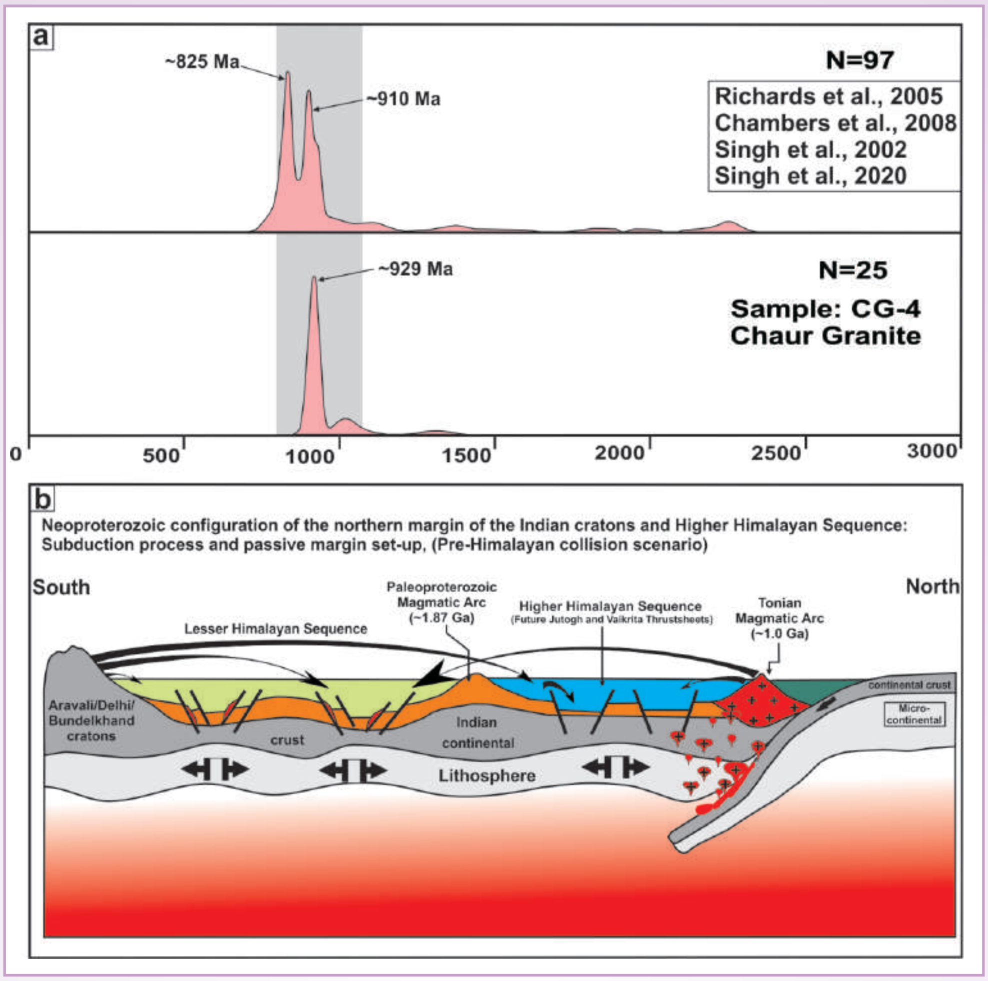

Fig. 5 : (a) Detrital zircon U-Pb age data generated from the (P1 and P2) age peaks sample locations, (b) Schematic diagram of the Neoproterozoic configuration of Indian cratons, which envisages an active Tonian magmatic arc (~1100-825 Ma) northern margin of the Higher Himalayan Sequence- an extensional tectonic setting (after Spencer et al., 2018; Mukherjee et al., 2019; Singh et al., 2022).

peraluminous and S-type granite. The primitive mantle normalized multi-element pattern exhibits a noticeable negative anomaly at P, Nb, Sr, and Ti which is a sign of the trait of calc-alkaline magmatic related subduction origin.

Geochemistry of continental rift basalts from Mandi-Kathindi section, Himachal Pradesh

Mafic volcanic and dykes from the Mandi-Kathindi section of Himachal Pradesh in the northwestern Himalaya were studied in order to constrain the nature of magmatism and its tectonic significance. These mafic rocks are identified as sub-alkaline basalt, basaltic andesite, showing tholeiitic affinity. Both rock types are characterized by similar mineralogical compositions overprinted by greenschist to lower amphibolite facies metamorphism. The Zr–Y–Nb–Th relationships indicates that both the rock type were derived from plume source whereas, low Nb/La (<1), similar LILE concentrations, and pronounced negative Nb, Zr, P, and Ti anomalies suggests that components other than mantle plume must have been involved in the generation of mafic rocks. Petrogenetic modeling indicates that the Mandi-Kathindi mafic rocks were generated at a depth corresponding to 3-4 GPa by partial melting ranging from 5% to 20% from the mantle plume, possibly in an intra-continental rift setting.

Low-density Indian continental crust explains complex continental tectonics

The integration of cathodoluminescence (CL) images, mineralogy of inclusions, and zircon U-Pb data of rocks

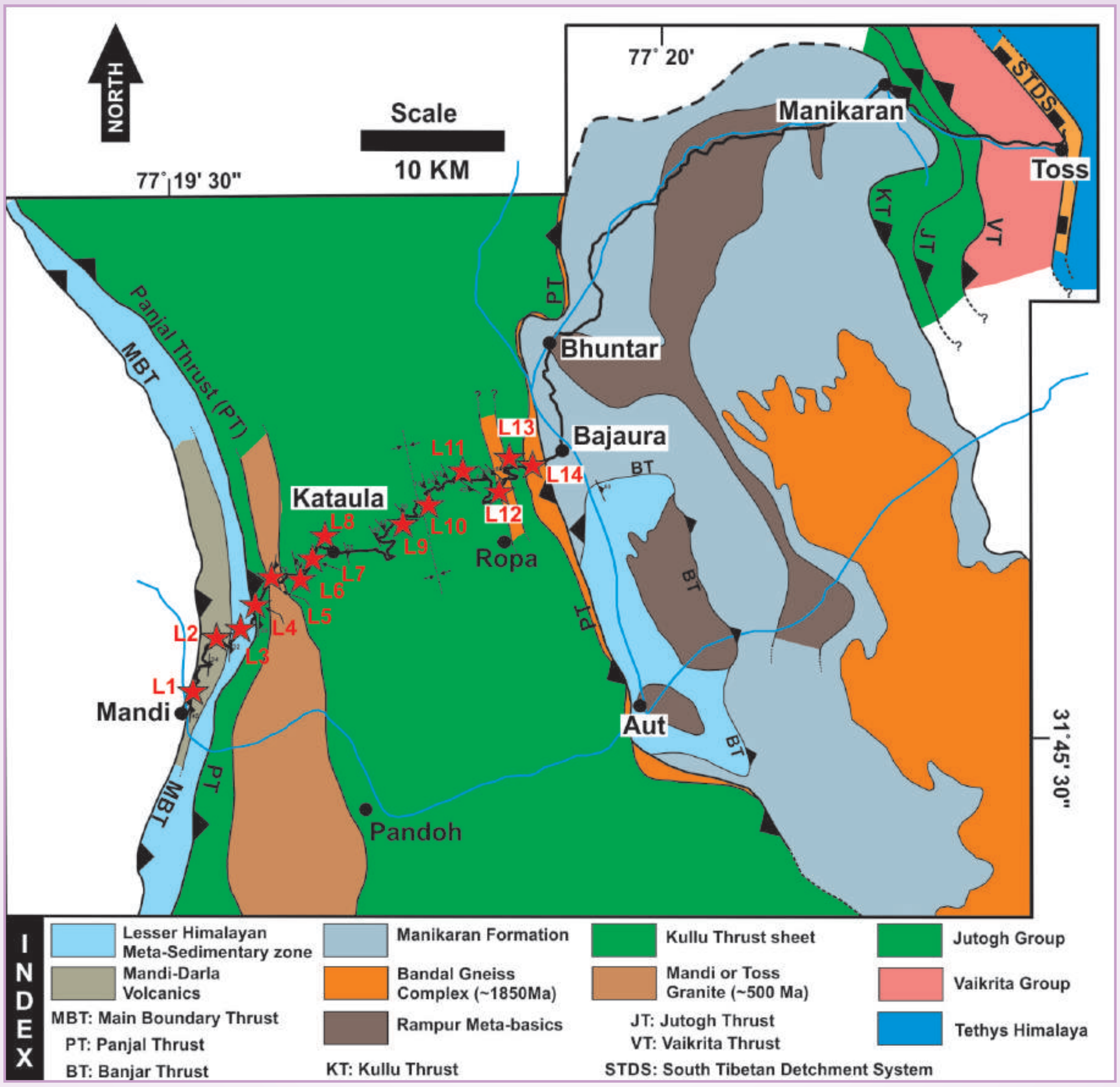

Fig. 6 : Geological and Tectonic map of the study area between Mandi-Kataula-Bajaura-Tosh sections of Himachal Pradesh. Sample locations are indicated by stars.

from the Himalayan Gneissic dome in the Tso Morari area, is undertaken to reconstruct and evolutionary history of subducted Indian crustal slice below Eurasia. Zircon is a faithful recorder of its precursor tectono-thermal events and it preserves the pressure-temperature–time (P-T-t) path. Using U-Th ratios aided by CL images of >50 gneiss zircons from the Tso Morari area, provide accurate identification of core, and mantle rim structure in the zircon growth during protolith formation and overgrowth during subduction and exhumation processes and also post-collisional metamorphism. It survives in varied pressure and temperature conditions from low-grade to Ultra-High Pressure (UHP)-grade metamorphism. Eocene age recovered from overgrown part of the zircons reveal, a period of subduction-related metamorphism. The cores at the same zircon, which show oscillatory zoning, are identified as inherited protolith. The growth of zircons in the crustal gneisses shows contrasting nature of metamorphic evolution as compared to the metamorphism of host gneiss, this study would add extra impetus to the long-standing principle debate between foreign vs in-situ model between a crustal rock and high-grade eclogite. This result has significant implications on the continental tectonics of the Indus Suture Zone, Himalaya.

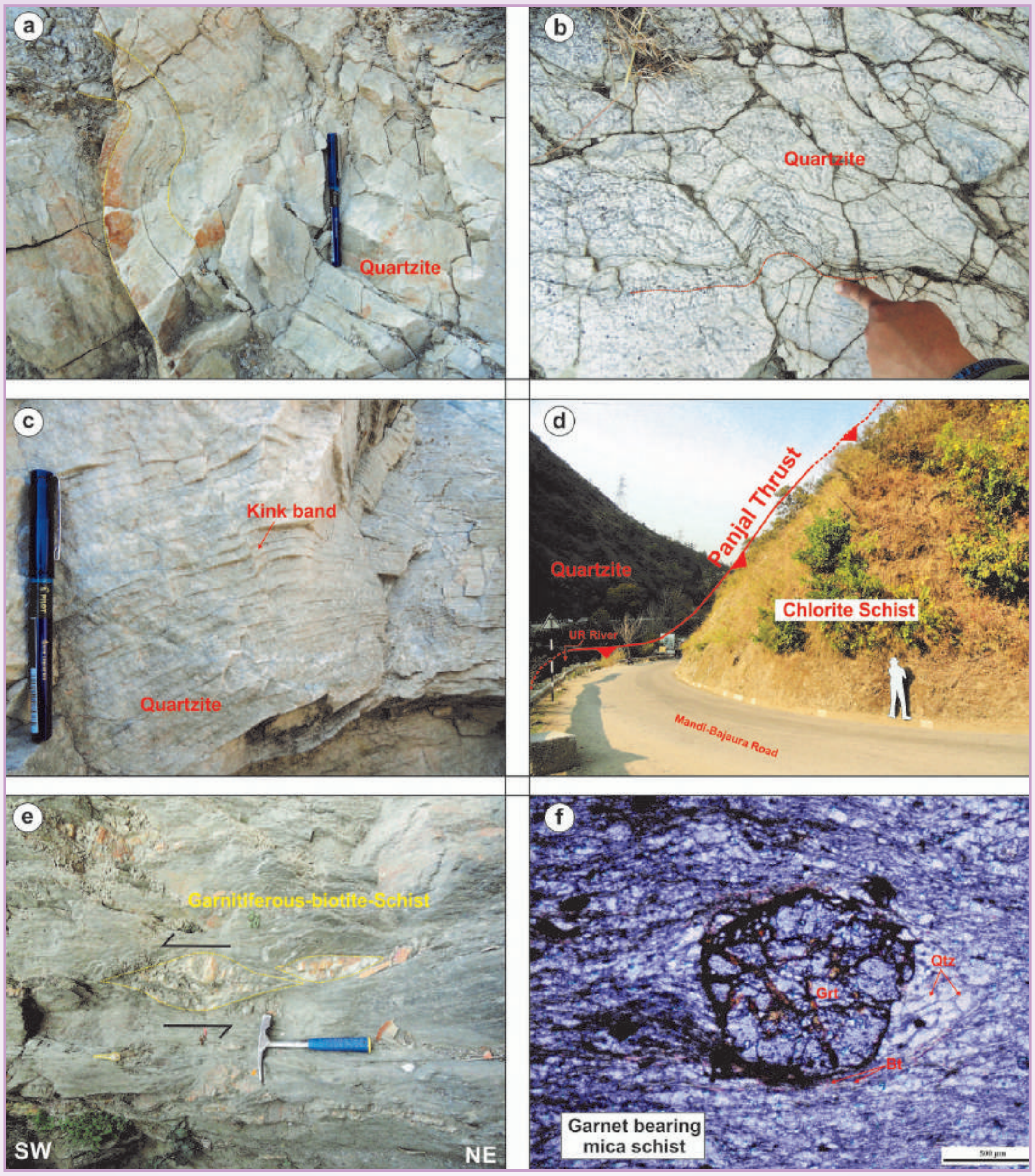

Fig. 7 : (a-b) Near Katindhi village, exposure of quartzite of Simla Group shows the development of fold, (c) development of foliation and kink band, (d) Location and contact zone of Panjal Thrust (PT) along the UR river on Mandi-Bajaura road traverse, (e) outcrop exposure of garnitiferous-biotite-schist and (f) a thin section shows garnet poikiloblasts containing inclusion of quartz, biotite and muscovite of Pandoh Syncline.

Activity:1B

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

(H.K.Sachan, Saurabh Singhal, Aditya Kharya and Perumal Samy)

Quartz-calcite veins of the ophiolitic mélange in the Indus Suture Zone preserve a diversity of fluid activity in the late stages of ophiolitic mélange formation. The microstructures of quartz and calcite veins indicate deformation temperatures between 200°C and 400°C. The $\delta^{13}C$ and $\delta^{18}O$ values of calcite veins from the ophiolitic melanges are within the mixing hyperbolas of marine and primitive-mantle fields in the mixing model (Fig.9). The oxygen isotope ratio of fluid inclusions along with the microthermometry data set indicates the

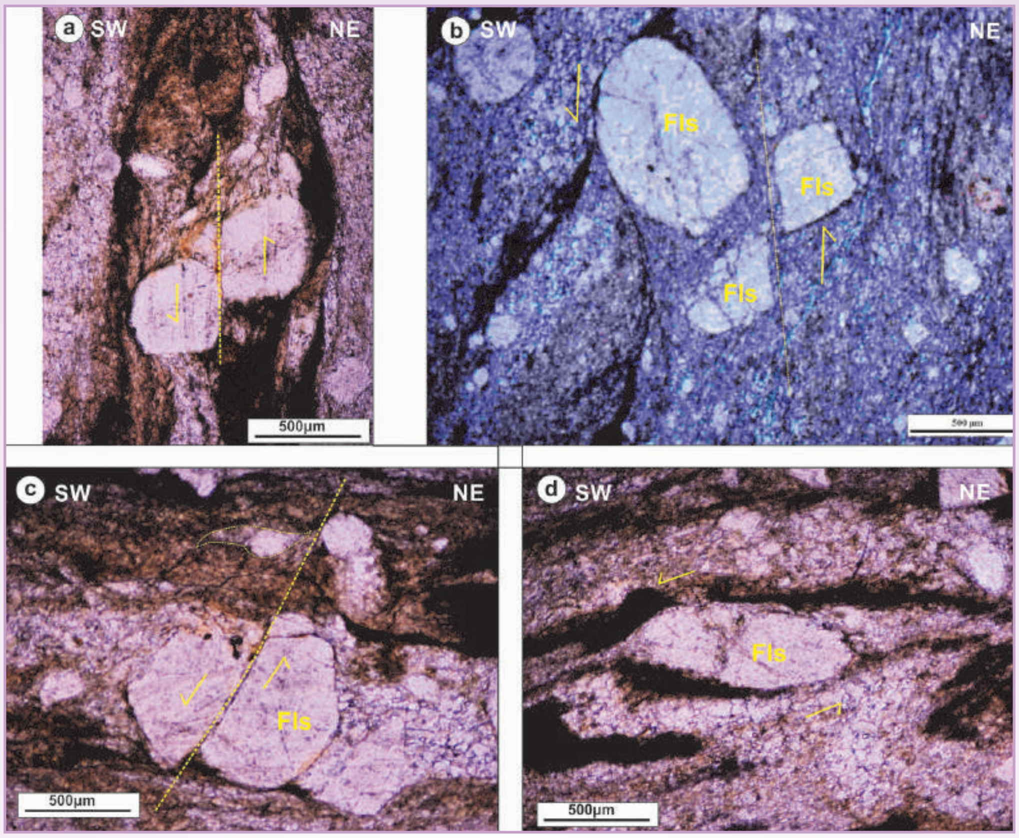

Fig. 8: (a-d) Photomicrographs showing rounded feldspar phenocrysts, stretched, fractured and indicating normal-sense of shearing in Augen-gneiss.

Mantle or ophiocarbonate source of fluid for the formation of the veins (Fig. 9). The Sr and Pb isotopic values of calcite veins from the Zildat Ophiolitic Melange (ZOM) suggest a mid-ocean ridge basalt (MORB) fluid source of vein formation that was radiogenically enriched by metasomatism in a supra subduction zone (Fig. 10). For the Shergol Ophiolitic Mélange (SOM), fluids may have originated from the enriched mantle (EM) and the depleted-MORB-mantle rocks (Fig. 10). It is inferred that the carbonic fluids were derived from ultramafic lithologies and an oceanic crust that formed the ophiolitic mélange rocks, which also host these veins. These source rocks have EM and MORB geochemical signatures that are also obtained in the quartz-calcite veins, as characterized by their C-O-Sr-Pb isotopic ratios. The magmatic saline fluid is inferred to have formed in the early stages of vein formation and to have been subsequently diluted, as exemplified by the presence of low-saline secondary aqueous inclusions. The microthermometry fluid pressure-temperature estimation of veins from the studied sections suggests that the maximum depth of emplacement of veining fluid was about 24.5 MPa (corresponding to ~ 2.5 km) at 336°C (Fig. 10). The vein-forming fluids (calcareous and siliceous) were introduced into the fractures that developed in the host as a result of deformation (Fig. 11).

The mineral chemistry, whole-rock geochemistry, and fluid inclusion study of the Karakoram migmatites from the Tangse strand were carried out to know the peak P-T condition and the fluid behavior for the migmatization in the Karakoram region. Based on textural relationships, the equilibrium assemblage of the studied section is plagioclase – amphibole (pargasite) – biotite – quartz – titanite – diopside – melt. Amphibole-bearing leucosomes typically have the assemblage Kfs + Pl + Qtz + Amp + Ttn + Cpx + Ap ± Bt ± Ms ± Zrn ± Mnz, with hypidiomorphic magmatic textures preserved. The leucosomes are comprised of euhedral to subhedral poikilitic amphibole grains (0.1 to 0.5 mm in length) and biotite, which are aligned along with the regional tectonic fabric. Amphibole grains have biotite, plagioclase, K-feldspar, and quartz inclusions. The fluid

ACTIVITIES

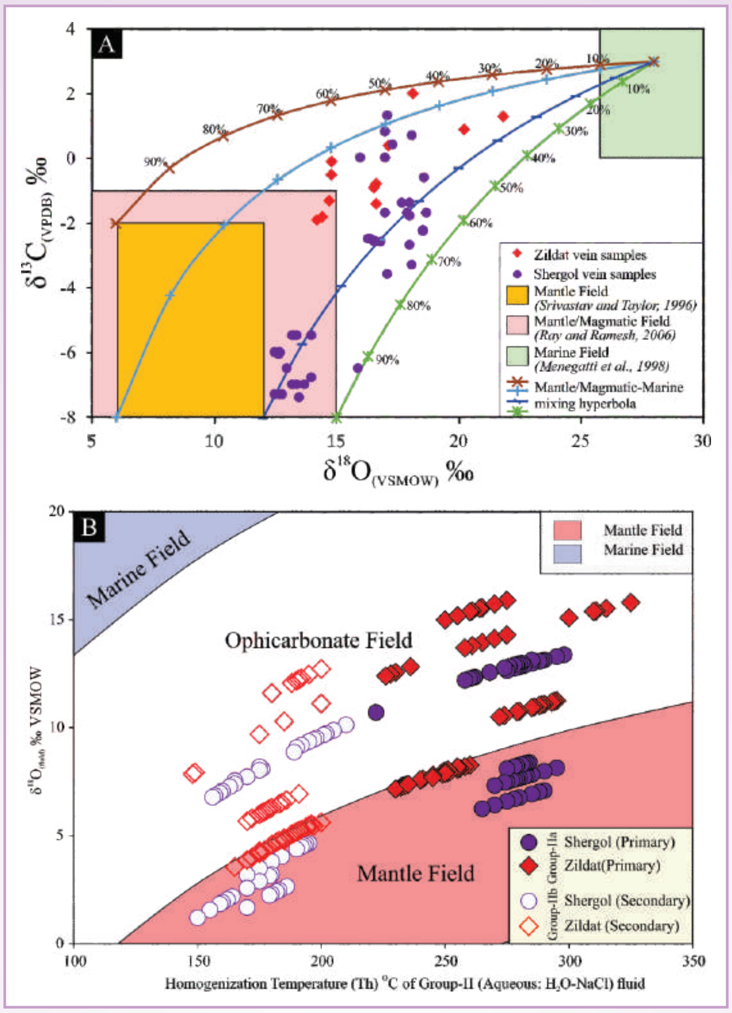

Fig. 9 : (A) Bi-variant carbon and oxygen isotope plot of the veins sample from the Zildat and Shergol ophiolitic melange. (B) The plot of aqueous fluid inclusion (H_2O-NaCl) homogenization temperature Vs. $\delta^{18}O$ (aq. fluid).

inclusion study indicates only monophase primary and secondary carbonic fluid inclusions present in quartz display eutectic temperatures between -56.9 and -56.6°C, suggesting pure CO_2 composition.

Peraluminous granite magmatisms in the Indus Suture zone

The melting of mantle and Juvenile mafic lower crust-derived Neo-Proterozoic Ladakh granitoids are known to occur in the southern margin of the Eurasian plate i.e. the Indus Suture zone while the melting and reworking of the Indian continental margin remain poorly understood. This study involves the combined petrographic, whole-rock major, trace elemental geochemistry, and ID-TIMS Sr, Nd isotopic studies from strong peraluminous granite in the southern margin of Ladakh granitoids, Indus Suture zone. The major elements record the evolution of Ladakh granite via fractional crystallization of plagioclase, K-feldspar, biotite, amphibole, and zircon, which supported the strong fractionation in REEs and strong Eu anomalies (0.4-.1.0). The tracer elemental budget in Ladakh granite represent Greater Himalayan crystalline metasedimentary rocks melting. These moderate to strong peraluminous granite (A/CNK = 1.00-1.18) have high potassic (1.52-0.86), sodic (9.60-7.96), and felsic fractionated granite of low maficity (0.5-3.5). Ladakh granites are fractionated S-type granite with syn-collisional affinity. They are also enriched in Rb, Ba, U, Th, and Pb and depleted in Ti, P, Zr, Hf, Nb, and Ta indicating a middle-upper continental crust affinity, with evolved continental crustal signature of high $(Sr^{87}/Sr^{86})_I$ = 0.698-0.719 and a large negative $\varepsilon Nd_{t=0}$ values of (-12.3) to (-4.2). The LG high ratios of

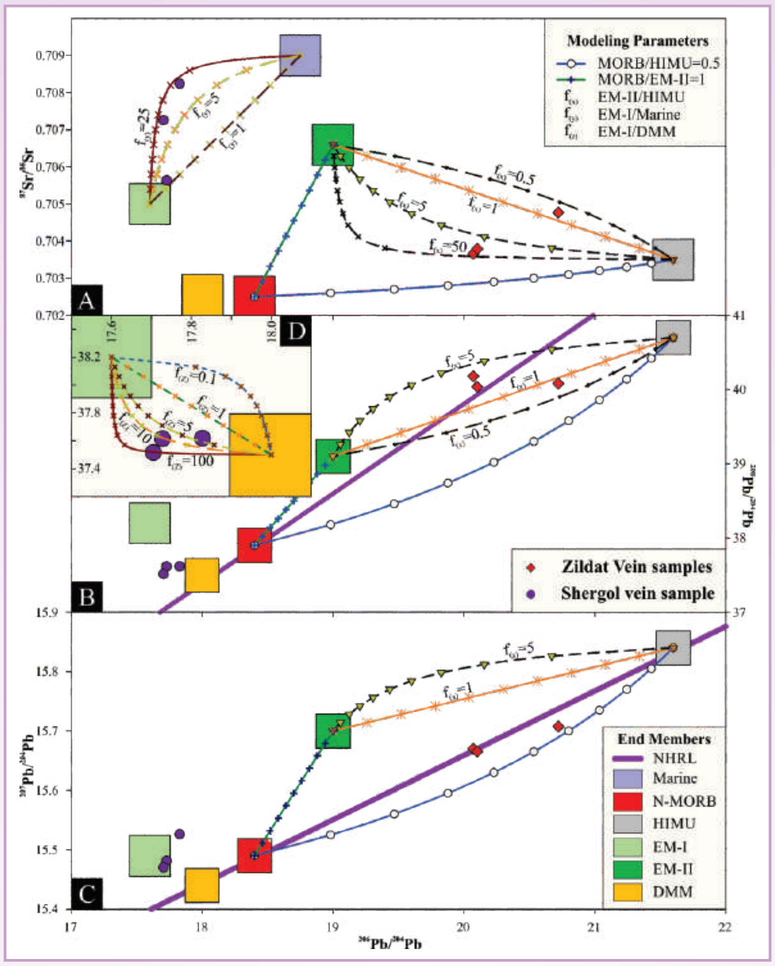

Fig. 10 : Sr-Pb measured isotopic ratio of veins from Zildat Ophiolitic Mélange (ZOM) and Shergol Ophiolitic Mélange (SOM) and two-component mixing model. Various end members shown were obtained from Hart (1984, 1988), (A) 87Sr/86Sr – 206Pb/204Pb mixing model, (B) 208Pb/204Pb – 206Pb/204Pb mixing model, (C) 207Pb/204Pb – 206Pb/204Pb mixing model, and (D) 208Pb/204Pb – 206Pb/204Pb mixing model in detail for SOM.

Al_2O_3/TiO_2(241.3-32.6), CaO/Na_2O (-0.61-0.17), Rb/Ba (1.87-0.08), Rb/Sr (6.91-0.22), CaO+FeO*+MgO+TiO_2 (1.21-6.42), CaO/FeO*+MgO+TiO_2 (0.6-1.73) indicating that they were sourced from two different heterogeneous crustal components of the source of radiogenic heat melting likely, i) medium to high-grade metasedimentary rocks (supra crustal rocks) of mature middle-upper crustal rocks melting and ii) Greater Himalayan crystalline rocks (metagranite). The normal plagioclase zoning in Ladakh granite represents a fractionated nature. The present study suggests that the genesis of fertile, early Cenozoic, syn-collisional, highly evolved peraluminous granitic magmas in the southern margin of the Indus Suture zone is related to the shallow partial melting of underthrusting northern Indian Gondwana margin below the Eurasian margin by convective upwelling Neo-Tethyan asthenosphere heat flux and energy after Neo-Tethyan slab breakoff. The Indus Suture zone records not only the melting of Juvenile Neo-Tethyan oceanic crust but also the melting and reworking of the Greater Indian Archaean-Proterozoic mature continental crust in the Indus Suture zone.

In addition to this, a multi-collector inductively coupled plasma mass spectrometer with a laser ablation system has been used to perform zircon hafnium (Hf) isotopic analysis, and a protocol is established for the measurement of Hf isotopes. Toward this, two zircon standards, Z91500 and Plesovice, have been used for Hf isotopic measurements at four different spot sizes (50, 40, 25, and 20 µm). The isotopic data for ≥25 µm have

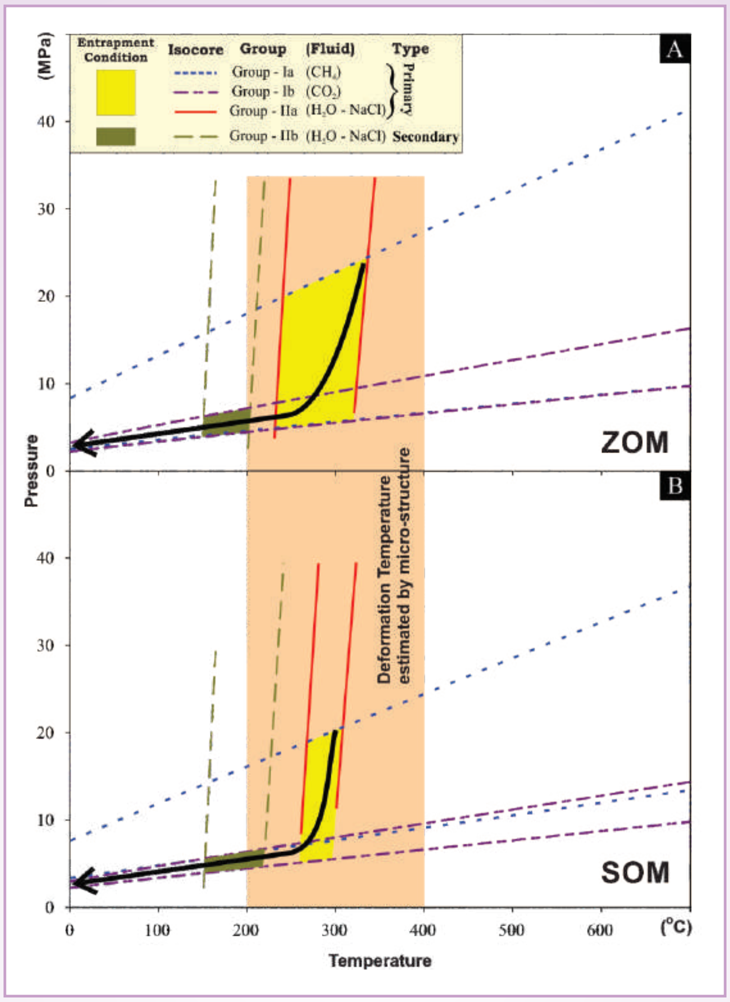

Fig. 11 : Pressure-temperature (P–T) diagram showing isochores of primary and secondary inclusions from veins for the study area. Schematic representation of P–T path and fluid entrapment stages in the broad range of P-T conditions recorded by quartz-calcite veins. A thick arrow line represents the exhumation path and shows the isochoric cooling condition for both mélange zones. (A) Fluid P-T condition and exhumation path for the Zildat Ophiolitic Mélange (ZOM). (B) Fluid P-T condition and exhumation path for the Shergol Ophiolitic Mélange (SOM).

an excellent agreement with published data, but for 20 m, the results are erroneous and irrelevant to the geological application. It has been observed that Hf beam intensity has a linear relation to the volume of the target (RM) ablated. $^{178}Hf/^{177}Hf$ ratio and εHf for both standards are comparable with the published recommended values. The present study indicates that $^{176}Lu/^{177}Hf$ ratio for Z91500 is more homogeneous than the Plesovice zircon. The $^{176}Hf/^{177}Hf$ isotopic ratio for 50 and 25 µm shows an excellent agreement with the previously reported data. However, for the 40-µm spot size, a slightly higher but negative offset of −123 and −105 ppm in $^{176}Hf/^{177}Hf$ ratio have been observed for Plesovice and 91500, respectively.

Activity: 2A

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

(Kalachand Sain, Priyadarshi Chinmoy Kumar and Pankaj Chauhan)

Fold-and-thrust orogenic belts preserve a structural record of complex deformations and are an important part of many orogenic systems worldwide. However, they have received less attention due to the lack of detailed understanding of the subsurface disposition that structurally controls the deformations prevailing within these regions. High-quality, three-dimensional (3D) seismic reflection data have been used to investigate the structural development and evolution of faults developed within a geologically complex region of the Upper Assam Basin, NE India which is bounded by fold-and-thrust orogenic belts. Furthermore, seismic textural responses have been studied in detail using 3D seismic data to decode the depositional environment of the Oligocene-Miocene subsurface sedimentary successions in the Upper Assam Basin of NE India. Different seismic experiments using an open source database have been performed to improve a detailed understanding of seismic interpretation techniques and their applications. In-situ glacier melt consisting of suspended sediment concentration has been investigated in detail over the acquired data from streams of Pindari and Kafni glaciers of the central Himalayan valley using techniques of Artificial Neural Network and Multi-Linear Regression analysis.

Activity: 2B

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

(Naresh Kumar, Devajit Hazarika, Gautam Rawat, Koushik Sen and S.S. Thakur)

Surface and sub-surface structures are obtained for different segments of the Himalaya using different geophysical and geological investigations. Passive source seismological techniques including travel time inversion, seismic tomography, and receiver function analysis have been adopted for the investigation of subsurface structure. Magnetotelluric investigations were also carried out to investigate shallow subsurface investigations. To study seismotectonic and earthquake source processes, modeling of earthquake source through waveform inversion technique have been adopted. Moreover, spectral analysis technique has been adopted to study source parameters of local earthquakes. The results have been interpreted based on geological concepts. This activity also includes geological investigation related to inverted metamorphism along with P-T calculations. Petrological study of migmatites and phase petrology of mafic xenoliths have been carried out. A detailed mineral-chemical study of allanite and monazite is being conducted. The outcome of the activity is illustrated below.

1D Velocity model and Seismotecotnics of the Kinnaur Himalaya

The 12 broadband seismological stations of the Kinnaur network of northwest Himalaya were used to monitor micro-earthquake activity. About 800 micro-earthquakes recorded from 2008 to 2012 within the magnitude range of 1.0 to 4.5, are relocated using the newly developed 1-D crustal velocity model (Fig. 12a). The velocity model developed using the VELEST program based on P- and S-phase data divides the upper 35 km thick crust into 8 layers in which Vp/Vs appears to be quite variable (Fig. 12b). This study infers that the 5-25 km depth range is seismically active beneath the Kinnaur Himalaya. The northern part, in and around the epicenter zone of Ms 6.8 Kinnaur earthquake of 1975, has anomalous high seismicity within the Tethyan Himalaya. This seismicity aligned nearly the N-S direction parallel to the Kaurik-Chango Normal Fault (KCNF) and perpendicular to the Higher Himalayan Seismic Belt (HHSB). Fault plane solutions of 9 earthquakes (M >3.0) indicate a predominant normal fault mechanism. The strike of these fault plane solutions is predominantly in the north-south direction similar to the Kinnaur earthquake (Ms 6.8) suggesting deformation in the upper crust parallel to the KCNF. A high concentration of microearthquakes is observed inthe HHSB within a 50 km wide zone around the MCT. However, unlike other parts of the HHSB, the earthquakes of M $\geq$5.0 is missing in this part. Focal mechanisms support the thrust deformation with strike aligned to major tectonics of the Himalaya in NW-SE direction suggesting thrusting of the Indian plate beneath the Himalayan wedge along the MHT. Stress inversion reveals NE-SW oriented compressive maximum principal stress within the Larji-Kulu-Rampur Window (LKRW), and WSW-ENE oriented extensive principle stress to the northern part of the Kinnaur Himalaya (Fig. 13).

Estimation of Earthquake Source Characteristics in Kinnaur Himalaya

The site and path effects are assessed in terms of site amplification and anelastic attenuation (quality factor), respectively, to obtain an isolated source term for estimating earthquake source parameters in the Kinnaur Himalaya. These terms are then applied to calculate the source parameters of 75 local earthquakes in the moment magnitude (Mw) range of 1.5 - 3.6. The site amplification curves and S-wave quality factors Qs(f) are determined and further utilized to correct the Fourier spectrum of earthquake records. The obtained source spectrum corrected for these two terms is compared with the theoretical source spectrum based on the Brune source model (Brune, 1970, J Geophys Res 75, 4997–5009). The root-mean-square error between the observed and theoretical spectrum is formulated by

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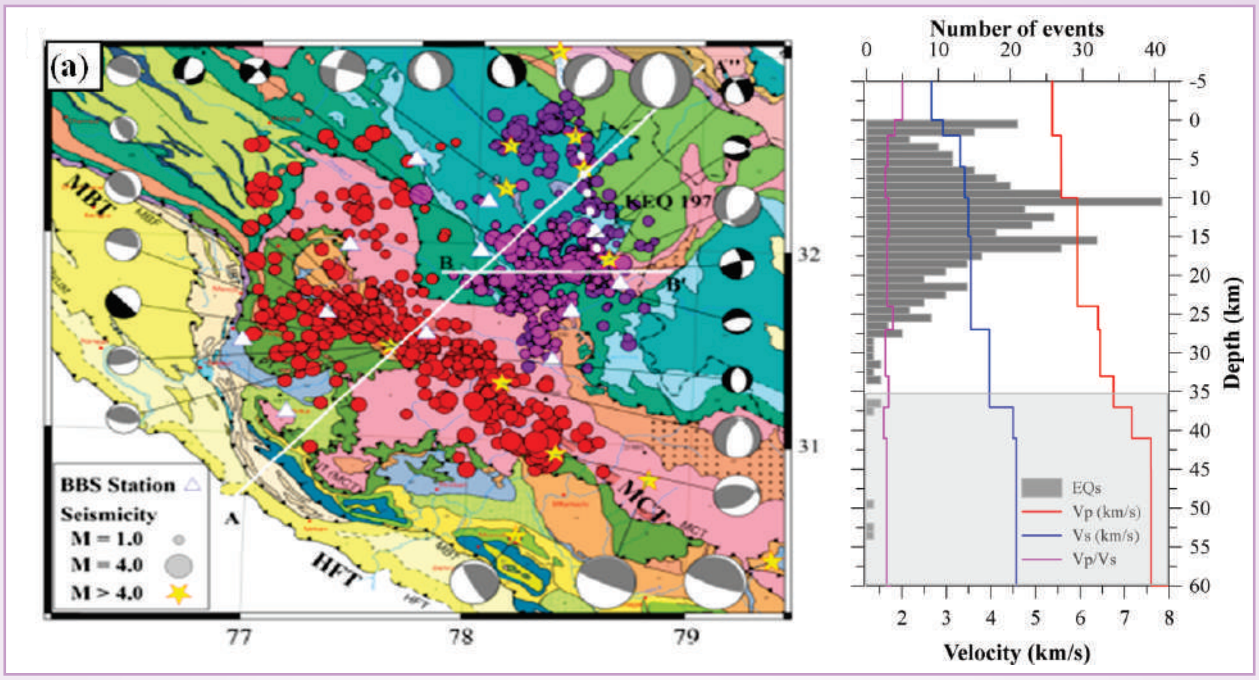

Fig. 12 : (a) Seismicity distribution of Kinnaur region (Magenta and violet circles) and rest of the study region (red circles) along with available focal mechanism solutions (FPSs).The major geotectonic features are shown following Thakur, (1992). (b) A new 1-D velocity models obtained for the P-wave (Vp - red line), S-wave (Vs – blue line), and Vp/Vs ration (magenta line) are shown. Grey histograms denote the distribution of focal depths of the relocated earthquakes. Poorly resolved velocity model below 35 km depth is masked.

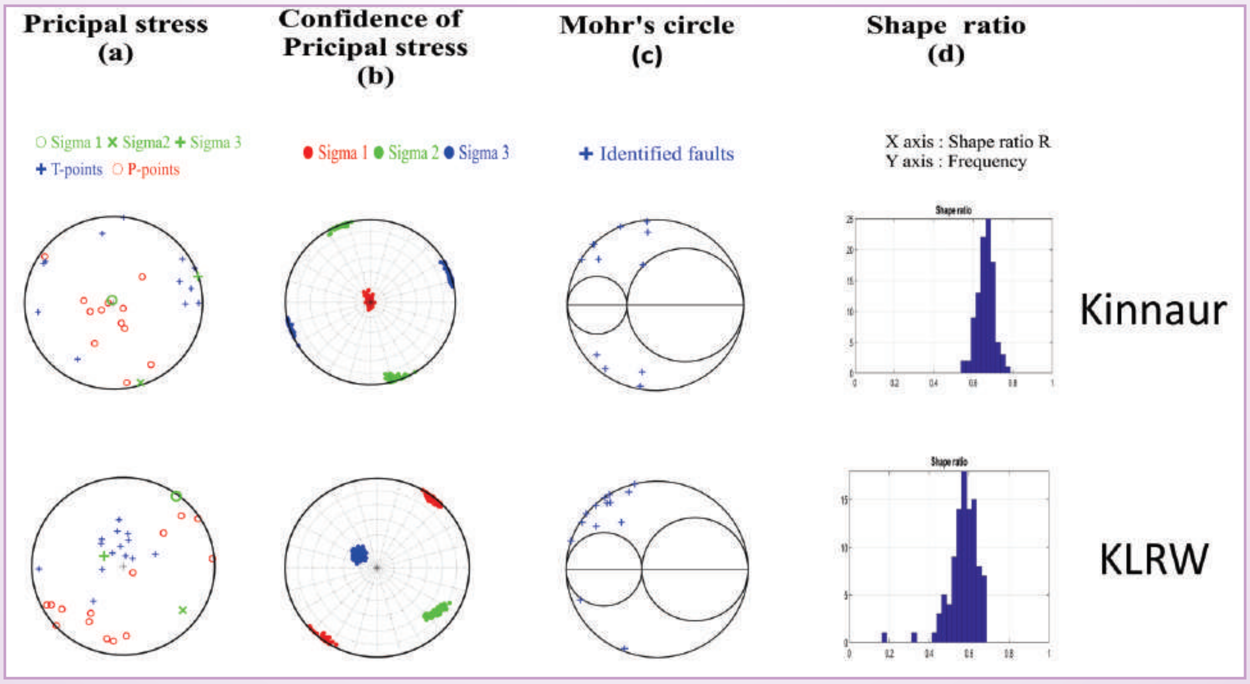

Fig. 13 : Stress tensor inversion results of two groups of earthquake data of the Kinnaur Himalaya (a) P/T axes projected in a semi-circle along with the principal directions (b) Principal stress directions with 95 % confidence level (c) Morh's circle diagram projecting the comparative variation of stress and (d) Shape ratio factors.

implementing iterative forward modeling. The obtained source parameters of 75 events reveal ranges of the seismic moment: 2.73 x 10^{11} – 3.44 x 10^{14} N-m, stress drop: 0.03–13 bars, source radius: 0.3–0.9 km, and radiated energy:5.64 x 10^{02}–1.19 x 10^{08} J. The results are useful for studies related to seismic hazards and earthquake risk reduction.

Shear wave velocity structure of NE India obtained through Rayleigh wave dispersion data

Tomographic images have been obtained for the crust and uppermost mantle using inversion of Rayleigh waveform data. The Bengal Basin comprises a thick layer of sediments with the thickness increasing from west to east and a sudden steepening of the basement on the eastern side of the Eocene Hinge zone. The nature of the crust below the Bengal Basin varies from oceanic in the south to continental in the north. Indo-Gangetic and Brahmaputra River Valleys comprise ~ 5–6 km thick sediments. Crustal thickness in the Higher Himalaya and southern Tibet is ~70 km but varies between ~ 30 and ~ 40 km in the remaining part (Fig. 14). Several patches of low-velocity zone present in the mid-to-lower crust of southern Tibet along and across the major rifts indicate the presence of either partially molten materials or aqueous fluid. The crust below the Shillong Massif and Mikir Hills are shallower. This observation indicates that tectonic forces contribute to the uprising of the Massif. The Bengal Basin is underlain by oceanic crust whereas continental crust is inferred below the Shillong Massif and Brahmaputra River Valley. For the southern Tibet/Lhasa block, two important findings are as follows (i) the Moho depth decreases from ~ 70 km west of the Yadong-Gulu rift to ~ 60 km toward the east which may be the effect of collision geometry to control the underplating of the Indian plate in this section of southern Tibet/Lhasa block and (ii) low-velocity zones are observed in velocity models at mid-crustal levels near or below the rift zones. This could be due to the presence of partial melt and/or aqueous fluids.

Seismotectonic of the Tidding-Tuting Suture Zone of the Eastern Himalayan Syntaxis

The Eastern Himalayan Syntaxis (EHS) is one of the most complex tectonic domains of the world that produced the largest intra-continental earthquake (Mw 8.7) ever recorded. Although several studies have been carried out in the EHS and adjoining SE Tibetan plateau, the seismicity, and seismotectonic of the NE edge of the Indian plate in the EHS (Tidding-Tuting Suture) are poorly understood due to a lack of seismological data. The present study aims to study seismicity and seismotectonics of the Tidding-Tuting Suture Zone (TTSZ) with special emphasis on the Lohit Valley region. The study region is shown in figure 15. This study utilizes seismological data recorded during 2007-2008 by 11 seismological stations of the Lohit Valley network, Arunachal Pradesh. In addition to this dataset, the seismicity data recorded by 8 broadband seismological stations of the Siang window and reviewed earthquake catalog data of the International Seismological Center (ISC) for the period 1950–2018 (http://www.isc.ac.uk) have been used for studying the

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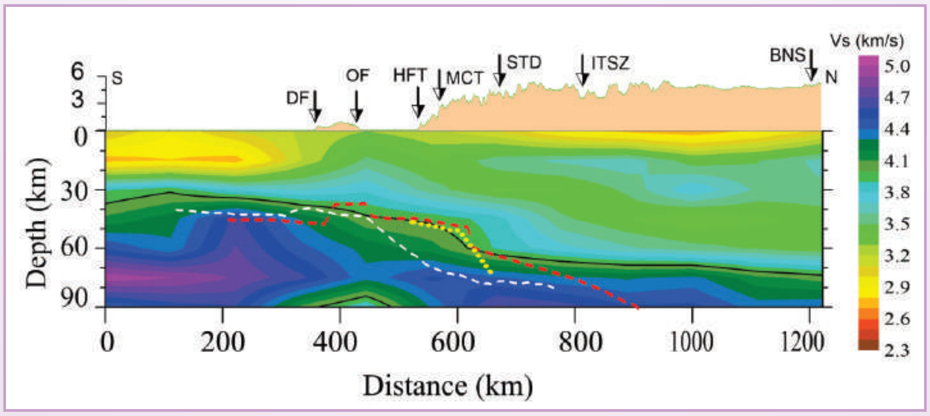

Fig. 14 : 2D Shear wave velocity variation along a north-south (91E, 22N - 91E, 32N) profile in NE India. Comparison of estimated Moho depth variation along the profile (black line, Vs present study) with that obtained by Priestley et al. (2008) (white dash line), Mitra et al. (2005) (red dash line), and Singer et al. (2017) (yellow dotted line). Abbreviations: DF: Dudhnoi Fault; OF: Oldham Fault; HFT: Himalayan Frontal Thrust; MCT: Main Central Thrust; STD: South Tibetan Detachment; ITSZ: Indus-Trangpo Suture Zone; BNS: Bangong Nujiang Suture.

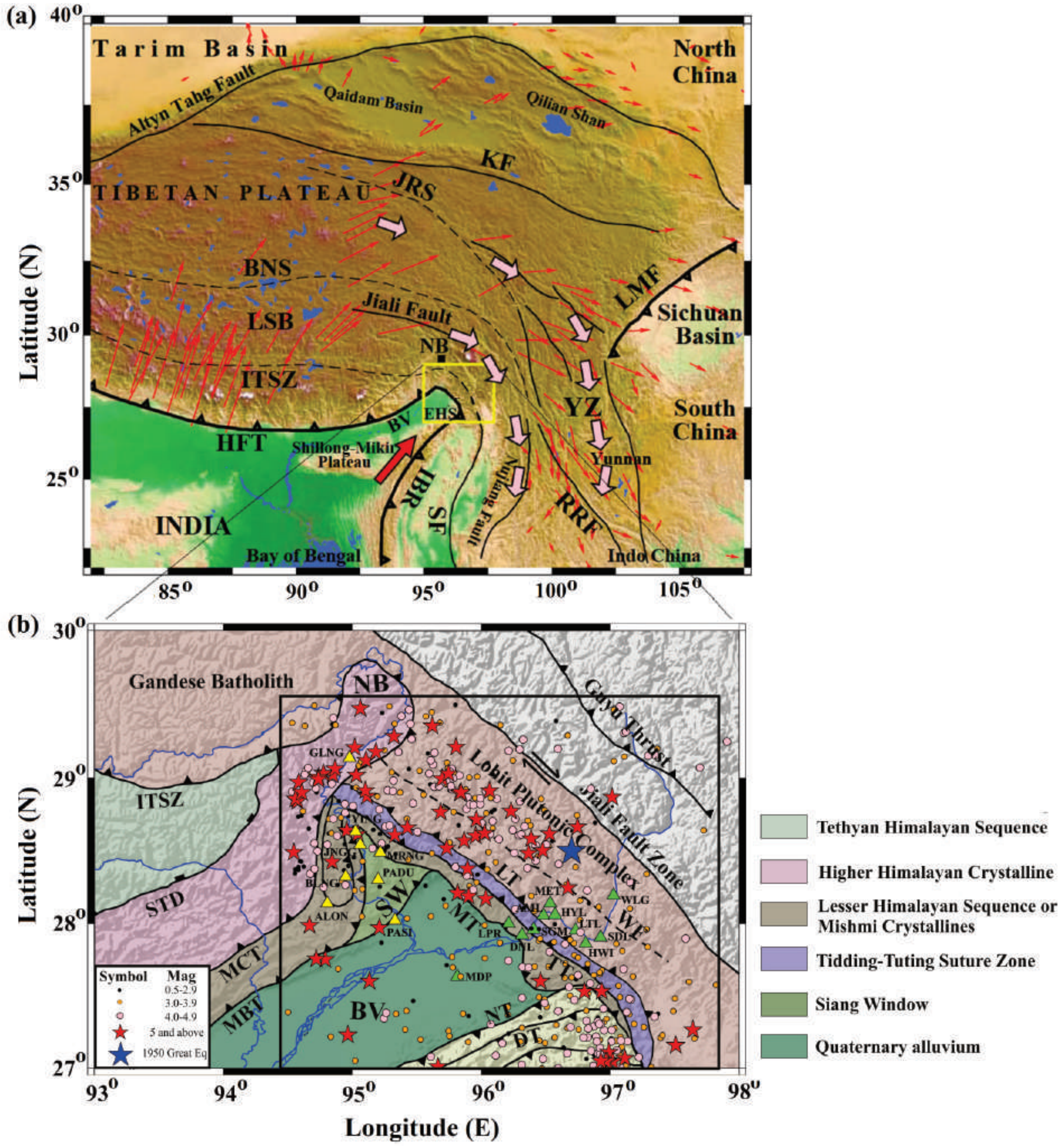

Fig. 15 : (a) Simplified tectonic map is shown with the topography of the Eastern Himalayan Syntaxis and surrounding regions with major tectonic features. The yellow rectangle marks the study area. (b) Close view of the study area with existing major faults. The tectonics features e.g. Himalayan Frontal Thrust (HFT), Indo- Burma Ranges (IBR), Indus-Tsangpo Suture Zone (ITSZ), Lhasa Block (LSB), Bangong Suture (BNS), Jinsha River Suture (JRS), Longmen Shan Fault (LMF), Sagaing Fault (SF), Kunlun Fault (KF), Namche Barwa antiform (NB), Yangtze platform (YZ), Brahmaputra Valley (BV); Main Boundary Thrust (MBT); Main Central Thrust (MCT); South Tibetan Detachment (STD); Siang Window (SW); Mishmi Thrust (MT); Tidding Thrust (TT); Lohit Thrust (LT); Walong Fault (WF); Naga Thrust (NT); Disang Thrust (DT); Jiali Fault Zone and Guyu Thrust are shown in the tectonic maps. Simplified geological units are highlighted in (b). The green and yellow triangles mark the location of the seismological stations of the Lohit Valley and Siang Window, respectively. The earthquake epicenters are shown as circles and stars.

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spatial distribution of seismicity in and around the study region. The study reveals that the TTSZ is seismically active up to ~40 km depth. In contrast, the seismicity in the Indo-Burma Ranges (IBR) is observed up to a depth of ~200 km suggesting the active subduction process of the Indian plate beneath the IBR (Fig. 16). This study suggests that the subduction process terminates north of ~27^{0} N Latitude and the indentation process of the rigid Indian plate into south-east Asia predominantly controls the seismicity north of the IBR. The seismicity and its linkage with the existing tectonic features are critically examined in the Lohit Valley and Mishmi Hills regions. Focal Mechanism Solutions (FMS) of 10 earthquakes (3.5 $\leq$ M $\leq$ 4.2) are evaluated with the help of the waveform inversion technique. The beach ball representations of the FMS are shown in figure 17. A NE–SW cross-section of the FMS of 11 earthquakes along the Lohit Valley, falling in the BB$^{/}$ cross-section with a 100 km swath is critically examined (Fig. 17). The results of the source mechanism study reveal that the closely spaced Mishmi, Tidding, and

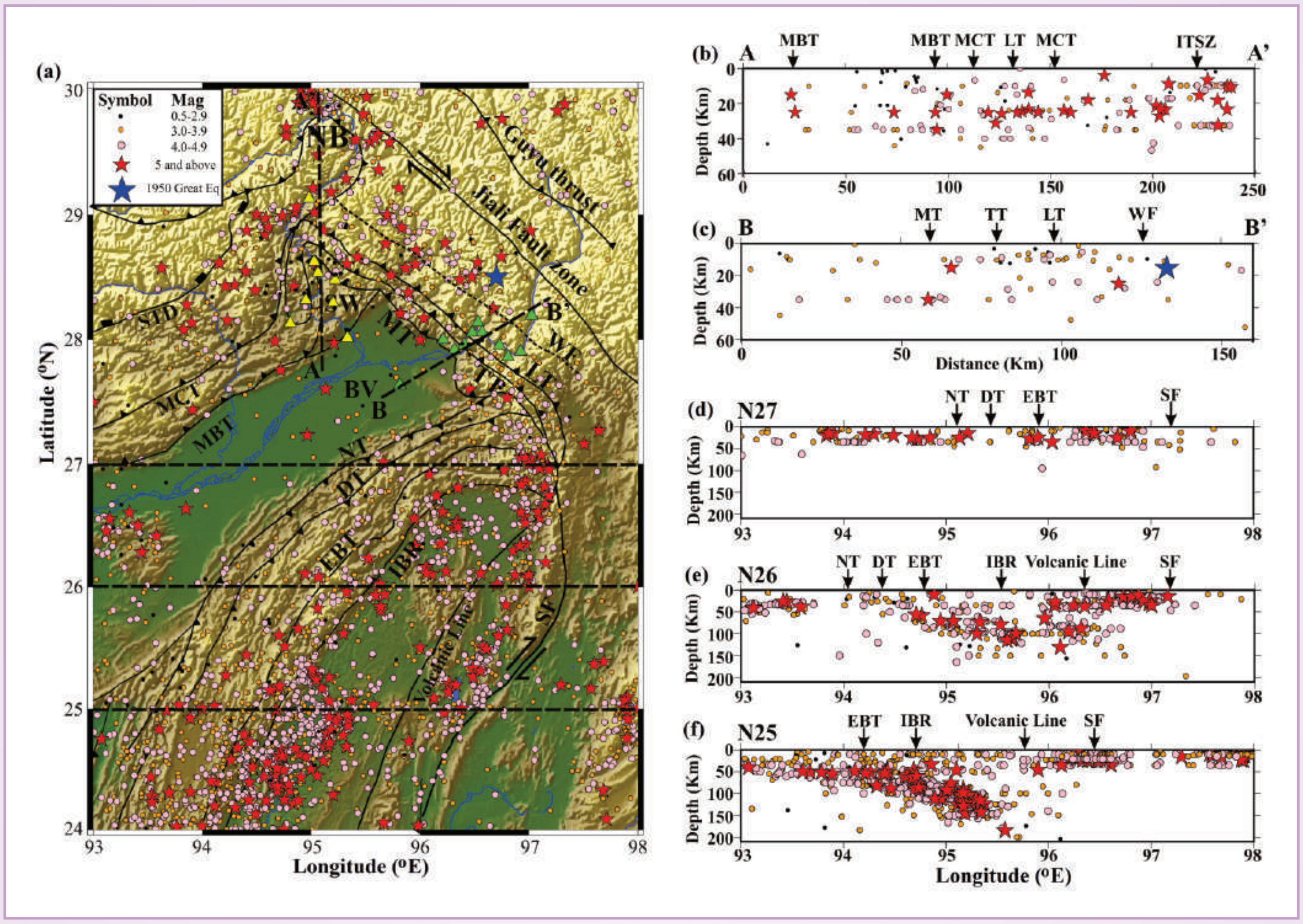

Fig. 16 : (a) Spatial distribution of seismicity in and around the Eastern Himalayan Syntaxis and Indo-Burma Range based on the earthquakes recorded by 11 seismic stations of the Lohit Valley network (green triangles) and 8 stations of Siang Window (yellow triangles) recorded during the period 2007–2008 and 2018–2019 respectively. Besides, reviewed catalog data of the International Seismological Centre (ISC) (http://www.isc.ac.uk) is used for regional seismicity. Depth distributions of earthquakes across Siang Window and Namche Barwa Antiform (AA$^{/}$) and along Lohit Valley (BB$^{/}$) are shown in (b) and (c). The depth distributions along three EW profiles centered at 25^{0}, 26^{0}, and 27^{0} latitudes (N) across the Indo-Burma convergence zone considering a 100 km swath area for each profile are shown in Figs. (d-f). Seismicity has been projected along these profiles. The tectonic features: IBR: Indo-Burma Range; SF: Sagaing Fault, NT: Naga Thrust; DT: Disang Thrust, EBT: Eastern Boundary Thrust, MBT: Main Boundary Thrust, MCT:Main Central Thrust, and STD: South Tibetan Detachment, LT: Lohit Thrust, TT: Tidding Thrust and Mishmi Thrust are shown.

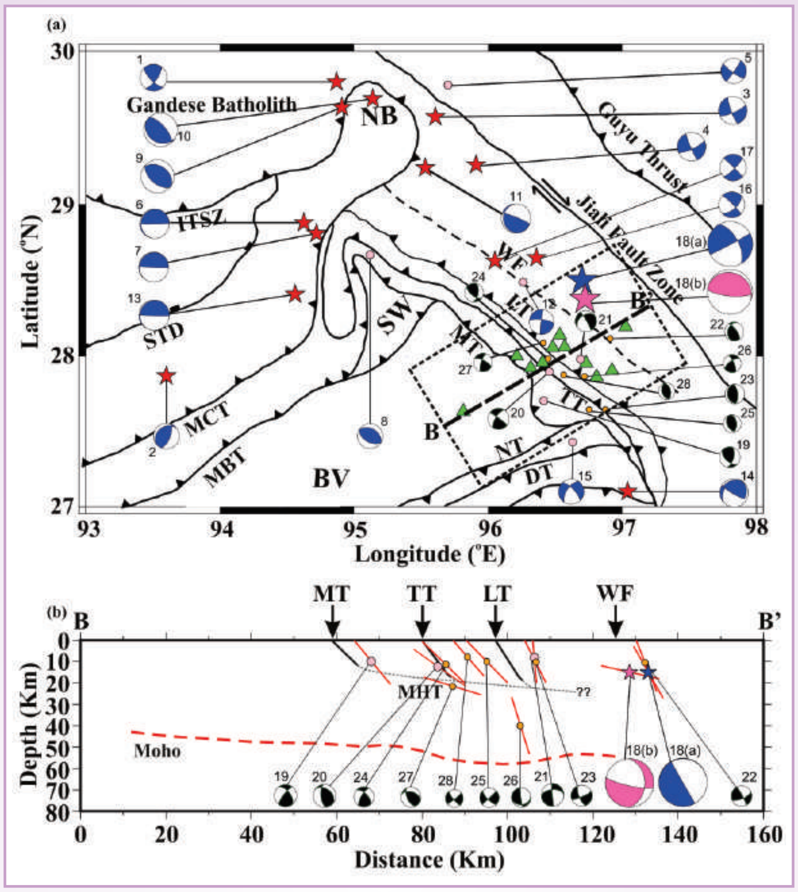

Fig. 17 : (a) Beach ball representations of focal mechanism solutions (FMS) of 28 earthquakes of the EHS are shown. The FMS computed through waveform inversion in the present study is presented by black beach balls. The FMSs obtained from the Global Centroid Moment Tensor (GCMT) and Nandy and Dasgupta (1991, Phys. Chem. Earth 18, 371–384.) are presented by blue beach balls. The pink star and corresponding beach ball are showing the epicenter location and thrust mechanism of the 1950 Great Assam earthquake as documented by Coudurier-Curveur et al. (2020, EPSL 531, 115928). (b) The FMSs are projected in the depth section along the BB$^{/}$ profile. The depth projected view of the inferred fault planes of the earthquakes is shown by red lines. The steep dipping fault planes are clearly visible for earthquakes that occurred in the region between the Mishmi Thrust and the Lohit Thrust. These faults possibly sole down to connect with the MHT shown by black dotted lines. The Moho is marked by the red dotted line based on previous studies (Hazarika et al., 2012, GJI, 188, 737–749).

Lohit faults are steeply dipping thrust sheets that accommodate the large crustal shortening owing to the indentation process and clockwise rotation tectonics (Fig. 17). The Walong fault is characterized by strike-slip motion which helps to facilitate the clock-wise rotation of crustal material around the syntaxis. Significant strain partitioning is anticipated from the variation of pressure (P) axes orientations indicating the effect of complex syntaxial tectonics.

Crustal Anisotropy study in the Kali River Valley, Kumaon Himalaya

Seismic anisotropy of the crust beneath the Kumaon Himalaya region has been investigated by shear wave splitting analysis to unravel deformation processes at the upper crustal depth. The S-wave splitting of 150 local earthquakes recorded by local seismological stations reveals a complex pattern of anisotropy in the upper ~20 km of the crust beneath the Kumaon Himalaya. The fast polarization directions are predominantly oriented along NE-SW and NW-SE with significant strength represented by the average delay time between fast and slow waves (~0.18 ± 0.03 s) (Fig. 18). The anisotropy is found to be maximum at a depth of ~10–15 km. The measurements of fast polarization direction and lineament analysis of Bouguer gravity data in the region

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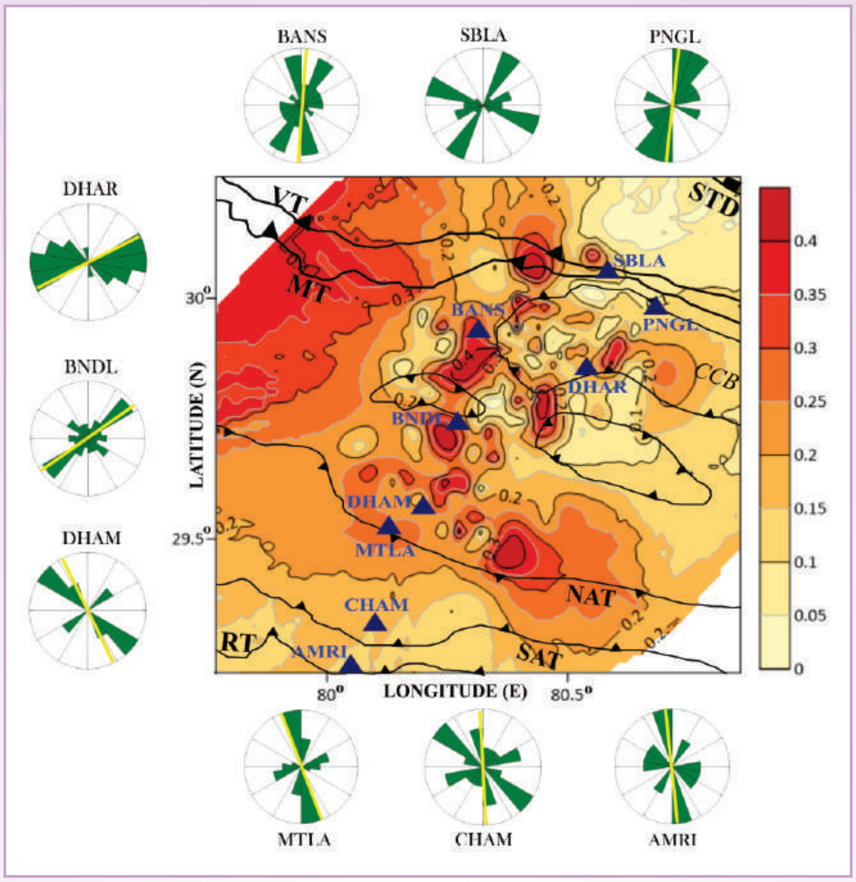

Fig. 18 : The delay time (δτ) contour map that represents the strength of anisotropy. The seismological stations are represented by blue triangles. The statistical variations of the Fast Polarization Directions (FPD) for individual stations are represented by green rose plots of bin size is 20◦. The mean FPD for the stations calculated by the Von Mises method is marked by a bold yellow line, except for the SBLA station which shows two contrasting FPDs.

indicate that the anisotropy originates due to the combined effect of stress-aligned micro-cracks, regional tectonic stress, and local geological features. The fast polarization directions in general show a good correlation with the trend of local lineaments. The lineament trends are observed to be different for different lithological units thereby emphasizing the fact that the deformation in the crust is highly complex. Based on the estimated average crack density (~0.024), it can be envisaged that the upper crust as a whole consists of intact rocks containing individual cracks without large fractures. The lineament and crack density variations suggest that the shallow crust in the Inner Lesser Himalaya is more brittle than the Outer Lesser Himalaya.

Occurrences of low-stress drop earthquakes in the eastern Ladakh-Karakoram zone

The Ladakh-Karakoram zone (LKZ) is a unique testing ground for understanding the geodynamic evolution of the Himalaya-Karakoram orogeny. The spectral analysis of microearthquake data ($1.9<M_L<4.3$) recorded during 2009-2012 by 10 seismological stations of the LKZ reveals that the region produces low-stress drop earthquakes. Analysis of selected 51 earthquakes shows the seismic moment (Mo) within the range of $1.2x10^{12}$ to $4.3x10^{15}$ Nm with stress drop values varying from ~0.06 to 64.36 bar. The low stress-drop earthquakes have significant implications for understanding seismogenesis. The earthquake cluster near the Tso-Morari crystalline is associated with the brittle shear failure on the faults (e.g. Zildat, and Karzok Faults), and the low-stress drop of the earthquakes is explained by the partial stress drop model. The low effective fault strength due to fault weakening mechanisms in the studied segment of the Karakoram Fault zone promotes aseismic creeping patches producing low-stress drop earthquakes at the expense of generating large earthquakes.This study provides the scaling relations between important source parameters for the first time in the region which can serve as useful inputs for the assessment of earthquake hazards.

Magnetotelluric studies around NCR (Budaun-Moradabad profile)

A magnetotelluric (MT) study has been carried out along an NNW-SSE profile of length ~100 km starting from Moradabad in the NNW to Budaun in the SSE. A total of 18 MT sites arecovered along this profile. The majority of the site is good in terms of data quality (Fig. 19). Few sites are excluded from further modeling due to very high resistivity variation.

The transfer functions of the sites in the profile are analyzed for dimensionality and directionality. A band-wise strike analysis was executed for the response. Predominantly regional dimensionality of resistivity distribution is 2D but some responses suggest 3D behavior. Masking those responses indicates period-dependent strikes. This period dependence may be correlated with the different structural orientations at different depths. An attempt has been made for a representative geo-electrical section to find whether the data is sensing any major feature in this profile or not. The combined and averaged strike analysis provides a strike of -47.5° or 52.5° (Figs. 20 and 21). Considering the regional trend of the Himalaya, the strike is fixed at -47.5°. The observed MT transfer functions are decomposed in this regional geo-electrical coordinate frame. The orientation of the profile is neither along the strike nor perpendicular to the strike.The decomposed TE and TM polarisation along the profile orientation have been modeled. The apparent resistivity weight is decreased using a high error floor for the apparent resistivity in comparison to phase. This approach further reduces the effect of distortion on the model. An inverted model for TM polarisation is shown (Fig. 21). The root mean square (RMS) misfit for TM polarisation is 4.2. The higher RMS misfit seems to be due to profile orientation or may require further insight on the estimation of MT responses. The TM polarisation is sensitive to conductivity variation with depth whereas TE polarisation is sensitive to lateral conductivity variation. The top conducting part in the range of 50-80

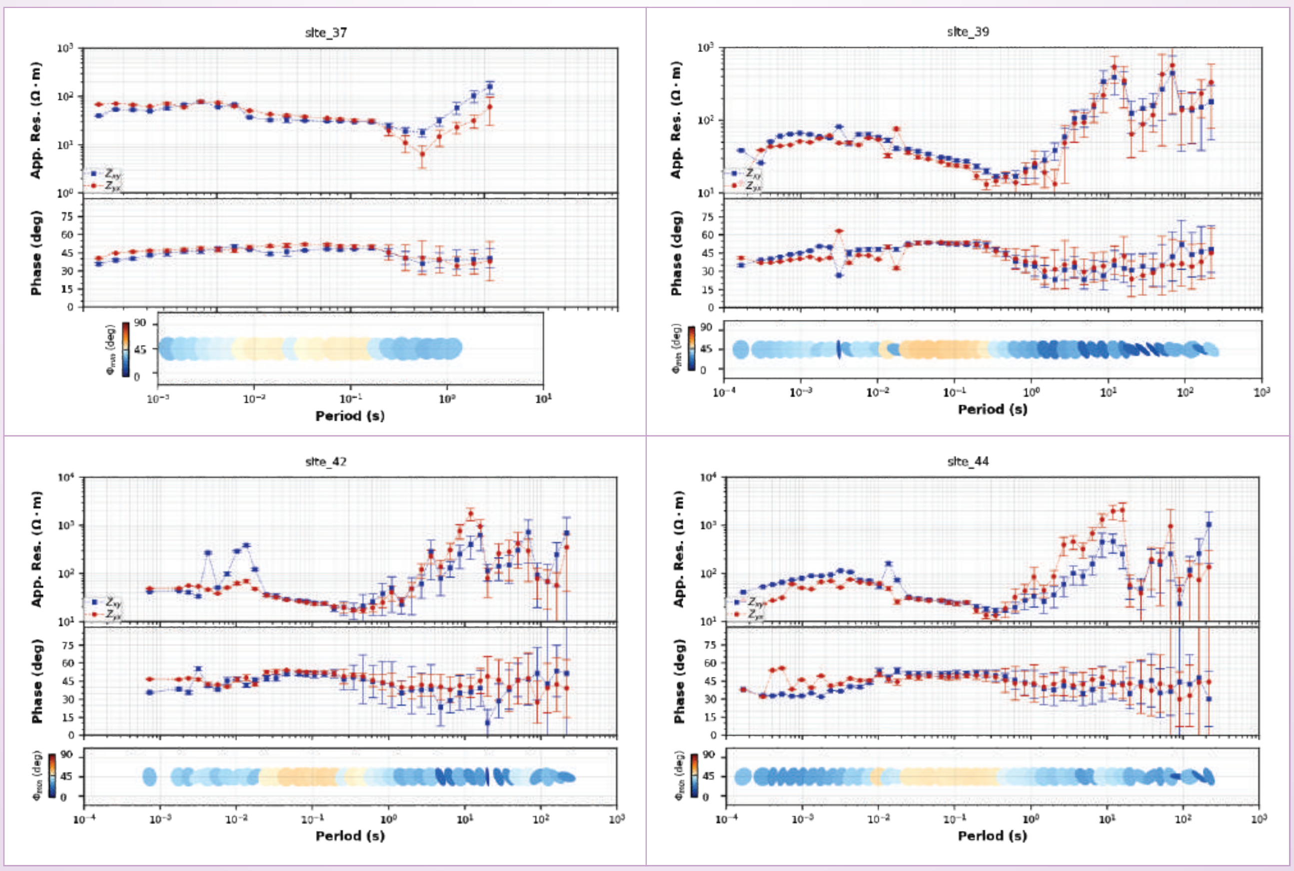

Fig. 19 : Apparent resistivity curves along Moradabad-Budaun profile at the representative sites.

ohm meters represents the depth of basement rock which is decreasing toward SSE and matches the regional tectonics. The bottom resistive part represents the Precambrian basement and the resistivity section of TM polarisation showsa break in the resistive basement (Fig. 22). It is interesting to note that the hypocenter of the Moradabad earthquake falls in this zone with a right-lateral strike-slip fault plane solution.

Metamorphic analysis from the Bhagirathi Valley, Garhwal Himalaya

The Himalayan metamorphic core in the Bhagirathi valley region of NW India consists of continuous exposures of the Lesser Himalayan gneiss and metapelite to the south and the higher-grade rocks of the Greater Himalayan Sequence (GHS) to the north. In this

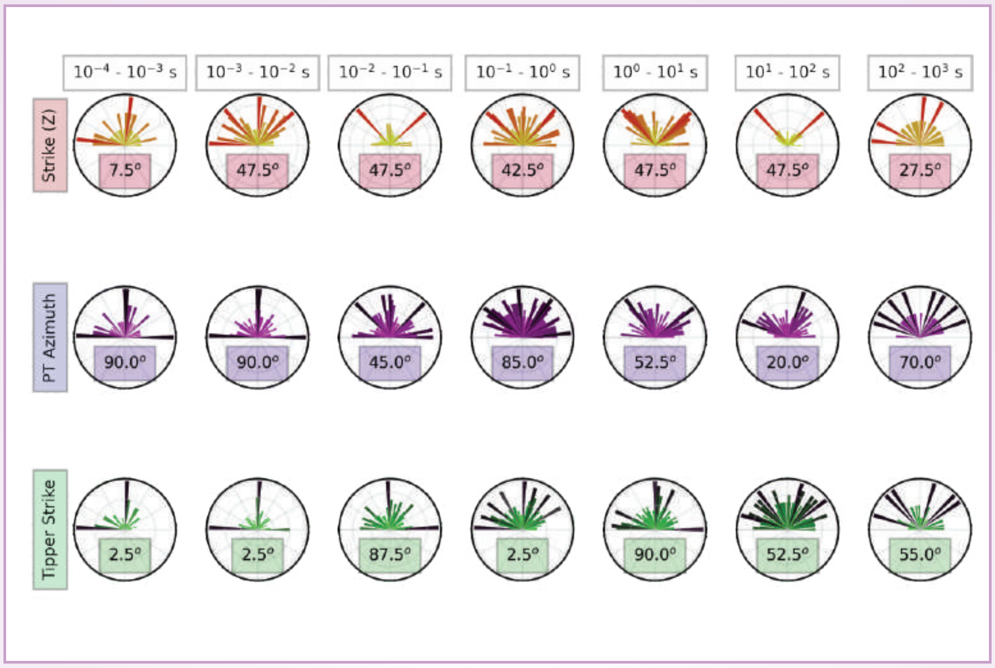

Fig. 20 : Bandwise different strike analysis.

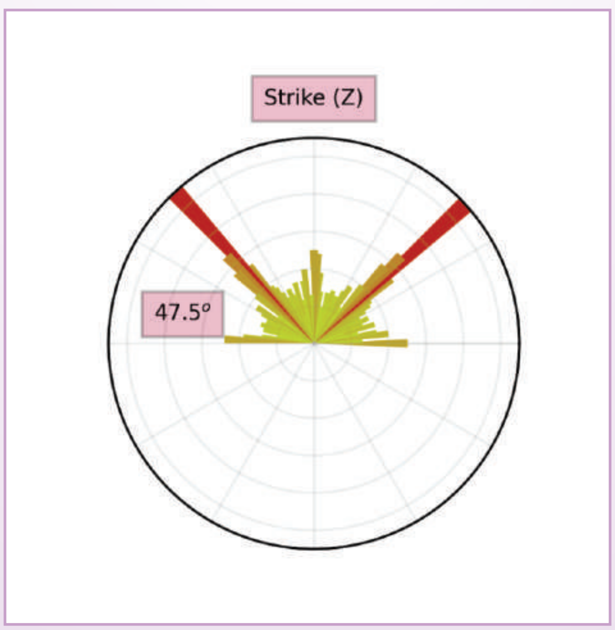

Fig. 21 : Combined strike analysis.

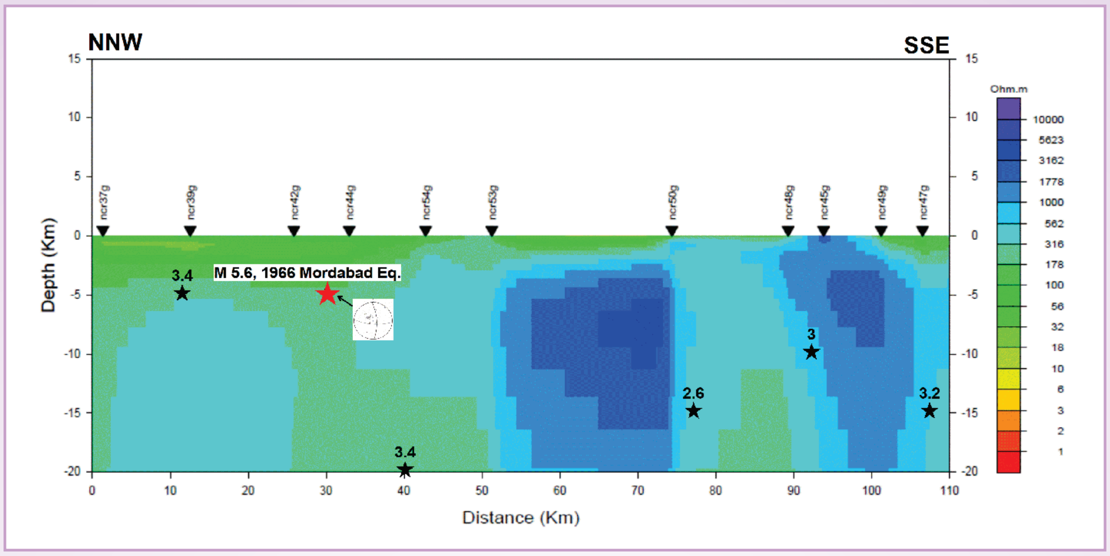

Fig. 22 : Inverted model for TM polarisation.

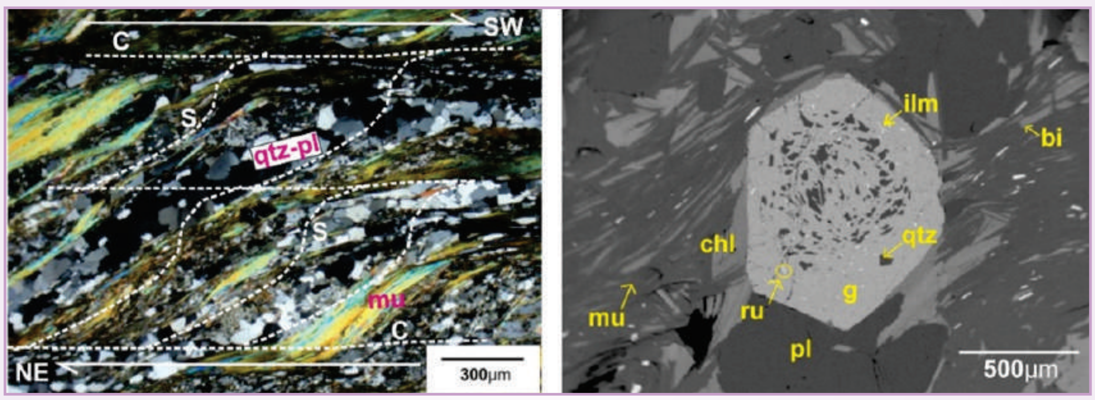

Fig. 23 : (*a*) S-C fabric marks the M2 and D2 events in GS 10.1. (*b*) GS 10.12 shows garnet with helicitic texture, enclosing an early inclusion fabric. The garnet core has schistosity orthogonal to the external D2 foliation and is interpreted to have grown pre-D2, whereas the rim has inclusion trails that curve sharply into concordance with the external schistosity indicating syn- to post-D2 growth.

study, the juxtaposition of Lesser Himalayan greenschist facies rock beneath the amphibolite grade rocks of the GHS is observed in a 2-3 km thick high strain zone identified as the MCT. Petrography and microstructural studies show that the lower part of the GHS, the MCT zone, and its footwall show a moderate *T*/ high *P* inverted metamorphic sequence with pre- to syn-kinematic, inclusion-rich garnet (Fig.23). On the other hand, the uppermost part of the GHS shows high *T*/ moderate *P* prograde metamorphism with post tectonic inclusion free garnet and shows evidence of partial melting in the outcrop scale (Fig.24). With the help of conventional geothermobarometry and P-T pseudosection modeling, it is envisaged that the uppermost part of the GHS and the lower part of the GHS including the MCT zone are two distinct tectonic slices with different metamorphic evolution. The protracted period of partial melting at the uppermost part of the GHS is more akin to a channel flow model. However, inverted metamorphism in the MCT zone, its exhumation, and propagation of deformation towards the foreland suggest accretion of new tectonic slices towards the south, for which an in-sequence shearing model is more consistent with our data. Our structural and metamorphic studies further indicate the presence of a shear zone within the GHS that separates the uppermost high *T*/ moderate *P* migmatized part from the lower inverted moderate *T*/ high *P* sequence (Fig.25). This shear zone is correlated with the regional High Himalayan Discontinuity (HHD) that extends along the strike of the Himalayan range.

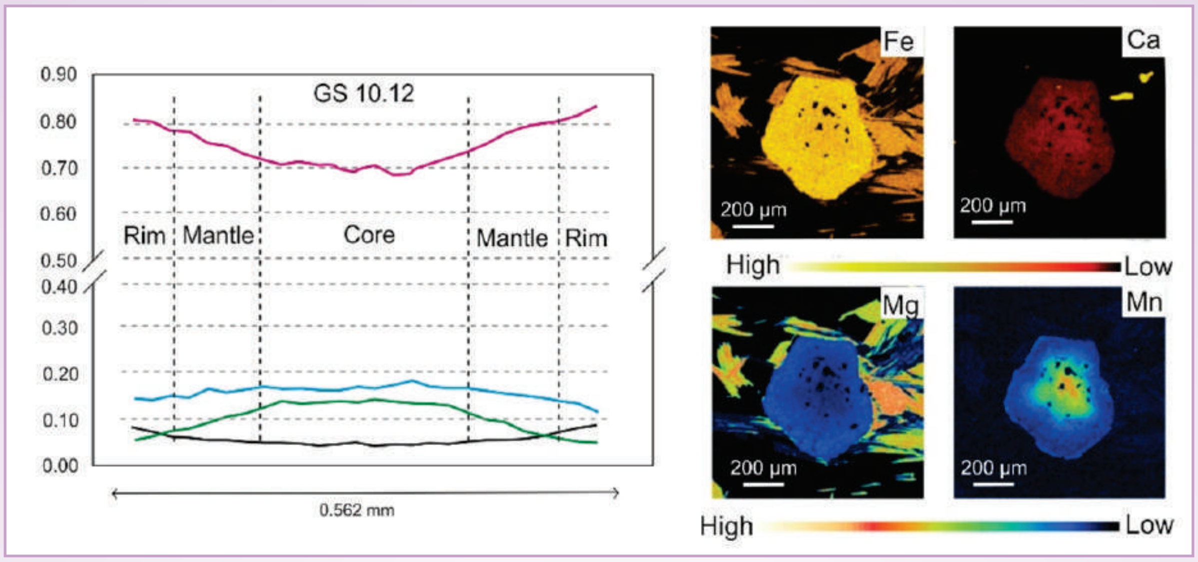

Fig. 24 : Rim to rim quantitative chemical compositional profile across garnet porphyroblasts (X_{alm}, X_{sps}, X_{grs}, X_{pyp}) for a studied sample. A qualitative X-ray map of Fe, Mg, Mn, and Ca content for sample GS10.12 shows a strongly zoned garnet.

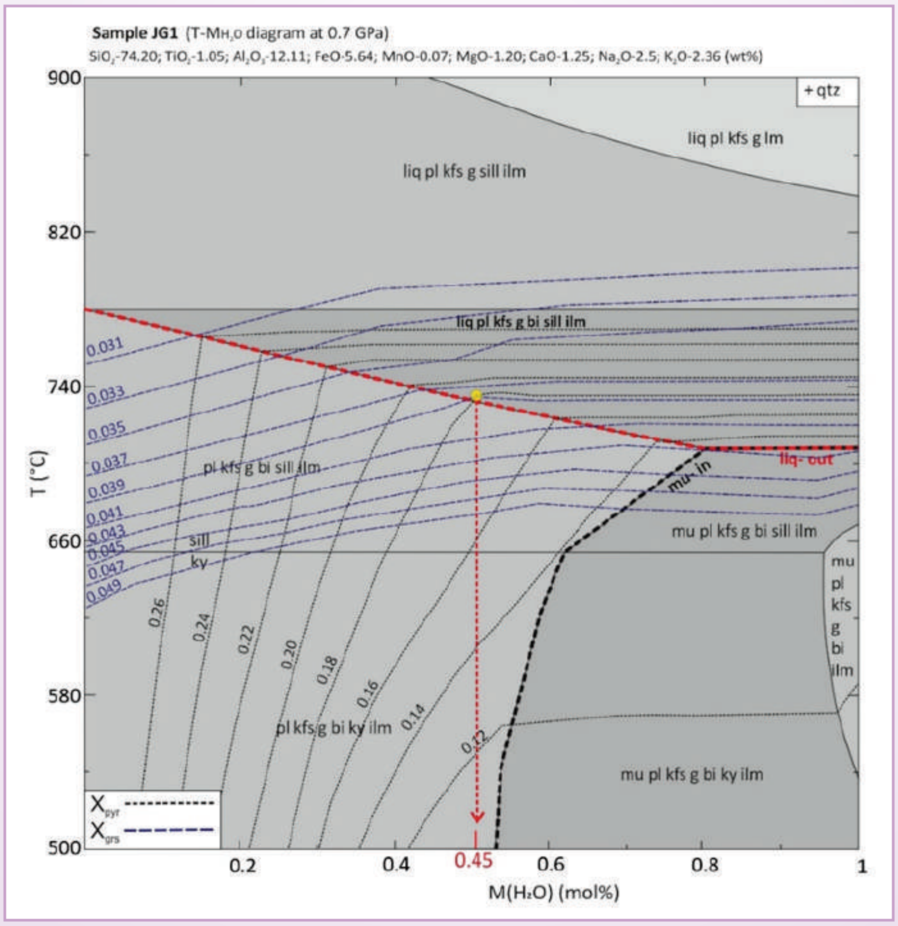

Fig. 25 : *T-M(H_2O)* pseudosection at 7 kbar contoured with X_{pyr} and X_{grs} in garnet to evaluate H_2O content for *P-T* pseudosection modeling of the sample JG1.

Occurrence of migmatites in the HHCS of the Dhauliganga valley, Garhwal Himalaya

The rocks at the higher structural level of the Higher Himalayan Crystalline Sequence (HHCS) of Dhauliganga valley, Garhwal Himalaya also known as a Badrinath formation have experienced migmatization. Petrographic characteristic features, like, as rounded to lobate undeformed quartz occurring in association with K-feldspar, large feldspar grains, and intergrown quartz and plagioclase in quartz-K-feldspar pods have been observed in migmatite rocks. Occurrences of such textures indicate partial melting in migmatite rocks. A petrographic study shows that the muscovite dehydration reaction was responsible for the partial melting of the rock. Study shows that monazite is the common accessory phase in the HHCS. Detailed mineral chemical studies of monazite have been carried out. Study shows that monazite has undergone brabantite and huttonite substitution.

Proposed a new mineral equilibrium in the field of metamorphic geology

A new metamorphic mineral equilibrium, i.e P–T–X (Fe–Mg) relations of cummingtonite-sillimanite-cordierite-quartz-H_2O equilibrium has been proposed.

Phase Equilibria study on mafic xenoliths of KKG, Himachal Himalaya

Phase petrology of mafic xenoliths of Kinnaur Kailash Granite (KKG), Sutlej Valley has been carried out. The study shows that mafic xenoliths were undergone excessive alteration. Research work on retrograde hydration is in progress.

Activity: 2C

Seismicity and seismic hazard assessment in the Himalaya

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

Re-Appraisal of Seismicity and Seismotectonics of the Himalaya

The Himalayan collision zone has been prone to intense seismic activity as evidenced by the occurrence of four great earthquakes in the past century. An attempt has been made to revisit the source zones of the present as well as past major earthquakes along the Himalayan seismic gaps by analyzing the earthquake activity and looking into the relationship between seismicity and the structural elements controlling them. The study highlights the possibility of the occurrence of a major/great earthquake in the Central Seismic Gap (Fig. 26). The microseismicity observed along the Himalayan arc shows bimodal depth distribution characterizing both the upper crustal and lower crustal deformation. The termination of past seismic ruptures on the Himalayan arc is controlled by the geometry of the MHT. The occurrence of past major earthquakes has imparted stress up-dip to the front, which has been added to the existing stress budget accumulated during the interseismic period and will accelerate the recurrence time and re-rupture of the Himalayan front in the future (Fig. 26). The moderate earthquakes occurring on the ramp section of the flat-ramp geometry of the MHT has more possibility of reaching to the frontal Himalaya, as has been observed during the 2005 Kashmir earthquake due to narrow decoupling zones.

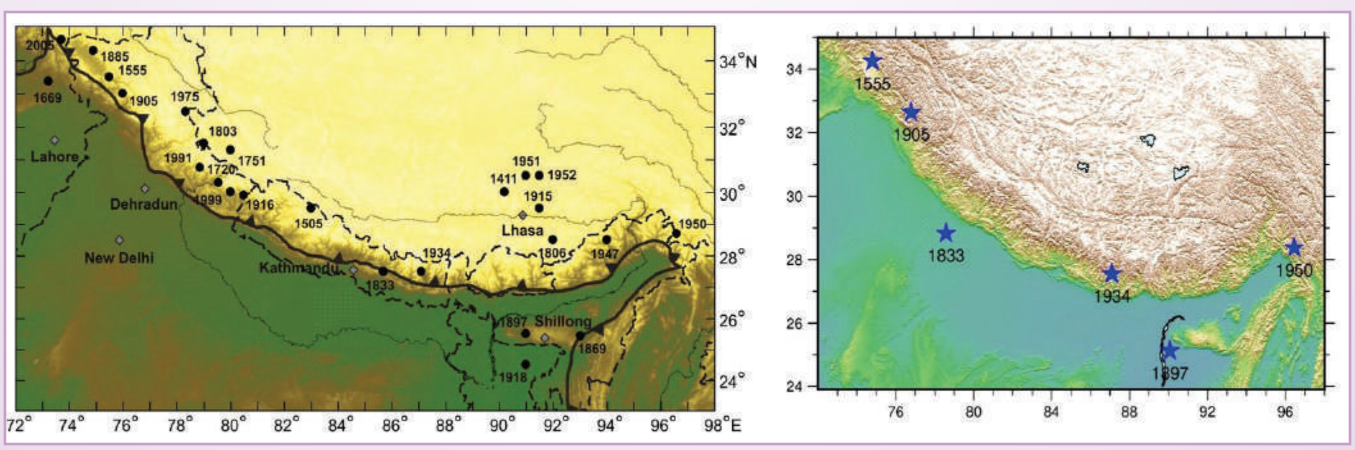

Fig. 26 : (a) The map shows the Himalayan Frontal Thrust (HFT), the major cities, and the significant earthquakes (after Rajendran and Rajendran, 2011). (b) Location of the past great earthquakes (blue star) along with the year of their occurrences.

Considering all these facts, it is necessary to have a better disaster management plan in place to counter seismic hazards in the countries surrounding the Himalayan-Tibet region.

Imaging of intra-crustal low-velocity layer beneath the Doda-Kishtwar region

The converted wave seismological data across the Doda-Kishtwar region in the Kashmir seismic gap of the northwest Himalaya has been used in this study (Fig. 27). The results based on the inversion of receiver functions (RFs) reveal, for the first time, the crustal velocity-structure with a Low-Velocity Layer (LVL). The crustal thickness varies from 47 km to 58 km from south to north, and the Main Himalayan Thrust exists at a depth between 21 to 26 km. The LVL with its top lying at 11 to 13 km extends down to a depth of 29 km and shows Vp/Vs of 1.9. This high value of Vp/Vs may be explained by the presence of fluid/fractional melt. It is envasiged that the presence of fluids/partial melts could be one of the possible reasons for the generation of upper-to-mid-crustal earthquakes (Fig. 28).

Site amplification for the seismically and tectonically active Garhwal Himalayan region

This work includes the computation of frequency-dependent shear-wave quality factor $Q_\beta(f)$ and site amplification for the seismically and tectonically active Garhwal Himalaya. The inversion technique of strong motion data is applied to obtain $Q_\beta(f)$ and site effect at each recording station. The strong motion data of eighty-two earthquakes of magnitude range $1.8 \leq M \leq 6.8$ recorded in the Garhwal region is used for this inversion algorithm. The comparison of site effects obtained by the present inversion scheme and the well-developed H/V technique (H/V is the ratio of Fourier spectra horizontal to vertical components) shows that site effects computed through the inversion technique have a close resemblance with these estimates from the H/V technique. Both horizontal components are used to establish the frequency-dependent $Q_\beta(f)$ relations at each station. The close resemblance of obtained $Q_\beta(f)$ relations at different stations suggests, the presence of an almost similar type of lithology i.e. hard rock at these

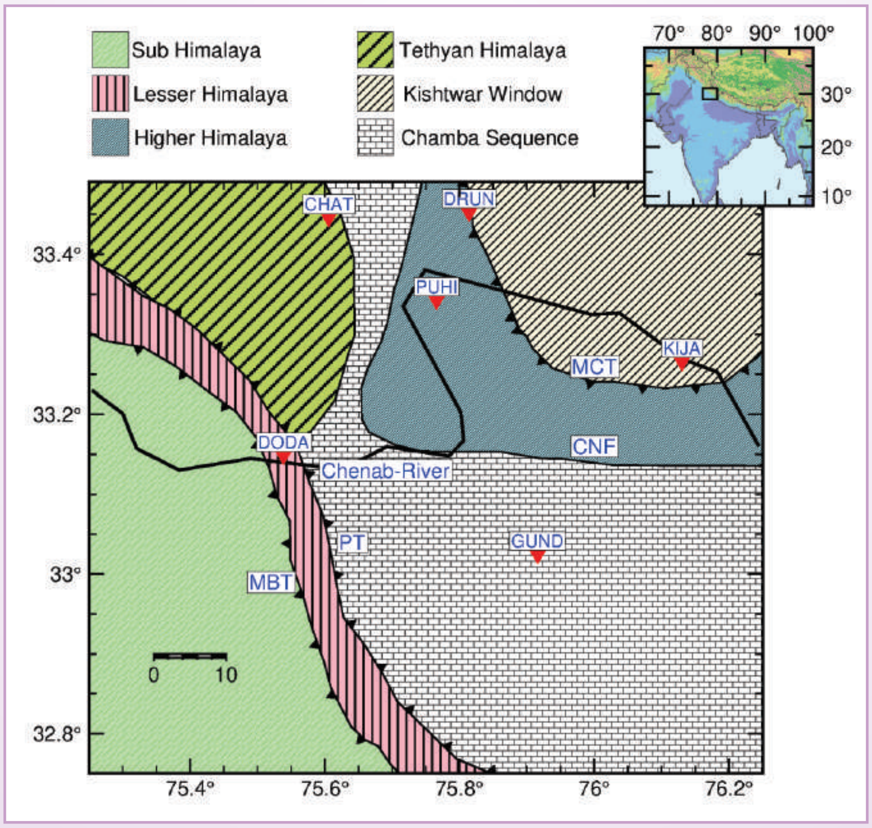

Fig. 27 : Locations of broadband seismological stations (inverted red triangles) in the Doda-Kishtwar region along with major tectonic units shown by different colours.

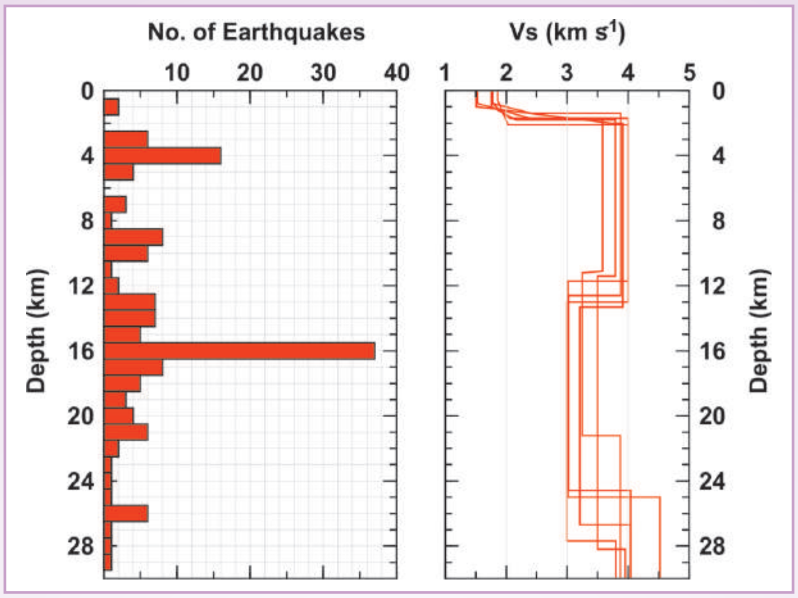

Fig. 28 : The depths of earthquakes (Mw≥2) compared with the shear wave velocity model (obtained from inversion) showing most of the seismicity within the low-velocity zone.

stations. A regional quality factor relationship of form, $Q_\beta(f) = (102 \pm 3.9)f^{(1.0\pm0.1)}$ is established for the Garhwal Himalaya based on modeled Q_β values of each station. This relationship reveals that low Qo value (<200) and high n value (>0.8) for the Garhwal Himalaya, which corresponds to a tectonically and seismically active region (Fig. 29).

SKS and SKKS splitting measurements beneath the Northwest Himalaya

A study on SKS and SKKS splitting is carried out in the northwest part of the Himalaya where the Delhi–Hardwar Ridge (DHR) is interacting orthogonally with the foothill regions to investigate seismic anisotropy. Teleseismic earthquake datawere recorded at 10 broadband seismological stations located at ABI (Adibadri), CKA (Chakrata), DBN (Deoband), DDN (Dehradun), GKD (Gaurikund) GTU (Ghuttu) KHI (Kotkhai) KSI (Kharsali) NHN (Nahan) TPN (Tapovan) were used in this study. A total of 47 reliable splitting parameters is estimated using rotation correlation and transverse component minimization methods. The splitting parameters (ϕ, δt) of the SKS and SKKS phases of these teleseismic earthquakes were estimated using SplitLab software. There are three different techniques integrated into this software: (1) the rotation-correlation technique, (2) the minimum energy technique, and (3) the minimum Eigenvalue technique. The splitting parameters (ϕ, δt) have been computed by analyzing SKS and SKKS phases of selected teleseismic earthquake data recorded at 10 broadband seismic stations. The azimuths of fast polarization directions (FPD) vary between 42^0 and 98^0, and the delay times vary from 0.3 to 1.6 s. The apparent thicknesses of the anisotropy layers underneath the stations vary from 35 to 184 km. The estimated delay time and FPDs are found to be scattered. Wide variations in delay times reveal that the anisotropy beneath the study area is complex in the form of multi-layered anisotropy and might be caused by the cumulative effects of the mantle flow arising due to continued collision between the Indian and Eurasia plates, and the foliation planes, arising both in the Himalaya and the Delhi-Haridwar Ridge (DHR). The diverse orientations of the FPDs found either in the present study or in earlier studies are associated with the complex deformation of the converging Indian lithosphere against the Eurasian plate along the diffused Himalayan plate boundary. The coherent observation of FPDs parallel to the strike of the DHR in the foothills of the Himalaya is proposed to be caused by structurally controlled strain-induced shearing. Similar observations were also found for other segments of the Himalaya where ridge–orogen interaction is quite active. Thus, the converging ridges along the foothills invariably affect the ongoing deformation vis-a-vis the seismotectonics of the sub-ducting Indian lithosphere along this plate boundary. Orogen parallel anisotropy found in the present study is associated with mantle flow as well as the foliations along the major thrust planes and is proposed to be caused by the subduction of the Indian

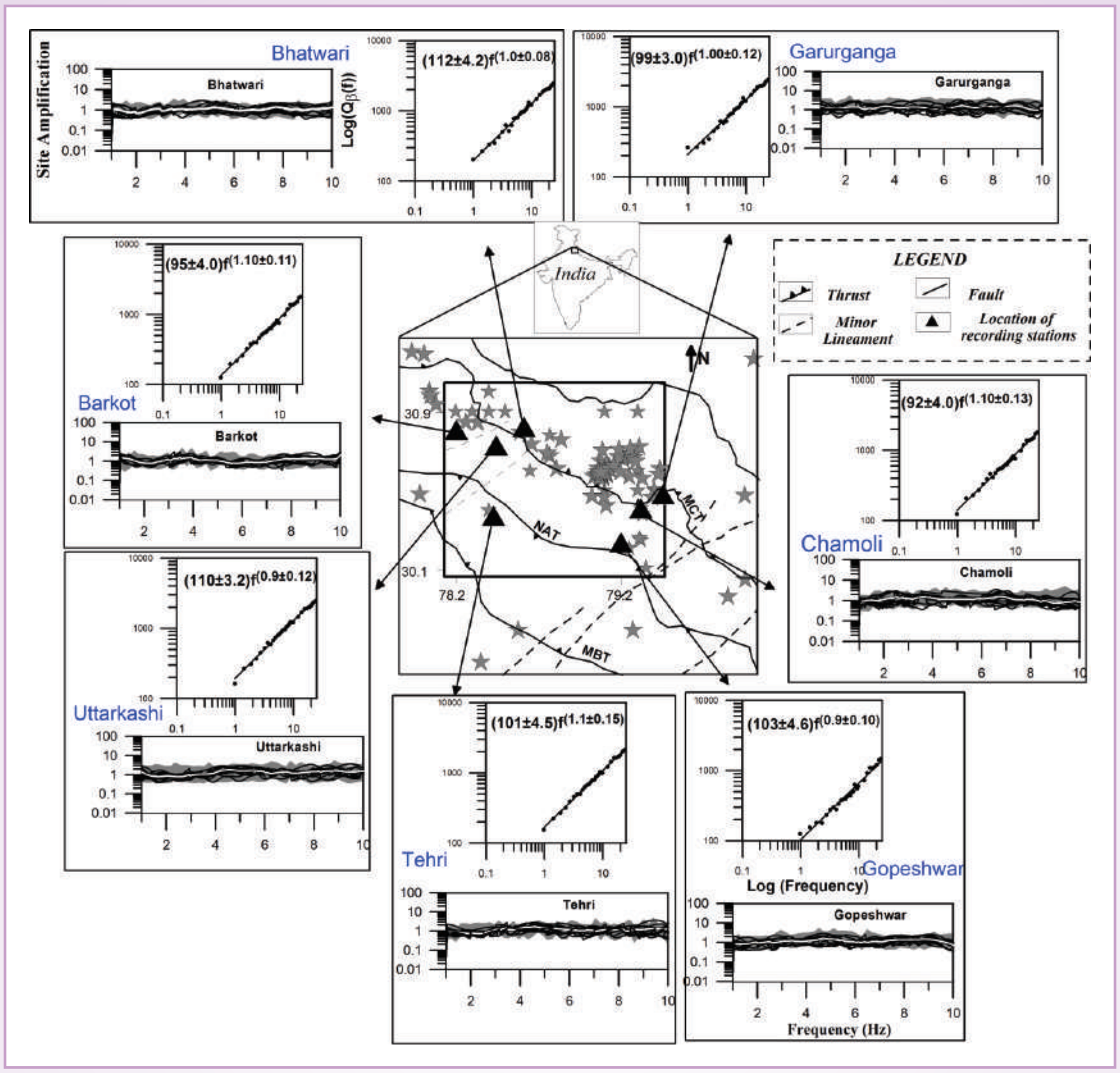

Fig. 29 : Site effects and $Q_\beta(f)$ relationship obtained at different recording stations. The black lines indicate the site effect obtained by various events, and the white lines are the average site effect curve.

plate beneath the Eurasian plate. The two-layered anisotropy model for the stations Adibadri, Gaurikund, and Chakrata reveals that the directions of fast axes in the shallow level beneath the stations are parallel to the strike of the DHR and are parallel to the APM direction of the Indian plate in the deeper level.

Micro-earthquake Investigation and source characterization study in and around Siang Valley of Arunachal Himalaya

The microearthquake data recorded from June 2019-February 2021 by 8 BBS stations of the Siang Valley network of Arunachal Himalaya are extracted and processed for the estimation of hypocentral parameters. Fault plane solutions (FPS) of earthquakes of M ≥ 3.5 are determined using the waveform inversion technique implemented on ISOLA software. The obtained FPSs are used to determine stress tensor inversion to get the stress pattern existing in the region. The maximum compressional axis (σ1), the intermediate axis (σ2), and the minimum compressional axis (σ3) orientations in the region have been estimated. A detailed study has been carried out on the felt earthquake that occurred in the Mechuka region of Siang valley. The hypocentral parameters, as well as FPS results of this event, are compared with the existing ISC data of previous years with a magnitude ≥ 4.8 that occurred in the studied area. The distribution of local as well as regional earthquake events shows that the Siang valley is a seismically very active region, its western part is more active compared

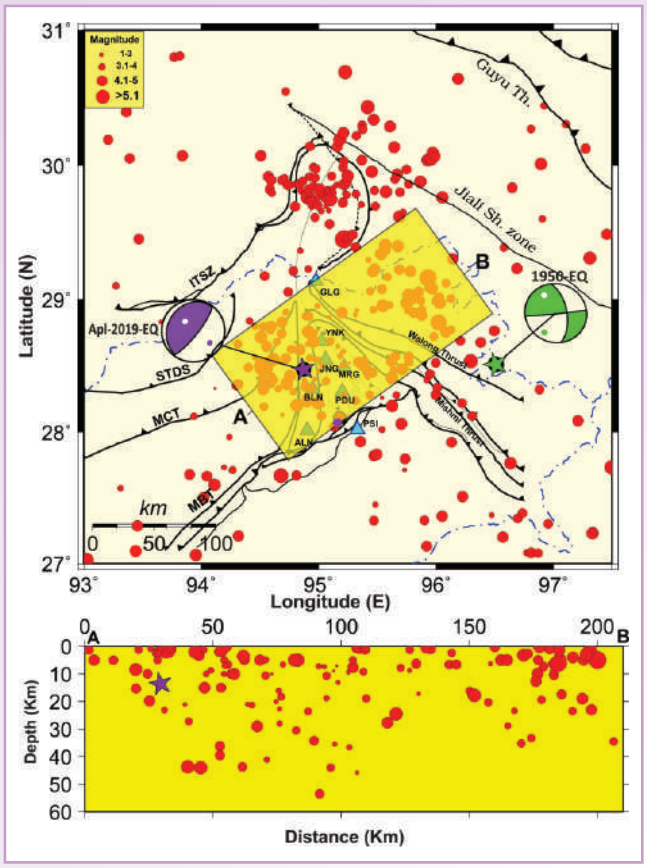

Fig. 30 : Map showing the major tectonic features and epicentral distribution of earthquakes recorded by 8 broadband seismological stations of Siang Valley from June 2019- February 2021. The Purple and green Beachballs are FPSs of the 2019 Mechuka earthquake (Yadav et al. 2021) and the 1950 great Assam earthquake (Ben-Menahem, 1975) respectively. The second panel shows the depth distribution of seismicity along transect A-B, and the purple star shows the focus of the 2019 Mechuka earthquake.

to the eastern part (Fig. 30). The cross-section along the NE-SW direction in this area shows deeper events in the Siang window compared to the Namche Barwa region. The spectral analysis of micro-earthquakes has been carried out in the Siang valley to determine stress drop, seismic moments, and source radius. The magnitude (M_L) used in the study ranges between $1.0 \le ML \le 5.9$, the stress drop value ranges from 0.5 to 114.5 bars, and seismic moments range from 2.30E+11 Nm to 6.86E+16 Nm, and the source radius from 116 m to 1392 m. The evaluated low-stress drop value shows the brittleness of the upper crustal region. In Siang valley, the concentration of seismic events around the major tectonic elements (i.e MCT, MBT, MT, LT, and Tidding Thrust), shows the development of a high strain region and shows the linkage between stress drop, seismicity, and tectonic elements. The variation of stress drop with seismic Moment, moment magnitude, and focal depth respectively are studied.

Seismotectonic and stress pattern of Chandigarh-Ambala region

Digital waveform data are collected from the seismological network of the Chandigarh-Ambala (CHD-AMB) region for the period February 2021 to March 2022. Local and regional earthquake events are extracted from the continuous record and are complied with the events of other seismological networks existing in this region of the northwest Himalaya to obtain precise hypocentral parameters. The FPSs are determined for local events with magnitudes ≥ 3.5 using P-wave first motion polarity as well as waveform inversion using ISOLA software. Most of the earthquakes of this network are aligned along the NS trending Mahendragarh-Dehradun fault, the FPS of the events determined along this fault is showing the strike-slip type of faulting with thrust component.

Activity: 3

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

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

A new mammalian faunal assemblage representing ruminants (Tragulids) was described from the late Oligocene Kargil Formation of the Ladakh Molasse Group. These fossils were attributed to *Nalameryx savagei* (Fig. 31). The description of new specimens from the type bed K/7b from the Kargil Formation led to a reinterpretation of the phylogenetic position of *Nalameryx* and the early evolutionary history of the Tragulidae. Based on our phylogenetic hypothesis, *Nalameryx* is nested within the living Tragulidae, making it one of the oldest known tragulid. Tooth isotopic data indicate that *Nalameryx* fed on plants that have grown under xeric conditions. This is in agreement with palaeoenvironmental information observed on plants from Turkish and Pakistani localities where *Nalameryx* has already been found. It was interpreted that this region of the world had a seasonal climate with an arid period during the late Oligocene. These results are the first quantitative paleoecological study directly observed on an Asiatic Paleogene ruminant.

A new species of fossil treeshrew were identified from the Lower Siwalik (middle Miocene) succession of Ramnagar area, (Jammu and Kashmir). The new fossil

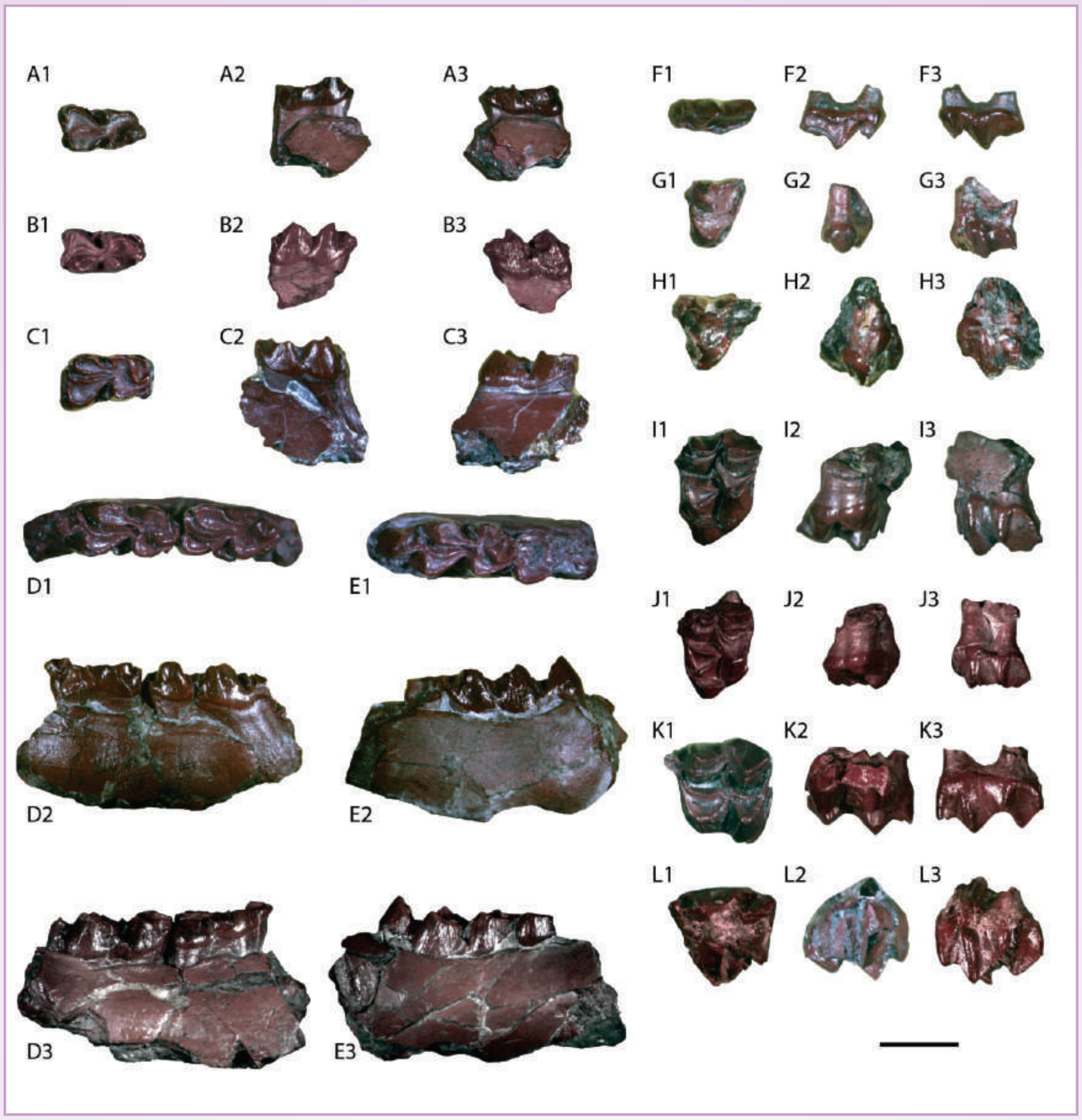

Fig. 31 : *Nalameryx savagei* (Nanda and Sahni 1990) remains were discovered in 2019 from the K/7b horizon of the Kargil Formation (late Oligocene, India). (a) WIMF/A 4808, left m1; (b) WIMF/A 4812, left m1 with associated drawing (in Orange, M-structure); (c) WIMF/A 4807, right m2; (d) WIMF/A 4801, partial lower right jaw preserving m2 and m3; (e) WIMF/A 4802, partial lower right jaw preserving m2 and m3; (f) WIMF/A 4811, left P2; (g) WIMF/A 4809, left P4; (h) WIMF/A 4810, left P4; (i) WIMF/A 4803, left M1; (j) WIMF/A 4804, left M1; (k) WIMF/A 4805, left M2; (l) WIMF/A 4806, left M2; in (1) occlusal, (2) labial, and (3) lingual views. The scale is 5 mm.

discovery is very significant as it represents fossil tree shrews and hedgehogs which are very poorly known from the Siwaliks. The new tree shrew was named as *Sivatupaia ramnagarensis,* and the present locality now represents the oldest record of fossil tupaiids in the Siwaliks and extends their time range in the region by ~2.5- 4 million years. In addition, fossil insectivore belonging to *Galerix rutlandae* was also reported. Besides tree shrew and insectivores a new assemblage of rodents such as *Democricetodon kohatensis*, *Kanisamys indicus*, *Sayimys sivalensis,* and *Antemus chinjiensis* was also identified.

For the first time, a new assemblage of microvertebrate and arthropod faunas has been reported from the Nurpur region of Himachal Pradesh, which erstwhile was known for mega mammalian fauna. The present assemblage consists of rodents such as *Karnimata* cf. *K. darwini* and Murinae indet; reptiles

ACTIVITIES

such as Crocodylia indet, 'Colubrinae' indet. or 'Natricinae' indet.; fishes such as Cyprinidae indet. and Perciformes indet.; and crab *Sartoriana* indet.

Biostratigraphic analysis of the mammalian fauna of the Siwalik Group of the Indian sub-continent was carried out. It is well known that the collection of Siwalik vertebrate fossils is about two centuries old and most of the earlier reports centered around the fossil discoveries. But in the last few decades, multidisciplinary studies involving lithology, biostratigraphy, magnetostratigraphy, geochemistry, biochronology, etc. have been carried out. These studies have provided new dimensions and significant advancements in understanding the various aspects of the Siwalik Group. Recent emphasis is on micro-mammals, particularly rodents, and rodent biochronology has emerged as a useful tool in correlating and dating the intra-regional localities of the Siwalik Group. The new findings of primates have helped in enhancing the knowledge of the Siwalik hominoids. The magnetostratigraphic studies provided absolute ages to various lithostratigraphic and faunal boundaries and also the first and last appearances of various taxa. The analytical studies on carbon and oxygen stable isotopes of palaeosols and fossil tooth enamel have assisted in interpreting the vegetational shift and dietary habitats of extinct mammals. The Siwalik-age fossils are well identified from several localities lying south of the Himalaya, this indicates the extension of the Siwalik biogeographic domain. The dispersal of the Siwalik faunas with respect to Africa/Arabia; Europe/west Asia; SE and East Asia was interpreted (Fig. 32). Simultaneously, there are several problems associated with the Siwalik biostratigraphy. Taxonomic revisions at the species level are required. Standard Reference Sections are to be finalized for the Indian Siwaliks. Several new stratigraphic units have been recognized and new names are given to a single unit in a restricted area, and this problem of nomenclature of new names requires attention. For Indian sections, additional magnetostratigraphic data is required to know the precise faunal events, it will help to correlate the different horizons of the Siwalik with its coevals in Europe, Africa, and Asia.

In NE India, Eocene larger foraminiferal biostratigraphy, depositional history, and paleogeography of the Sylhet Limestone of the Mikir Hills of Assam were carried out. The Eocene Epoch (56 to 33.9 Ma) represents a dynamic geologic interval with a complex interplay of tectonics and climate. It is

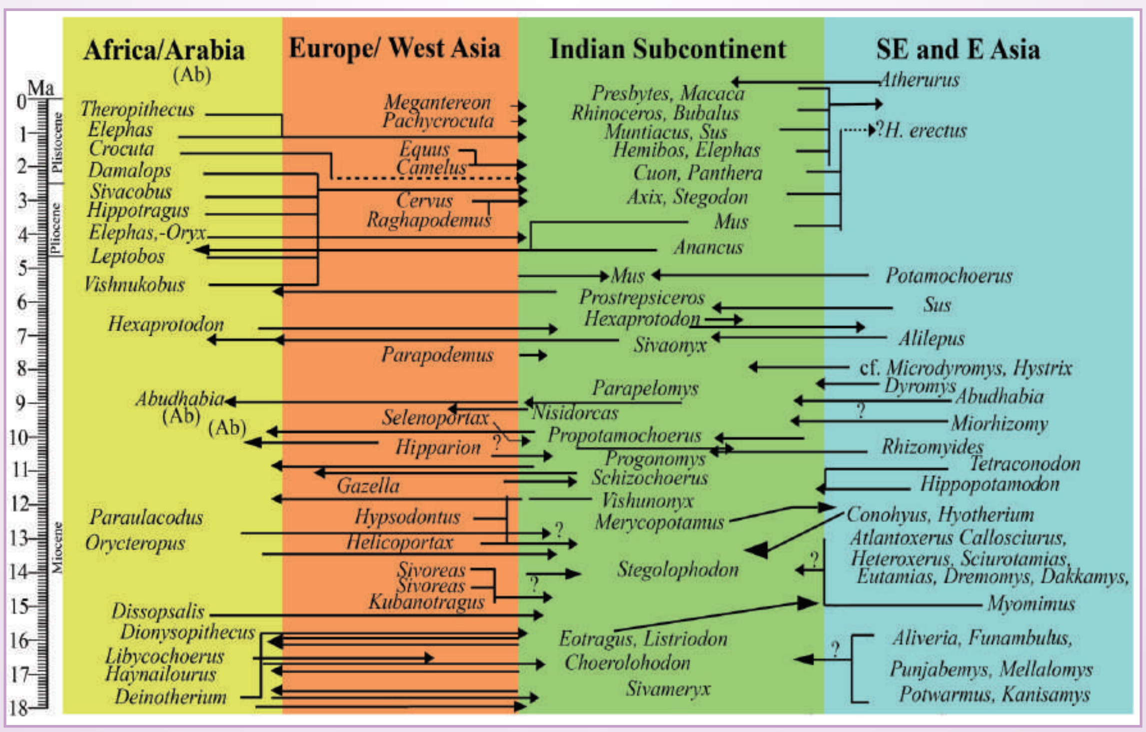

Fig. 32 : Major dispersals of mammals to and from the Indian subcontinent. Broken lines: direction of dispersal not certain (after Nanda et al. 2022).

characterized by a plethora of climatic conditions that include the transition from a warm, ice-free "greenhouse" to a cool "icehouse" world. Several short-lived hyperthermal events associated with large perturbations of the global carbon cycle are known to punctuate the time interval as evident from the carbon isotope records from both oceanic and continental realms. The Eocene sediments are best exposed in northeast India where it has two facies: basinal and shelfal based on their fossil contents. Less data is yet available on biostratigraphy and paleoenvironment from the Mikir Hills. Thus, our objective was to make a detailed study of the Eocene larger foraminiferal biostratigraphy and to reconstruct the depositional and paleogeographic history of the Sylhet Limestone in relation to the India-Asia collision and events in the Neo-Tethys Sea.

This study presents results of integrated larger foraminifera biostratigraphy, lithofacies, and stable carbon isotope (δ^{13}Corg) analysis carried out in the Sylhet Limestone of Dillai Parbat Limestone Mine succession, Karbi Anglong District, Assam. Larger foraminiferal assemblages (Figs. 33 and 34) assign a middle Eocene age to the studied succession of Sylhet Limestone. The Shallow Benthic Zone (SBZ) 13 and SBZ 16-18 and a barren interval in between are recognized in the studied part of the Sylhet Limestone.

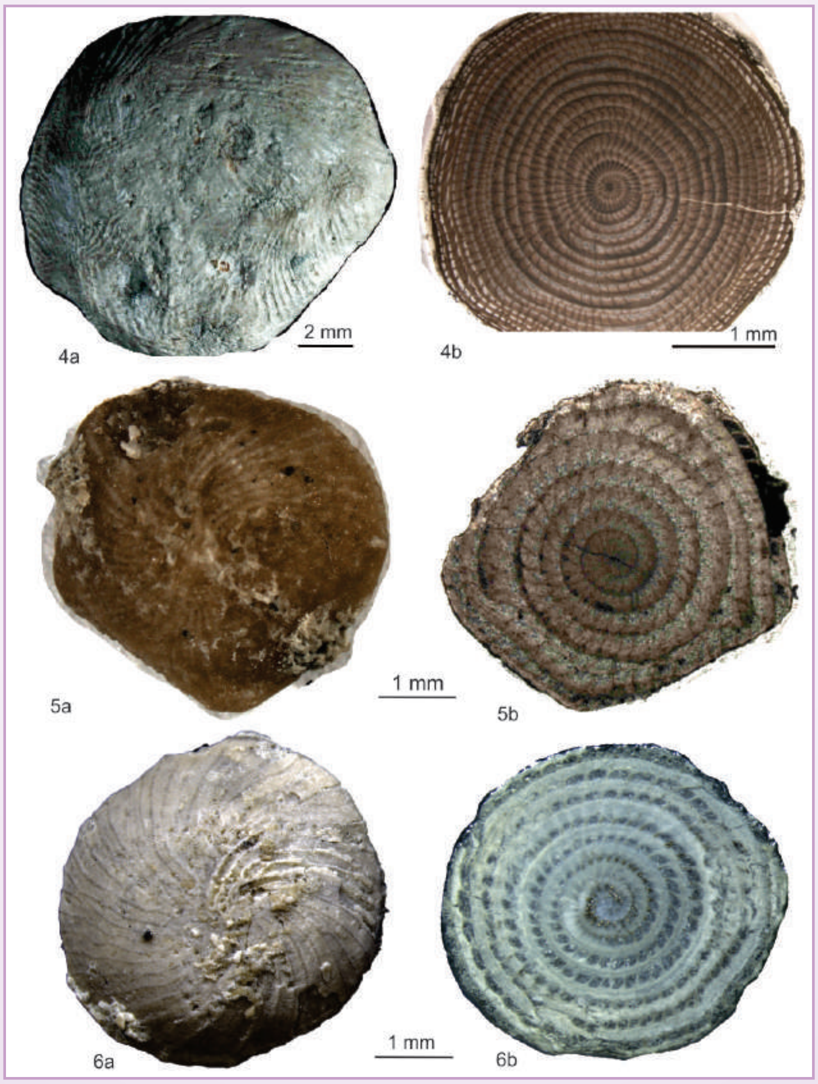

Fig. 33 : Specimen 4a-b, *N. verneuili* D'Archiac and Haime 1853, form B, sample No.3, WIMF/A 3721; Specimen 5a-b, *N. striatus* (Bruguiere 1792), form A, sample No. 33, WIMF/A 3722; Specimen 6a-b, *N. praediscorbinus* Schaub 1981, form B, sample 6. WIMF/A 3722.

ACTIVITIES

The SBZ 13 Zone (early Lutetian) is represented by fossiliferous limestone at the base of the section and is inferred to have been deposited in a subtidal environment. The overlying barren interval lies in the arenaceous interval and is likely deposited in subtidal channel sand shoaling bars. The upper part of the section is marked by SBZ 16-18 (late Lutetian to Bartonian) and was deposited in subtidal channel sand inner neritic zone environments, followed by intertidal marl to subtidal limestone (Fig. 35). The stable organic carbon isotopic data reveals a sharp negative excursion at about 34-35 m of the succession, which may be correlated with Middle Eocene Climatic Optimum (MECO) and/or vegetation types. This and earlier studies from India and elsewhere indicate that during the middle Eocene, the Neo-Tethys Sea was open and connected through the East and West coasts of India, Northeast India, western Himalaya, and most of the Middle East and southeast Europe. This vast area produced an enormous amount of petroleum.

In addition, the spatial-temporal heterogeneity in a small post-glacial lake of the Lahaul Himalaya and its influence on paleoclimate reconstruction is explored. The depocenter of the lake (CC) received ~ 2.5 times higher average sedimentation compared to the shore margin (CPT) (Fig. 36). Despite the distinct sedimentation rate in the depocenter and shore margin, environmental magnetic and total organic carbon (TOC) records showed similar environmental signals over equivalent periods (Fig. 31). The depocenter core provided high-resolution lacustrine environment,

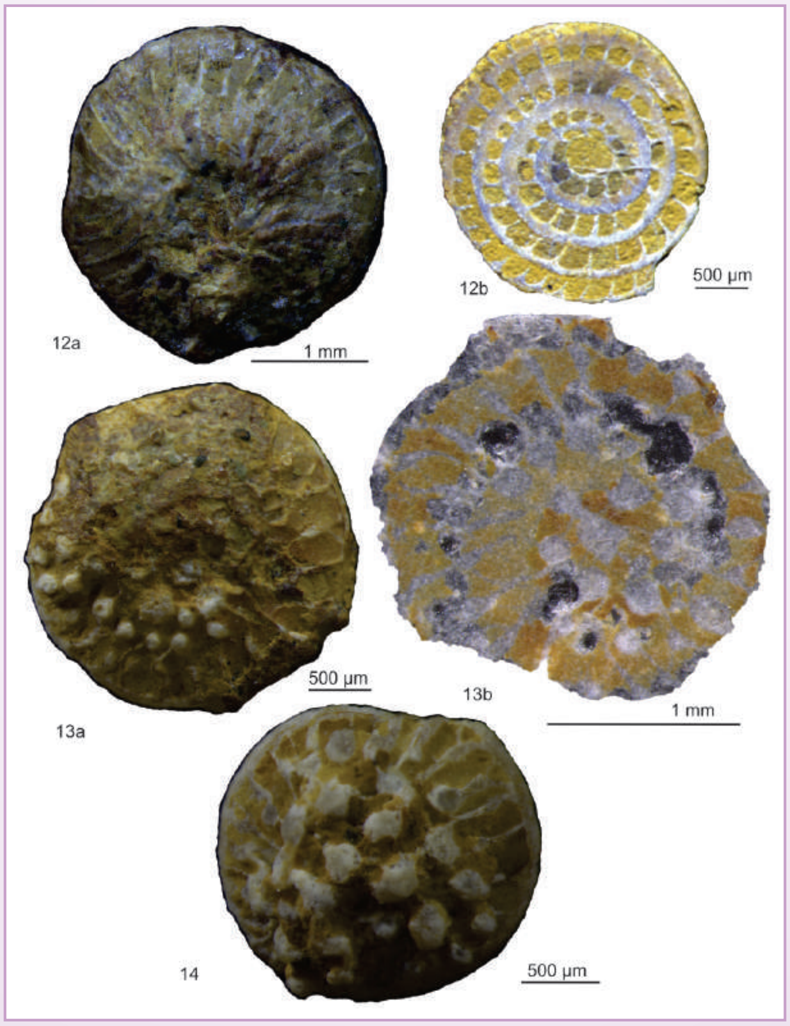

Fig. 34 : Specimen 12a-b, *N. striatus* (Bruguiere, 1792), form A, sample No. 32, WIMF/A 3725; Specimen 13a-b, *N.* cf.*ptukhiani* Kacharava 1962, form A, sample No. 32, WIMF/A 3726. Specimen 14, *N. praegarnieri* Schaub 1981 form A, sample No. 31, WIMF/A 3727.

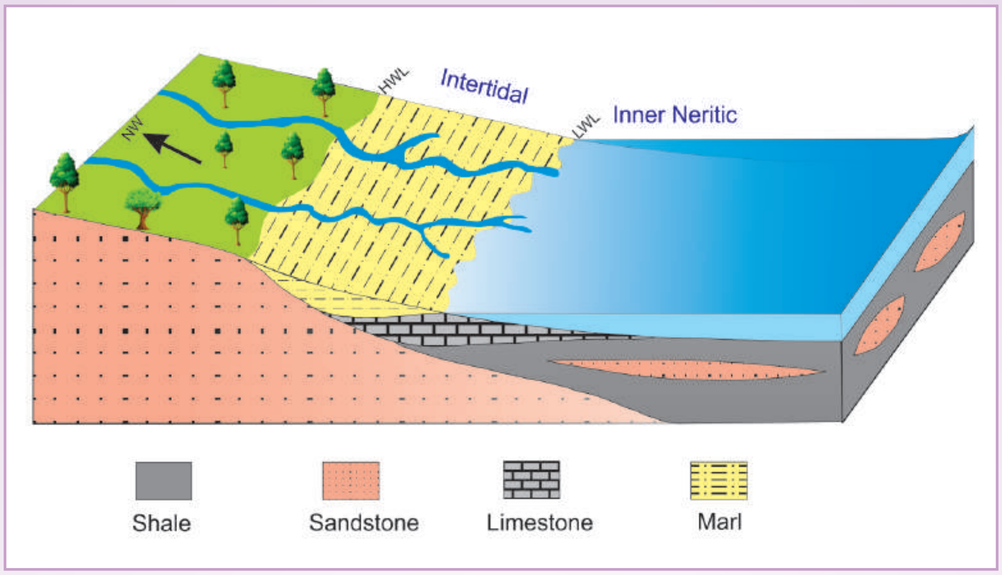

Fig. 35 : Schematic depositional model for the Sylhet Limestone showing progradation of intertidal to subtidal channels depositing sandstones overlain by neritic shales. Limestones were deposited mainly in subtidal conditions and marl in an intertidal environment. Sediment supply was from the northwest (the figure is not to scale). High water level (HWL) and Low water level (LWL) are shown.

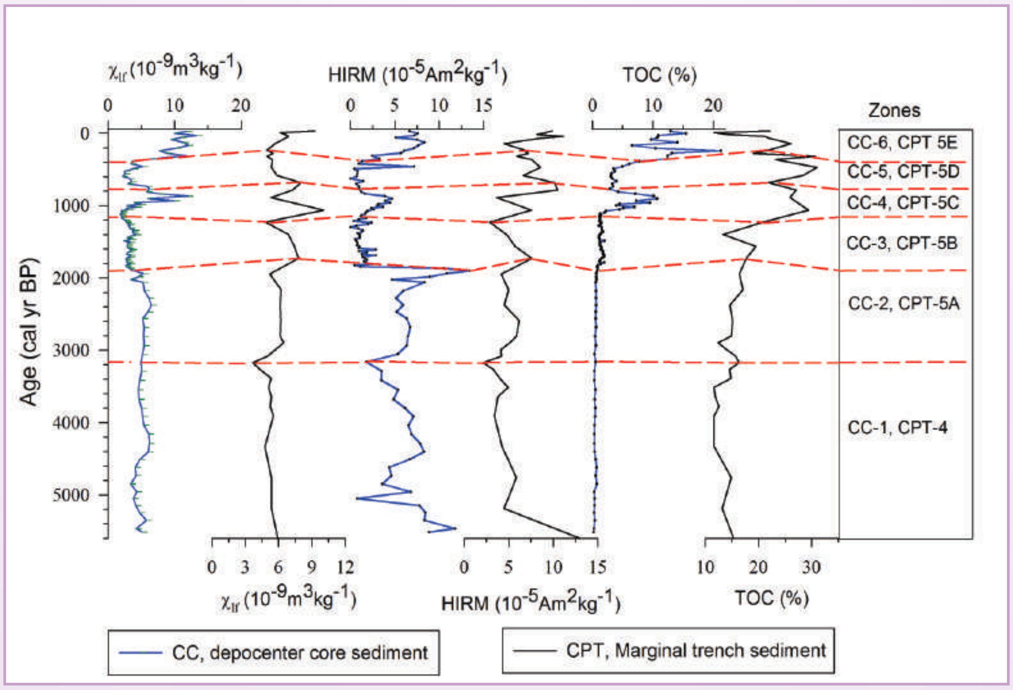

Fig. 36 : Comparison of environmental magnetic parameters and total organic carbon of the depocenter CC and shore CPT profiles.

whereas the marginal trench recorded major shifts in paleoclimate over a longer time scale. New multi-proxy data showed strengthened Indian summer monsoon (ISM) during medieval climate anomaly (MCA) and weakened ISM during the little ice age (LIA) in the NW Himalaya (Fig.37).

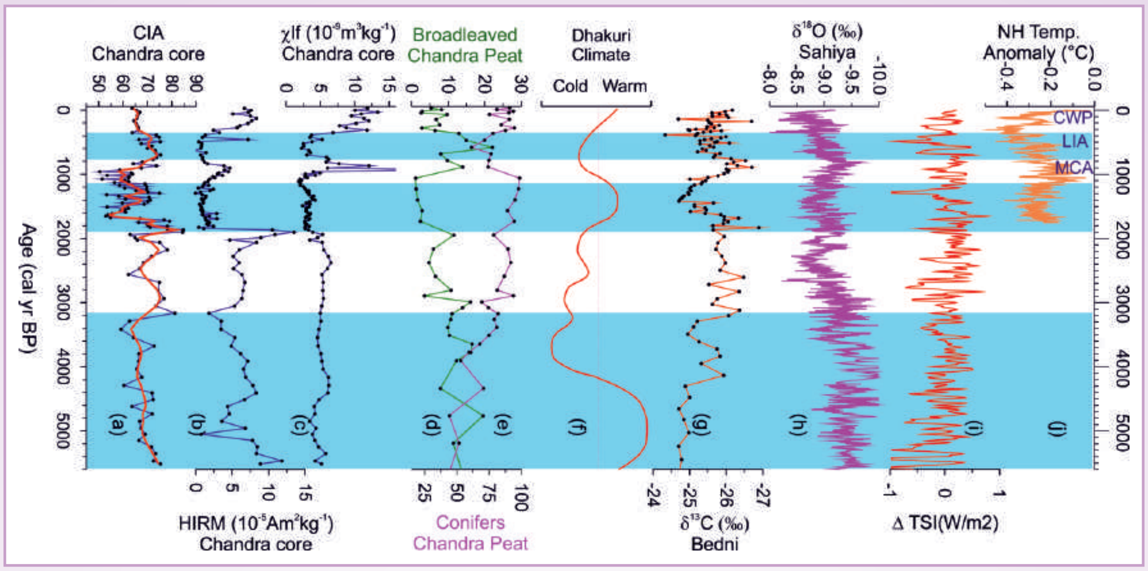

Fig. 37 : Comparison of multi-proxy (CIA, HIRM, and χlf) (a–c) results of the depocenter CC with (d–e) Broadleaved and Conifer pollen data from marginal shore CPT, Lahaul (Rawat et al. 2015a), (f) carbon isotope data from Bednikund lake, Garhwal Himalaya (Rawat et al. 2021a and b), (g) oxygen isotope data from Shaiya cave speleothem, Garhwal Himalaya (Kathayat et al. 2017), (h) total solar irradiance (Steinhilber et al. 2009) and (i)NH temperature anomaly (Mann and Jones 2003).

Activity: 4A

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

(R.J. Perumal, Pradeep Srivastava, Anil Kumar, Som Dutt, Chhavi Pandey, Pinkey Bisht, and Subhojit Saha)

Lake and debris flow records

Variation in lake levels and hydrology over the Trans-Himalaya and Tibetan Plateau (TP) is reconstructed by studying the deltaic sequences of Pangong Tso. Three phased lake level changes are observed during the past 3 ka. Further, to understand the vertical extension of these deltaic sequences, an electric resistivity tomography (ERT) survey was conducted over the selected sections of Pangong Tso. Data was collected in 2D and 3D profiles. The 2D data suggests the extension of these sequences up to 12 – 16 m on the sub-surface (Fig. 38), whereas at the surface these are exposed only to 2-6 m above the lake level.

Debris flow susceptibility analysis of the Leh valley by detailed investigation of sediment availability, topographic conditions, and their relation with known events was quantified by the index of connectivity (IC) model, the Flow-R model, and the Weights of evidence (WOE) method. The IC and Flow-R models are found to be counter-supportive and effective in delineating areas that could be affected by flows. The WOE-based model determines the probability of the rare and extensive flows that results from the downward integration of other drainage networks in an open fan area.

Speleothem responses to climate

Oxygen isotopes record from the Mawmluh cave, Meghalaya suggests a pronounced weakening of the Indian summer monsoon in northeastern India from 4.25 kyr BP that lasted till 4.0 kyr BP, and linked with the cold-arid 4.2 kyr BP global event (Fig. 39). However, the intensity and timing of the event largely vary in different parts of the Indian subcontinent. Northwest and Peninsular India suffered 1000 years of protracted and abrupt aridity due to this event whereas northeastern India evidenced only 200 years of low precipitation. The palaeoclimatic records from central India suggest a gradual lowering of rainfall during the Northgrippian to Meghalayan transition.

Paleoglacial responses to climate

The Yankti Kuti valley which is located in the transitional climatic zone of the upper Kali Ganga catchment of the Kumaon Himalaya has witnessed multiple glacier advances since the Marine Isotopic Stage 3 (MIS 3).

The field survey and optically stimulated luminescence (OSL) dating of moraines from the valley

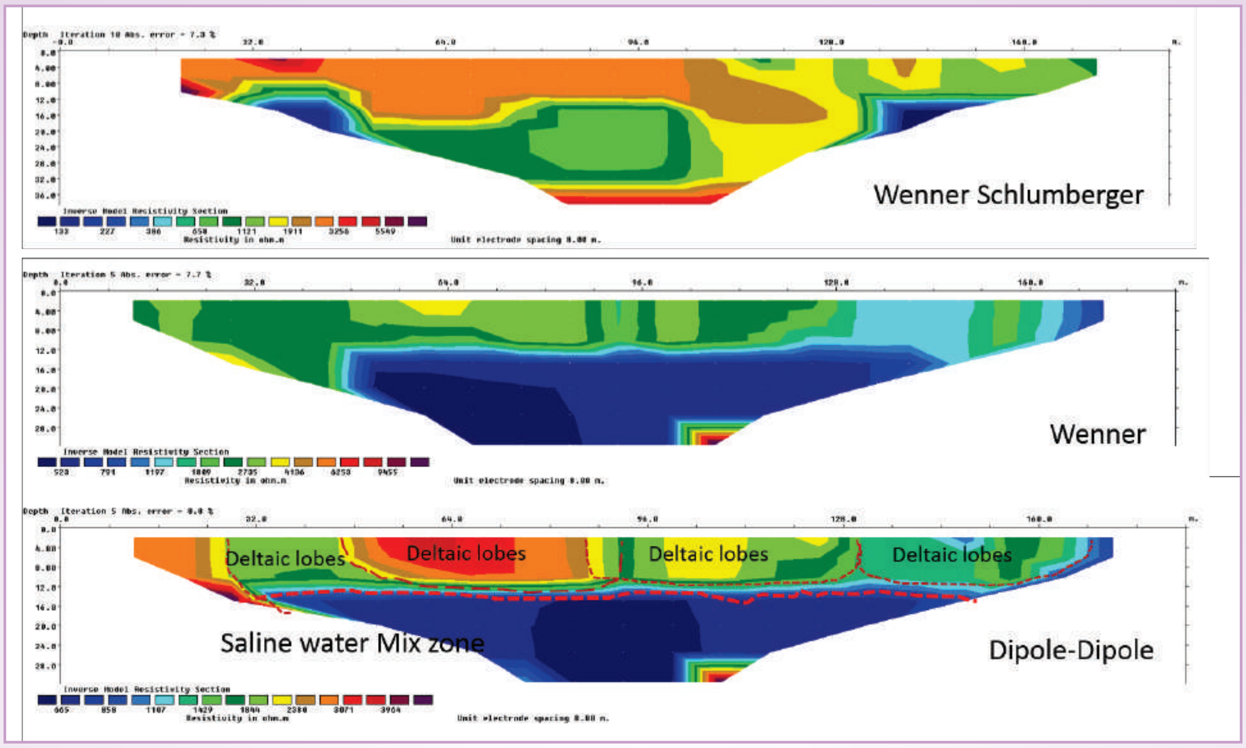

Fig. 38 : 2D electric resistivity tomography (ERT) suggests the extension of these sequences up to 11 – 16 m under the sub-surface, whereas at the surface these are exposed only to 2-6 m above the lake level. The variations in the resistivity values are clear and show four lobes that have extended to ~11-12 m in the subsurface.

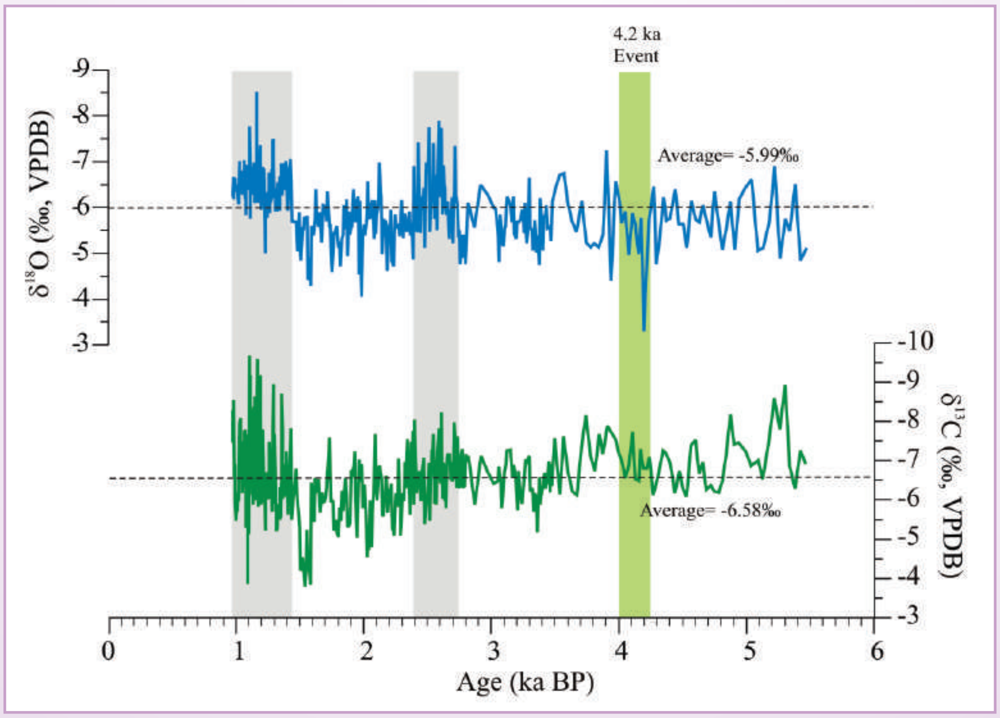

Fig. 39 : Indian summer monsoon variability in northeast India between 5.5 and 1.0 kyr BP reconstructed through Oxygen and Carbon isotopes time series of stalagmite KMS-6 from the Mawmluh Cave, Meghalaya.

provides a record of glacial fluctuations between marine isotope stages (MIS 3) to the Mid-Holocene. The chronology of moraines shows glacial advances in the valley during 52.8±3 – 50.4±3 ka (MIS 3), ~36.4±1.8 to 34.5±2.2 ka (late MIS 3), followed by its termination that continued until ~ (~30.3±2 ka). The second glacial advance took place during ~22.2±1.1–21.4±1.2 (global last glacial maximum; LGM), one re-advance/standstill occurred following MIS 2 at 16.1±0.1 ka (late-glacial) and ~4.4±0.4–4.2±0.1 ka (Mid-Holocene) in the Central Himalaya. The study is in accordance with earlier observations made from the monsoon-dominated central Himalayan region. It provides a robust chronology and climatic evidence indicating significant ice volume depicted by the moraine height during MIS 3, implying that the moisture-deficient valleys of semi-arid Himalayan regions respond sensitively to enhance precipitation. The study suggests regional synchronicity of glacier response to climate variability since MIS 3 and was in accordance with the synoptic-scale, climatic perturbation triggered by the North Atlantic millennial-scale climate oscillations. The observations are summarised in figure 40.

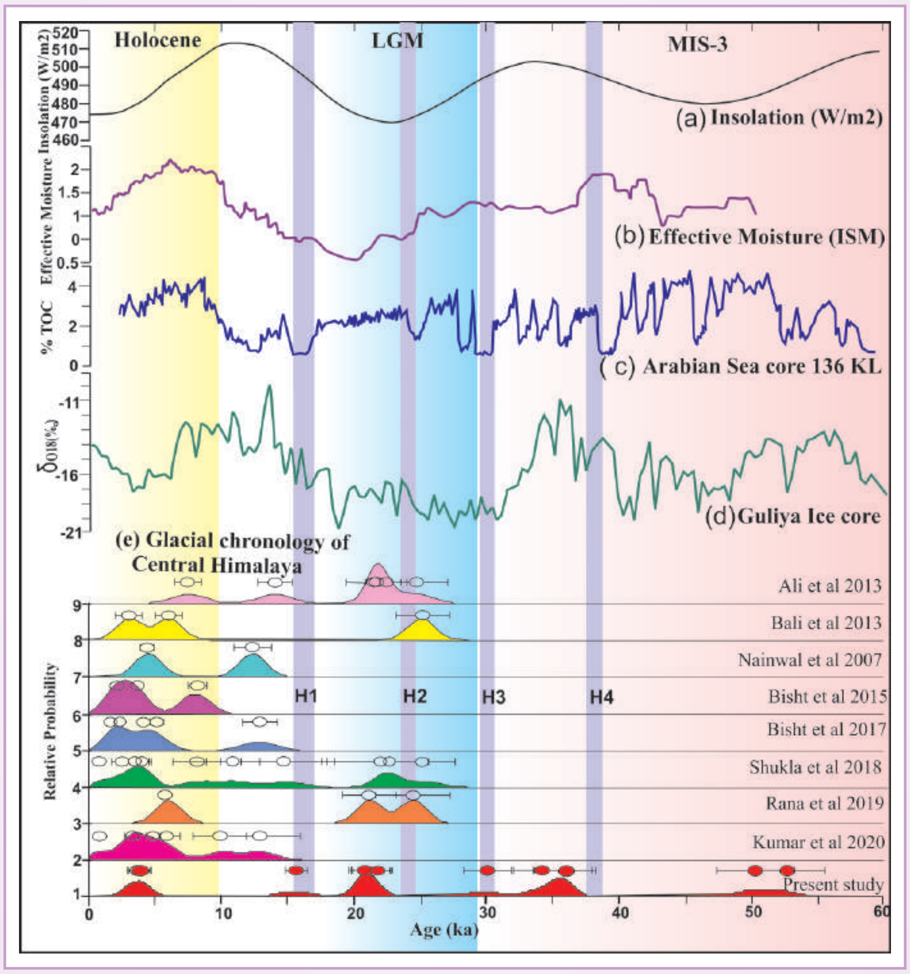

Fig. 40 : (a) Changes in insolation (June insolation 30° N), (b) Effective moisture (Herzschuh, 2006), (c) Total organic carbon (TOC %) from an Arabian Sea core (Schulz et al., 1998), and (d) The oxygen isotopic record of Guliya Ice core (Thompson et al., 1997). These datasets are used as a climate proxy to show the variability of ISM during the last 60 ka. Enriched δ^{18}O values in (d) are coeval with the increased insolation, effective moisture, and TOC values and suggest a wetter climatic phase with a strengthening of monsoon-related precipitation, (e) Comparison of the chronology of the present study with the chronology from the other parts of the Central Himalaya. Note that the late-MIS-3 was associated with enhanced Indian Summer Monsoon. Consequently, the depleted δ^{18}O values and decreased increased insolation, effective moisture, and TOC values suggest colder phases in LGM and Mid Holocene with the weaker monsoon. The MIS-3 stage of glaciation is well represented in the present study but was missing in earlier studies.

ACTIVITIES

Aerosol dynamics

Performed first multiyear (2015–2020) random observation of equivalent black carbon (eBC) aerosols from variable microclimates with different anthropogenic influences along Gangotri Glacier Valley during world-renowned Char-Dham Yatra. First in-situ observations of ambient eBC depict a significant reduction in mass concentration levels during COVID-19 lockdown-2020 at Dehradun city in Doon Valley.

Pre-Cryogenian evolution from the Lesser Himalayan basin

Sedimentation pattern in Rautgara Formation (Lesser Himalaya)

Sedimentological facies analysis from Mesoproterozoic (~1.6 Ga) Rautgara Formation, Lesser Himalaya, identified the presence of mixed (wave-tide) energy estuarine depositional setting. A total of five facies associations have been identified i.e., i) tidally influenced fluvial, ii) wave dominated shoreface-foreshore, iii) Tidal flat iv) tidal channel and v) Intertidal tidal channel-bar complex. An ENE-WSW paleo-shoreline condition was inferred where sediments were brought down by the N/NW flowing river systems. A mesotidal range (2-4m) is inferred by the preservation of the wave-dominated facies. The thickness and compositional maturity of the sediments pointed toward a passive margin deposition formed by the ~1.8 Ga back-arc rifting succeeding the 1.9 Ga magmatic arcs in supercontinent 'Columbia'.

Molar Tooth Structure (MTS) from Deoban Limestone (Lesser Himalaya)

Bending of Molar Tooth (MT) ribbons, reworking as clasts, and microcrystalline nature suggests early formation before significant lithification. Positive C-isotope value, moderate total organic carbon (TOC: 0.1-0.9), and presence of microbial laminae support the microbial origin and sub-oxic to dysoxic condition. CO_2 generated during microbial oxidation of organic matter combined with wave loading during storms possibly generated MT cracks.

Activity: 4B

Ecology and climate dynamics of the Himalaya – Cenozoic to Present

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

Geological fieldwork was carried out in and around Chamoli, Central Garhwal Himalaya, and, the Mussoorie area, Dehradun. During the field trips, more than 250 sediment samples were collected from peat sections and river sections, and tree-ring samples were also collected from 129 trees. Figure 41 represents the study areas in the Himalaya and adjoining regions.

The collected samples have been analyzed for grain size using the Laser Particle Size Analyzer (LPSA), and Total Organic Carbon (TOC) using TOC-Analyzer. The grain-size data corroborates the lithology of the peat section, from Chamoli, Central Garhwal Himalaya. Top ~20 cm is dominated by silt and clay with peat and thus, darker in colour, ~20 – 45 cm is dominated by silt & clay, ~45 – 85 cm is a dark peat layer dominated by silt, ~85 – 125 cm, the bottom-most part of the section, lighter in colour, is dominant of sand and suggestive of higher energy condition of deposition (Fig. 42).

The sediment core samples (around 60 numbers) from the Bay of Bengal have also been processed for environmental magnetic and TOC analysis, which will be utilized for climate and Himalayan weathering reconstruction during the Late Quaternary.

The interplay of El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) on Indian summer monsoon (ISM) modulation has been investigated during the reporting year. The late-Pleistocene to Holocene climatic records, ecology (diatom), and energy-based modeling from the upstream of Baspa River Valley, Himachal Pradesh have been studied. The Holocene paleoclimatic records have been generated from the mid-altitude monsoon front area (Kotikanasar and Chakrata peat). A study on microbial-mediated calcium carbonate precipitation in Shahashtradhara cave was carried out. The Granulometric characterization of glacial flash flood facies identified from the Rishi Ganga, Uttarakhand (upper Alaknanda Valley) flood event of 2021 was also performed. The behaviour of environmental magnetism and organic carbon in high-altitude Bugyal peat deposits (So Khahrg Bugyal, Chopta area, Uttarakhand, India) and its application for climatic studies were carried out. The environmental magnetic characterization of fluvioglacial and cultural level in the ITBP Camp, Sangla sedimentary profile, Himachal Pradesh was also performed.

Two major wet and warm (1839-1890 AD and 1929-1959 AD) and two arid (1890-1929 AD and 1959-2003 AD) phases of the climate were observed in the Renuka Lake. It has also been observed that the relationship between ENSO and ISM was weakened and the influence of IOD increased the Indian summer monsoon rainfall

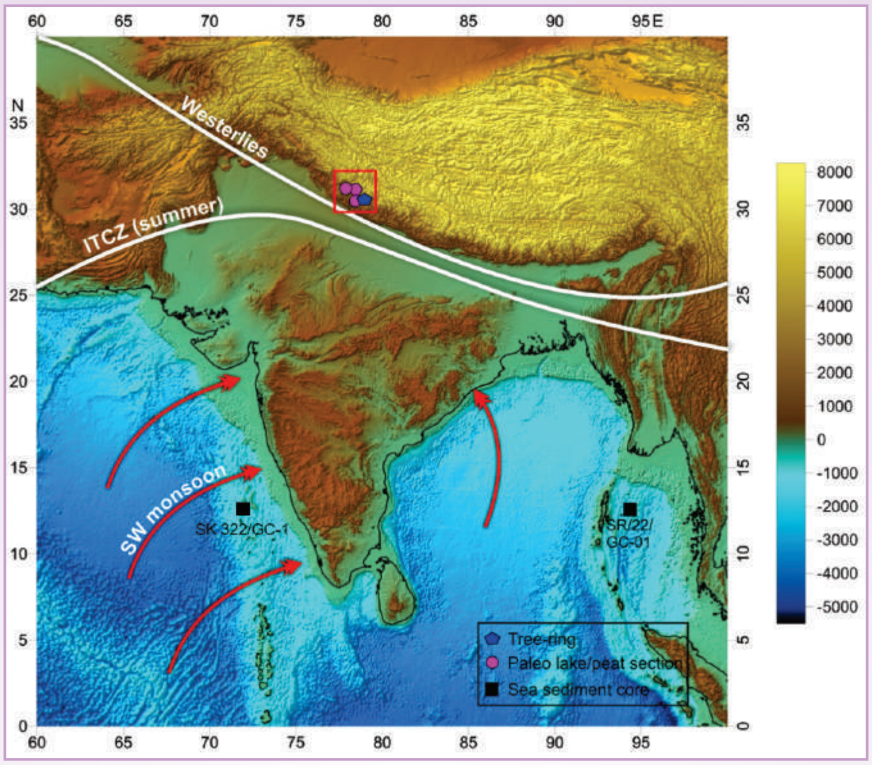

Fig. 41 : Map of the study areas in the Himalaya and adjoining regions.

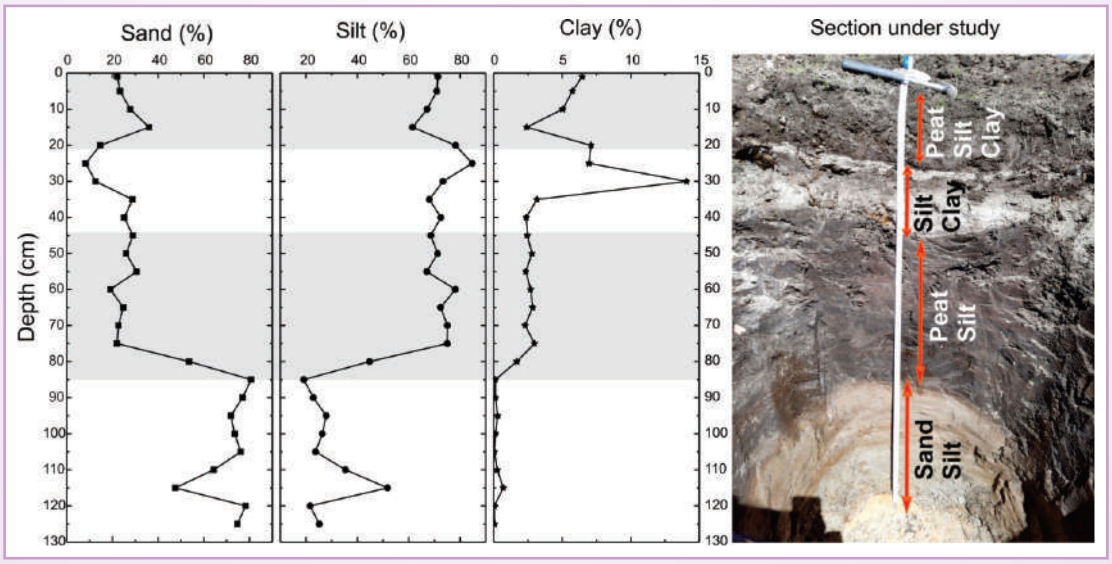

Fig. 42 : Down-depth grain-size variation corroborates the lithology in the peat section from Mana, Chamoli, and Central Garhwal Himalaya.

despite the strong El-Nino year (1997), the Indian summer monsoon rainfall remained above normal.

Dendrochronology

Ring-width chronology was prepared using *A. pindrow* trees growing in Din Gad valley, Dokriani glacier region, Uttarakhand. Tree-growth response of *A. pindrow* captured a strong relationship with climate parameters (temperature and precipitation) and the winter mass balance of the Dokriani glacier. The signal identified in response function analysis was further used to reconstruct the 247 years (AD 1769-2015) long winter mass balance of the Dokriani glacier. The reconstructed series, the longest record, captured mass loss and mass gain during AD 1887-1917, 1793-1823, and, AD 1827-1857, 1925-1955, and 1968-1998, respectively.

Multi-century long tree-ring width chronologies were also prepared from the western Himalaya, which revealed the positive influence of precipitation over tree growth.

Activity: 5

Geological and geomorphic controls on landslide for risk assessment and zonation in the Himalaya

(Vikram Gupta, Khayingshing Luirei, Swapnamita C. Vaideswaran)

Landslides and related mass movement activities are common, and ubiquitous in the mountainous region, however, it has been observed that in recent times their magnitude and frequency are increasing in the Himalayan region. This is primarily due to changes in climatic conditions as well as the increase in anthropogenic activities. The change in climatic conditions is mainly in the form of increased incidences of concentrated rainfall as well as more area falling under the influence of rainfall. The year 2021 has witnessed abnormally higher incidences of extreme rainfall and subsequently increased incidences of landslides and slope instabilities in the state of Himachal Pradesh and Uttarakhand. This has caused the loss of lives and damage to the environment and infrastructure. It is, therefore, necessary that a regional-scale landslide susceptibility mapping of the states be carried out. During the reporting year, the study mainly focused on different aspects of landslides in both the states of Himachal Pradesh and Uttarakhand which are briefly described hereunder.

Regional scale Landslide Susceptibility Mapping of Himachal Pradesh

Himachal Pradesh has a prolonged history of landslides and related mass movement activities. To reduce the loss of lives, it becomes important to identify and understand the potential landslide susceptible zones in an area so that appropriate mitigation steps could be taken to reduce the associated risk. One such step is to prepare the Landslide Susceptible Map (LSM) of the area. The landslide susceptibility maps evaluate the spatial relative probability of occurrence of the landslide taking into consideration various geological, geomorphological, hydrological, anthropogenic, and climatic factors using appropriate models.

The data preparation in the form of building an inventory of active landslides and thematic maps for the possible conditioning factors of landslides is the prerequisite for the preparation of the landslide susceptibility map of an area as it is believed that the potential landslides in an area would occur under a similar set of conditions under which it had occurred in the past. Therefore landslide inventory map depicting all the active landslides was prepared by identifying landslides on the high-resolution satellite images from the google earth platform. Many landslides were cross-checked and validated in the field. An inventory of 2034 active landslides was prepared. Individually, these vary in size from as small as 10 m^2 to as big as 9.0 km^2. The total aerial coverage of all the landslides is ~ 60.5 km^2 which is ~ 0.11% of the study area. In the study, 70% of all the landslides i.e. 1424 landslide incidences are randomly selected for the preparation of the landslide susceptibility maps, and the remaining 610 landslides are used for evaluating the efficiency of models. A total of eleven independent landslide conditioning factors were selected. These are lithology, slope angle, slope aspect, elevation, plan and profile curvature, distance to road, thrust, drainage, topographic wetness index, and land-use type.

To prepare the susceptibility map of the area, two bivariate models viz. weight of evidence (WoE) and information value (IV) were adopted, and the overall weight of each conditioning factor was calculated for both models. Subsequently, the Landslide susceptibility index (LSI) at each pixel was obtained by summing up the relative weights of each conditioning factor of landslide using a raster calculator in the ArcGIS. LSI indicating the relative probability of the occurrence of landslides in an area has been classified into five different classes of landslide susceptibility varying from very high, high, medium, low, and very low zones. It has been observed that LSM prepared using WoE exhibits that very high and high susceptible zones cover 9% and 21% area of the study region, while moderate, low and very low landslide susceptibility zones cover 27%, 29%, and 14% of the area, respectively. The LSM prepared by the IV method also exhibits more or less similar results in terms of landslide susceptible zones in the study area. The areas occupied by the very high and high susceptible zones cover 7% and 18% area of the study region, while moderate, low, and very low cover 26%, 29%, and 19 % of the area, respectively. Further, it has been observed that high to very high landslide-prone zones are located at an elevation range of 2001 m to 4000 m on the southern facing slopes with slope inclination of > 50°. These high and very high landslide susceptible zones are mainly located in the Higher and Tethyan Himalaya, while low and very low landslide susceptible zones are located at lower altitudes mainly in the Lesser Himalaya, Outer Himalaya, and Indo-Gangetic plain.

The performance and the validation of the models were evaluated using the success rate curve (SRC) and prediction rate curve (PRC) using 70% of the total landslides and the remaining 30% of landslides, respectively. It has been observed that the area under the curve (AUC) in the SRC is 85.8% and 82.4%, while in PRC is 86.4% and 84.7% for the WoE and IV models, respectively. This indicates that the maps prepared using both models are more or less similar and have higher accuracy and efficiency in view of upcoming landslide incidences in the area.

Landslides in the MBT zone, Ukhaldhunga area, Kosi River valley Kumaun Lesser Himalaya

Landslide is one of the major modifying agents of landforms in the MBT zone in the Ukhaldhunga area in Kosi River valley. In the MBT zone total of 11 landslides, both active and dormant landslides, have been considered (Fig.43). The settlements of Bakule, Dabara, Bawas, and Dauna villages are nestled in old landslide debris. The bedrocks are highly sheared with multiple joint sets that form wedges that are favorable to the mass movement. In the Parewa-Dauna area, the erosion by Kamchiya Sot has exposed more than 60 m thick sections of landslide debris. At site No. 1 the rocks are traversed by five prominent joints (J_1, J_2, J_3 and J_4) that form wedges towards the open/daylight hill slope. The type of landslide observed is rockfalls and the detached masses have traveled a distance of about 2 km from the crown of the landslide. The later phase of the landslide occurred in the Siwalik bedrocks as the landslide debris is mainly composed of black shales and sandstones of the Siwalik Group. The second landslide (Site No. 2) is about 1.5 km from the MBT zone where small-scale rock fall is taking place intermittently. Here the bedrock comprising quartzite is traversed by four prominent joint sets, the bedding plane is also an important fracture plane. The joint sets and the bedding planes form wedges on the daylight hill slope. The third investigated site (Site No. 3) is 0.5 km upstream from

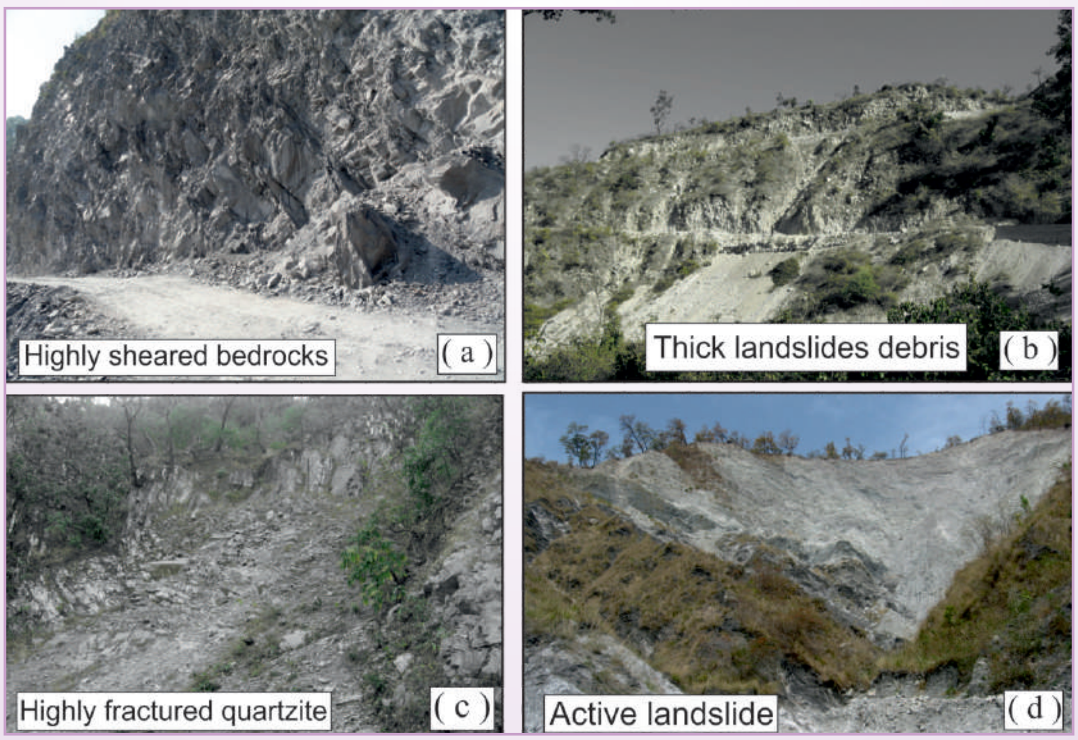

Fig. 43 : Landslides and its related landforms in the Ukhadhunga area of the Kosi River valley. (a). Road cut induced landslide in highly shear bedrocks, (b). Thick landslide debris in the immediate footwall of the MBT, (c). Active landslide taking place in highly fractured quartzite of the Jaunsar Group. (d) Active landslides taking place in highly sheared bedrocks in the immediate hanging-wall block of the MBT at Dabara.

site No. 2, here also the type of landslide is rockfalls. A total length of about 0.5 km of the road section is affected by the rockfalls, which are taking place intermittently. In this section of the valley slopes of the Kosi River are steep, the wedges formed by intersecting joins have facilitated the detached boulders and rock fragments to fall under gravity. The bedrock is cut across by two fracture planes forming a wedge on the daylight slope; one of the fracture planes is the bedding-parallel foliation S_1. At Site No. 4, the intermittent rockfalls are taking place along a triangular facet where the slopes are very steep. Here the intersecting fracture planes fall in the SW quadrant and form prominent wedges. At Site No.5, two data have been collected from either side of the affected area. On the southern end of the daylight zone, the intersecting joint sets have formed prominent wedges in the NW and SW quadrants while on the northern end two prominent joint sets have formed wedges on the daylight side on the western side. Site Nos. 6 and 7 represent opposite valleys where the valley slopes are mainly towards the east. Site No. 6 has affected the road section of about 300 m; the multiple join sets have formed wedges and the country rock is phyllitic quartzite. Site No. 7 represents the severest landslides that have affected the road section between Betalghat and Dabara; the type of landslides taking place is rockfalls. The intersecting joint sets have formed wedges on the daylight slope and the joints are closely spaced rendering the slope very weak. Landslide in Site No. 8 is taking place in country rocks composed of an alternation of phyllite, quartzite, and slate sequence. This landslide is recent and active, which is generating volumes of debris and forming fresh debris fans near Dabara village where fresh material is being deposited every monsoon along the Gaunchil gadhera. The Parewa-Dauna section in the MBT zone is one of the most affected sections by the occurrence of landslides though at present the hill slopes are relatively inactive. Both the slopes in the hanging wall and footwall blocks have been affected by landslides, as thick columns of debris, and fans are observed. Exposed sections and levels of debris fans suggest multiple phases of landslide events.

Origin of tectonic landform in the hangingwall of the South Almora Thrust, Kumaun Lesser Himalaya

The paleolake of the Champawat in the outer Lesser Himalaya of Kumaun resulted from tectonic activity along a localized system of normal faults in the immediate hanging wall of the South Almora Thrust. The lake originated before 17 ka and the water drains out after 13 ka. The lacustrine sediments are exposed at four sites and are of varying thickness and the length measures about 3 km (Fig.44). At Site 1 the lacustrine sediments are exposed along the road cut and section is about 8.30 m but the total thickness of the lacustrine sediment in this site cannot be ascertained due to the thick vegetation downslope. The base of the exposed sediment is comprised of thick peat deposits further upward it is made of an alternate sequence of mud and sand horizons, and this site is at 1690 m asl. A few meters apart from Site 1, Site 2 is also comprised of the same sedimentological units with peat at the base of the exposed section followed upward by alternating units of mud and sand sequences. At Site 2 also the total thickness cannot be measured as the contact between the lacustrine and bedrock is not observed. Sites 3 and 4 are almost at the opposite bank of the small stream a tributary of the Kaflang Gadhera; Site 3 is the only site where the contact between the lake sediments and the basement rocks is exposed. The sediment thickness is about 4.8 m and the bottom layer is made up of peat of about 2m while the upper sequence of 2.8 m thick is made up of silty brown mud. Site 4 is at the height of 1615 m asl and is exposed just at the bank of Kaflang Gadhera and the exposed section measures about 7 m; whereas the thickness appears much more than this as the landform is greatly modified by human settlement. Site 4 is almost composed of peat with a few cm sand layers in between the thick peat. The distance between Site 1 and Site 4 is almost 3 km apart and the elevational difference between them is 46 m. The highest point at which the lacustrine deposit is at 1690 m asl which is the top of Site 1 and this height is taken as the highest elevation at which the lake existed. A strand line has been drawn for probable extension of the lake and observed that much of the lower part of the Champawat settlement falls below 1690 m asl. Faulting and deformed Quaternary sediments are observed in the paleolake sections. Contact between the lake sediments and the bedrock is exposed only at one section; this being the peripheral part of the lake this cannot be the actual ignition date or the earliest sediments of the lake. Two distinct sedimentation patterns are observed the bottom is made up of black carbonaceous mud followed upward by the alternation of sand horizons and black carbonaceous mud; while towards the top alternating units of brownish mud and sand, sequences dominate. The monotonous thick black carbonaceous mud towards the bottom suggest deposition under reducing condition, followed upward by the alternation of black carbonaceous mud and sand horizons which suggests interruption of the calm sedimentation by higher energy deposition. The uppermost sequence of brownish mud

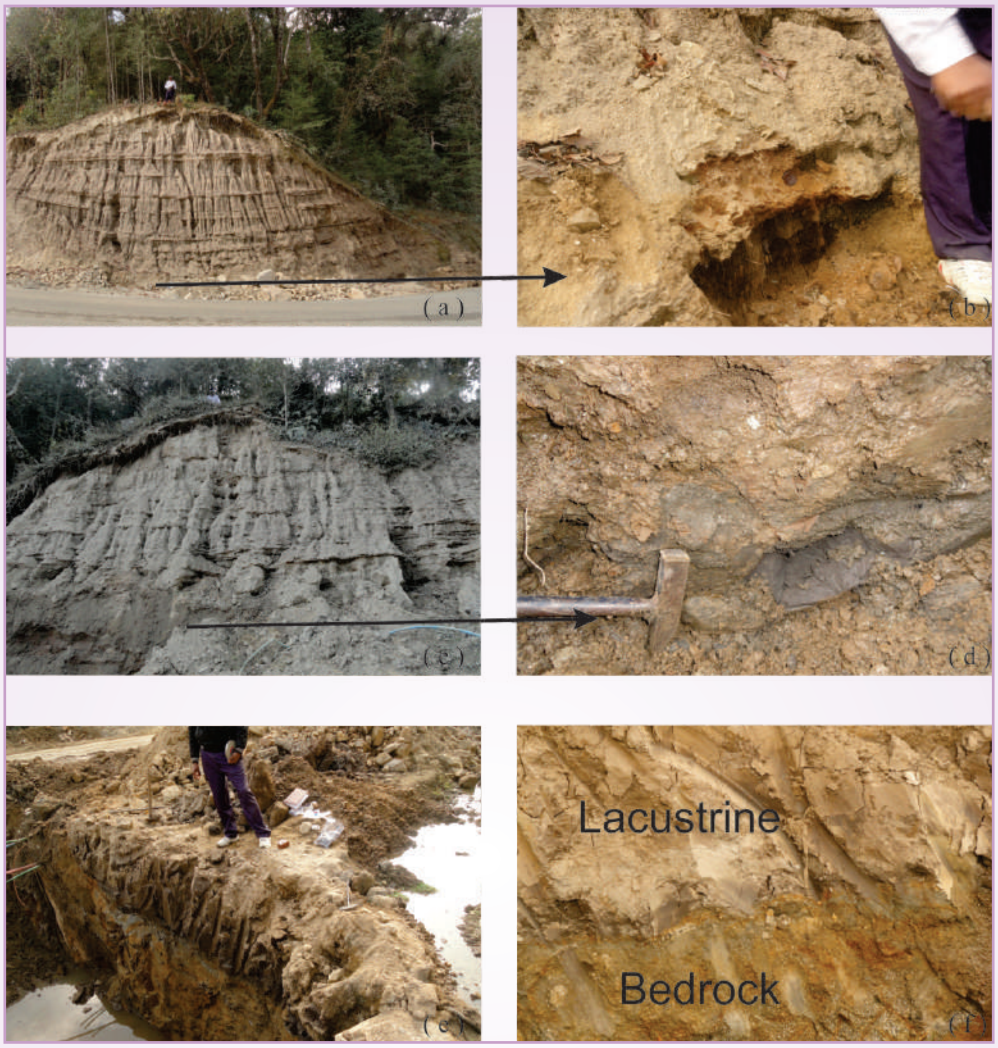

Fig. 44 : a-d, Field photographs showing thick lacustrine deposits comprising of an alternating sequence of black carbonaceous mud and sandy layers, e-f, Showing contact between lacustrine deposit and the underlying bedrocks.

and coarse sand was deposited in shallower condition. The sandy horizons are made up of coarse-grained feldspar and quartz and mica flakes derived from highly weathered bedrocks of Champawat Granitoids. In most of the lake sections, the thickness of the mud layers is thicker than the sandy layers, which may suggest that deposition in calm conditions; while in the uppermost lake section sandy layer becomes thicker and coarser and dominated by small rock fragments towards the top with thin mud layers. The exposed lake sediments are devoid of deformed sediments.

Near-Realtime study of landslide displacement in the Chakrata and adjoining regions in Uttarakhand

With the focus on the development of tribal lands by the Government, and ambitious development plans, like road building, and commercialization, it is imperative to analyze the land stability conditions. Therefore, the region around the Chakrata Block and adjoining regions were taken up for Permanent Scatterer Interferometric study (PSI) time-series analysis. Total of 62 scenes from Sentinel 1 radar satellite with a good baseline were used over a period starting from 4 March 2020 to 30 March 2022. The SRTM-DEM and Google-Earth images have also been incorporated for a complete layover of the time series to understand the velocity of point scatterers around the region. Thick vegetation in this region greatly affects the coherence values. Also, over the entire 62 scenes, the variation of tie-points on the master image shows a rapid change in back-scatter values. It is seen, that the dry season provides a more coherent interferogram than the rainy season. Overall, the slides show a cumulative displacement even up to 200 mm, with a velocity of about 100 mm/year. The slides are seen to be accelerated in the post-monsoon times. In bigger slides like Kunain and Amraha, it was very difficult to collect scatterers, and coherence was seen to be low. However, the area around these slides shows a cumulative displacement of 137-200 mm within the study period, with a velocity of 66-100 mm/year at some points. The analysis shows that landslides are active in the Chakrata region. The slides are aggravated during rains. However, it is also seen that development activities like road cutting and construction of houses are also rapidly increasing the quantum of slope displacement velocities, as well as spatial extent. Geological formations and subsurface processes seem to control the Kunain major slide in Chakrata, which shows even upto 100 mm/year displacements at points where coherence could be obtained. This Near-Realtime study using PS-InSAR is a major contribution to a Realtime Early-warning System in the region, which will assist in the mitigation and management of a disaster.

Activity: 6A

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

(Kalachand Sain, Manish Mehta, Vinit Kumar, and Sameer K. Tiwari)

Status of Glacier surface changes in Doda and Suru River basins

The stakes data shows that the cumulative net balance of the Pensilungpa glacier (PG) was ~ (-)-8.1 x10^6 m^3 we in 2019-2021 (02 years) with a specific balance of (-) 1.12 m we. However, the Equilibrium-Line Altitude (ELA) of the glacier is located at 5232 m asl, while the Accumulation Area Ratio (AAR) of the glacier is about 0.43 (Fig.45). Whereas, estimated the meltwater discharge of the Parkachik stream for the periods of September and October (2 months) between 2017 and 2021. The volume of water discharged from the glacier was estimated to be 31 x10^6 m^3 (43 days) in 2017, 26.49 x10^6 m^3 (42 days) in 2018, 54.40 x10^6 m^3 (51 days) in 2019 and it was 36.06 x10^6 m^3 (49 days) in 2021 (Fig.46).

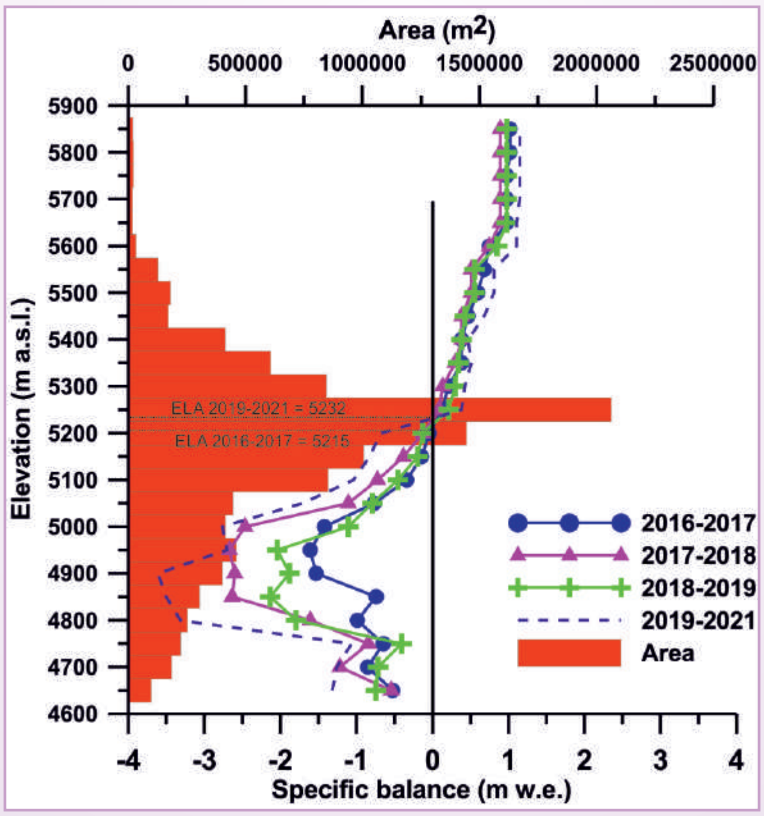

Fig. 45 : Specific mass balance gradient vs elevation (2016/17 to 2019/21). Area distribution of PG is derived from field measurements (stakes and pits). Between elevation 4800 and 5000 m a.s.l. the glacier experienced high ablation (less debris cover) compared to lower areas (4670 to 4800 m a.s.l.; thick debris cover).

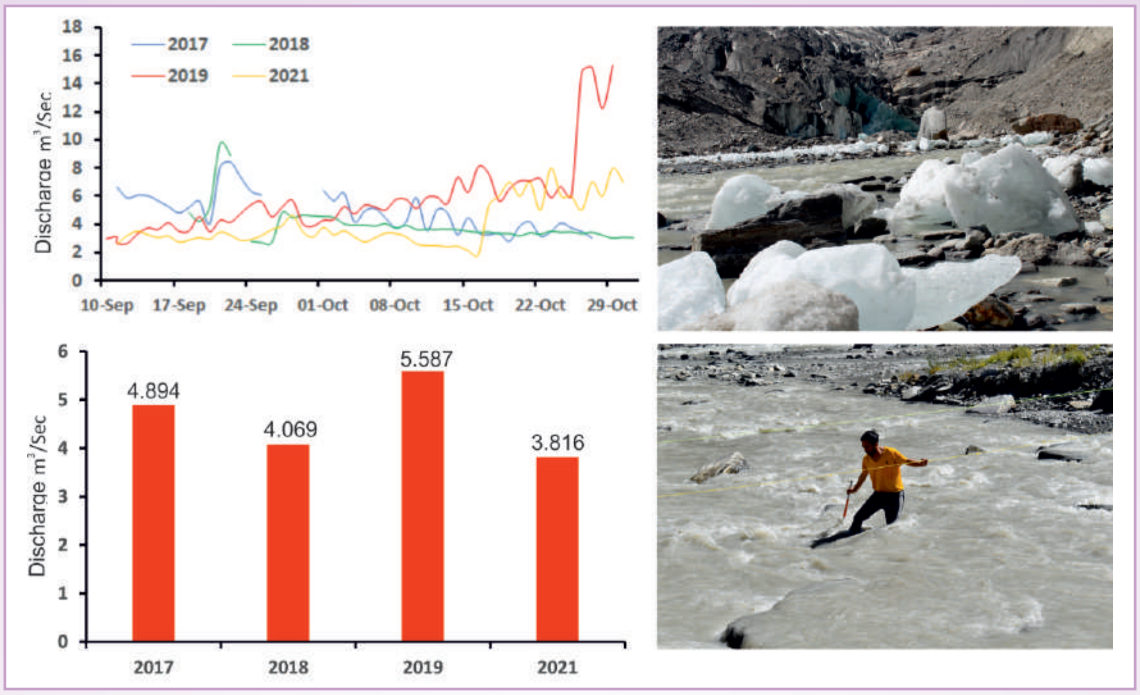

Fig. 46 : Line and bar diagram showing the discharge of the Parkachik glacier between 2017 and 2021 in September and October. Photograph showing the snout break and discharge measurements of the Parkachik glacier.

Fig. 47 : Field photographs showing the snout position of the glacier in 2015 and 2019, (A and B, respectively) at PG and (E and F, respectively) DDG. The red circle on the photograph (B and E) is indicating the area vacated by the glaciers and red arrows (in photographs A, B, and E, F) are showing the reference points. C, D, and G, H the close-up view of the reference points used for measuring the snout retreat with the help of a chain tape survey.

The field data show that the snout of Pensilungpa glacier (PG) receded ~18 ±7 m between 2019 and 2021. Field observations also reveal that the collapse of an ice cave formed at the central part of the glacier snout which was seen in 2019 but was absent in 2021 and this could be a probable reason behind the enhanced retreat of the right flank (Fig. 47). The cumulative volume of ice lost at the snout of the Pensilungpa glacier was estimated to be 7.53×10^4 m^3. The result of field-based data shows that the snout of the Parkachik glacier (PKG) receded by ~150 m on the left side, whereas on the center and right side of the glacier no changes have been observed. The Durung Drung glacier (DDG) retreat is ~33 ±20 m during 2019-2021. Furthermore, the remote sensing studies show that the DDG retreated 624±547 m with the rate of 13 ±11 ma^{-1} between 1971 and 2019, while PG retreated 270.5±27 m with the rate of 5.6 ±0.56 ma^{-1} in the same period (Fig. 47). However, the PKG retreat 210.517 ±111 m with the rate of 4.2 ±2.2 ma^{-1} between 1971 and 2021. During the period between 1999 and 2002, it is observed that the PKG advanced 44.3 ±25 m.

Assessment of water recharge source of geothermal systems in Garhwal Himalaya

The geothermal systems in the Himalaya are complex, and their genesis, circulation pattern, and processes of sustenance are largely unknown. The present study aims to systematically analyze the characteristics of oxygen and hydrogen isotopes, major ion data, and strontium ratio (87Sr/86Sr) of geothermal systems, river waters, and rainwater to understand the movement of groundwater and the mechanisms for the formation of geothermal systems in the region. Further, the strontium isotope was also used to understand the fluid source of geothermal systems. Field observations show that geothermal waters have a higher temperature, hydraulic pressure, and elevated δD and δ18O values than river waters. Thus, large river systems are not the principal recharge source of geothermal systems. Meteoric water (rain and snowmelt) in high mountains can infiltrate and circulate deep down the active tectonic belts or sutures and recharge geothermal systems. The cold surface water evolves into high-temperature thermal water after deep circulation and is discharged as a geothermal spring at the surface, under a high water-head difference. Therefore, the large-scale geothermal systems in the Garhwal Himalaya develop and are maintained by rapid groundwater circulation and interaction with a heat source. Further, the water temperatures of these systems in the Garhwal Himalaya have remained the same over the period 1975–1994 as reported by Geological Survey of India and 2010–2016 (present study) with an error of < 5%.

Assessment of Geothermal Renewable Energy with reference to Tapoban Geothermal fields, Garhwal Himalaya

The energy potential of geothermal resources at Tapoban geothermal field, situated in the orogenic region of the Chamoli district of Uttarakhand state in the Himalaya, is investigated based on physical parameters, reservoir temperature, borehole depth, and geochemical indicators. It is a prospective field of geothermal water exploitation for both electrical and non-electrical usages. The anomalous geothermal gradient due to the active Main Central Thrust (MCT) zone plays a significant role. To explore the feasibility of exploitation, the surface water temperature and pH from existing geothermal springs have been calculated which are ranging from 45°C-93°C and 6.2-7.3, respectively. The study based on dissolved silica geothermometry shows an average reservoir temperature of ~125 ± 2.0°C. The springs emerge from the prominent joint/ weak zone in the country rock with the discharge of hot water up to 300 liter/minute. The total geothermal heat energy of the reservoir is estimated as ~874.35×10^{11} KJ. The energy estimated for the binary power geothermal plant is ~1.02 MWe and 0.71 MWe for 20 years and 30 years, respectively. This energy can be increased by manifolds by operating the binary cycle power plant technique at multiple sites for electric generation. The heat capacity from two dominant hot springs from the Tapoban geothermal resource was found to be ~0.84 MWt, which can be harnessed by the local people for direct usage. The annual energy use from this reservoir is ~15.89 TJ per year with a capacity factor (CF) of ~ 0.60, indicating that the energy reserve of the Tapoban geothermal field can be used for low to moderate scale energy production to partially meet the energy gap and future requirements.

Hydrological (discharge and sediment) and meteorological observations

Three automatic water level recorders were used for round-the-clock discharge monitoring and one has been installed over the meltwater stream of Dokriani Glacier (Fig. 48). The hydrological response of Dokriani Glacier over 15 years (1995-1998 and 2011-2012) was evaluated using automatic water level recorders (mechanical and digital contact-type) and automatic weather stations (AWS). It has been observed that there is an increase in the lagtime as well as time to peak discharge. Such changes could be

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Fig. 48 : Establishment of gauging site (~3800 m asl) near the snout of Dokriani Glacier with the installation of automatic water level recorder (non-contact) and manual gauge.

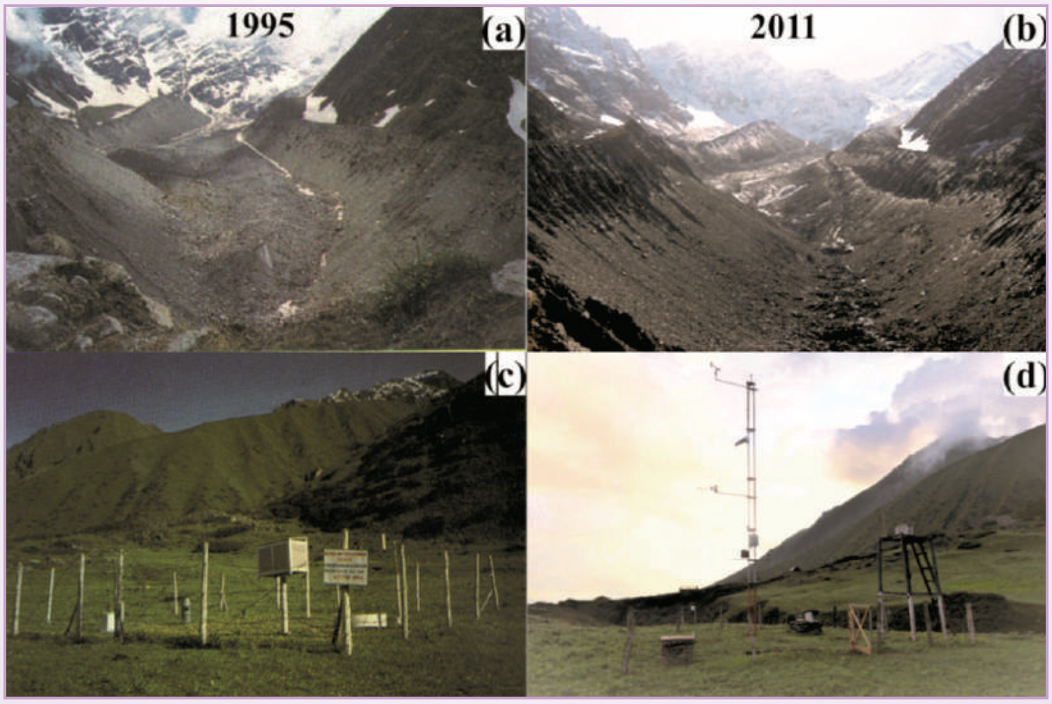

Fig. 49 : View of the snout and ablation zone of Dokriani Glacier in 1995 (a), 2011 and (b) meteorological observatories established by NIH (c) & WIHG (d). (a& c from Singh and Ramasastri, 1999).

attributed to the recession of the glacier, an increase in debris cover as well as other morphological changes in the drainage system of the glacier. The maximum number of high discharge peaks are observed during the late evening or nighttime, indicative of meltwater generation and flow that regulate the evolution of the glacier drainage system and meteorological conditions (Fig. 49).

Considering the increasing number of planned hydropower projects (run-of-the-river projects and small hydroelectric schemes) in the river basins of the Himalaya, it is recommended that an integrated sediment monitoring program (SSC, SSL, SSY, erosion rate, facies detection, etc.) should be initiated. This should be done for the longterm at different elevation zones to understand the influence of topography and climate on weathering processes and their associated transport characteristics (Fig. 50).

These integrated process-based studies will help assess socio-economic issues faced by the stakeholders in the ecologically fragile region of the Himalaya. An extensive survey of the Himalayan glaciers revealed active glacier dynamics, well-developed crevasses, and supraglacial drainage systems feeding water, sediment, and debris into the crevasses (Fig. 51). This indicates that these crevasses may behave as a medium of transportation for the large supraglacial sediments to the subglacial zone where they go through the abrasion process and are flushed out as silt and/or sand-size sediments.

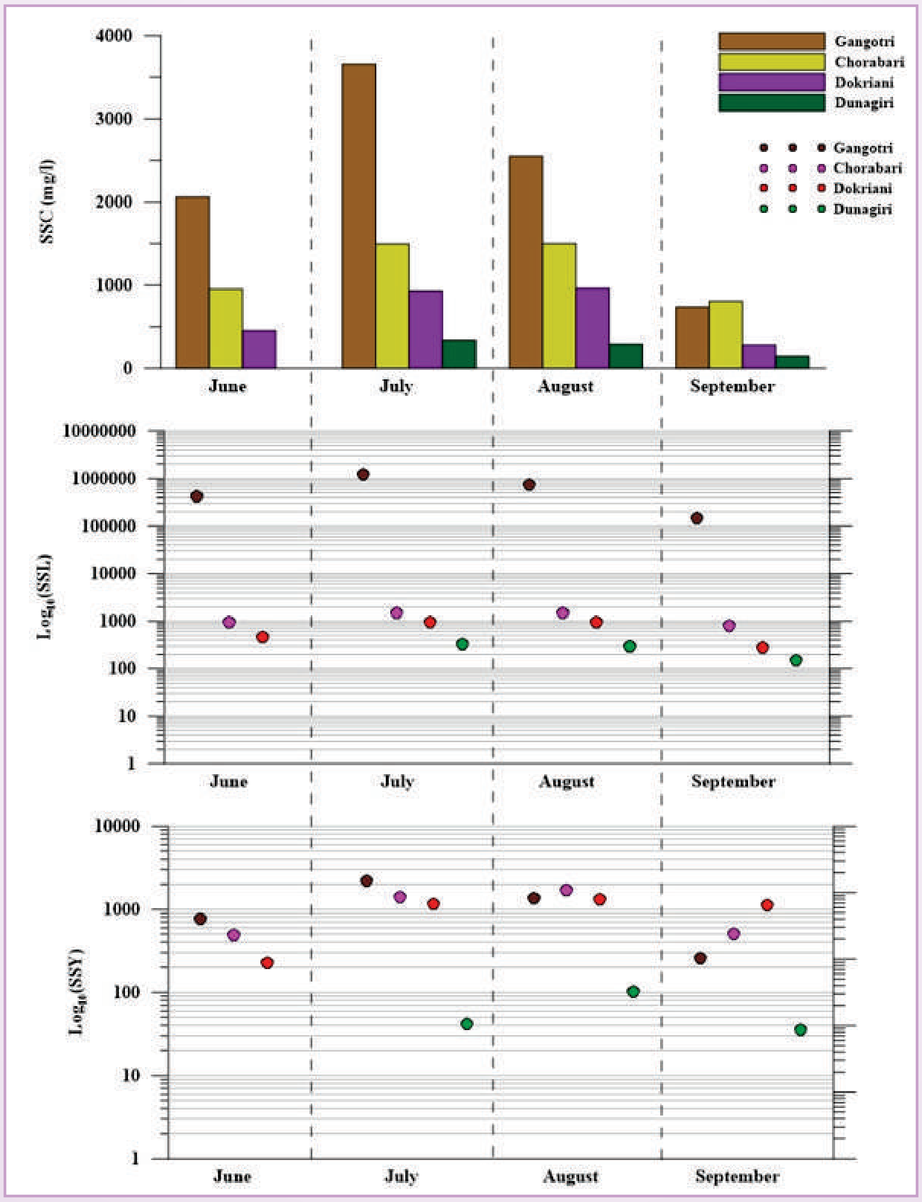

Fig. 50 : Distribution of suspended sediment concentration (SSC), suspended sediment load (SSL), and suspended sediment yield (SSY).

ACTIVITIES

Fig. 51 : Field photographs showing sediment distribution over glaciers, sediment-laden ice, crevasses with sediments, and meltwater transporting sediments.

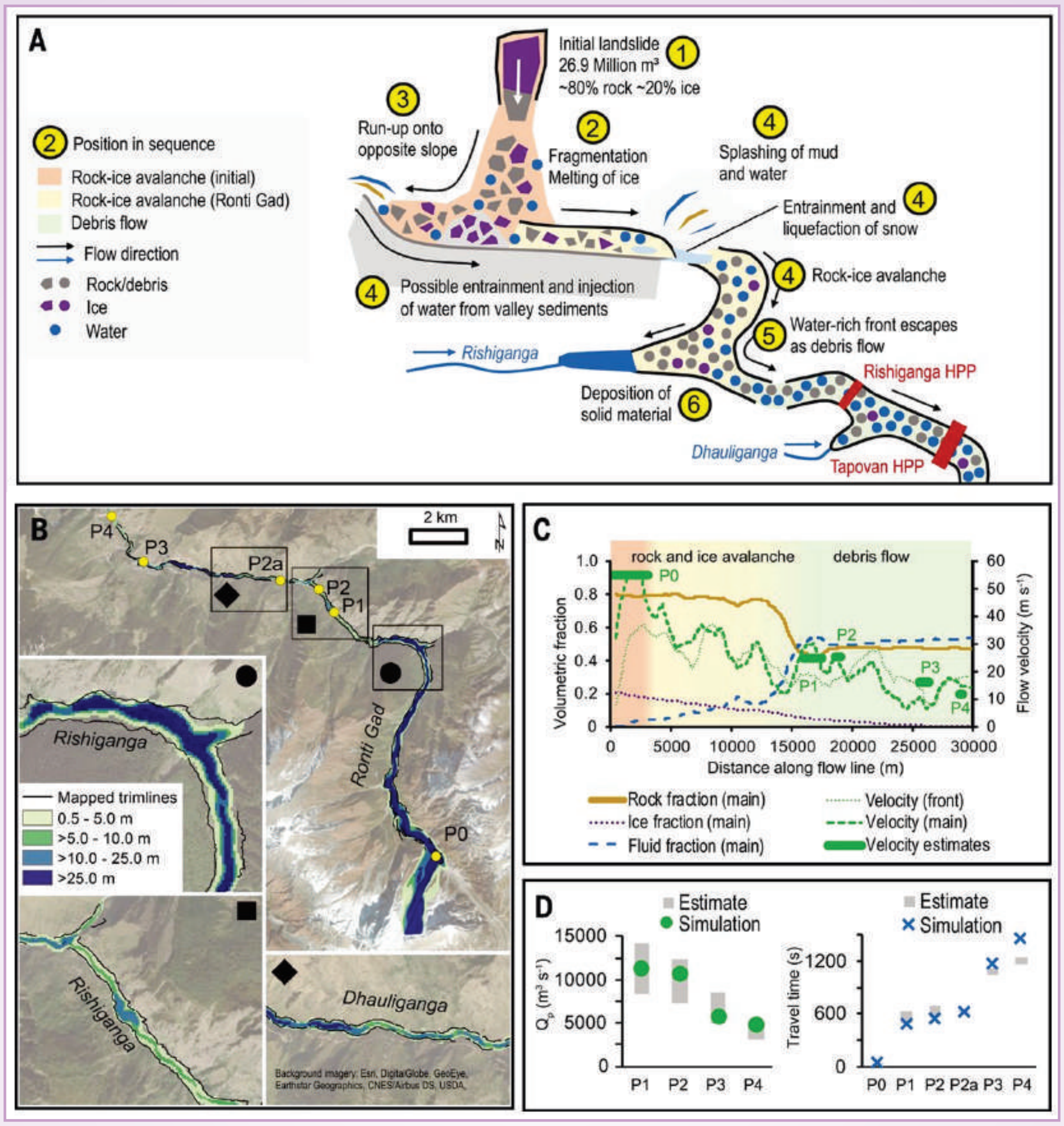

Fig. 52 : Flow evolution scenarios and simulation. (A) Schematic of the evolution of the flow from the source to Tapovan. (B) Maximum flow height simulated with river flow, showing the observed trim lines for comparison. P0 is the location of the velocity estimate derived from seismic data, and P1 to P4 are locations of velocity estimates based on videos and satellite images. (C) Along-profile evolution of flow velocity and fractions of rock/debris, ice, and water simulated with r.avaflow. "Front" refers to the flow front, whereas "main" refers to the point of maximum flow momentum. (D) Simulated and estimated peak discharges and travel times at the above locations.

Geological and geophysical investigation of Chamoli disaster (7 February 2021)

The disaster of 7 February 2021, Chamoli district (Uttarakhand, India) was studied based on satellite imagery, numerical modeling, and field witnesses which reveals that ~27 × 10^6 cubic meters of rock and glacier ice collapsed from the steep north face of Ronti Peak. The rock and ice avalanche rapidly transformed into an extraordinarily large and mobile debris flow that transported boulders greater than 20 meters in diameter and scoured the valley walls up to 220 meters above the valley floor (Fig. 52). The intersection of the hazard cascade with down valley infrastructure resulted in a disaster, which highlights key questions about adequate monitoring and sustainable development in the Himalaya as well as other remote, high-mountain environments.

Anoteworthy sequence of precursory signals of

ACTIVITIES

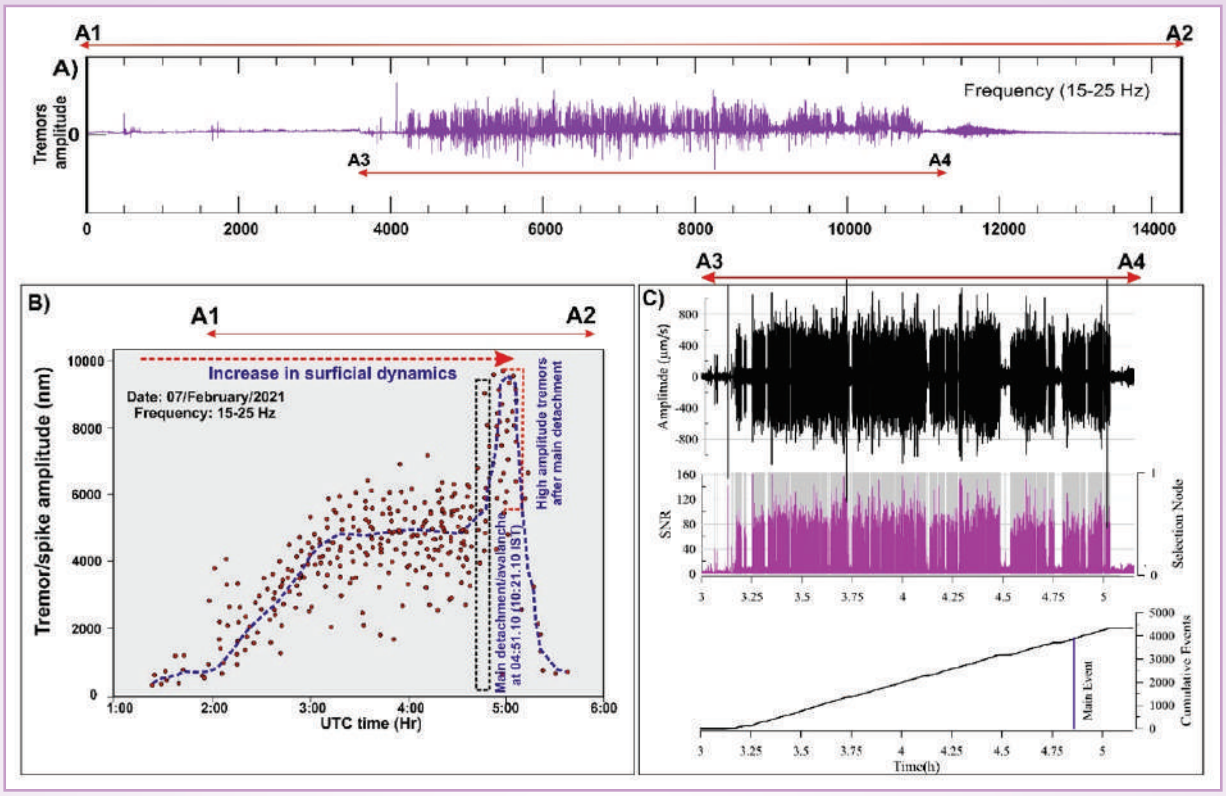

Fig. 53 : Correlation coefficient trace of precursory seismic signals. (A) The continuous sequence of precursory tremors follows the (red dashed line) threshold, above which precursory tremors are detected. (B) A standard tremor based on the high signal-to-noise ratio (SNR) is selected for correlation coefficient trace in a 4 h moving window. (C) The waveform spectrogram shows the dominancy of tremors amplitude after ~ 4000 s (~ after 3:00 UTC, 07/02/2021).

main failure/detachment preceded by a dynamic nucleation phase was found in seismological data. The rock-ice avalanche appears to have been initiated by seismic precursors which were continuously active for 2:30 h before the main detachment. The seismic amplitude, frequency characteristics, and signal-to-noise ratio variation of detected tremors indicate static to dynamic changes in the nucleation phase located at the source of the detached wedge. The characteristics of seismic data distinguished debris flow and hitting obstacles from other seismic sources and allowed the estimations of debris flow speed. The seismic signals were analyzed and verified with field evidence to estimate the associated impacts and velocity of dynamic flow. The proximal high-quality seismic data allowed us to reconstruct the complete chronological sequence and evaluate impacts from the initiation of the nucleation phase to its advancement (Fig. 53). Furthermore, it is suggested that real-time seismic monitoring with the existing network and future deployment of an integrated dense network can be used for forecasting of flow events and hazard mitigation in the downstream.

Activity: 6B

Hydrogeology-Himalayan Fluvial Systems and Ground waters

(Santosh K. Rai and Rouf A. Shah)

Rock weathering in the Ganga-Brahmaputra (G-B) River catchments has significant control of the CO_2 level in the atmosphere and hence influences the climate on longer time scales under greenhouse conditions. Towards this, the CO_2 mediated silicate regulates the long-term changes in the global climate. However, the alternative mechanism of silicate weathering is also possible if it is mediated through H_2SO_4,which consumes no CO_2 from the atmosphere. Geochemical and isotopic results obtained for the Teesta River system were used to infer the role of Sulfuric Acid in continental weathering, Riverine Strontium fluxes, and Hydrological Processes in the Basin. In addition, stable isotope measurements were conducted on Doon groundwater and Rivers to infer their plausible recharge sources. The salient points may be summarized as the role of H_2SO_4 in continental weathering is important. It is evident from the results that [Sulfate] in Teesta is higher (92±47 μM) than regional rainwater (~5 μM). It implies that ~half of the cations are from H_2SO_4-mediated weathering. The study also reveals that the CO_2 uptake (Sil. ~4.9×10^5 moles/km^2/y) and release H_2SO_4-Carb (~3.9×10^5 moles/km^2/y) at the outflow. Further, these rates are nearly in balance.

The dissolved Sr and ^{87}Sr flux to the Bay of Bengal (Brahmaputra River) were estimated to be 1×10^7 moles/yr and 7.1×10^5 moles/yr, respectively. It contributes to 0.03% of the global riverine supply to the oceans. Evidence of early melting and Rainout Processes in the Teesta basin with rapidly increasing altitude contributes a larger proportion (35±4) %. Results for the stable isotopes & major ions in the Ground Waters from Karstified litho-units from the Doon Valley → Lower slope (6.9±0.13) & intercept (1.8±0.81) than LMWL(11.4±1.4) → Evaporation prior to their entry. Lower d-excess (<12) → summer precipitation as major recharge (1500-2500 m asl).

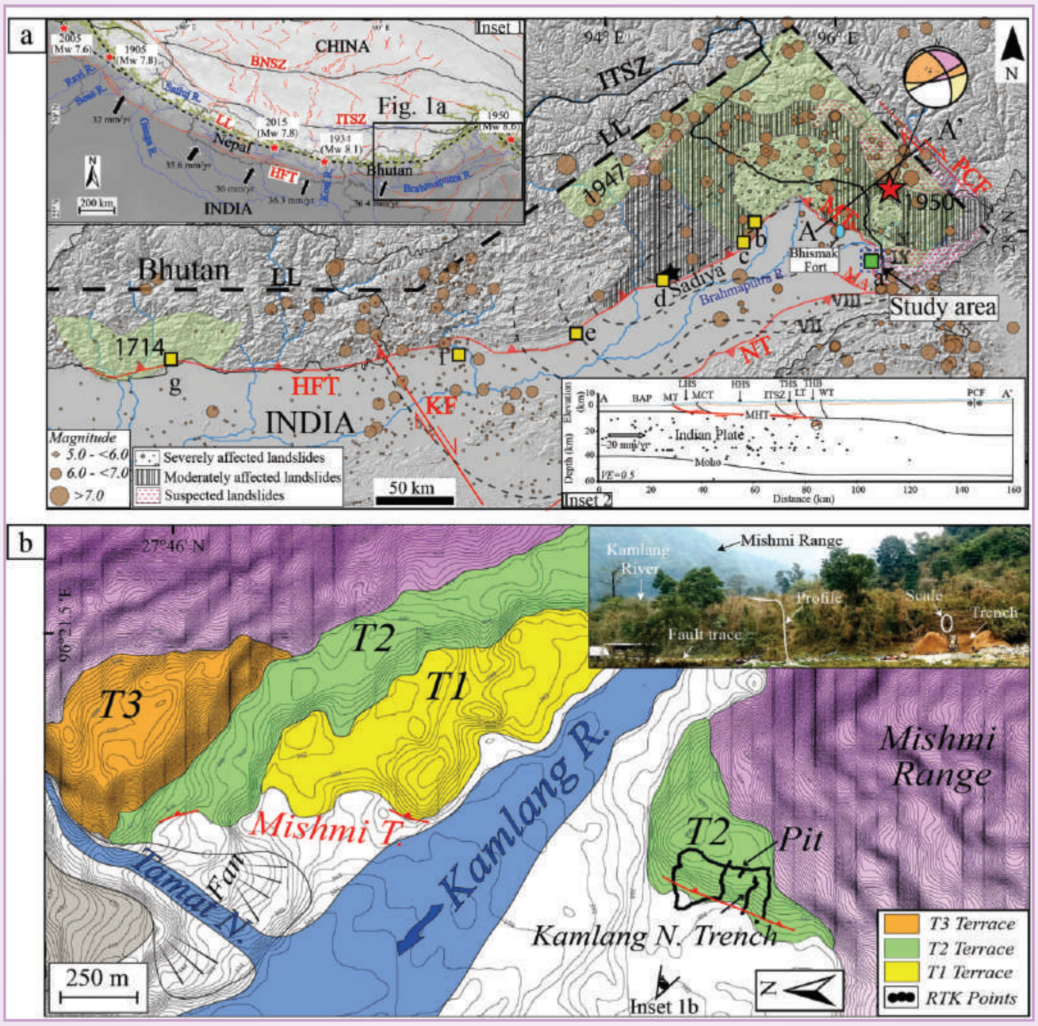

Fig. 54 : (a) Regional seismo-tectonic map of the eastern Himalaya showing the study area at a-Kamlang Nagar (green solid square), rupture zones of major historical earthquakes (after Singh et al. 2021). (b) Geomorphic map of the study area showing the landforms and trench site prepared with Cartosat-1A DEM of 5 m resolution. Contour map of 2 m interval generated on imagery procured from http://www.nrsc.gov.in (Source: NRSC, ISRO/DOS). Inset shows field photograph of N-S trending 14 m high fault scarp. RTK points denote Real Time Kinematic GPS survey points. Inset 1 shows the epicenter of the last millennial earthquakes in the Himalaya and the Indo-Eurasian plate convergence (black arrows). Inset 2 shows the generalized cross-section AA′ across the MR (refer to line AA in the main figure) with the seismicity (black dots).

Activity: 7

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

(*R.J. Perumal, Rajesh S., P.K.R. Gautam, Vikas Adlakha*)

Paleoseismological trench investigation on fault scarps in the Eastern Himalaya

Several paleoseismological trenches excavated along the eastern Himalayan front over the last two decades have provided insight into the rupture dynamics of several earthquakes in A.D. 1255, 1713/14, 1934, and 1950. Previous paleoseismological research works were confined only to the HFT, without any considerable attempts in the Eastern Himalayan Syntaxis (EHS) or Namche Barwa. Although complexity exists due to the eastward increase in plate convergence and segmentation of the Indian plate in the Brahmaputra Valley, very little is known about the seismogenic behavior of the frontal Mishmi Range (MR) of the EHS, which strikes roughly perpendicular to the main Himalayan arc. Previously, the 1950 earthquake rupture was reported on the E-W striking HFT at Pasighat. Though the 1950 earthquake (Mw 8.6) rupture with an anomalously high slip of >30 m was estimated by tectonic geomorphological investigation in the MR, the actual co-seismic slip remains undocumented. To address this discrepancy of an abnormally higher slip, the first paleoseismological trench investigation was conducted on a fault scarp at Kamlang Nagar in the MR of Arunachal Himalaya, India (Fig. 54). Our work is the first of its kind in the EHS (Figs. 55 and 56), and our trench records the 1950 earthquake surface rupture along the Mishmi Thrust (MT).

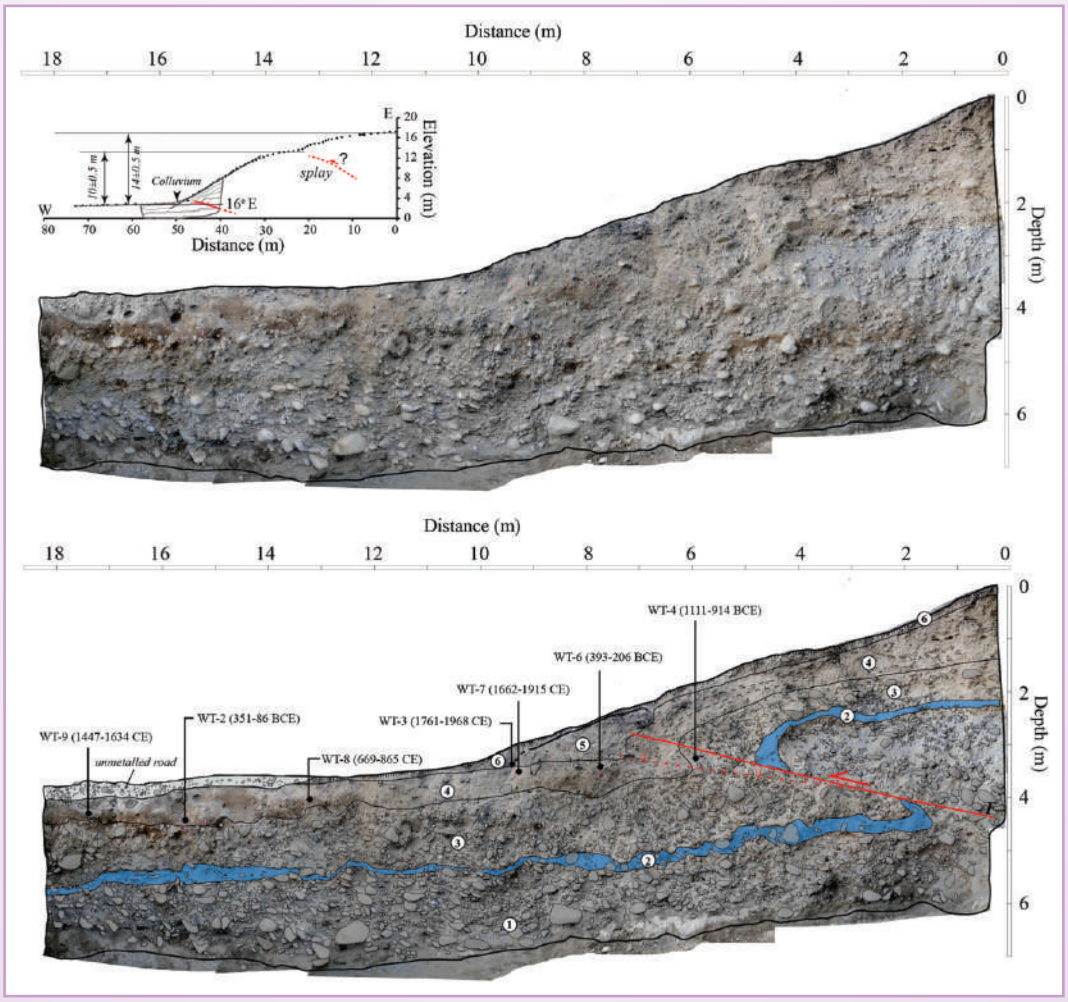

Fig. 55 : Photomosaic of the Kamlang Nagar trench showing the different soil units displaced along fault "F" (red line). Inset shows the scarp profile with two distinct offsets of 10 and 14 m, and the location of the trench (photomosaic).

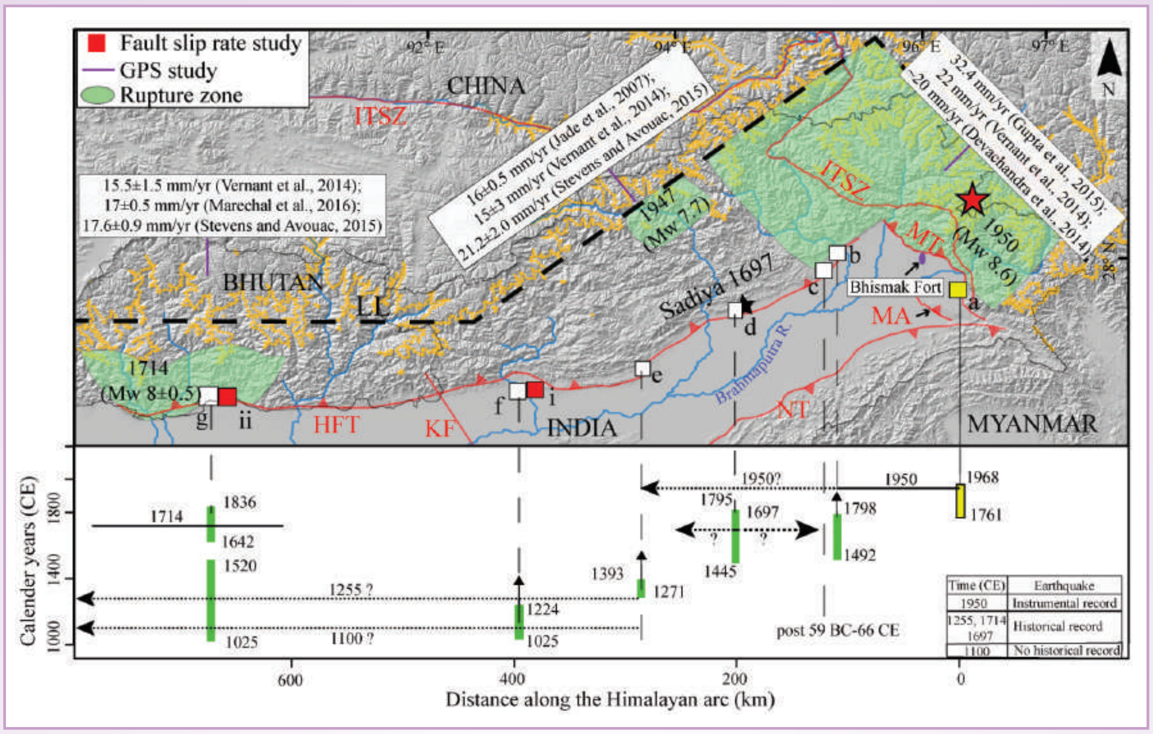

Fig. 56 : Map of the eastern Himalaya between 90 and 97°E longitudes along the Himalayan front showing rupture zones of historical and instrumental earthquakes (light green polygons), location of previous trenches at g-Sarpang Chu, f-Nameri, e-Harmutty, d-Hemibasti, c-Marbang, b-Pasighat represented as white solid squares with present trench a-Kamlang Nagar shown as a yellow solid square, and locations of fault slip rate studies of Burgess et al. (2012) and Berthet et al. (2014) at i-Nameri and ii-Sarpang shown as red squares. LL is the locking line at a 3.5 km elevation contour. GPS convergence rates estimated for different segments of the eastern Himalaya are given in boxes. Spatio-temporal distribution of surface ruptures along the eastern Himalayan front given below corresponds to the trenches a-f in the map given above. Horizontal solid lines denote the extent of earthquake ruptures and their uncertainty (dotted with arrowhead). Vertical green bars with an arrow are a probable extension of calibrated charcoal ages. The epicenter of the 1697 Sadiya earthquake is shown as a black star. Black arrows are the locations of Bhismak Fort (purple ellipse) and Manabhum Anticline (MA).

Middle-to-Late Miocene Exhumation history along Uttarkashi-Gomukh transect

Total 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. Total 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. Slide preparation for AFT and ZFT analysis is under process.

Crustal velocity, interseismic geodetic strain rate, and its correlation with topography in the Garhwal-Kumaun Himalaya

One of the major objectives of this activity is to understand the regional geodetic interseismic strain rate in the Garhwal-Kumaun region. Interseismic strain rate is one of the vital parameters one could track in the collisional margin to study the possibility of significantly large earthquakes. This has greater implications particularly if the region belongs to a 'Seismic Gap'. The Garhwal-Kumaun region is a part of one of the declared seismic gaps in the NW Himalaya known as the 'Central Seismic Gap -and the other is the Kashmir Seismic Gap. Besides, the region has greater importance in terms of seismic hazard, where significant large earthquake like the 2015 Mw 7.2 Gorkha-Nepal is anticipated owing to its lateral structural continuity with the Nepal Himalaya. Monitoring of interseismic strain rates would also help to understand the spatio-temporal changes in the strain accumulation and release processes in a collisional margin and hence to know the phase of the seismic cycle of a region. But in a tectonically complicated region like the Himalaya where a multitude of imbricate thrust systems including active faults are present, there the strain accumulation and release processes are utterly non-linear; which demands, densification and close monitoring of crustal velocity changes at varied spatio-temporal resolutions for a reliable recurrence interval estimation.

Regional crustal velocity and the surface shortening rates

Figure 57 shows the estimated regional crustal velocities of the study region in the International Terrestrial Reference Frame (ITRF2008) using data from the WIHG network, local network, and the surrounding International GNSS (IGS) stations.

In the Himalayan mobile belt, the crustal velocities are oriented towards the northeast as that of the movement of the Indian Plate. However, crustal velocities along the Himalayan arc increase from 48.62 ± 0.10 mm/a in the Garhwal Sub-Himalaya to 49.63 ± 1.05 mm/a in the Kumaun Sub-Himalaya. Whereas, across the Arc velocities decreases from 48.81 ± 0.14 mm/a in the south of HFT to 41.24 ± 0.02 mm/a in the

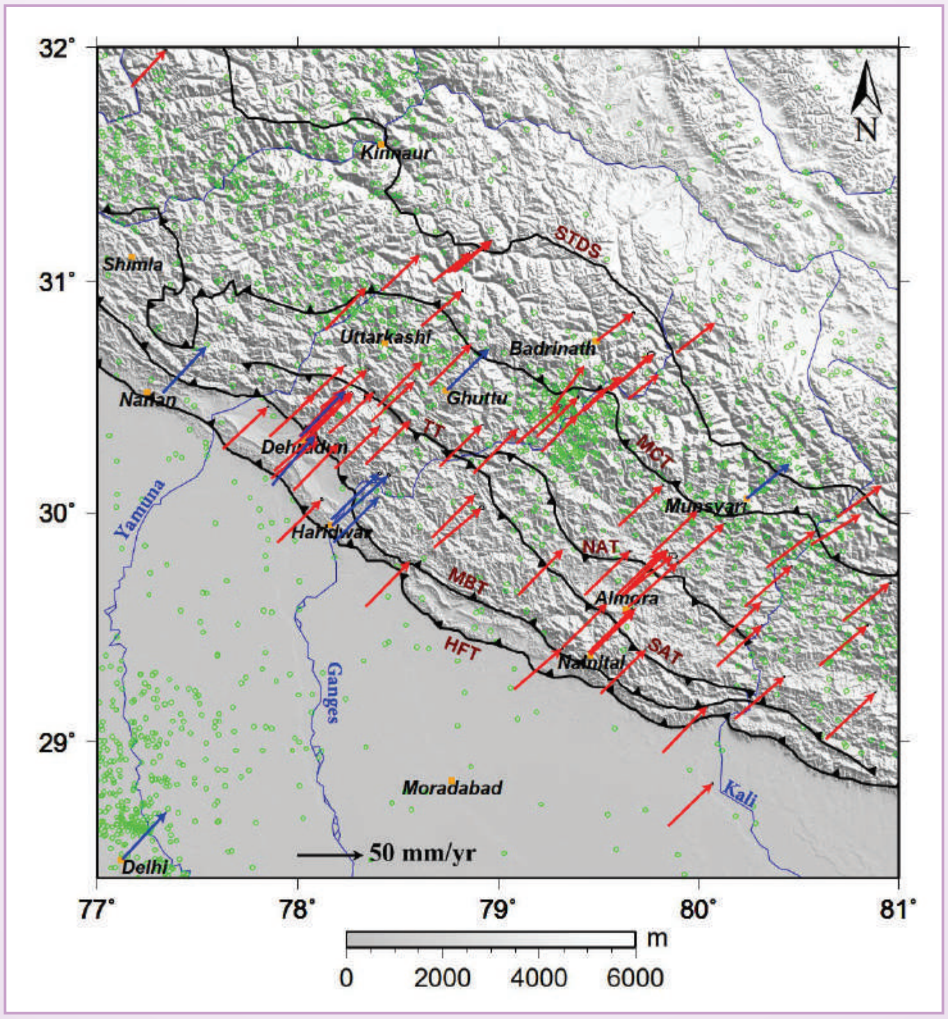

Fig. 57 : Velocities of the GPS stations in the Garhwal–Kumaun region in ITRF2008. The blue arrows represent the velocities of WIHG GPS permanent stations whereas the red arrows are campaign site locations. The seismicity of the region is marked as green circles. The blue rectangle is the area where strain rates are estimated.

ACTIVITIES

Higher Himalaya. The shortening rate of the Indian crust has been estimated by taking the residual velocity between the Haridwar station situated south of HFT and the Hanle station on the Eurasian plate. The estimated rate shows a 16 ± 0.8 mm/a crustal shortening in the Garhwal Himalaya. The linear surface shortening rates between Higher and the Lesser, Lesser and the Sub and Sub and the Gangetic plains across the Garhwal region are also estimated as 7.38 ± 0.24 mm/a, 2.40 ± 0.02 mm/a, and 1.26 ± 0.02 mm/a respectively. The linear surface shortening rate estimated across the Kumaun Himalaya is 17.62 ± 4.6 mm/a. Also the linear shortening rates of 5.41 ± 0.55 mm/a and 0.72 ± 0.22 mm/a are observed between the Higher and the Lesser and the Lesser and the Gangetic plains across the Kumaun Himalaya respectively.

Correlation of the second invariant of geodetic strain-rate with regional seismicity

Crustal strain rates in the Garhwal–Kumaun region were calculated from the GPS estimated crustal velocities based on the modified least square approach and subsequently computed the second invariant of strain rate as shown in figure 58.

The figure 58 shows the localities of different strain-rate zones; namely, the High compression zone (HCZ), Extensional deformational zone (EDZ), Equal strain-rate zone (ESZ), and the Low strain-rate zone (LSZ). The HCZ regions are above ~100 nstrain/a and confined just south of the Physiographic Transition (PT2) zone which separates the Outer and the Inner Lesser Himalaya. It is evident that the Tons thrust and the north Almora thrusts which separate the Outer and the Inner Lesser Himalaya act as a structural barrier between the high compressional zone and the extreme low strain-rate zones. Here the strain-rate increases from ~ 100 nstrain/a to a maximum value of ~ 200 nstrain/a towards the Badrinath region at the north of the MCT.

The intercomparison of geodetic strain rate with seismicity as reported earlier suggests that low strain-rate zones present within the locking width are more likely to produce a great earthquake. Figure 59 shows the interseismic geodetic strain rate plotted against the

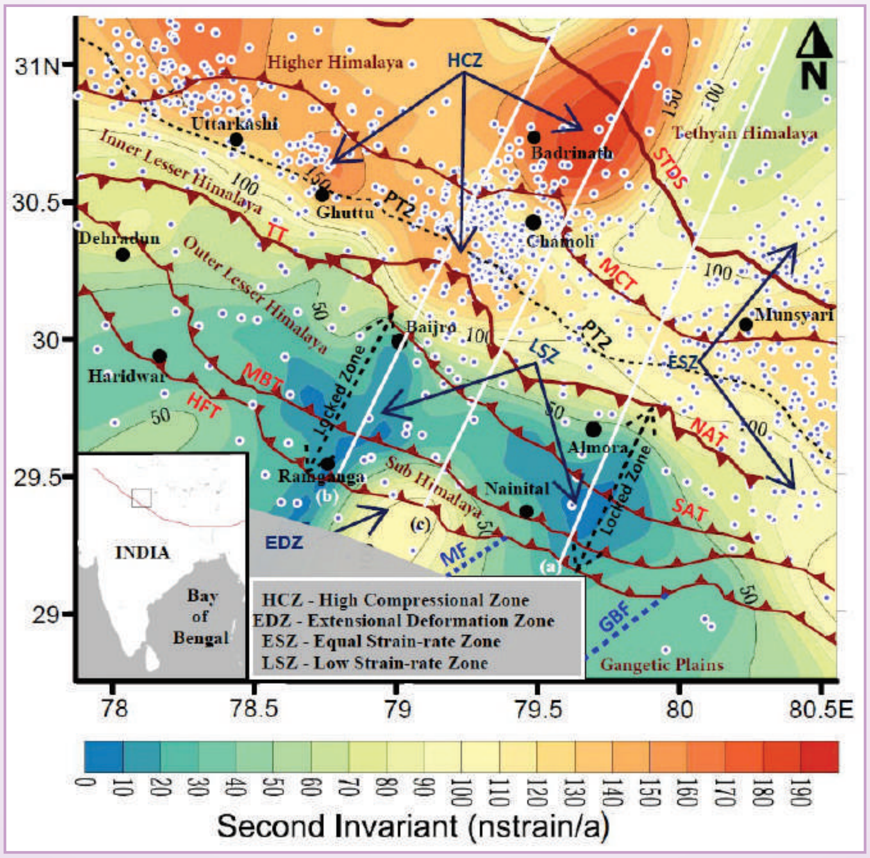

Fig. 58 : Second invariant of strain rate in the Garhwal–Kumaun Himalaya. Coloured contours represent the total strain rates in the region as a scalar quantity.

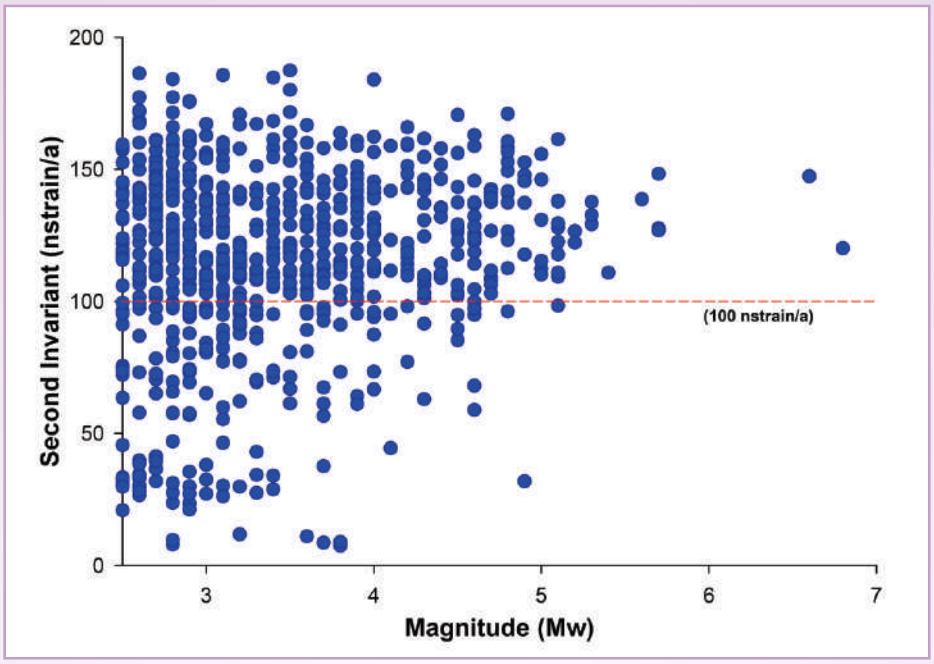

Fig. 59 : The second invariant of strain rate above and below the 100 nstrain/a barriers is plotted against the earthquake size.

earthquake size in the study area. Most of the earthquakes in the study region occurred in the high strain rate zones (> 100 nstrain/a) including the two significant earthquakes, the 1999 Mw 6.6 Chamoli and the 1991 Mw 6.8 Uttarkashi earthquakes. It is observed that the high compressional zone which lies in the Himalayan seismic belt close to the MCT, shows moderate to strong magnitude earthquakes having recurrence intervals of ~ 5 to 7 years. Thus the region away from the frontal part of the locked zone and towards the Himalayan Seismic Belt (HSB) the stored elastic strain energy is sequentially draining and thereby weakening the possibility for the occurrence of large earthquakes as long as the region maintains its current level of seismicity.

The region that lies < 100 nstrain/a, mainly in the Outer Lesser Himalaya is considered highly locked and shows strong interseismic coupling. This region within the low strain rates is not witnessed any significant earthquakes (Mw > 5) in the last 50–60 years. Paleo seismological studies also suggest that there are no transverse rupture zones of any great historical earthquakes in the Outer Lesser and the Sub-Himalayan sections within the LSZ. Thus, there is no dissipation of strain energy as seismic or aseismic slips. But the concern is about the possibility of a major or a great earthquake as there is evidence of many such earthquakes reported from the other frontal part within the locked portion of the great Himalayan arc. The estimated recurrence interval of such an Mw 7.0 event in the Himalayan region is about 100 years. Thus when the region exceeds its elastic limit then a large earthquake can produce a large rupture extending towards the HFT and the Gangetic plain. Thus the regions marked as interseismic low strain rate corridors in figure 58 have the potential for a large earthquake. The estimated surface locking width of Ramganga-Baijro and Nainital-Almora LSZ is ~72 and ~75 km respectively from the HFT. However, considering the possible recurrence of the 1905 Kangra earthquake, the Sub- and the Frontal Himalaya are long overdue for such an earthquake. It is yet to explore the possibility of strain diffusing factors that may put off or create uncertainties on the occurrences of large events in the Sub and the Frontal Himalayan regions due to the existence of EDZ.

Correlation of interseismic strain rate with regional topography

The correlation of strain-rate profile with topography would explain the mechanism of strain-rate transfer from the Higher to the Frontal Himalaya. As we traverse north across the thrust systems in the Garhwal–Kumaun Himalaya the topography increases, hence the gravitational potential energy. An attempt has been made to understand the mechanism of strain transfer towards the frontal, by unraveling (1) how the strain-rate changes as one moves across-the-thrust systems. (2) the

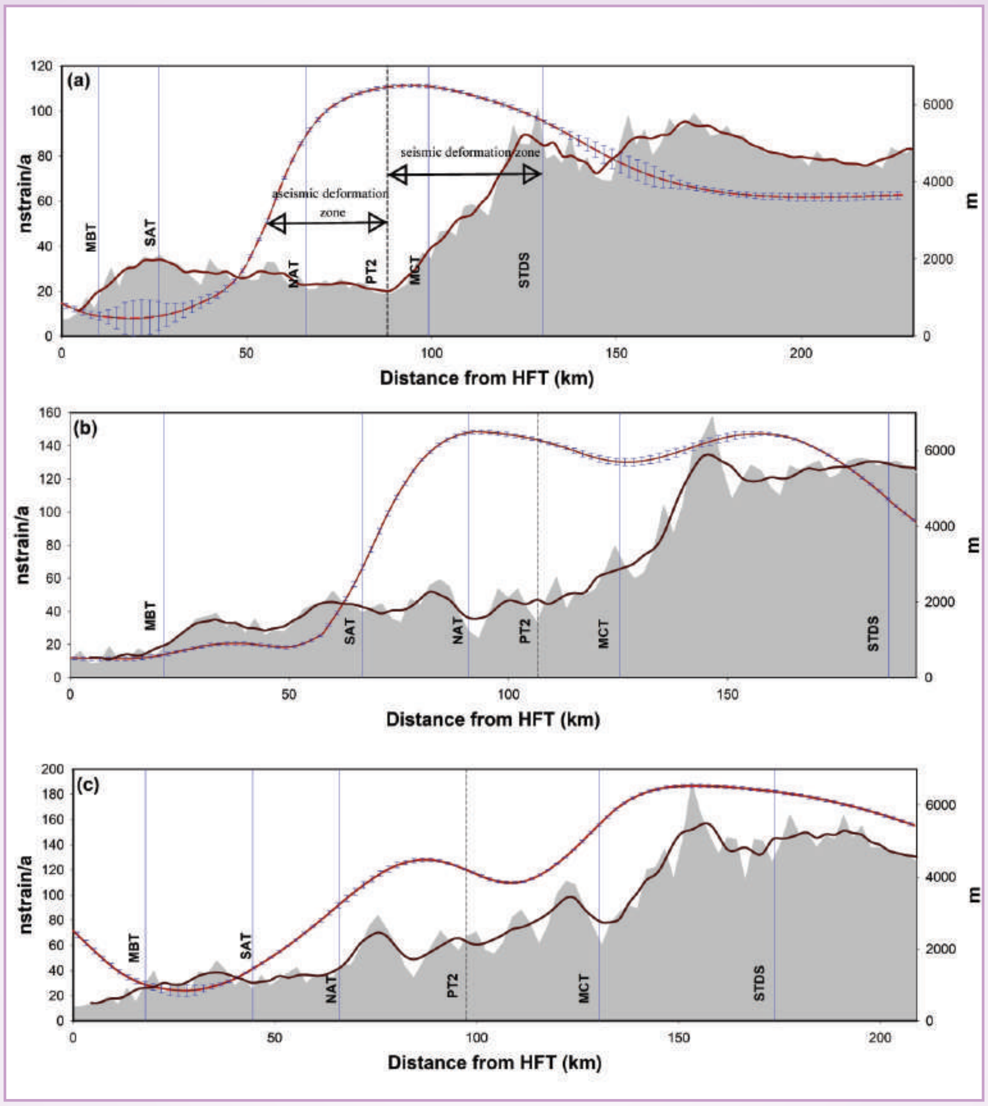

Fig. 60 : Strain rate Vs Topography across three profiles. (**a**) Across Nainital-Almora in LSZ, (**b**) Ramganaga-Baijro in LSZ, and (**c**) Ramnagar-Badrinath begins from EDZ. The red lines with error bars indicate the strain rates and their uncertainties along the profiles. The grey areas represent the elevations and brown lines show the mean elevations along the profiles.

role of subsurface Lesser Himalayan duplex system on across-the-thrust strain rate and (3) how the overburden topography affects strain-rate distribution in terms of Gravitational potential energy (GPE) change. Accordingly, three strain-rate-topography profiles were taken and shown with their locations given as white straight lines in figure 58. Figures 60 (a) and (b) represent the profiles taken over two low strain rate corridors namely Ramganga-Baijro and Nainital-Almora and the third one is the Ramnagar-Badrinath profile starting from EDZ to HCZ. A mismatch is observed between the strain rate and the topography in both profiles 4(a) and 4(b); particularly, in the Lesser Himalaya where the strain-rate changes from low to high values and is seen out-of-phase with the topography. However, in figure 60 (c) the strain-rate matches reasonably well with the first-order topography.

The observed out-of-phase behaviour of strain rate with topography across LSZ elucidates that the strain transfer process from HCZ to the frontal part is not aided by the GPE change, but mainly regulated by the structural complexities involved with the sub-surface Lesser Himalayan duplex system. The duplex systems are significant in keeping the strain rates higher in the Inner Lesser Himalaya even in the absence of seismicity but efficient to hold and transfer the strain aseismically. While for the case of the Ramnagar-Badrinath profile (c) the well-correlated strain rate with first-order topography suggest that the strain transfer mechanism is mainly regulated by the change in GPE.

Testing and operationalization of field Relative Gravimeter in WIHG

Field gravity observations in the Himalaya are quite sparse. A new field gravimeters called 'Galileo LG-1' have been made operational in the Institute after completing the necessary testing and calibrations. The instrument is fully functional and acquired different sets of data in cyclic as well as in the profile mode. As part of understanding the sub-surface mass density changes, the sedimentary thickness of the Dehradun basin, as well as the uplift of mountain fronts a data acquisition survey, was carried out all along a 130 km long profile from the Indo-Gangetic plains to the Mussorie region. More such profiles across the Siwalik hills are in progress to study the uplift dynamics. Besides base station tie surveys were also initiated between WIHG and the primary Absolute gravity base station of Survey of India in Dehradun.

SPONSORED PROJECTS

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)

The sate-of-the-art Multi-Parametric Geophysical Observatory (MPGO) at Ghuttu, Garhwal Himalaya is generating continuous data from different geophysical and atmospheric fields for earthquake precursory research. These records of different time series have denoted temporal variations at a high sampling rate (0.01 s to 15 min) at two sites Kopardhar and Dhopardhar. WIHG also has a broadband seismometer and Global Positioning System network in the Garhwal-Kumaon Himalaya around this observatory.

Seismic activity in the vicinity of MPGO Ghuttu

The Himalayan region records high seismic activity in a narrow zone at the boundary of the Lesser and Higher Himalaya. This crustal scale seismicity is mainly located within the upper crust with a high concentration between 10-25 km depth. The Ghuttu region of Garhwal Himalaya located within the Himalayan seismic belt has a high occurrence of small-to-strong size earthquakes. The earthquake source parameters of 67 local and shallow focused earthquakes $2.2 \leq M_L \leq 5.2$ have been estimated using *S*-wave spectral analysis considering the Brune circular model of earthquake occurrence. The seismic moments of the earthquakes vary from 1.51×10^{13} to 4.87×10^{16} N.m. The stress drop and source radius range from ~1.0 to 65.2 bar and ~100 to 1100 m respectively. The majority (70 %) of these shallow focus earthquakes have low-stress drop ($\leq$10 bar). It indicates that the upper part of the crust is brittle, which has low strength to withstand the accumulated strain energy originated due to India-Asia collision producing micro and moderate magnitude earthquakes. The data of different parameters are processed and analyzed during the occurrence of moderate and higher magnitude earthquakes at Ghuttu and the surrounding region of ~300 km distance.

Detailed information on the small and moderate magnitude earthquakes (M3.0) that occurred within a 300 km distance from the MPGO observatory for the years 2021-2022 is used after calculating the seismic index. The moment magnitude was obtained from the seismometer waveform data and calculate the seismic index based on earthquake size and distance (Molchanov *et al.*, 2003):

$$K_s = (1 + R^{-M/2})^{-2.33} \text{ x } 10^{0.75M}/10R \quad ....(i)$$

Where R = distance from the observation point and M= Earthquake magnitude.

The information on earthquake epicenter distance, magnitude, and seismic index are also plotted in figure 61. These criteria are adopted to search the anomalous behavior before the occurrence of the earthquake.

Assessment of different components of borehole and atmospheric data set

Continuous data of different parameters recorded in a 10 m deep borehole and some atmospheric components are extracted at Kopardhar, MPGO site. The time series of different parameters for one year are plotted in figure 61. Earthquake data are collected based on information from the website of the National Centre for Seismology (NCS), New Delhi. About 30 earthquakes in the magnitude range 3.0 – 4.7 occurred during this period with a distance of ~300 km from the observatory. The seismic index of these events with reference to the MPGO observatory has been estimated for further analysis. These values are shown in figures 61(a) and (b). The size of red and magenta colors denotes the magnitude of earthquake events while its y-axis scale represents the epicentral distance from MPGO, Ghuttu, and seismic index. The temporal variation of radon emanation in the soil recorded at 10 m depth from the surface is shown in figures 61c. The other meteorological and hydrological parameters like rainfall precipitation, the subsurface temperature measured at different depths within the borehole, atmospheric temperature, and atmospheric pressure, etc. are also plotted simultaneously in figure 61. The first inspection shows a high variation of radon concentration with a high drop in concentration during the monsoon period. During this period there is high rainfall which indicates that the radon has a strong effect on its emanation. During the monsoon period, high changes are observed in the radon concentration because of changes in the water level and changes in the pores of the soil which get saturated with water, and therefore other anomalies are suppressed. This hydrological effect is observed every year and therefore the data of over 10 years have been used to make the relation between radon concretion and rainfall

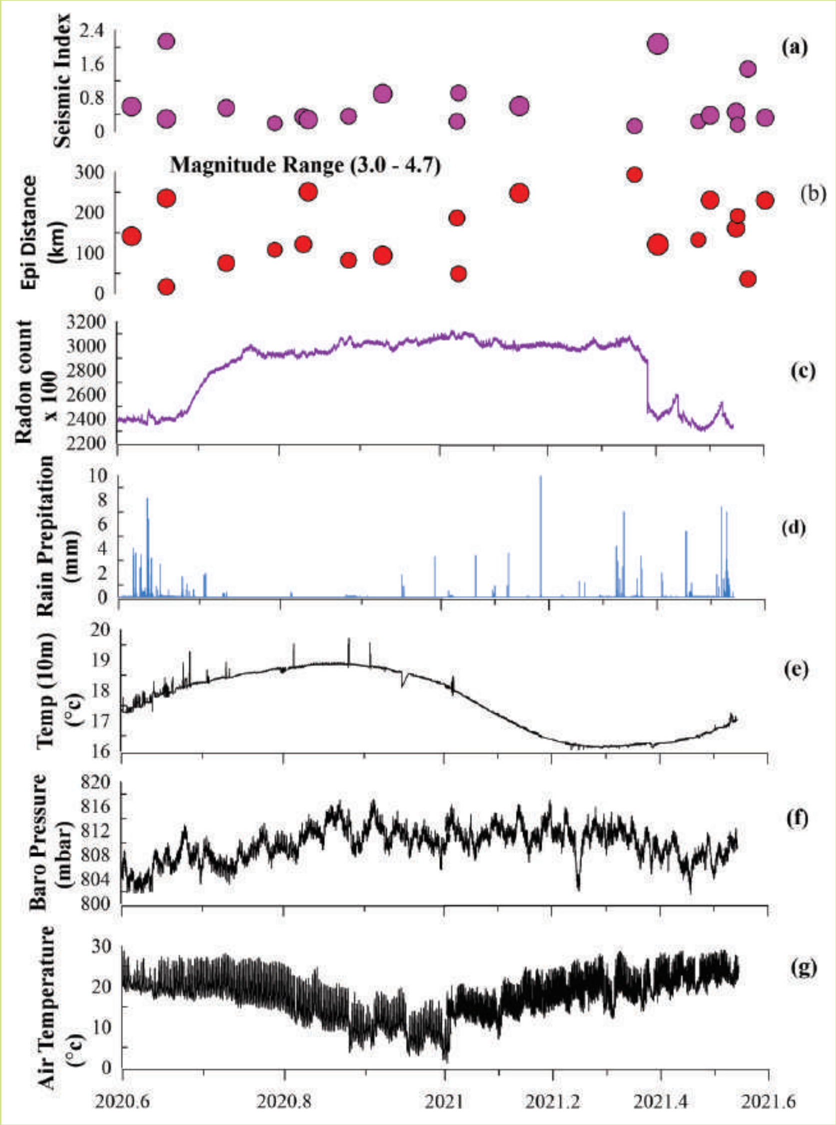

Fig. 61 : Plots of the borehole time series of 2020-2021 along with earthquake information. (a) seismic index (b) earthquake epicentral distance and magnitude (c) soil radon (d) water level (e) rainfall (f) temperature 30 m depth (g) temperature 50 m depth (h) atm Pressure (i) atm. Temperature.

precipitation or water level changes. These relations are used to remove the hydrological effect and assess the radon time series for seismic variability. Increasing depth decreases the amount of temporal change in the temperature. Atmospheric temperature and atmospheric pressure have very high daily fluctuations interlinked with each other and are influenced by solar radiation. These two parameters also show annual variation suggesting seasonal changes.

The changes are noticed in the radon concentration but the effect seems to be less. During the monsoon period, July to September, there is high rain precipitation during which changes in the water level measured through 68 m borehole is the highest. The soil radon concentration is also highly changed in this period suggesting a drastic change in concentration and also high fluctuations. The environmental data, the atmospheric temperature, and atmospheric pressure also have seasonal variability, however, its effect on the radon data is less compared to the rainfall and water level changes. It indicates that radon an inert gas varies due to hydrological changes. There is a need to recognize these seasonal and short-period trends and remove them from the radon data to assess the changes associated with seismic events. Attempts were made in the past to recognize these and separate them from the data. Recently, Chuhan et al. (2020) has done a brief analysis based on multi-linear trending to obtain the inter-variability of different parameters on the radon variability. All the earthquake events that occurred within 300 km of distance from the observatory are micro- or low-magnitude earthquakes. The seismic index of these events is less than 2 which indicates that the radon variability can have a negligible effect due to earthquake occurrence.

Estimation of earthquake source parameters and site effect

Estimating the source parameters of total 66 numbers of micro to moderate earthquakes has enabled the derivation of the empirical relationships among the source parameters for the Ghuttu Garhwal seismic region in the north-western Himalaya (Fig. 62). These events are recorded from 2010 to 2021 by the seismometer and the accelerometer. The study region has a history of occurrence of shallow focus micro-earthquakes with low-stress drop values that can be better understood with the partial stress drop model and low effective stress models. The frequency of micro-earthquakes is high which is attributed to the ongoing local scale adjustments due to the strain accumulation in the region. The present study shows the low values of stress drop (1.0 – 65.2 bar), which reveals the low strength of the rocks that constitute the upper crust and are less capable of storing stress for a longer period.

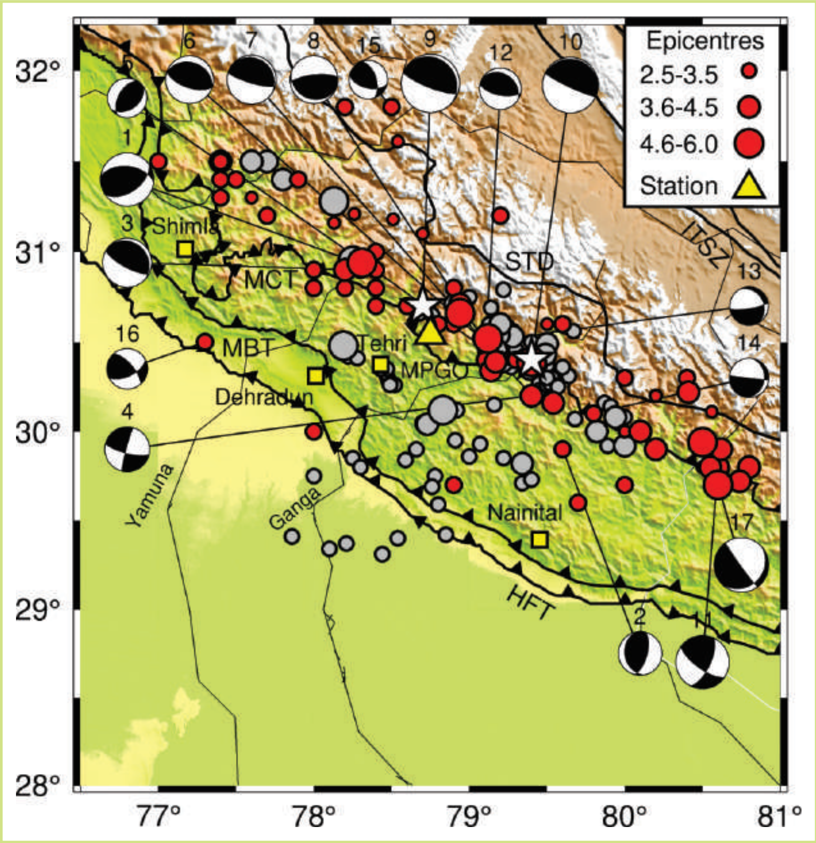

Fig. 62 : Relief map of the Garhwal –Kumaun Himalaya showing the major tectonic boundaries viz., HFT- Himalayan Frontal Thrust; MBT- Main Boundary Thrust; MT (MCT-I) - Munsiari Thrust; VT (MCT-II) - Vaikrita thrust; STD- South Tibetan Detachment; ITSZ- Indus Tsangpo Suture zone; KF- Karakoram fault. The triangle (filled yellow) represents the MPGO seismic station. The rectangle (filled yellow) depicts the important cities in the Garhwal-Kumaun Himalaya. The circles (filled red) show the epicentral locations of small to moderate earthquakes from January 2010 to April 2021 and the circles (filled grey) show the background seismicity. The white-filled stars show the location of the 1991 Uttarkashi and 1999 Chamoli earthquakes. The blue rectangular box is the study area which is shown in detail in the inset. The black beach ball shows the focal mechanism solution for 17 earthquakes taken from published data.

Thus, with increasing strain, rocks undergo brittle fractures and adjustments, leading to frequent micro earthquakes. To initiate the rupture process, a particular amount of stress should be accumulated over time in the entire fault plane or parts of the fault as it happens in the partial stress drop model. In the present study, small earthquakes were considered, and estimate their moment magnitude (M_w), which is important for predicting ground motion at low magnitudes. An empirical relation between moment magnitude (M_w) and local magnitude (M_L) is developed for local earthquakes that can be useful for effective seismic hazard assessment and tectonic studies in the Ghuttu region of northwest India. The local magnitude, moment magnitude, and seismic moments of the earthquakes are in the range of 2.2 to 5.2, 2.4 to 5.5, and 1.51×10^{13} to 4.87×10^{16} Nm respectively. Linear correlation is observed for the seismic moment with respect to local magnitude (M_L), source radius (r), and stress drop, while corner frequency is seen to be inversely correlated with M_0 and M_w. This study is important in simulation of strong ground motion, and seismic risk mitigation.

The data were continuously recorded through a 3-component accelerograph during the occurrence of 32 moderate magnitude earthquakes and obtained the PGA values. The Horizontal-to-Vertical component (H/V) ratios are obtained from the records of accelerographs for further analysis. The H/V ratio of individual components NS and EW and the resultant horizontal component H was performed. Horizontal PGA is obtained from two horizontal components. The ratio is mainly between 1.25 to 3.0 except for one value at one horizontal component reaching 4.0, but the resultant is 3.0 for this event also (Fig. 63). The H/V does not depend on the earthquake magnitude. Its value is 2.0 for the strongest Mw 5.5 and some lower magnitude earthquakes also have higher values. However, the value varies with distance, exceeding the value of 2.0 for some events of distance less than 40 km and two events at ~80 km. It may indicate that site amplification may depend on the site conditions and have a heterogeneous site effect for the region around the observatory but may depend on the locations of the epicenters. Figure 63 shows the contour map plotted for the H/V of the 32 earthquakes that occurred in the Garhwal-Kumaun region. In Garhwal Himalaya, the values are close to 1.5 and 1.8 which signifies the presence of hard rock such as granite, quartzite, and gneiss of high compactness in the region whereas the adjacent region constitutes relatively soft rock like schist and limestones.

Study of radiation exposure due to indoor radon and thoron in and around Ghuttu window

Measurements of indoor ^{222}Rn, ^{220}Rn, and their progeny concentrations were performed in the Ghuttu region of Garhwal Himalaya for radiation protection purposes. The measured concentrations were used to estimate the inhalation doses received by the public. The measured values were found to depend upon different seasons. The annual effective dose attributed to ^{222}Rn, ^{220}Rn, and their progeny exposure was estimated in the range of

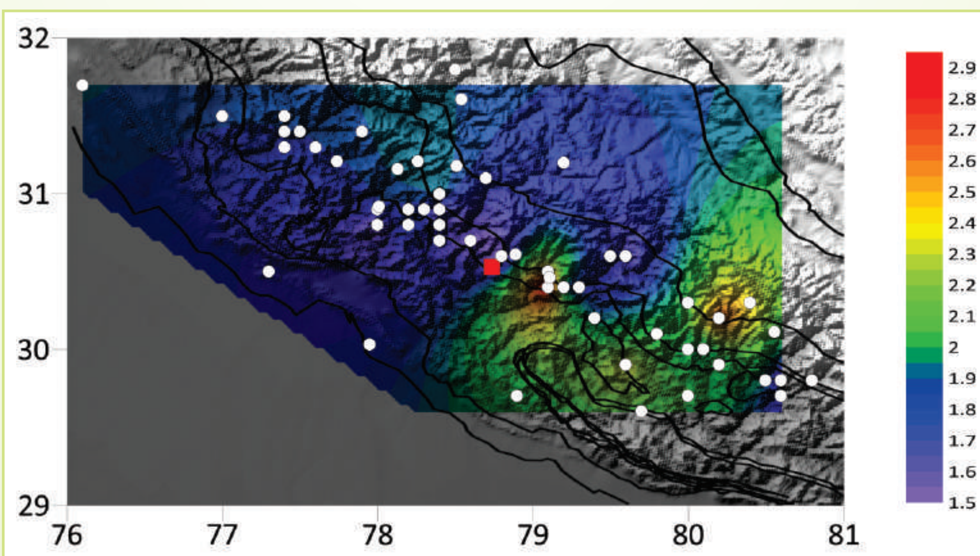

Fig. 63 : Lateral variation of horizontal to vertical (*H/V*) ratio observed for the PGA data with epicentral distance at MPGO Ghuttu (small red rectangle) for the earthquakes shown with white circles.

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0.93–2.37 mSv per year with an average of 1.54 ± 0.42 mSv year. No significant health risk is found to be associated with exposure to these radiations. ^{222}Rn is the radioactive noble gas present in the environment which is a decaying element of the Uranium radioactive series. Uranium is a trace element present in all types of rocks and soils and therefore ^{222}Rn gas is important in measuring the exposure dose quantities to the inhabitants at the indoor level. Assessment of ^{222}Rn, ^{220}Rn, and their progeny concentrations at the indoor level is very important as the exposure of these nuclides has a radiation effect on the health. ^{220}Rn also subjects special significance in the radiation dose. A property of ^{222}Rn, ^{220}Rn, and their progeny have high diffusivities as it has a great ability to stick to the surface. When an ambient aerosol particle is attached to the decay product of the ^{222}Rn (218Po, 214Pb, 214Bi, and 214Po), ^{222}Rn progeny-rich aerosol forms, and these aerosols reach into the respiratory tract through inhalation and are responsible for the damage of lung tissues which causes lung cancer.

Construction materials, cracks in walls and tap water, etc. are the main sources of indoor ^{222}Rn accumulation. Information related to the soil types, rocks, distribution of lithology, and geology is the main feature of the ^{222}Rn assessment. At the indoor level building materials, ventilation conditions, types of flooring, house types, and climate conditions are the most common factors that affect the indoor ^{222}Rn and its progeny concentration. The diffusion length of ^{222}Rn is more than the thickness of the material so that ^{222}Rn gas can easily be liberated into the air from the matrix through pores or capillaries. ^{220}Rn has a low diffusion length as compared to ^{222}Rn due to its very short half-life period. The presence of faults and tectonic activity also plays an active role in the exhalation process from the deep layer of soil. The Himalayan region is also associated with active fault zone. The present study region, the Ghuttu area is seismically highly active which is situated along the MCT and holds different types of geology. Due to tectonic activity around and along the MCT region there may be a huge change in the ^{222}Rn concentration. A total of 20 houses are selected for radiation concentrations in 10 villages of the Ghuttu region which are situated around MPGO Ghuttu. Out of 20 selected houses, 13 houses are built from mud and stones whereas 7 houses are made up of cement, concrete, iron, etc. Furthermore, out of 20 selected houses, 10 houses are poorly ventilated with a door of small size. The measurements were carried out for three different seasons, summer (March to June), rainy (July to October), and winter (November-February). The present investigation has been performed by using LR-115 (type-II) (cellulose nitrate) an alpha particle detector (SSNTD) having 12 µm thickness attached to a polyester base (thickness 100 µm), which is a passive method. These detectors were fixed in a twin cup pinhole dosimeter for the assessment of ^{222}Rn and ^{220}Rn concentrations and the progeny concentrations were measured using DTPS and DRPS methods. The gamma dose rate was found to vary from 0.25 ± 20% µSv per hour to 0.44 ± 20% µSv per hour with an average value of 0.33 ± 19% µSv per hour in the region. Figures 64 and 65 show the measured values of gamma dose rates in the

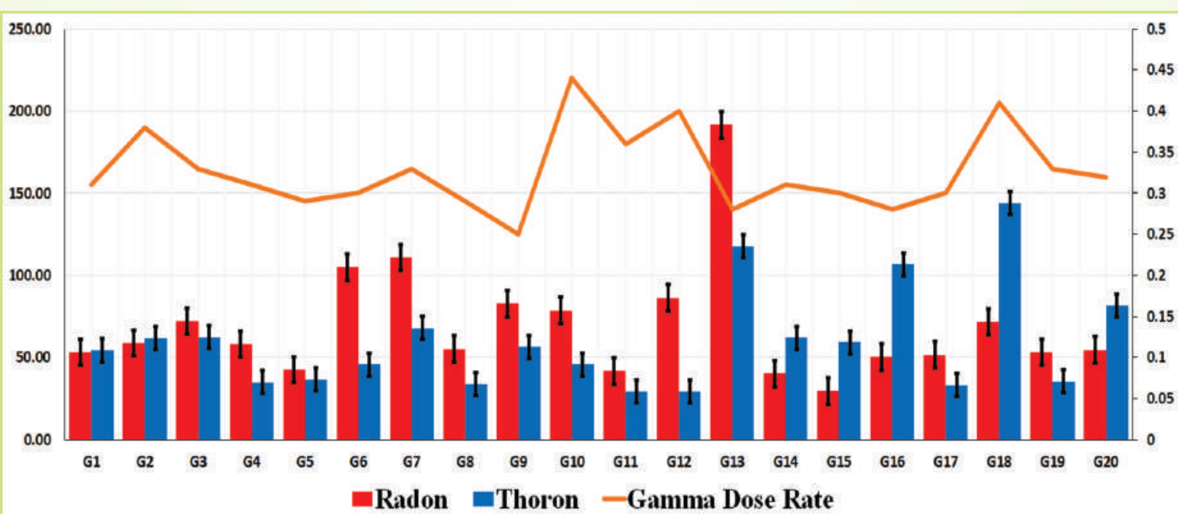

Fig. 64 : Indoor Rn/Rn concentration and gamma dose rate in the close approximate of MPGO Ghuttu (after Sajwan et al., 2021). G3 and G4 are the records at MPGO, Kopardhar, Ghuttu

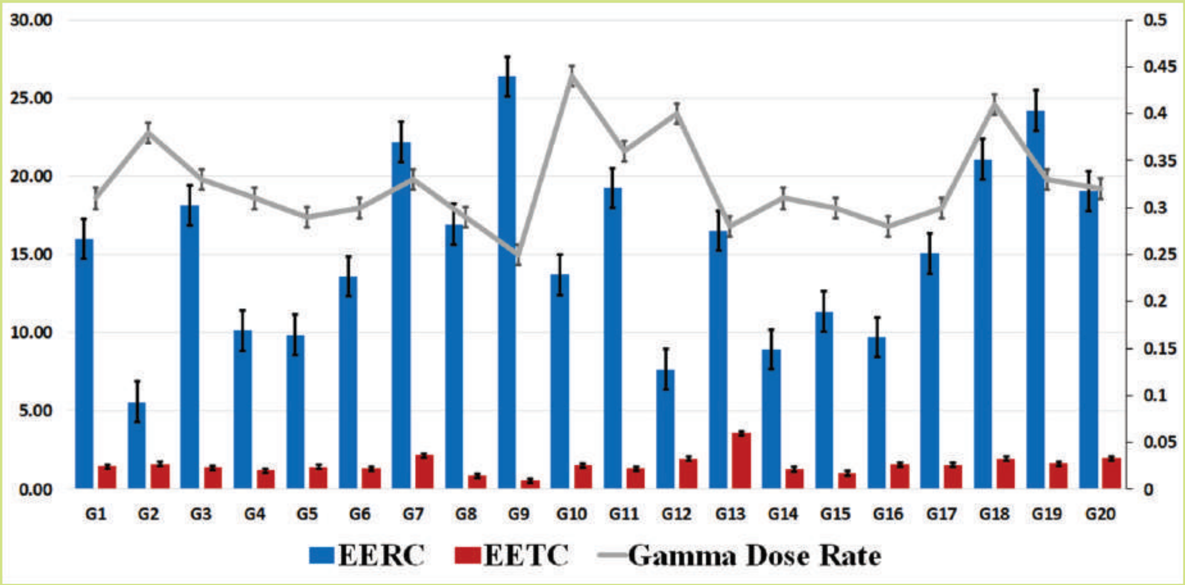

Fig. 65 : Indoor EERC/EETC concentration and gamma dose rate in the close approximate of MPGO Ghuttu (after Sajwan et al., 2021). (EERC – Equilibrium equivalent radon concentration; EETC - Equilibrium equivalent Thron concentration). G3 and G4 are the records at MPGO, Kopardhar, Ghuttu.

indoor air of different locations in the study area.

The ^{222}Rn concentration level inside the dwellings was in the range of 29–192 Bq/m^3. The average ^{222}Rn concentration was measured as 70 ± 36 Bq/m^3, which is comparably higher than the global average value (40 Bq/m^3). The concentration measured in the poorly ventilated mud houses was found to be very high. The estimated range of indoor ^{220}Rn concentration is 29–144 Bq/m^3 and the measured average concentration for ^{220}Rn is 60 ± 31 Bq/m^3. It is also higher than the corresponding global average value (10 Bq/m^3). The annual ^{222}Rn and ^{220}Rn concentrations of each dwelling are shown in figure 64. The measured radiation was very high due to variation in the geological condition and mainly due geologically active region in the MCT zone. The study was focused on the variation of radioactivity concentration due to the effects of construction material, ventilation conditions, and meteorological parameters (temperature, humidity, rainfall, etc.). The maximum concentrations of ^{222}Rn and ^{220}Rn levels were found in the winter season and the minimum in the summer. The low concentration in the summer is mainly due to the high rate of ventilation in the selected houses. In the summer season, generally, windows and doors of the houses remain open, and due to good ventilation condition rate of air exchange increases. The measured value of radiation doses due to ^{222}Rn, ^{220}Rn, and their progeny have shown no significant health risk in this region. ^{220}Rn progeny contributes about 28% to the total Annual Inhalation Dose (AID). It clearly shows that ^{220}Rn progeny are also an important nuclide for health risk point of view so it cannot be neglected.

Co-seismic variation and noise analysis of Gravity data based on Superconducting Gravimeter

A side-by-side noise analysis of Superconducting Gravimeter (SG) data and comparison of trillium 240 Broad Band Seismometer (BBS) with the SG OS051 in the seismic normal mode frequency band. Several observations have been carried out about the noise sources that could affect SG in the seismic normal modes frequency band. The study describes the background noise associated with gravity measurement through SG. A comparison of the noise of SG with the trillium 240 Broadband Seismometer; concludes that SG has a high SNR ratio compared to BBS. SG has been used to monitor very long-period signals such as earth tides, polar motion, surface deformation, and mass shifts.

To judge the suitability of SG in providing useful information to seismology and normal mode studies, it is also important to determine its noise characteristic compared to other well-recognized instruments such as a Broadband seismometer. An instrumental noise that exists in the gravity spectrum of SG is described as a parasitic mode. This mode of internal noise results from the rotation of the superconducting sensor due to the mechanical shock of the instrument. The frequency of this mode differs from instrument to instrument but is typically around 10 mHz. This noise frequently appears as a spectacular peak in the gravity spectrum even at environmentally quiet times. A mechanical shock to the gravimeter resulted during Helium transfers in the Dewar, cold head cleaning, or occurrence of moderate to higher magnitude local earthquake often excites this parasitic mode. This is an additional noise in the gravity data of SG, which has to be detected and removed for analyzing the data that includes the frequency band of this noise. A possible search of this parasitic mode and its influence on the noise level in the normal mode band of SG is also performed during the current study.

Different types of noise are associated with SG data, limiting the precision of observation of gravity signals of interest. These noises include instrumental self-noise, e.g., data acquisition noise or sphere resonance effects, and/or environmental noise, e.g., seismic or meteorological origin. The observatoryis situated within tectonically and seismically active Garhwal Himalaya, so it is difficult to obtain data with low environmental noise for five consecutive days to carryout noise analysis. Gravity variations may also be influenced due to seismotectonic aspects, situated in the MCT zone, and other local tectonic faults. The observatory is very close to the Ghuttu window. This analysis consists of calculating the Power Spectral Densities (PSDs) of calibrated gravity records data from SG by applying a Fast Fourier Transform (FFT). The calibrated gravity signals were used after removing the effect of tides, pressure, and 9th-degree polynomial drift in Nm s^{-2} with a 1 Hz sampling rate to compute the PSDs. The gravity records of five consecutive days during the quietest' period of observation were chosen when no local/regional micro-earthquakes or other disturbances are present.

Total four sets of low environmental noise datasets have been selected for periods from 04.10.2019 to 08.10.2019,06.06.2019 to 10.06.2019, 05.08.2011 to 09.08.2011, and 01.07.2011 to 05.07.2011 to calculate PSDs. The SG-051 has an average self-noise level of 10 dB relative to 1 $(nm/s^2)^2$/Hz, which is at intermediate frequencies (from 10^{-3} to 10^{-2} Hz) for almost all PSD plots. At frequencies around 0.05 Hz and between 0.1 Hz to 0.2 Hz, two minimal microseismic peaks lie around 23 dB and 21 dB relative to 1 $(nm/s^2)^2$/Hz). At frequencies around 0.04 Hz and 0.1 Hz, the minimal microseismic peaks lie at 30 dB and 21 dB relative to 1 $(nm/s^2)^2$/Hz. The principle recorded artifacts are noise spikes and offsets in the SG data, well-known noises generated due to local and regional aspects for the free earth oscillation (FEO) data. These are apparent sudden changes in gravity that are also resulted from lightning falls that occur without any apparent cause. Local moderate and higher magnitude earthquakes generate gravity changes that appear as a sudden decrement in the form of spikes for a duration of ~90 s and a dawn jump of ~4000 nm/s^2 (Fig. 66). A bigger and closer earthquake has a longer duration (red arrow) and a significant decrement in gravity. The offset is found to be of the same length as the width of excitation in the amplitude of the Z-component of co-located Broadband Seismometer. These have base widths (from trigger time to coming back to the initial state) of 40 s, 90 s, 55 s, and 87 s for selected local earthquakes having magnitudes 3.7, 2.9, 3.7, and 5.2. Therefore, the amplitude of the spike depends upon the magnitude, focal depth, and epicentral distance of earthquakes. It has been reported that beneath the MCT and Higher Himalaya, a partial molten/aqueous fluid are accumulated. The co-seismic change confirmed the mass deformation/upliftment of the site, while the other sudden fall in gravity during earthquakes shows the possibility of modes of excitation of upliftment from the mean state or ground state. Because most of the nature of earthquakes in Himalayan regain along the MCT boundary are thrust faults. These spikes are removed by fitting straight lines to a short segment of good data on each side of the affected part according to the requirements of analysts.

A co-seismic change occurred after the Mw 9.1 Japan earthquake on 04 April 2011 due to a local earthquake of Mw 5.3 with a seismic offset of 45 Nm/s^2. To calculate a co-seismic gravity change, an offset is obtained using the data of 60 minutes before and 60 minutes after the earthquake's origin time. The data were divided into two parts, 60 minutes times of pre-seismic and post-seismic duration denote initial and later base levels of gravity, indicating the offset amplitude of co-seismic changes. After the earthquake, oscillation of parasitic mode is also assessed and measured. A value of 27.83 mHz of frequency and quality factor $Q = 242 \pm 2$ was obtained during the above local earthquake with co-seismic changes. This is interesting for the co-seismic case, little change in frequency compared to ambiently occurring parasitic mode's frequency, we found a significant difference in Q value.

However, this mode has been considered ineffective in practical applications because its frequency is far from the tidal frequency band in which SG data have been mainly targeted. At present, SG data is also being

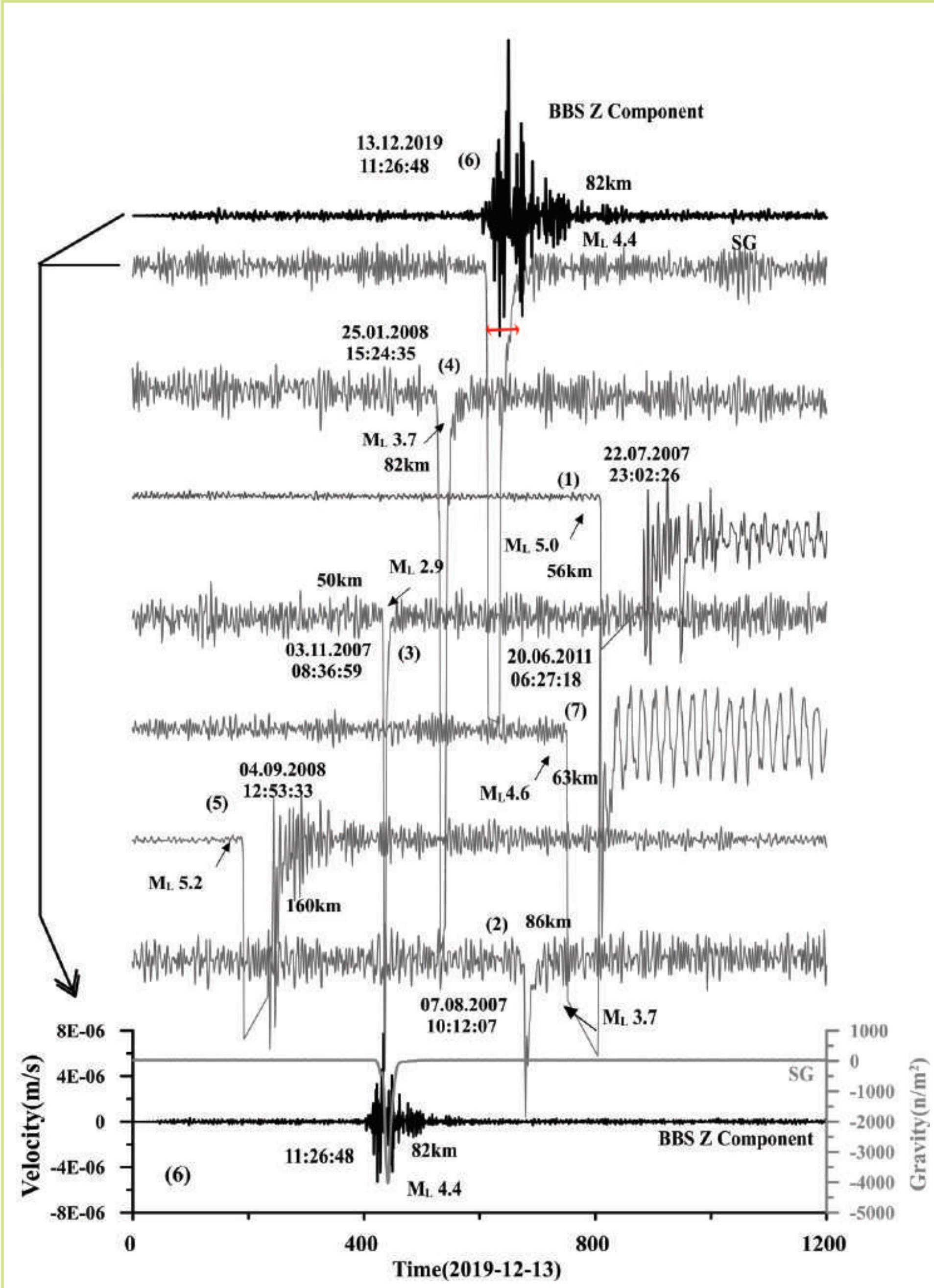

Fig. 66 : Sudden changes in gravity and co-seismic changes due to the local earthquakes recorded on the superconducting gravimeter (SG) (Gray colour), Ghuttu, and black colour waveform of the co-located Broadband seismometer

used in long-period seismology. For seismological applications, the existence of this parasitic mode is effective because the frequency of the mode also lies close to or within the frequency band of the normal modes of the Earth's free oscillations. However, in our case, it is out of and to the higher frequency band of the normal modes of the Earth's free oscillations. It is also observed that the parasitic mode is not perfectly harmonic. There is some energy leakage around the central frequency, even if the quality factor is relatively high. As a result, if this mode lies in the normal mode band, it can be contaminated by the side lobes of this noise, depending on the excitation mechanism. During the continuous excitation of the free oscillations of the Earth above 1.5 mHz, the noise level of the SG is higher than that of a co-located STS-1 seismometer. This implies the existence of instrumental noise in the SG observations. In the analysis of SG data, it is found that parasitic mode frequencies do not lie in the seismic normal mode band.

Uttarakhand State Disaster Management Authority (USDMA) Sponsored Projects

One Year Monitoring of Vasudhara Tal, Purvi Kamet (Raykana) Glacier, Dhauliganga valley, Uttarakhand India

(Kalachand Sain, Manish Mehta and Vinit Kumar)

Vasudhara Tal is located at the confluence of the snouts of Purvi Kamet and Raykana glaciers at an altitude of 4680 m asl. The glacial lake is ~14 km from Sepuk (road head) in Chamoli District. It has formed by the coalescence of numerous supra-glacial lakes in the lower part of the ablation zone (near the terminus). A few lakes are on the verge of coalescing with Vasudhara Tal. Based on satellite data (remote sensing techniques) from 1968 to 2021 and field observations (handheld GPS point data), the Vasudhara Tal was mapped.

The field observations and historical satellite data indicate that the area of Vasudhara Tal increased between 1968 and 2021 (Fig. 67). In 1968 there was no supraglacial pond on Raykana Glacier and only two small lakes were formed with a total lake area was ~0.14 km^2(Fig. 67A). Whereas, as observed in 1990 along with the two existing lakes (since 1968), some small and new lakes were developed with total lake area increased to ~0.22 km^2(Fig. 67B). Similarly, in 2017 the number of lakes and lake area increased to ~0.72 km^2 (Fig. 67C). However, at present (in 2021, Fig. 67D), some lakes have been drained out and new supraglacial ponds and ice cliffs have been developed over the glaciers. The total lake area estimated in 2021 is ~0.59 km^2. The lake area has been reduced between 2017 and 2021 and this suggests an uneven behaviour of the Vasudhara Tal expansion and reduction since 2017. The presence of supraglacial and proglacial lakes on Raykana and Purvi Kamet glaciers makes the area vulnerable to the GLOF threat in the future.

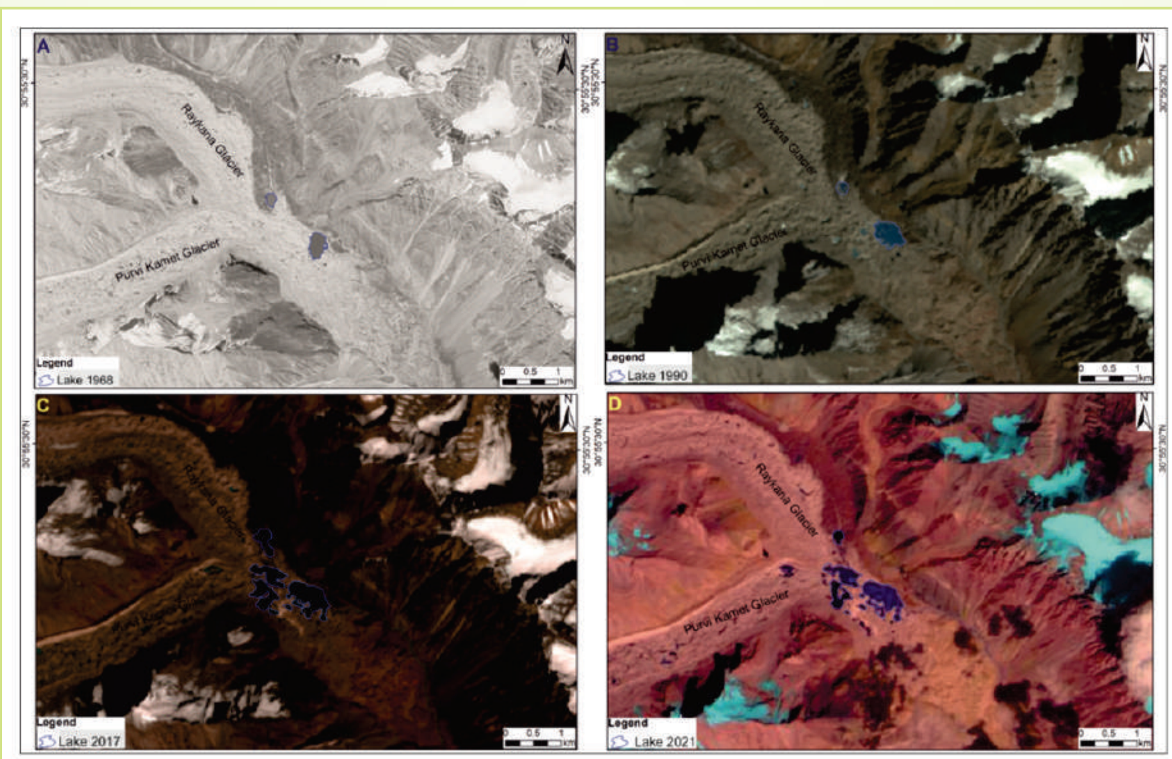

Fig. 67 : (A) CORONA 1968 image showing only two lakes at the Raykana glacier. (B) 1990 LANDSAT TM image clearly shows the formation and expansion of new and existing lakes. (C) and (D) are the LANDSAT OLI and Sentinel images showing the changes in the lake area between 2017 and 2021.

SPONSORED PROJECTS

SERB- DST Sponsored Project

Hydrological cycle analysis in valleys of Pindari-Kafni glaciers, Kumaun Himalaya

(Pankaj Chauhan)

This study comprehends two adjacent glacier valleys, Pindari and Kafni. The Pindari and Kafni Glaciers are located in the upper ridges of the Kumaun Himalaya, to the southeast of Nanda Devi and Nanda Kot (Fig. 68). The Pindari Glacier (30°16'5″–30°19'10″N and 79°59'00″–80°01'55″E) gives rise to river Pindar which meets river Alakananda at Karnaprayag in the Garhwal district. These glaciers have a long trail of historical observations dating back to 1845. The Kafni Glacier (30°13'05″N 80°03'20″E) gives rise to the Kafni River, which is a tributary of the Pindar River. The streams emerging from the Pindari and the Kafni Glacier valley confluence at Dwali (valley base: 2500 m asl) constitute the river, Pindar.

The main objectives of the project are to quantify the glacier melt discharge of the two adjacent glacier valleys i.e. the Pindari and Kafni in the Kumaun Himalaya, and to collect the water samples for isotopic study and quantification of the sediment budget in glacier melt. A number of field investigations have been carried out during the reporting period. It is aimed to estimate the evaporation and potential evapotranspiration in the valleys and alsoto estimate the snow, glacier, and rain contribution in the glacier valley, using isotopic analysis. Daily and inter-annual based sediment budget was estimated in both glacier valleys. Meteorological data was collected to correlate with hydrological parameters to understand the hydrological system in the valley.

Multiple Linear Regressions

The Multiple Linear Regressions (MLR) approach was used to evaluate the performance of the Artificial Neoral Network (ANN) model against that of an alternative time series and data-driven model. In addition, time-series analyses for the daily time steps were carried out using similar data sets to those used in the ANN simulations, and performance statistics were used to compare the results.

The inputs are processed using the resulting synaptic weight between the input, hidden, and output neurons, adding to the activation function. The extent of these links relies entirely on the architecture of the

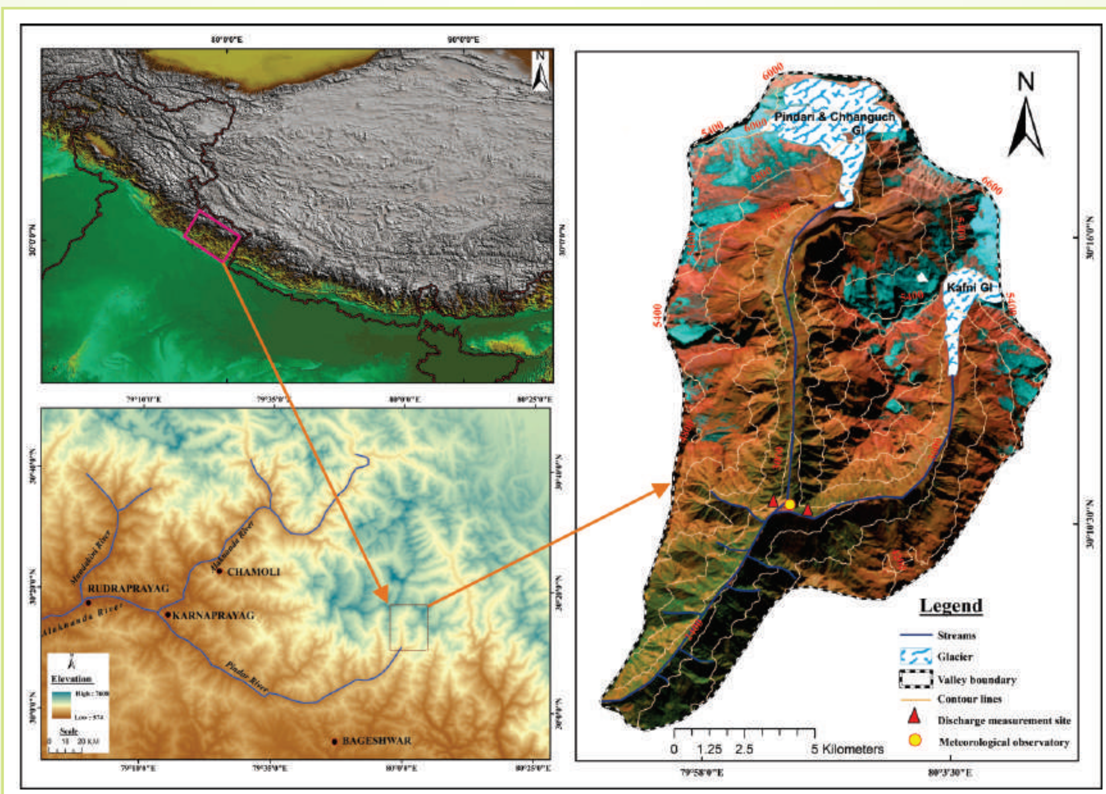

Fig. 68 : Map of the study area.

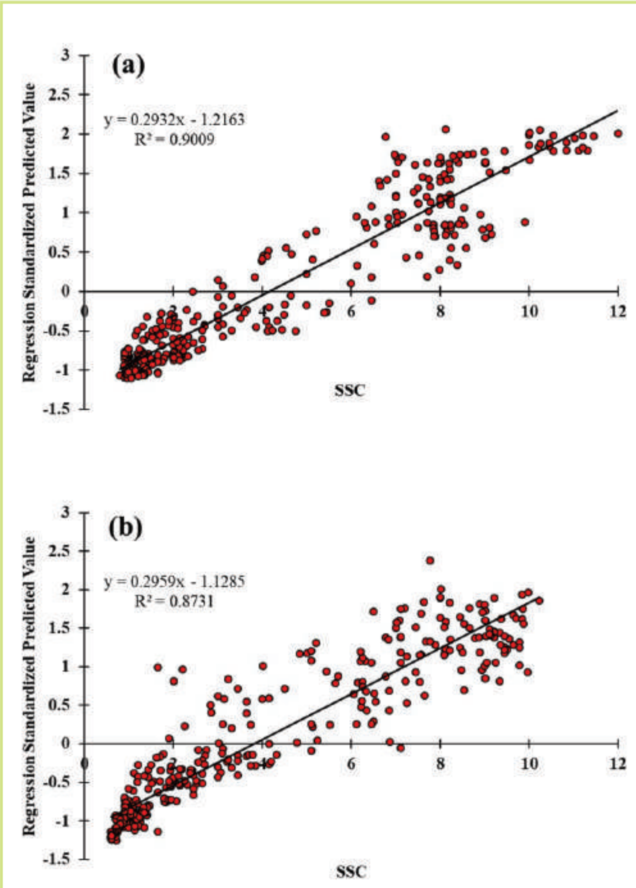

Fig. 69 : Correlation of predicted and observed values, (a) from the Pindari glacier stream and (b) Kafni glacier stream.

network. Likewise, the number of such connections relies directly on the architecture of the network. The more complicated a network is, the more synaptic weights it needs to compute. Therefore, the relevance of the factors based on raw weight values is frequently hard to determine. MLR analysis provides predictions for Suspended Sediment Concentration (SSC) which are shown in figures 69a,b. It shows that the predicted SSC from the Pindari glacier stream (Fig. 69a) achieved a better correlation with a value of (R^2= 0.9009) than the SSC from the Kafni glacier stream (Fig. 69b) (R^2 = 0.8731). If the collection of independent variables consists of more than one variable coupled with one continuous dependent variable, MLR is the right approach to apply. If the nature of the dependent variable measurement is at least at the interval level, MLR might be applied to investigate the link between a group of independent factors and one continuous dependent variable. The essential measure revealing the dependence of SSC on temperature, precipitation, and discharge parameters is the standardized coefficients used for comparing the impacts of independent variables (Beta coefficient). The results revealed that the precipitation and SSC are not proportional since precipitation has a negative Beta coefficient in Pinadri and Kafni glacier streams.

Forecasting of suspended sediment concentration

The results suggest that Multilayer Perceptron (MLP) is exceptionally relevant to SSC simulation when viewed as a regressive model. The intriguing conclusion here is to overestimate SSC values in all models. Furthermore, nearly no outliers exist for MLPs, while Radial Basis Functions (RBFs) often make such mistakes, demonstrating that MLPs are better fitted to the hydrological conditions encountered. There is a significant association between mean daily SSC and

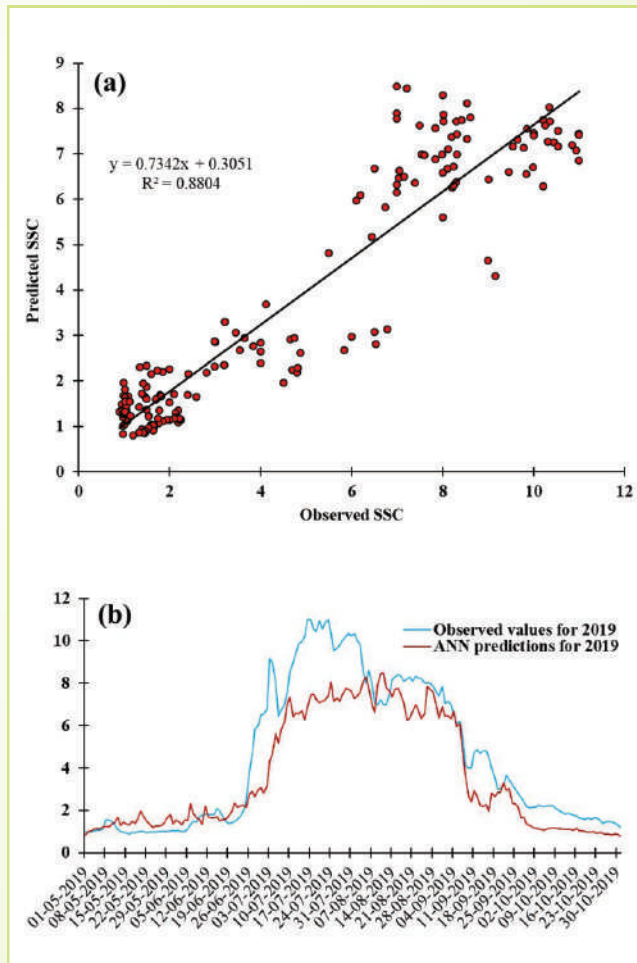

Fig. 70 : (a) Relationship between predicted and observed SSC, (b) show day-wise the graphical presentation of observed and predicted SSC in 2019 from Pindari glacier stream.

discharge ($R^2 = 0.9$). However, the lesser correlation for day-to-day data shows that the rainfall and temperature of both variables are associated poorly at the diurnal level. The demonstration was carried out on the relationship between SSC vs. discharge, SSC vs. temperature, and SSC vs. precipitation in Pindari and Kafni glacier streams. Figure 70a shows a good correlation and achieved the value of $R^2 = 0.73$, a representation of the observed and ANN predicted SSC from the Pindari glacier stream (Fig.70b).

Whereas the relationship value between observed and predicted SSC resulted in $R^2 = 0.90$ from Kafni glacier streams (Fig. 71a), which is much better than the Pindari glacier stream. The presentation of the predicted and observed SSC can be seen in figure 71b.

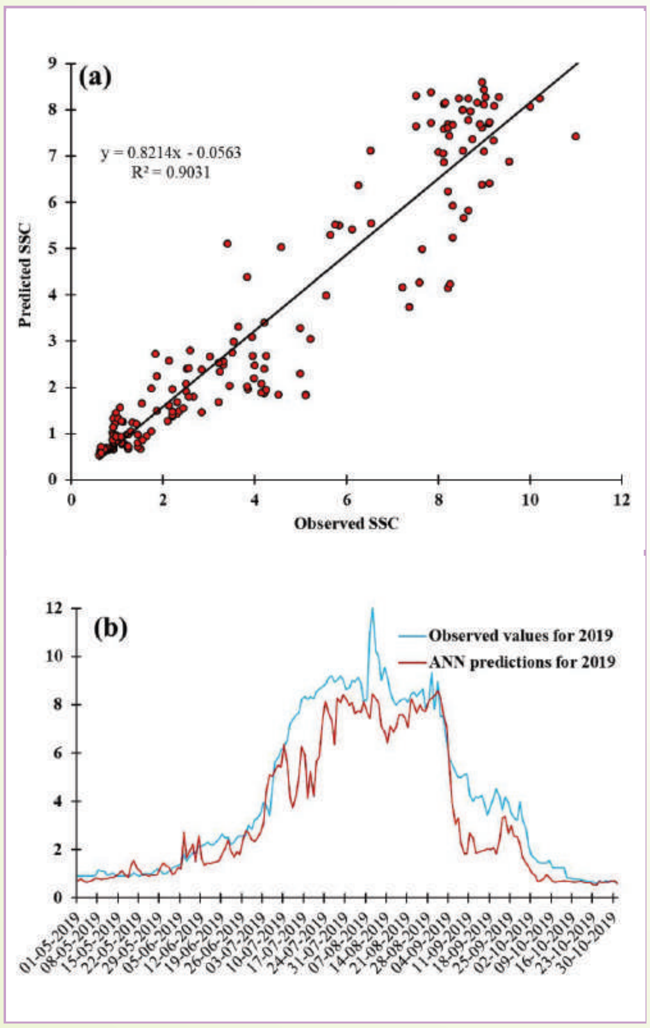

Fig. 71 : (a) Relationship between predicted and observed SSC, (b) show day-wise the graphical presentation of observed and precited SSC in 2019 from Kafni glacier stream

The SSC was observed in 2017 and 2018 and predicted in the part of the testing dataset from the Pindari and Kafni glacier streams. The MLP model provides better and more precise forecasts for the observed findings.

Artificial Neural Network accuracy and models comparison

Percent model output accuracy is shown in figure 72. Employed models i.e. MLP and RBF present in individual streams. The results clearly show that extreme events such as flood and landslides are not

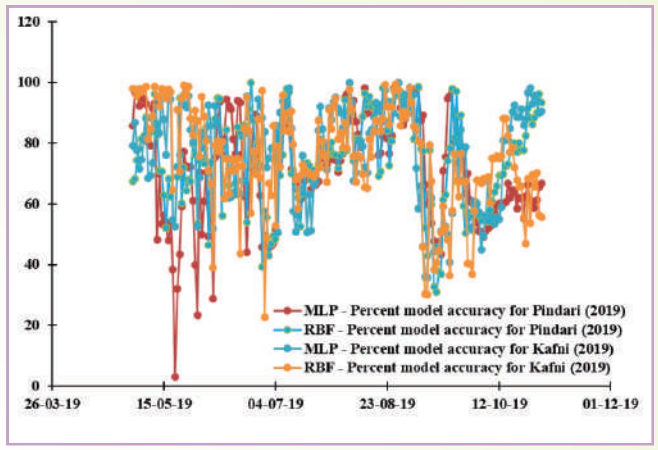

Fig. 72 : MLP and RBF developed model accuracy in percent with the day-wise presentation of Pindari and Kafni glacier streams.

predictable considering the research area based on the collected *in-situ* hydro-meteorological data. In light of the results, it is thought that there are other factors, such as solar radiation, that affect discharge values and thus sediment transport. Sustained multi-year observations using machine learning applications could improve regional water resources assessment and management and regulate the policy to develop multi-purpose hydroelectric projects in the region.

MoES Sponsored Project

Geochemistry and Geochronology of the Tethyan Ophiolites of the Indo-Myanmar Orogenic Belt, Northeast India: Geodynamic and petrogenetic implications and mineralization

(A. Krishnakanta Singh)

An ophiolite is a segment of the oceanic crust and upper mantle, tectonically exhumed on land due to obduction. Ophiolites provide direct evidence about the structure and composition of the oceanic crust along with the underlying mantle and also its interaction with melt, which enables us to define the possible tectonic setting during its formation. Earlier studies have proposed the existence of Mid-Ocean Ridge Basalt (MORB), island arc tholeiites (IAT) generated in Supra-Subduction Zone (SSZ), and Ocean Island Basalt (OIB) of plume source in the ophiolite is evidence of different tectonic origins with distinct geochemical signatures.

During the period, the bulk-rock and PGE data is discussed along with the mineral chemistry of depleted mantle peridotites from the northern part of the Nagaland Manipur Ophiolites (NMO), to explain the fractionation behavior of PGE during magmatic evolution and their genetic implications. The distribution patterns of PGE and REE along with the mineral chemistry of the ultramafic rocks were also discussed which helps us to understand the geochemical processes that affected the mantle section of the ophiolite before exhumation on land.

The lithology of the study area comprises ultramafic tectonic (dunite-harzburgite-lherzolite), ultramafic-mafic cumulates (pyroxenite-gabbro), mafic intrusives, volcanics, and volcano-clastics dominated by basalt, spilite, and marine sediments. Thus, a well-preserved crust-mantle sequence can be found in this zone. A sharp contact between the ultramafic and the mafic rocks has been observed, which lie in close association. Sheeted dykes, which are considered major litho-units in other ophiolites, are missing in the NMO. Fresh exposure of harzburgite, which is high in chromite was also encountered in the field. Dunites in the study area are often found associated with chromitites. In a few places, highly altered dunite pods, and lenses are also observed along with dunite boulders. At places, preeminent exposures of pyroxenites are also observed. Lherzolite and harzburgite show varying degrees of serpentinization. Towards the southern part of the NMO, chromitites are also well exposed, associated with peridotites.

Harzburgites are comprised of olivine, orthopyroxene, and minor clinopyroxene. Olivine is dark pinkish in colour with distinctive fracture, clinopyroxene, and orthopyroxenes are both found associated with olivine, all of which have anhedral to subhedral shapes (Fig. 73a, b). Cr-spinels are usually altered to magnetite, but relatively fresh, small Cr-spinel

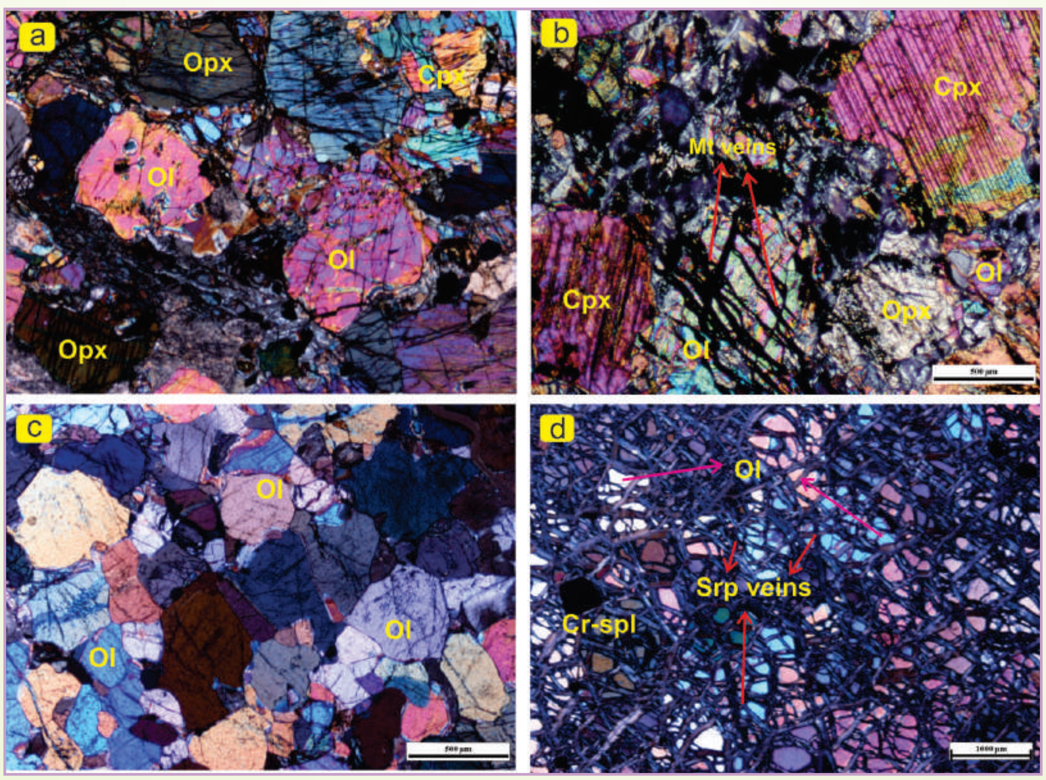

Fig. 73 : Photomicrographs (a) Porphyroclasts of orthopyroxene, clinopyroxene, and olivine in harzburgite; (b) Porphyroclasts of orthopyroxene, clinopyroxene, olivine along with magnetite(mt) veins in harzburgite; (c) Dunite showing equigranular and polyhedral olivine grains with triple-point junctions; (d) Dunite composed mainly of granular olivine showing mesh textures with a small number of Cr-spinels.

grains are also observed. Dunite is mainly composed of 96–98 % equigranular and polyhedral olivine grains showing triple-point junction among grain boundaries (Fig. 73c). However, a few olivines in sheared dunites exhibit mesh textures and indicate modification along cracks and grain boundaries with a relict olivine core (Fig. 73d). Where olivine and some orthopyroxene borders changed to serpentine, the honeycomb texture was also observed.

Geochemically, the studied ultramafic rocks are harzburgite and dunite. Harzburgite shows SiO_2 = 38.37-40.76 wt.%, CaO = 0.56-1.29 wt.%, Al_2O_3 = 0.36-1.58 wt.%, with low Fe_2O_3 = 6.22-10.14 wt.%, and MgO = 39.61-39.79wt.%. Dunite shows SiO_2 = 34.83-41.30 wt.%, CaO = 0.14-1.04 wt.%, Al_2O_3 = 0.07-0.39 wt.%, Fe_2O_3 = 7.80-10.11 wt.%, and MgO = 38.70-49.21 wt.%. Most of the studied ultramafic rocks have LOI typically >4 wt. % ranging from 5.19 to 12.01 wt. %. The chondrite-normalized REE pattern of ultramafic rocks of the NMO is shown in figure 74a. These NMO harzburgite samples show a slightly U-shaped REE pattern with enrichment of LREE and almost flat HREE patterns [$(La/Sm)_N$= 2.55-3.90 and $(Tb/Yb)_N$= 0.41-0.83]. They have been compared with the harzburgites from Xigaze ophiolites and Luobusa ophiolite, southern Tibet. Dunites with enriched LREE ($(La/Sm)_N$ = 1.85-4.11) and slightly enriched HREE ($(Tb/Yb)_N$ = 0.51-1.09) show a higher concentration of REE >1 in comparison with dunites from Xigaze ophiolites, Tibet and Dalabute Ophiolite, NW China (Fig. 74b).

The analyzed ultramafic rocks have high and variable platinum-group elements (PGE) abundances with ΣPGE = 125.6-142.8 ppb in harzburgite and 248–360 ppb in dunite. The concentration of cumulate pyroxenites and tectonic peridotites was found to be between 34 and 164 ppb in a prior study from central Nagaland and Manipur, which is lower than the NMO data. NMO harzburgite samples show slightly enhanced PGE when compared to harzburgite from the Cota block of the Zambales ophiolite complexes (ZOC) in the Philippines. In comparison to harzburgite from the western Yarlung-Zangbo suture zone in Tibet, where IPGEs (Os, Ir, and Ru) exhibit a distinct pattern, with depletion of Os, Ru, and slight enrichment of Ir, whereas PPGEs (Rh, Pt, and Pd) are depleted but exhibit nearly the same pattern. Deficient PGEs display a unique pattern with Os and Ru depletion in figure 75a. The NMO dunite samples show PGE patterns similar to the dunites from Aldan-shield, Urals but the studied dunites are slightly enriched and when compared to dunites from the western Yarlung-Zangbo suture zone, Tibet

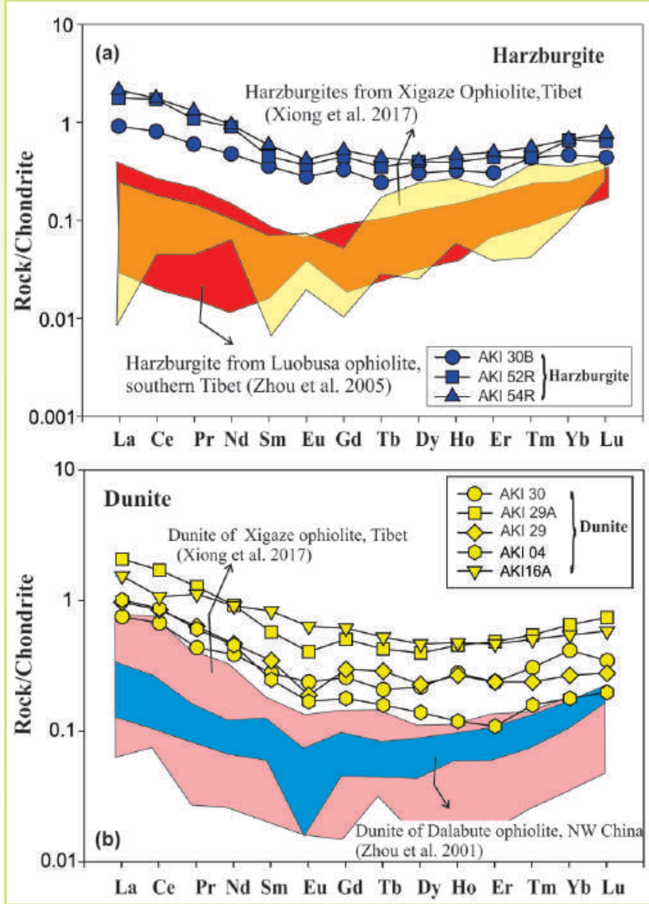

Fig. 74 : Chondrite-normalized REE pattern of (a) Harzburgites are compared with the harzburgites from Xigaze ophiolites (Xiong et al., 2017) and harzburgite from Luobusa ophiolite, southern Tibet (Zhou et al., 2005) (b) Dunites are compared with the dunites from Xigaze ophiolites, Tibet (Xiong et al., 2017) and Dalabute Ophiolite, NW China (Zhou et al., 2001). Normalizing values after Sun and McDonough (1989).

both the comparison has been done to represent whether the tectonic features of ophiolites show similarity or not. The studied dunites show depletion in Iridium group PGE (IPGE) and somewhat similar in Palladium group PGE (PPGE) (Fig. 75b).

The acquired mineral chemistry data were shown in several discriminating plots in order to comprehend the tectonic environment responsible for the production of the present investigated depleted mantle rock. All of the samples on the Fo vs. CaO plot have magnesium-rich and CaO-poor natures, indicating that they are mantle olivines (Fig. 76a).

The Cr# of cr-spinel (chrome–spinel) can also be

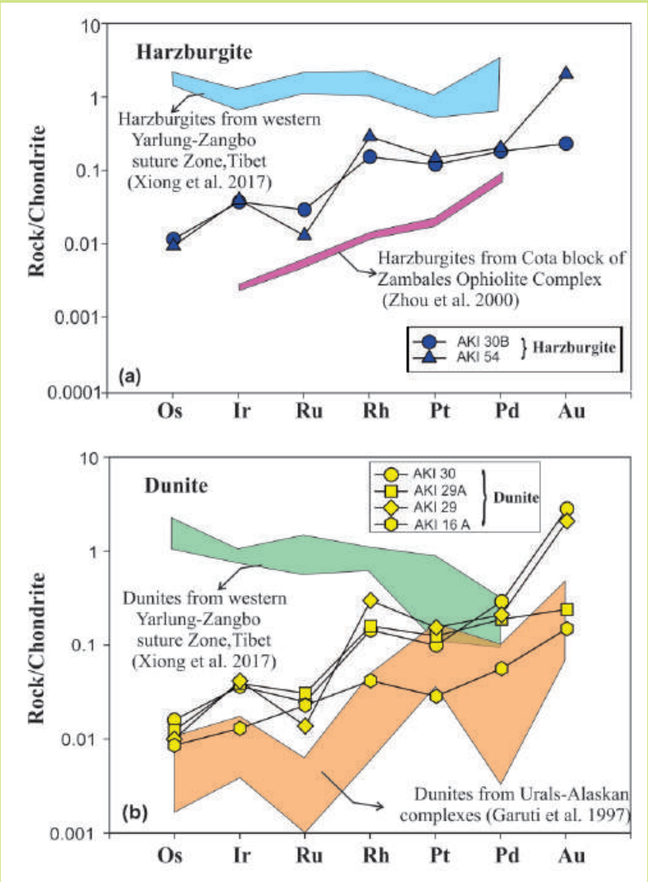

Fig. 75 : Chondrite normalized PGE patterns of (a) Harzburgite samples are compared with the harzburgite from the Cota block of Zambales ophiolite complexes (ZOC), and dunites from western Yarlung-Zangbo suture zone, Tibet (b) Dunite samples are compared with the dunites from Aldan-shield, Urals and dunites from western Yarlung-Zangbo suture zone, Tibet.

used to assess the degree of partial melting experienced by cr-spinel-bearing ultramafic rocks (harzburgites and dunites) using the equation: [F = 10x1n(Cr#) + 24]. Cr# in harzburgite cr-spinels is similar to a melting degree of 16.48 % -21.04 % (avg. 19.60 %), whereas Cr# in dunite cr-spinels is similar to a melting degree of 19.04% - 22.19% (avg. 20.85%). As a result, a progressive increase in the melting degree of these harzburgites and dunites (20 %) was forecasted. According to our findings, NMO's harzburgite and dunite are the remaining peridotites that melted widely in the presence of water. The Al_2O_3 (spinel) vs. Al_2O_3 (melt) plot (Fig. 76b) shows the Al_2O_3 concentration of the melt in equilibrium with Cr-spinels in harzburgite and dunites, which was calculated using regression lines based on previously published data on chromite-melt inclusions in MORB and arc lavas. The estimated melt compositions from the high-Al and high-Cr chrome spinels from the NMO; Oman ophiolites; Khoy ophiolites and Mayari-Cristal Ophiolite, Eastern Cuba are shown for comparison. Therefore, it is believed that dunites and harzburgites in the NMO constitute the remnant mantle section of extensive partial melting in a subduction zone's mantle block.

Observations of the present study on whole-rock, mineral chemistry, and PGE geochemistry suggest that the investigated depleted mantle harzburgite and dunites have been fertilized by reaction with percolating basaltic melt in the mantle wedge region of the subduction zone. Later, due to subduction and collisional processes between the Indian and Myanmar plates, the entire oceanic lithosphere along with the studied depleted mantle rocks was obducted on land to the west of the Indian continental plate.

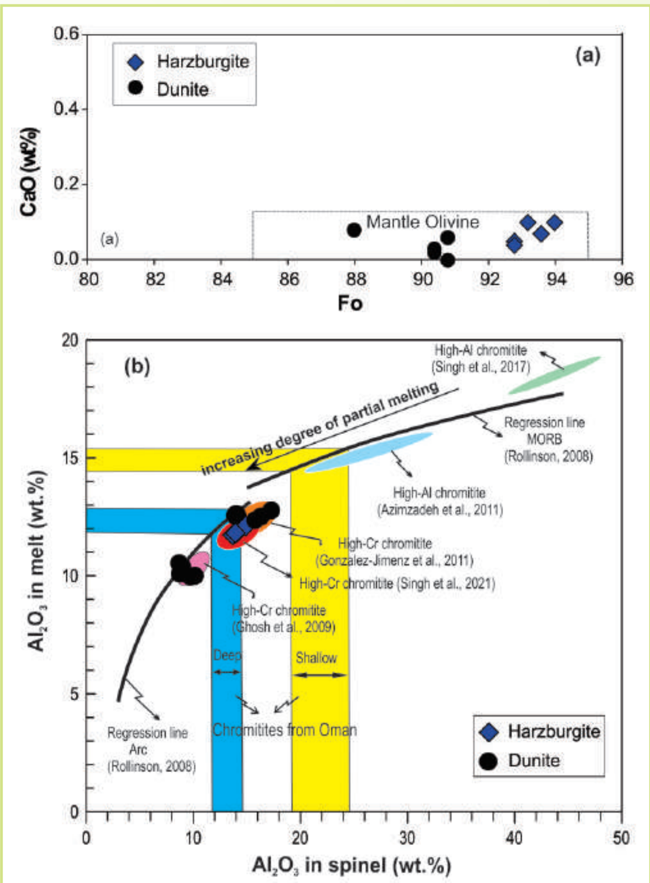

Fig. 76 : Binary plots of (a) CaO wt% vs Forsterite content plot of Olivine from Ultramafic rocks from Nagaland-Manipur Ophiolite. (b) Compositional relationship of Al_2O_3 spinel vs. Al_2O_3 melt of the NMO harzburgite and dunite.

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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)

Endogenic and exogenic processes are evolving the landscape of the Himalaya since its formation in Cenozoic time by the collision of Indian and Eurasian continental landmasses. Among the exogenic processes, weathering is a major phenomenon that in itself is governed by the climate, topography, vegetation, and lithology of the area. In the Indian context, weathering studies are meager, though a few studies are documented in Peninsular India, almost no work has been done in the Himalayan sector because of the lower preservation potential of weathering profiles owing to its dynamic nature. However, several slopes are relatively stable, and climatic conditions are favourable in developing the in-situ weathering profiles over bedrock. One such slope is identified from Lesser Himalayan terrains encompassing porphyritic granite rocks and a 6.9 m thick profile (Fig.77) was identified at the road cut-face near Lawari village along Tilwara-Ghansali road. The surface of the profile was peeled off up to 10-20 cm inward to avoid surficial contamination and representative samples weighing approximately 1-1.5 kg are collected from different zones of the profile. The representative samples were analyzed using X-ray Fluorescence and Inductive Coupled Plasma-Mass Spectrometry for the major, trace, and rare earth elemental behaviour. Also, the weathering products were dated by using U-series isotopes to decipher the in-situ weathering rate. U-series isotope analysis was carried out at the Wollongong Isotope Geochronology Laboratory (WIGL), University of Wollongong, Australia.

The intensity of weathering is evidenced by the high chemical index of alteration(CIA) value (~72) in the upper zones of the profile. A-CN-K characterizes the global weathering trend parallel to the A-CN tie line which goes up to the illite zone. With the intensification of weathering, most leachable elements, Ca, Na and K deplete consistently. These are chemically active and leach out of the porous sites of the weathering zones. Si also shows a significant decrease in weathered zones. Loss of silica in weathering products is related to the

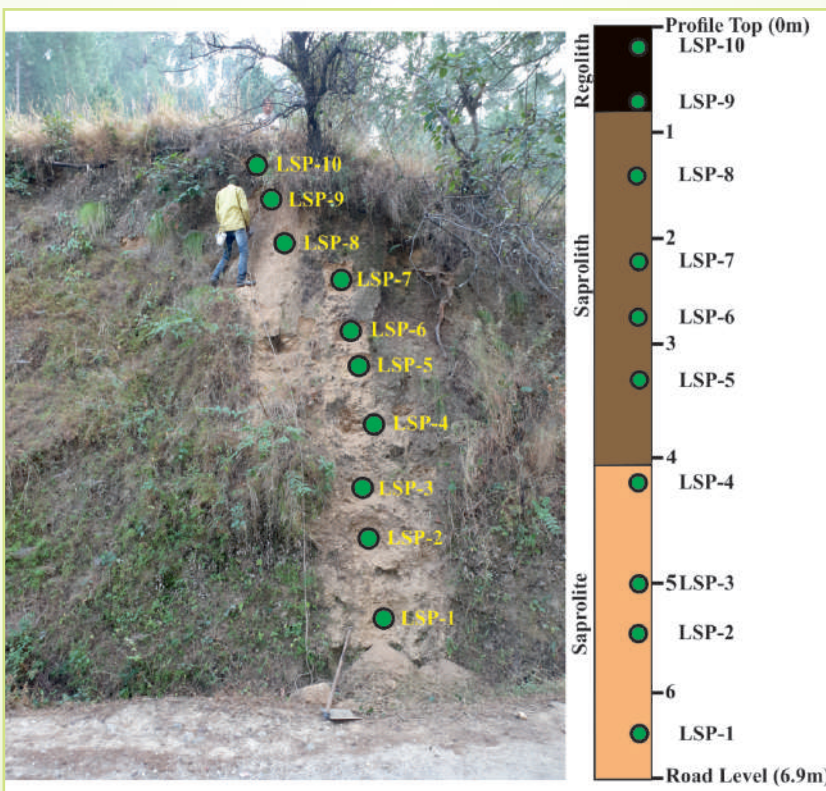

Fig. 77 : Studied weathering profile exposed along the road showing the sampling location and numbers.

mass loss of weathered material from the profile. Al increases from least altered rock to regolith zone with the increased extent of weathering. Al is a conservative element and oxidizes rapidly forming very stable aluminum oxides in aqueous media. An increasing trend in relative mobility is also seen for Mn.

The U concentration decreases while that of Th increases with the intensification of weathering towards the regolith zone. The rock exposed on the basal zone of the profile is altered up to some extent and demonstrates disequilibrium in activity ratio. A fresh rock sample is also collected from approximately 10 m offset of the profile along the road but it is also showing evidence of weathering with ($^{230}Th/^{238}U$) activity ratio greater than 1. As a consequence, the least altered rock exposed at the bottom of the profile is chosen as the reference to calculate the weathering age of overlying zones.($^{230}Th/^{238}U$) is greater than 1, and also greater than that of least altered rocks (LAR), throughout the weathering profile. U isotopes are also fractionated due to weathering. ($^{234}U/^{238}U$) is less than 1 throughout the profile, but a slight increase is noticed with the intensification of weathering. The computed weathering rate is 20 mm/kyr with the oldest regolith zone having ~280 ka weathering age. A nonlinearity is observed in the timescales of development of weathering profile with zones of intensified weathering during ~110 kyr to ~100 kyr and ~40 kyr to ~50 kyr. This increase in weathering rate during particular times can be related to a warm and moist climate favourable to weathering (Fig. 78). Previously published time series $\delta^{18}O$ datasets from the core record of Owen Ridge, NW Arabian Sea, and continental stalagmite records from Sanbao Caves from China have been used to understand the temporal variation in precipitation intensity. Intensified weathering during specific periods is in accordance with the fact that a moist climate enhances the weathering rate. Comparatively higher rate of soil removal by erosion than the rate of production by weathering infer the absence of preservation of soil/ weathering profiles on unstable slopes in the Himalayan sector. Rather, only stable slopes have the preservation potential of weathering/ soil profiles, signifying the topographical controls on weathering profiles. Weathering rate produced during this study is comparable with the previously published weathering rate of granitic/ granodioritic rocks worldwide by using U-series isotopes. Granite weathering rate was derived by Mathieu et al., (1995) from Brazil and by Suresh et al., (2013) from Australia by using U-series isotopes and the reported values were 50 mm/kyr and 10-24 mm/kyr respectively. By using the same proxy, weathering rates

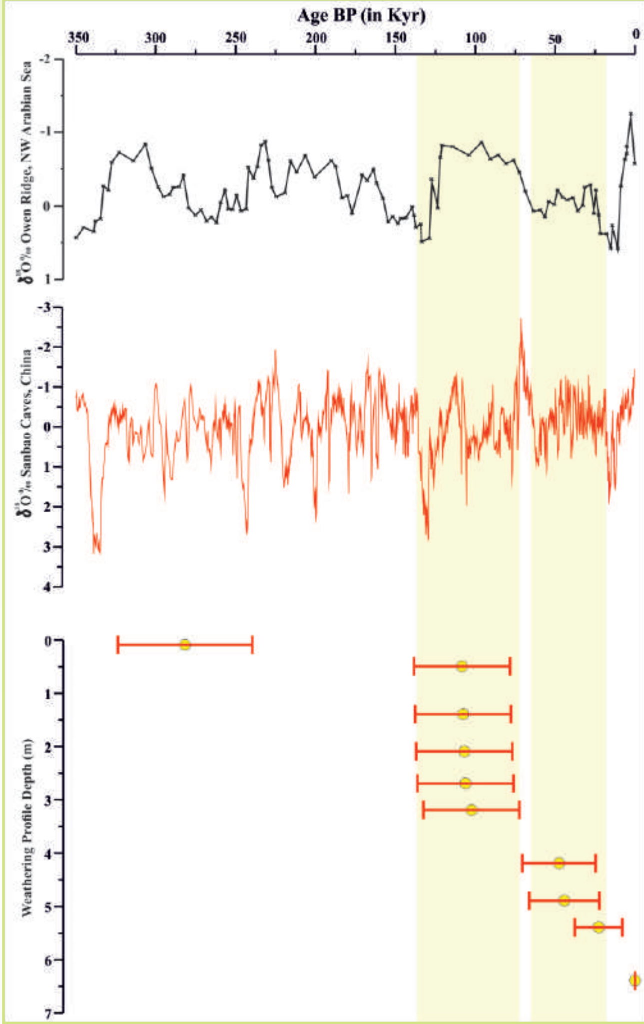

Fig.78 : Weathering ages computed by using U-series isotopes showing temporal non-linearity with intensified weathering zone during warm and moist climate while correlated with previously published datasets on O isotopes.

of granodioritic rocks were computed from Australia by Dosseto et al., (2008) and (2011). The weathering rate in these terrains ranged between 15 and 50 mm/kyr.

Observations in the present study on whole-rock, mineral chemistry, and PGE geochemistry suggest that the investigated depleted mantle harzburgite and dunites have been fertilized by reaction with percolating basaltic melt in the mantle wedge region of the subduction zone. Later, due to subduction and collisional processes between the Indian and Myanmar plates, the entire oceanic lithosphere along with the studied depleted mantle rocks was obducted on land to the west of the Indian continental plate.

MoES Sponsored Project

Seismic monitoring and seismological parameters evaluation in Garhwal-Kumaun region of Himalaya

(Ajay Paul)

In this project, data acquisition is carried out by a seismological network consisting of seismological stations in the Garhwal Himalaya and adjoining Himachal Pradesh (Fig. 79). Each station is equipped with Trillium-240 (broadband) seismometer and Centaur digitizers. The seismic stations are (i) Adibadri (ii) Tapovan (iii) Gaurikund (iv) Chakrataand (v) Dehradun in the Garhwal region and (vi) Nahan and (vii) Kotkhai in Himachal Pradesh. Analysis of earthquake event data indicates that the earthquakes are occurring in a narrow zone, south of the MCT. The magnitude ranges from 1.0 to 5.7 and the majority of events lie within 25 km depth.

Estimation of site response functions for the central seismic gap of Himalaya, India

In the analysis of seismic hazards of a particular region, the site response functions play a significant role. Site response functions in the Garhwal-Kumaun region of the central seismic gap become more important as the estimated possibility of manifestation of the earthquake ($M \geq 8$) is 31% in a time window of fifty years. This emphasizes the importance of the analysis of seismic hazards in this region. The site effect or response functions have been assessed for the central seismic gap region using 87 local events recorded at 50 sites located in the central seismic gap region of the Himalaya. Among 50 stations, 9 stations are located in Higher Himalaya, 30 stations are situated in the Lesser Himalaya, 06 stations are present in Sub-Himalaya, and the remaining 05 stations are situated in the Indo-

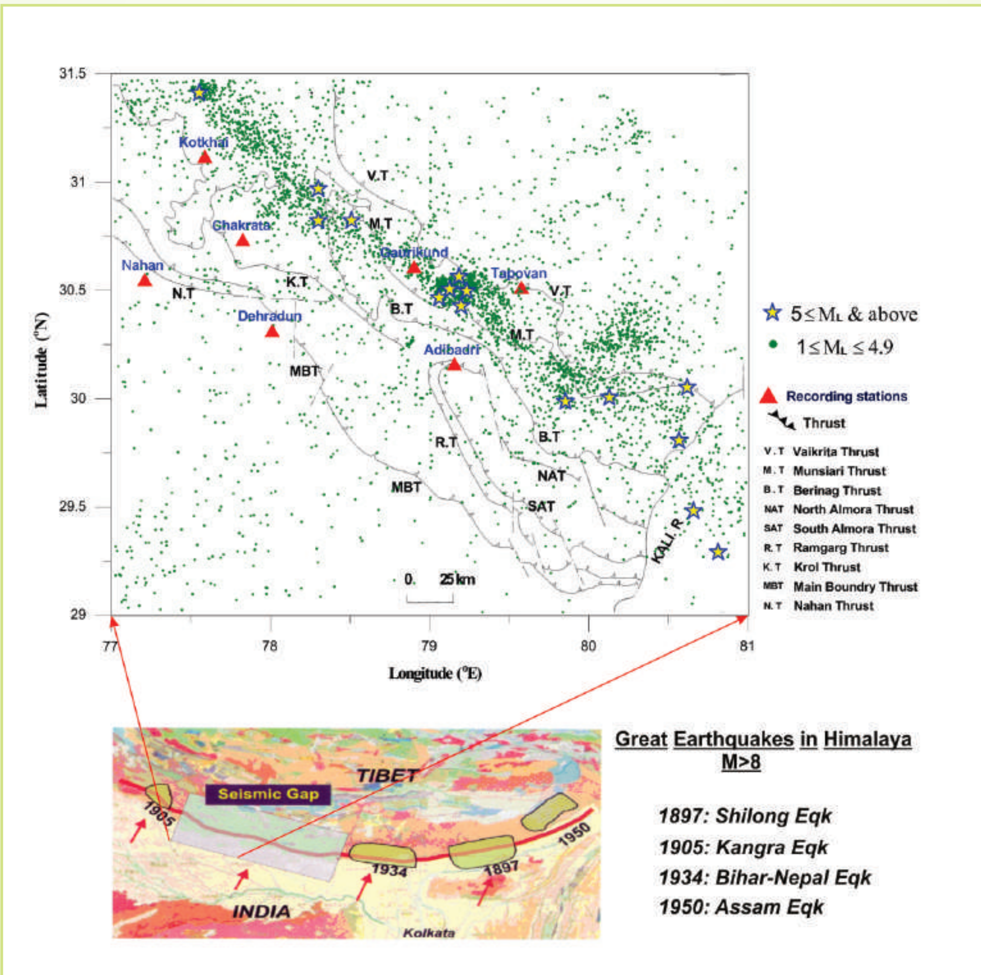

Fig. 79 : Seismicity of the study region occurred 2007 to 2020 plotted over the simplified tectonic map. The seismological stations are shown by red triangles.

Gangetic plain. Here, the horizontal-to-vertical spectral ratio method has been used for evaluating the site response functions. The site response functions have been evaluated at different frequencies related to various types of structures. The estimated mean site response function value at the principal frequency (predominant) is found to be 6.2 for Higher Himalaya, 6.5 for Lesser Himalaya, 7.03 for Sub-Himalaya, and 9.6 for the stations located in the Indo-Gangetic plain. Further, the estimated site response functions and the station's broad geology have been correlated with each other. With the help of estimated site response functions at various frequencies corresponding to various story structures, the seismic hazard in the central seismic gap area has been evaluated. The calculated site response functions are further useful for different studies like for simulation in strong ground motions and evaluating the earthquake source parameters

Implications of study of seismicity and landslides in the Garhwal Kumaun region

In the epicentral location map of the Garhwal-Kumaun region, three clusters are visible, Cluster-1 is located in the western part of the study area and its aerial coverage is ~3179 km^2. It covers the 1991 Uttarkashi earthquake rupture zone and the area to the west of it. The spatial distribution of earthquakes in this cluster is scattered; they are mainly located between the Beringag Thrust and the Munsiyari Thrust. The landslides in this cluster are also scattered and mainly located along the drainage. With earthquake and landslide counts of 145 and 300 respectively, this zone exhibits earthquake and landslide density of ~24% and 36% respectively. The 1991 Uttarkashi earthquake generated 183 landslides immediately after the earthquake and 360 landslides during the succeeding rainy season of 1992.

Cluster-2 is located in the central part of the study area and its aerial coverage is ~2291 km^2. It covers the 1999 Chamoli earthquake rupture zone and the area to the west of it. This is the most pronounced of all three clusters. It includes the highest number (328 earthquakes) of seismic events located between the Munsiyari Thrust and the Vaikrita Thrust. The majority of the earthquakes in this cluster are of magnitude <3.1 (Fig. 79). With earthquake and landslide counts of 328 and 313 respectively, this cluster exhibits earthquake and landslide density of ~75% and 53% respectively

Cluster-3 is located in the eastern part of the study area near Munsiyari and its aerial coverage is ~4220 km^2. This cluster is scattered in the Uttarakhand Himalaya, though all the earthquakes of magnitude >2.1 are clustered oblique to the strike of the Himalaya between the Munsiari Thrust and the Vaikrita Thrust, and further north in the Tibetan plateau.

The landslides and earthquakes distributions indicate higher seismic activity and high landslide density in the Chamoli region (Zone II)

MoES Sponsored Project

Tectono-thermal evolution of the Karakorum migmatites along Shyok and Tangtse Valleys, India: Implications on the tectonics of Karakorum region

(*H. K.Sachan and Aditya Kharya*)

During the reporting period, samples of migmatites were collected from the Tangtse and Shyok valley to study their mineralogy and geochemical aspects. A detailed mineral and, fluid inclusion petrography of the Tangtse region was carried out. Based on textural relationships the equilibrium assemblage of the Tangse region is interpreted as plagioclase-amphibole (pargasite)-biotite-quartz-titanite-diopside-melt. Amphibole-bearing leucosomes in Tangtse area typically have the assemblage Kfs + Pl + Qtz + Amp + Ttn + Cpx + Ap ± Bt ± Ms ± Zrn ± Mnz, with hypidiomorphic magmatic textures preserved. The leucosomes comprised euhedral to subhedral poikilitic amphibole grains (0.1–0.5 mm in length) and biotite, which are aligned along with the regional tectonic fabric. Amphibole grains have biotite, plagioclase, K-feldspar, and quartz inclusions. The amphibole grains display irregular zoning or retain green–brown cores and green rims that have plagioclase inclusions. Small, commonly anhedral, clinopyroxene grains occur with euhedral plagioclase and quartz.

K-feldspar, and quartz are anhedral to subhedral. K-feldspar is large irregular grains with shapes that vary from slightly embayed to highly irregular corroded boundaries. Plagioclase forms large irregular, commonly twinned grains that range from 0.3 to 0.8 mm in length and display both embayed and straight crystal boundaries. Embayments in plagioclase grains commonly contain quartz. Plagioclase grains contain inclusions of quartz and biotite and display myrmekite textural intergrowth with quartz and K-feldspar.

Biotite occurs as tiny crystals replacing amphibole and feldspar and also appears as a medium- to coarse-grained flakes distributed in quartz-feldspar-amphibole matrices. Quartz occurs as large irregular grains displaying wavy undulatory extinction. Furthermore, quartz grains have straight, indented boundaries and inclusions of plagioclase and amphibole.

Electron microprobe analyses of the various minerals (amphibole, biotite, and feldspar) from the Karakorum migmatites of Tangse region suggest that biotite is dominantly annite with Mg/(Mg + Fe) values ranging between 0.42 and 0.61 apfu. Amphiboles are calcic with CaO values ranging from 10.5 to 12.4 wt%, are consistent with pargasite compositions according to the IMA 2012 classification provided by Hawthorne et al. (2012), and cation for amphiboles are calculated using the excel program provided by Locock (2014). Plagioclase varies between oligoclase and andesine in composition from $Or_{1.0}Ab_{82.5}An_{16.5}$ to $Or_{3.6}Ab_{67.8}An_{28.6}$, and alkali feldspar ranges in composition from $Or_{98.0}Ab_{1.9}An_{0.1}$ to $Or_{87.7}Ab_{12.3}An_{0.0}$. The presence of the amphiboles in the tangse migmatite advocate the water fluxed melting in the studied section.

The fluid inclusions were classified into primary and secondary as observed in quartz grains of the studied samples. Primary inclusions are present in clusters as well as solitary inclusions. These inclusions exhibit negative crystal shapes and oblong and ovoid shapes and are typically monophase at room temperature (ca. 25 °C). Secondary fluid inclusions occur in the form of transgranular trails that are trapped in healed microcracks. These secondary fluid inclusions are monophase and display ovoidal and rectangular shapes. Some primary fluid inclusions show extensive re-equilibration features as they exhibit plentiful deformation textures such as necking, hook, stretching, and annular shapes. Additionally, minute satellite inclusions surround the larger inclusions.

The primary (monophase) fluid inclusions display eutectic temperature (Te) between − 56.9 and − 56.6 °C, which indicates that the fluid involved throughout the migmatitzation is pure carbonic. These primary CO2 inclusions were homogenized into the liquid phase within the range between − 17 and − 31 °C, while most primary inclusions were homogenized between − 23 and − 29 °C. The secondary fluid inclusions also show eutectic temperatures (Te) between − 56.8 to − 56.6 °C, indicating pure CO2 composition. The secondary CO2 inclusions were homogenized into the liquid phase between – 1 and − 11 °C, whereas most of the secondary inclusions homogenized between − 7 and − 11 °C.

A preliminary mineral and fluid inclusion petrography of Shyok valley migmatites were also carried out. Electron microprobe analyses of selected Shyok samples were carried out. The preliminary fluid inclusion study indicates the presence of monophase primary and secondary inclusions in the Shyok region.

SERB Sponsored Project

Fluid-P-T evolution of ultramafic-mafic rocks from Spongtang ophiolite, Ladakh, India: Implications for geodynamics of Himalayan mountain chain

(H.K. Sachan and Aditya Kharya)

Various Mafic and ultramafic rock samples were collected from the ophiolites of the Spongtang region of Ladakh Himalaya to study their mineralogy and geochemical aspects. Preliminary mineral petrography, Fluid inclusion petrography were carried out. Samples were powdered for the whole rock and elemental geochemistry. Samples were prepared for mineral chemistry (EPMA), and Mineral REEs.

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)

After the second phase of fieldwork in Dibang valley from February to March of 2021, the collected samples (40) have been processed for Fission track analysis and are now ready to dispatch Apatite Mounts of 20 samples and Zircon mounts of 18 samples for thermal irradiation at FRMII, Germany. For the AMS study in Lohit Batholith, we are now preparing cubes from 20 samples. 8 Migmatite Samples of Lohit valley and Dibang valley have been prepared for Geochronological analysis by Heavy mineral separation(Apatite and Zircon) and Mounting and Polishing of desired grain and sent to Delhi where SIMS facility has for the precision of dating. Eight ZHe and two AHe ages across the major tectonic boundaries of the Lohit Valley, Eastern Himalaya have been obtained. The ZHe ages are mainly obtained from the frontal LHS and northeastern most litho-unit of Eastern Lohit Plutonic Complex range from 6.94±1.17 to 12.51±2.84 Ma while AHe ages could only be obtained from the hanging wall of the WT from the eastern LPC due to absence of euhedral apatite mineral grains in the Lesser Himalayan Sequence (LHS) rocks. The AHe ages vary between 1.73±0.15 and 3.56±0.42 Ma. The thermal history was assessed by applying QTQt thermal-modeling software and obtained the exhumation rates using 1D AGE2EDOT thermal model. Analysis of additional 9 samples for AHe and 5 samples from ZHe have been completed at the University of Michigan Thermochronology Lab for (U-Th)/He Analysis.

UCOST sponsored project

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

(*Chhavi Pandey*)

The purpose of this study is to investigate the human risk of exposure to black carbon (BC) air pollutants in a diverse range of microenvironments located all along the foothills of the Indian Himalaya. The present study provides an overview of a pilot assessment of people's exposure to BC in a variety of outdoor settings along the foothills of the Himalayas in different locations in the cities namely, Haridwar and Dehradun in Uttarakhand. Throughout the course of these investigations, both mobile and fixed observations were carried out. A portable AE51 Aethalometer was utilized for the random sampling of equivalent black carbon (eBC) concentration in the above-mentioned locations. Multiple roads in the city center of the above cities that are normally crowded with heavy traffic have been surveyed using mobile recording equipment. During random mobile measurements at various sites, the maximum and minimum mean eBC concentrations were found 49.94 μgm^{-3} and 5.93 μgm^{-3} respectively. For five static locations, the maximum and minimum mean eBC concentrations are 32.99 μgm^{-3} and 8.05 μgm^{-3} respectively. The preliminary findings regarding the eBC levels in various places are graphically presented in figure 80.

SERB Sponsor project

Three Dimensional Attenuation tomography from strong ground motion data for Garhwal region, India

(*Parveen Kumar*)

Spatial variations of attenuation characteristics have been explored for the Garhwal and Kumaon regions. It is revealed that the Kumaon region has a low value of *P*-wave quality factor (Qα) and *S*-wave quality factor (Qβ) as compared to Garhwal, which means the Kumaon region has a high rate of attenuation than the Garhwal region. Hence, it is suggested that the Garhwal region has a high seismic hazard potential zone as compared to its adjacent Kumaon region. The site effects from the

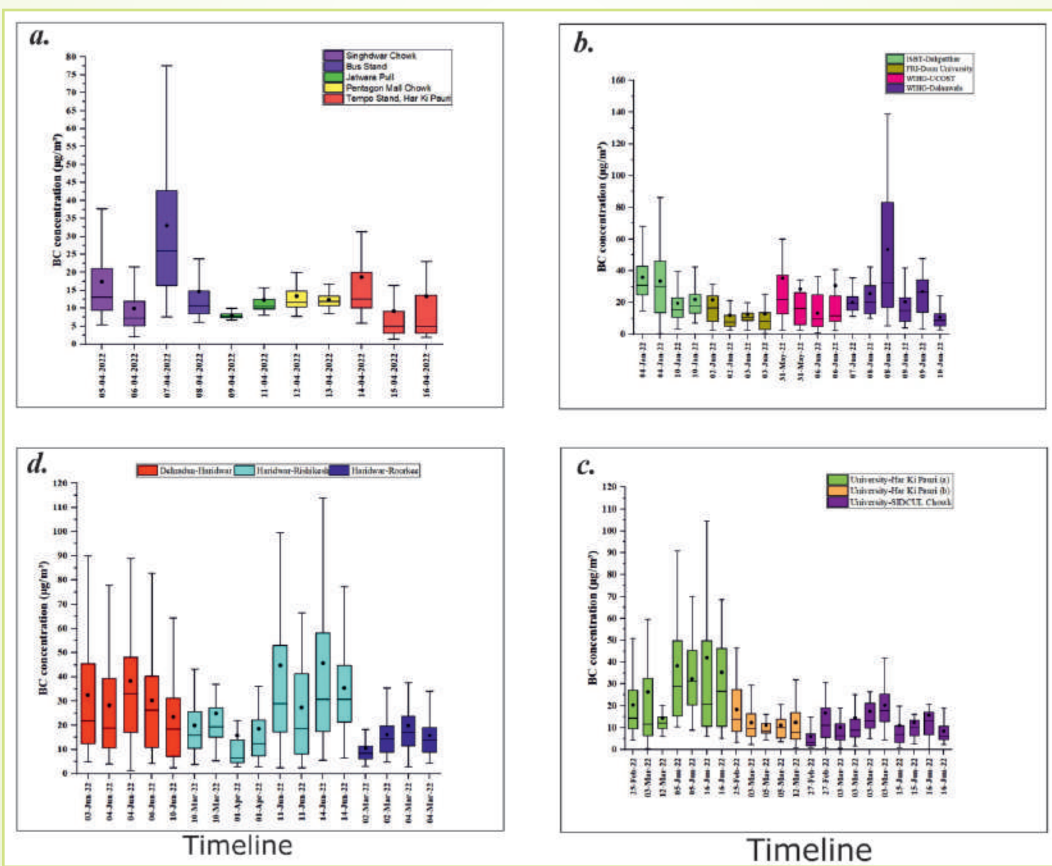

Fig. 80 : Random observation of BC at different microenvironments along Himalayan foothills.

inversion of strong motion data have been computed for the Garhwal region. It is suggested that site effects obtained at each station are almost similar. This similarity is due to the presence of hard rocks at these stations. These hard rocks are responsible for an almost flat site effect at each station. A three-dimensional attenuation structure has been obtained after incorporation of obtained site effect, and this model is interpreted in terms of the identification of potential seismic hazard zone in the study region. It is proposed that in the study area, the region lying toward the northern side of the MCT (higher Himalaya) provides a high value of the quality factor, which makes this region a high seismic hazard potential zone as compared to the southern side of the MCT (Lesser Himalaya). The three-dimensional attenuation model proposed a low-quality factor zone along the MCT from the depth of 15 to 30 km, which may correspond to the presence of fluids or partial melts at this depth along the MCT. The present work provides important inputs in terms of attenuation and site effect, which prove to be very useful for the preparation of a seismic hazard map of the region, and the simulation of strong motion data. The present results can also be used for earthquake source characterization study. The project tenure has been completed in May 2021.

SERB Sponsored Project

Structure and seismic anisotropy pattern around the Kumaon-Garhwal region-A seismological study

(Narendra Kumar)

Teleseismic earthquake data recorded by 8 broadband digital seismic stations deployed in the Kumaun-Garhwal and adjoining areas of NW Himalaya were analyzed to investigate the seismic anisotropy in the upper mantle. Shear-wave splitting parameters (fast polarization direction, ϕ, and delay time, ∂t) derived from the analysis of core-refracted SKS/SKKS phases provide first-hand information about seismic anisotropy and deformation in the upper mantle beneath the region. A total of 209 measurements of shear-wave splitting parameters have been obtained from the two years of collected high-quality teleseismic data. The analysis shows considerable strength of anisotropy (∂t 0.6-2.8 s) with average ENE-WSW-oriented fast polarization orientation at most of the stations while other one either along with the absolute plate motion (APM) of the Indian plate or parallel to strike of the Himalayan mountain belt. The Fast axis direction observed at stations close to between the MBT and MCT aligns parallel to the strike of local geological faults and orthogonal to absolute plate motion (APM) direction of the Indian plate. The large variation in the splitting strength and fast polarization trends around the Kumaun-Gharwal and adjacent in NW Himalaya have invoked both lithospheric and asthenospheric anisotropy. The crust, intra-crustal low-velocity layer (LVL), and upper mantle discontinuities at 410 and 660 km beneath the Kumaun-Garhwal Himalaya were also studied. The modeling result suggests that the crust-mantle boundary varies from 42 to 54 km. The LVL, delineated with a high Poisson's ratio beneath all stations suggests the presence of the fluid in the upper crust. This causes shallow seismic activity in this region. The early conversion time at 410 discontinuity estimated from the stacked receiver function and 2D migrated image with reference to the standard time of the IASP91 velocity model indicates the thick transition zone, maybe due to the effect of low temperature or the presence of water content. The cold MTZ around the Kumuan-Garhwal region suggests that the geodynamics of the asthenosphere has been modified, reflecting large velocity anomalies, indicating cool undertrusted Indian plate has reached up to the upper mantle transition zone.

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109. Yadav, R.R., Negi, P.S. & Singh, J. 2021: Climate change and plant biodiversity in Himalaya, India. Proceedings of the Indian National Science Academy, 87(2), 234-259.

110. Zaccarini, F., Garuti, G., Luvizotto, G.L., de Melo Portella, Y. & Singh, A.K. 2021: Testing Trace-Element Distribution and the Zr-Based Thermometry of Accessory Rutile from Chromitite. Minerals, 11(7), 661, (https://doi.org/10.3390/min11070661).

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111. Jayangondaperumal, R., Malik, J.N., Thakur, V.C., Rao, P.S., Baghel, P., Pandey, A. Singh, I., Sahoo, S. & Gadhavi, M.S. 2022: Paleoseismology along the Foothill Zone of Central Himalaya, Uttarakhand, India, Pre-Congress Field Trip 25-29 FEB 2020, 36 International Geological Congress (IGC), 1-60 pp.

Book Chapter

112. Meena, N.K., Gaury, P.K. & Mahajan, A.K. 2021: The Climatic and Anthropogenic Influences on Himalayan Glacial and Non-Glacial Lakes. In Quaternary Climate Change over the Indian Subcontinent, CRC press, 21-41 (https://doi.org/10.1201/9781003083238).

SEMINARS/SYMPOSIA/WORKSHOP/TRAINING COURSE ORGANIZED

5th National Geo-Research Scholars Meet (NGRSM) (July 22-23, 2021)

The Wadia Institute of Himalayan Geology (WIHG), Dehradun has successfully organized 5th National Geo-research Scholars Meet (NGRSM) through webinar during 22-23 July 2021. The NGRSM started in 2016 as a regular annual event of WIHG with a view to encourage young researchers and students for improving their research interests, providing them a platform to share their research work, receive feedback from the peers and refine their ideas. The event also provides them an opportunity to interact with eminent geoscientists and understand the latest trends in Geoscientific research. Like the previous year, this year also the 5th NGRSM was organized. The theme of this 5th NGRSM webinar is "Earth Sciences for Sustainable development", which covered presentations of established researchers on the topics such as; Natural Resources, Water Management, earthquakes, Monsoon, Climate change, Natural disasters, River systems, etc. The two days webinar included 18 invited talks from distinguished eminent speakers and 14 research scholars from all around the nation. The enthusiasm and deliberations of budding researchers were excellent. More than 350 participants joined this event from different Universities/Institutes/ Organizations in India and their queries during the talks showed the interactive sessions of this meeting. This event started with the welcome address by Dr. Kalachand Sain, Director, WIHG. Prof. Ashutosh Sharma, Former Secretary DST, chief guest, and patron of this event delivered his inaugural address. In his address, he emphasized the need of earth sciences in groundwater, glaciers, other water resources, climate change and its solution, science and technology, and mitigation of natural hazards. Prof. Sandeep Verma, Secretary SERB in his address as the guest of honour of this event elaborated on the opportunities for researchers. Prof. Ashok Sahni, Chairman of Governing Body of WIHG,

Some moments during the 5th National Geo-Research Scholars Meet (NGRSM) addressed the webinar. He motivated young scholars and blessed the listeners for the success of this meeting. Prof. Shailesh Nayak, Chairman of RAC WIHG also addressed the participants, wherein he spoke on various advanced techniques, which can be used for the sustainable development of society. Dr. Parveen Kumar and Dr. Pankaj Chauhan were the convenor of the webinar.

42nd Annual Convention, Seminar and Exhibition on Exploration Geophysics

(December 1-3, 2021)

The Wadia Institute of Himalayan Geology (WIHG), Dehradun,and Association of Exploration Geophysicists (AEG) have successfully organized the "*42nd Annual Convention, Seminar and Exhibition on Exploration Geophysics*" during December 01-03, 2021 through virtual mode at WIHG, Dehradun. The convention had a special theme on "*Himalayan Geology and Exploration Geophysics*" with reference to *Natural Hazards, Minerals, and Hydrocarbon Exploration*. The main goal of the convention is to strengthen geoscientific awareness in the country through effective coordination of research and investigation in the exploration geophysics and allied disciplines.The convention was started on December 01, 2021, with welcome addresses by Dr. A. K. Chaturvedi (Secretary, AEG) and Dr. V. M. Tiwari (President, AEG & Director NGRI, Hyderabad). One day workshop was conducted on the first day on the topic "*Artificial Intelligence for Advanced Interpretation of 3D Seismic Data*" coordinated by Dr. Kalachand Sain and Dr. Priyadarshi Chinmoy Kumar in the morning session. In the afternoon session, Geodata Processing & Interpretation Centre (GEOPIC), Oil and Natural Gas Corporation (ONGC), Dehradun conducted a workshop on "*New Frontiers in Hydrocarbon Exploration*". The inaugural program of the Seminar was held on 2nd December 2021 with the Dr. Hari Narain Memorial Lecture delivered by Prof. Shailesh Nayak, Director NIAS, Former Secretary, Ministry of Earth Sciences (MoES). Dr. Nayak delivered the lecture on the topic "*Goals for Geoscience Research in Coming Decades*". The AEG-Sriram Srinivasan Award was conferred to Dr. Deepak Kumar Sinha, Director, Atomic Minerals Directorate (AMD) Department of Atomic Energy, Govt. of India. The AEG Best Thesis Award was conferred to Dr. P.C. Kumar, Scientist, WIHG, Dehradun for his Ph.D. thesis entitled "*A novel approach for enhanced interpretation of 3D seismic data using meta-attributes: examples from Taranaki Basin, off New Zealand*". The theme of the Seminar on December 02, 2021, was (i) Seismicity-tectonic linkages in the Himalaya and precursory studies and (ii) Novel approaches for Mineral Exploration and Orebody Modeling. There were total 7 invited talks from distinguished scientists and professors like Dr. C.P. Rajendran (India), Prof. Jean-Philippe Avouac (USA), Prof. György Hetényi (Switzerland), Prof. Shashidharan

Address by Dr. Kalachand Sain, Director, WIHG & Chairman

(GSI, India), Prof. Mark Jesell (UWA). The second day of the seminar on December 03, 2021, was based on the themes (i) Geo-Hazards and extreme Hydrological events and (ii) Hydrocarbon and Other Energy Resources exploration towards self-reliant India. Dr. Rasik Ravindra (Former Director, National Center for Antarctic and Ocean Research (NCAOR), Goa), Prof. T.N. Singh (Director, IIT, Patna), Prof. Matt J. Westoby (UK), Rajesh Kumar Srivastava (ONGC), Dr. Neeraj Mathur (OIL, Duliajan), and Rajesh Katyal (NIWE, Chennai) delivered invited distinguished lectures. About 200 researchers from different Institutions and Universities participated in the webinar. Dr. Devajit Hazarika and Dr. Pradeep Srivastava conducted the conference with the necessary support and guidance of Dr. Kalachand Sain (Director, WIHG & Chairman).

AEG-Sriram Srinivasan award to Dr. Deepak Kumar Sinha

AEG Best Thesis Award to Dr. P.C. Kumar

AWARDS AND HONOURS

- Dr. Kalachand Sain was awarded J.C. Bose National Fellow in 2021.
- Dr. Kalachand Sain was awarded National Award for Excellence in Geosciences by the Ministry of Earth Sciences (MoES), New Delhi.
- Dr. P.C. Kumar and Dr. Kalachand Sain received the “Best Paper Award” by WIHG, Dehradun.
- Dr. P.C. Kumar was awarded Associateship of the Indian Academy of Sciences, Bangalore in 2021.
- Dr. P.C. Kumar received NASI-Young Scientist Platinum Jubilee Award in 2021.
- Dr. P.C. Kumar received the “Best Doctoral Thesis Award”, by the Association of Exploration Geophysics (AEG).
- WIHG team was awarded the “Best Stall Award” in the research field at “Rise in Uttar Pradesh 2021”, a Mega Exhibition, held during December 16-18, 2021 at Ghaziabad, UP.
- Dr. Anil Kumar was conferred the Dr. J. G. Negi Young Scientist Award 2021 by Indian Geophysical Union (IGU).
- Dr. Sameer Tiwari received N. N. Chatterjee Award-2021 by the Geological Society of India.

Ph.D. THESES

Sl. No	Name of Student	Supervisor	Title of the Thesis	University	Awarded / Submitted
1.	Amrita Dutt	Dr. A.K.Singh Prof. Rajesh K Srivastava	Geochemical and Isotopic studies of the Tethyan Ophiolitic Sequences in the Eastern Himalaya	B.H.U. Varanasi	Awarded July 2021
2.	Shailendra Pundir	Dr. Vikas Adlakha Prof. Santosh Kumar	Magmatism, Deformation and Exhumation History of the southern Asian Plate Margin of Karakoram, India	Kumaun University, Nainital	Awarded August 2021
3.	Arjun Pandey	Dr. R.J. Perumal Prof. H.B. Srivastava	Active tectonics and pattern of strain release along the north-eastern Himalayan Frontal Thrust between Saralbhanga and Subhansiri valleys	B.H.U. Varanasi	Awarded June 2021
4.	N. Lakhan Singh	Dr. A.K. Singh Prof. B.P. Singh	Geochemical and geochronological studies of magmatic rocks of the Khardung-Shyok valley, western Himalaya, India	B.H.U. Varanasi	Awarded September 2021
5.	Rowtu Ramu	Dr. Kalachand Sain	Detection and Quantification of gas Hydrates in Krishna-Godavari basin from seismic data”	Osmania University, Hyderabad	Awarded October 2021
6.	Harsh Gupta	Dr. Gagan Ananad Dr. Santosh K. Rai	Study of rheological and tribological properties of metal oxide nanoparticles blended lubricating oil	University of Petroleum and Energy Studies, Dehradun	Awarded, November 2021
7.	Somak Hajra	Dr. Devajit Hazarika Dr. Sanjit Kumar Pal	Structure of the crust and upper mantle beneath the Kumaon Himalaya	IIT (ISM), Dhanbad	Awarded November 2021
8.	Naveen Kumar	Dr. A.K. Singh Dr. Naresh Kumar	Petrology and geochemistry of acid magmatic rocks of Riwasa and Nigana Area, District Bhiwani (Haryana), India	Kurukshetra University, Kurukshetra	Awarded December 2021
9.	Dhamodharan S.	Dr. Gautam Rawat Dr. D.S. Bagri	Imaging Geoeleoctrical Structure along the Satluj Valley, North Western Himalaya, India using Magnetotelluric method	HNB Garhwal University, Srinagar, Uttarakhand	Awarded March 2022
10.	Subham Choudhary	Dr. Koushik Sen Prof. Santosh Kumar	Assessing Oxidation State, Carbon Cycle and Magmatic History of Mantle Rocks from Sung Valley Complex, Meghalaya, NE India	Kumaun University, Nainital	Awarded May 2021

11.	Anju K. Joshi	Dr. Kalachand Sain	Delineation and quantification of gas hydrates in Krishna-Godavari Basin using well log and seismic data	Osmania University, Hyderabad	Awarded February 2022
12.	Satyabrata Das	Dr. Santosh K. Rai Prof. Sushanta Sarangi	Geochemical and Isotopic studies of water and sediments of Teesta River Basin, lower Brahmaputra system: Implication for chemical and physical erosion	I.I.T. (I.S.M.) Dhanbad	Awarded March 2022
13.	K. Premi	Dr. A.K. Singh Prof. A.K. Sen	Petrogenesis of mantle rocks and chromitite in southern Manipur ophiolite complex, NE India	Indian Institute of Technology, Roorkee	Submitted January 2022
14.	Ms. Richa Kumari	Dr. Naresh Kumar Dr. Parveen Kumar Dr. Sandeep	Investigation of Various crustal parameters of Kinnaur Himalaya using seismological data	B.H.U., Varanasi	Submitted February 2022
15.	Ms. Shantajhara Biswal	Dr Kapesa Lokho Prof. Kuldeep Prakash	Biostratigraphy, depositional history and paleogeography of the Sylhet Limestone Formation, southeastern Mikir Hills, Northeast India	B.H.U., Varanasi	Submitted March 2022
16.	Ishwar Singh	Dr. R.J. Perumal	Active Tectonic investigations between the Dibang and Lohit river valleys, NE Himalaya, Arunachal Pradesh	B.H.U. Varanasi	Submitted March 2022

PARTICIPATIONS IN SEMINAR / SYMPOSIA / MEETINGS / TRAINING

- Workshop on "*A Primer on Biodiversity and Ecology of Freshwater Ecosystems of the Western Ghats*" organized by Pune Knowledge Cluster (PKC) and Agharkar Research Institute (ARI), Pune during April 15-30, 2021.

  Participant: Sudipta Sarkar

- Industrial training on "*Artificial Intelligence and IoT*" organized by the Institute for Design Of Electrical Measuring Instruments (IDEMI), Ministry of Micro, Small and Medium Enterprises, Govt. of India (MSME) from April 19 to May 11, 2021 (virtual mode).

  Participant: Pankaj Chauhan

- Industrial training on "*Artificial Intelligence*" organized by the Centre for Development of Advanced Computing (C-DAC), Ministry of Electronics and Information technology, Govt. of India during June 15-30, 2021.

  Participant: Pankaj Chauhan

- Workshop on "*The excavation at Vadnagar: scientific investigations and new dimensions in the history of western India vis-a-vis the sub-continent*" during July 6-7, 2021 (Virtual mode).

  Participant: Anil Kumar

- *5th National Geo-Research Scholars Meet (NGRSM)* held at Wadia Institute of Himalayan Geology, Dehradun on July 22-23, 2021 (virtual mode).

  Participants: All scientists & research scholars of WIHG, Dehradun

- Refresher Course on "*Ground Geophysics and Geophysical Logging for Mineral Exploration*" conducted by Training Institute, Geological Survey of India, Hyderabad from August 30 to September 04, 2021.

  Participant: M. Rajanikant Singh

- 42nd Annual Convention, Seminar, and Exhibition on Exploration Geophysics organized by Wadia Institute of Himalayan Geology, Dehradun, and Association of exploration Geophysicists (AEG) during December 1-3, 2021 (virtual mode).

  Participants: Naresh Kumar, Jairam Singh Yadav, Priyadarshi Chinmoy Kumar, Sameer K Tiwari, A.K. Singh, Paramjeet Singh, Pankaj Chauhan, Chinmay Haldar and Swapnamita Choudhury

- Training course on "*Litho and bio facies analysis of Marine Succession in NW Himalaya*" organized by Geological Survey of India, Lucknow during December 13-17, 2021.

  Participants:Prakasam M. and Kapesa Lokho

- The 1st Indian Quaternary Congress (IQC)-2022, organized by the Association of Quaternary researchers (AoQR) in BSIP, Lucknow, Uttar Pradesh, during January 19-21, 2022 (virtual mode).

  Participants: Anil Kumar and Pinkey Bisht

- 58th Annual Convention of Indian Geophysical Union (IGU) on "*Recent Advances in Earth Sciences with Special Emphasis - Natural Hazards*" jointly organized by Indian Geophysical Union and North-Eastern Hill University, Shillong during February 2-4, 2022 (virtual mode).

  Participants: Sushil Kumar, Ajay Paul, Dilip Kumar Yadav, Anil Kumar, Narendra Kumar, Praveen Kumar and Chinmay Haldar

- Geoscience Standing committee meeting at Indian Space Research Organisation (ISRO), Bangalore on February 15, 2022.

  Participant: R.J. Perumal

- National Green Tribunal (NGT) meeting on "*Impact of Mining in the neighbouring regions*" conducted by Kerala Pollution Control Board (KPCB) on March 14, 2022.

  Participant: R.J. Perumal

- 36thInternational Geological Congress (IGC) hosted by the Ministry of Mines (MoM), Ministry of Earth Sciences (MoES), Government of India, and the Indian National Sciences Academy (INSA) during March 20-22, 2022 (virtual mode).

  Participants: Rajesh S., Prakasam M., Kapesa Lokho

DISTINGUISHED LECTURES DELIVERED IN THE INSTITUTE

Sl. No.	Name of Speaker	Event	Date
1	Dr. O.P. Mishra Director, National Center for Seismology, MoES, New Delhi	National Technology Day Lecture "Seismological Research: Advanced tool for inclusive growth and sustainable development"	May 11, 2021
2	Prof. Arun Deep Ahluwalia Ex. HOD, Department of Geology, Panjab University, Chandigarh	World Environmental Day "Earth and Environmental Sciences Outreach for sustainable Nation Building"	June 5, 2021
3	Dr. Shekhar C. Mande Secretary, DSIR and Director General, Council of Scientific & Industrial Research, New Delhi	Prof. S. P. Nautiyal Memorial Lecture	June 17, 2021
4	Hon'ble Dr. V. K. Saraswat Member NITI Aayog, GoI and Chancellor Jawaharlal Nehru University, New Delhi	Foundation Day Lecture	June 29, 2021
5	Prof. Somnath Dasgupta INSA Senior Scientist, Indian Statistical Institute & Honorary Professor, IISER, Kolkata	J. B. Auden Memorial Lecture "The Higher Himalayan Crystallines, Sikkim, Eastern Himalaya: A collage of tectonic blocks-Insight from P-T-t modelling"	September 08, 2021
6	Shri Vishal Shastri Executive Director- Head of GEOPIC, ONGC, Dehradun	Founder's Day Lecture "Energy Scenario & Indian Hydrocarbon Sector"	October 23, 2021
7	Prof. Ashutosh Sharma Institute Chair Professor, Dept. of Chemical Engineering, IIT Kanpur, and Former Secretary to the GoI, Dept. of Science and Technology, New Delhi	W. D. West Memorial Lecture "Science, Technology, and Innovation in the New Millennium"	November 29, 2021
8	Mr. Shrikant N. Chitnis Executive Director – HoI KDMIPE- ONGC, Dehradun	New Year Talk "Hydrocarbon Exploration Gamut: Advances and Challenges"	January 07, 2022
9	Prof. Vinod K. Gaur Former Secretary, Dept. of Ocean Development (MoES)	National Science Day "Engaging with the Grandest Geodynamic Phenomenon on Earth - Vignettes from a Personal Odyssey"	February 28, 2022

DISTINGUISHED LECTURE SERIES RELATED TO CELEBRATIONS OF “AZADI KA AMRIT MAHOTSAV”

Azadi ka Amrut Mahotsav is an initiative of the Government of India to celebrate and commemorate 75 years of progressive India and the glorious history of its people, culture, and achievement. In connection with the "*Azadi ka Amrit Mahotsav*", WIHG, Dehradun organized Distinguished Lecture Series by Eminent Scientists and Renowned Professors. During the reporting period, 28 distinguished lectures were organized (coordinated by Dr. Devajit Hazarika).

Sl. No.	Name of Speaker	Topic of the lecture	Date
1	Prof. J. Srinivasan Distinguished Scientist, Divecha Centre for Climate Change, Indian Institute of Science	Understanding the variation of the Indian monsoon during the past 22,000 years	May 27, 2021
2	Prof. J. R. Kayal Former Deputy Director General (Geophys), Geological Survey of India, Kolkata	Recent Large Earthquakes in NE India: Source zones and active faults	June 02, 2021
3	Prof. Walter D. Mooney U.S. Geological Survey Menlo Park, CA 94025-3591	The Seismicity and Tectonics of the Ocean-Continent Collision, Andaman Islands to Indonesia	June 07, 2021
4	Dr Ingo Andreas Pecher School of Environment University of Auckland	Dynamic gas hydrate systems: Possible implications for seafloor stability and carbon cycling	June 11, 2021
5	Prof. Simon Klemperer Department of Geophysics, Stanford University	Continental subduction re-imagined: Mapping the mantle suture beneath Tibet using regional $^{3}He/^{4}He$ analysis of geothermal springs	June 16, 2021
6	Prof. Jyotiranjan S. Ray Director, National Centre for Earth Science Studies Thiruvananthapuram, India	Quaternary Volcanism in India: the story of Andaman volcanoes"	June 18, 2021
7	Prof. Peter Molnar University of Colorado, USA	Topic: “Growth of the Tibetan Plateau and hypotheses for the underlying mantle dynamics"	July 05, 2021
8	Dr G. Parthasarathy National Institute of Advanced Studies Indian Institute of Science, Bengaluru	Researches on Critical Minerals in Sustainable development and Make in India Success	July 07, 2021
9	Prof. A.K. Jain CSIR-Central Building Research Institute, Roorkee, Uttarakhand	Remobilized Precambrian terranes in the Himalaya	July 09, 2021

10	Dr Abhijit Mukherjee Department of Geology and Geophysics, Indian Institute of Technology Kharagpur , India	Groundwater of future India	July 13, 2021
11	Prof. Ramaswamiah Srinivasan Divecha Centre for Climate Change Indian Institute of Science,Bengaluru, India	Archaean Crust of the Dharwar Craton - nature of the basal of an eroded mountain belt	July 29, 2021
12	Prof. Timothy A. Minshull School of Ocean and Earth Science, University of Southampton, European Way , Southampton UK	Continental Extension Leading to Breakup: 3D perspectives	August 02, 2021
13	Prof. Christopher C. Gilbert Department of Anthropology , City University of New York, New York	New Insights into Primate Evolution and Biogeography from the Indian Siwaliks	August 11, 2021
14	Prof. T.R.K. Chetty CSIR-National Geophysical Research Institute Hyderabad, India	Proterozoic Orogens of India: Special focus on the Southern Granulite Terrane	August 18, 2021,
15	Prof. Xiujuan Wang Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese Academy of Sciences Qingdao, P.R.China	Geophysical evidence on the occurrence and distribution of gas hydrate in the northern slope of South China Sea	August 23, 2021
16	Dr. Rajiv Nigam CSIR-National Institute of Oceanography Goa, India	Role of Geology/Paleontology in Marine Archaeology: Examples from Lothal and Dholavira	August 27, 2021
17	Prof. Mrinal K. Sen Department of Geological Sciences Jackson School of Geosciences The University of Texus at Austin, United States	Geophysical Inverse problems and uncertainty quantification	September 06, 2021
18	Prof. Kusala Rajendran Center for Earth Science, Indian Institute of Sciences, Bengaluru, India	Revisiting historical earthquakes in the Himalaya aided by modern-day examples	September 15, 2021
19	Dr. Hemant Kumar Dixit Business Manager, GeoSoftware Far East, CGG Services India Pvt Ltd, Mumbai, India	Advances in Quantitative Seismic Reservoir Characterization	September 20, 2021
20	Dr. Dhananjay Kumar Geophysicist at BP, Houston, Texas, United States	Frequency-dependent seismic AVO modeling and analysis	October 11, 2021
21	Prof. Rasik Ravindra Former Director, National Center for Antarctic and Ocean Research (NCAOR), Goa, India	Impacts of vanishing ice from the Arctic (Ocean) on the world environment	October12 , 2021

22	Prof. Nigel C. Hughes Dept. of Earth and Planetary Sciences University of California, USA	Ups and downs in the Himalaya: applying data from fossils to reconstruct the assembly of the core of Asia	October18, 2021
23	Prof. Igor Maria Villa University of Milano – Bicocca, Milan, Italy	Past and Future: a roadmap for Himalayan Geochronology	January 10, 2022
24	Prof. Talat Ahmad Vice-Chancellor of University of Kashmir, Hazaratbal, Srinagar, Jammu and Kashmir	Geochemical and isotopic characterization of the Tso Morari eclogites:constraints on their genesis & protolith charecteristics	February 25, 2022
25	Prof. Rodolfo Carosi Dipartimento di Scienze della Terra, Università di Torino, Italy	Fault, shear zones and tectonic-metamorphic discontinuities in the metamorphic core of the Himalaya	March 02, 2022
26	Dr. Rajender Kumar Chadha Raja Ramanna Fellow, CSIR-National Geophysical Research Institute (NGRI), Hyderabad, India	Earthquake ground motion: Concerns for critical structures like Nuclear Power plants and Dams in India	March 24, 2022
27	Dr. Priyank Jaiswal College of Arts and Sciences, Boone Pickens School of Geology, Oklahoma State University, OK	How Imaging changes structural stories. A case study of Naga Thrust, Assam, India	March 28, 2022
28	Dr. Prantik Mandal CSIR-National Geophysical Research Institute (NGRI), Hyderabad, India	Passive source seismic Imaging of the Uttarakhand Himalaya	March 31, 2022

LECTURES DELIVERED/ INVITED TALKS BY INSTITUTE SCIENTISTS

Name of the Institute Scientists	Program Organizer/Venue/ Institute	Date	Topic/ Title of lecture
Pinkey Bisht	Virtual Seminar Series of the Stratigraphy and Chronology Commission (SACCOM) of INQUA on Advances in Stratigraphy and Geochronology	May 06, 2021	Chronology and climatic implications of the late Quaternary glaciation in Central Himalaya with special focus in the Upper Kali Ganga valley, Uttarakhand
Akshaya Verma	Dolphin (P.G) Institute of Biomedical and Natural Sciences, Dehradun (Virtual mode) at World Environment Day	June 05, 2021	Rainwater harvesting and rejuvenation of Himalayan Springs
Devajit Hazarika	National Institute of Technology (NIT), Agartala (Virtual mode)	June 07, 2021	Basic Computational techniques in seismology
Devajit Hazarika	National Institute of Technology (NIT), Agartala (Virtual mode)	June 08, 2021	Analysis of seismograms in SEISAN software
Amit Kumar	1st Basic Mountaineering Course organized by the Indo Tibetan Border Police Academy, Mussoorie	June 10, 2021	Elementary knowledge of glacier, snow and avalanche
Santosh K. Rai	Hindi workshop at Wadia Institute of Himalayan Geology, Dehradun	June 21, 2021	हिमालय में प्राकृतिक कार्बन डाई ऑक्साइड का उत्सर्जन एवं अवशोषण
Anil Kumar	Workshop on "The excavation at Vadnagar: scientific investigations and new dimensions in the history of western India vis-a-vis the sub-continent" organized by Archaeological Survey of India at Vadodara, Gujarat (virtual mode)	July 07, 2021	Luminescence dating and its application in Archaeology: Case study from Vadnagar excavation site
Chhavi Pandey	National Conference on "Advances in Theoretical Physics, Material and Atmospheric Sciences" VSKC Govt. PG College, Vikasnagar, Dehradun, Uttarakhand	July 16, 2021	Short-Lived Climate Pollutants and our Environment
Prakasam M.	Vel Tech Deemed to be university, Chennai.	August 17, 2021	Climate – Past, Present and Future

Vikram Gupta	Graphic Era Hill University, Dehradun.	August 21, 2021	Career Opportunity in Geosciences.
Naresh Kumar	Webinar on "Earthquake Precursor Study and Earthquake Early Warning System" organized by National Disaster Management Authority (NDMA) and National Center for Seismology (NCS) New Delhi	September 01, 2021	Multi-Parametric Geophysical Observatory, Ghuttu, Garhwwal Himalaya for Earthquake precursory research
Vikram Gupta	Himalayan Diwas organized by Wadia Institute of Himalayan Geology, Dehradun	September 09, 2021	Landslide Hazards in the Himalaya
Naresh Kumar	37th General Assembly of the European Seismological Commission held in Corfu, Greece (virtual workshop).	September 19, 2021	(i) Redefining the rupture geometry of Mw 7.8 Kangra 1905 earthquake based on shear wave velocity structure and recent seismicity (ii) Decadal continuous geophysical data observations at MPGO Ghuttu in the Garhwal Himalaya
Barun Mukharjee	Central Geological Programming Board Committee-X/ 17th /Meeting (Virtual Mode), Geological Society of India	October 01, 2021	Mineral Ore Genesis
M.R. Singh	"Azadi ka Amrit Mahotsav" celebration atModern Higher Secondary School, Dehradun	October 14, 2021	Geology and future prospects in India
Chhavi Pandey	Workshop on "Modern research Areas in Physics", Dept. of Physics, Manipal Institute of Technology, Manipal, Karnataka, India (virtual mode)	November 16, 2021	Effect of Himalaya on India's Climate: with special reference to BC Air Pollutants
Vikram Gupta	Army on Infrastructure Development, Cantonment, Dehradun	November 25, 2021	Landslide and Development in the Central Sector of Himalaya
M.R. Singh	"Azadi ka Amrit Mahotsav"celebration at Innovative Academy Bishnupur	November 29, 2021	Geology and future prospects in India
Chhavi Pandey	ID Refresher Course on "Environmental Protection & Disaster Management" organized by UGC- Human Resource Development Centre, Gauhati University, Guwahati	December 01, 2021	Black Carbon Air Pollutants and Climate Change

Naresh Kumar	42nd Annual Convection and Seminar on Exploration Geophysics organized by WIHG, Dehradun and Association of Exploration Geophysicists Hyderabad, India held during 1-3 December 2021 (virtual workshop)	December 02, 2021	Status of earthquake precursory study in India with special reference to Multi-Parametric Geophysical observation
Naresh Kumar	Workshop on "India-Russia Scientific webinar on Disaster Management Technologies" (virtual mode)	December 02, 2021	Earthquake Precursory Research through MPGO
Kalachand Sain	42nd Annual Convection and Seminar on Exploration Geophysics organized by WIHG, Dehradun and Association of Exploration Geophysicists Hyderabad, India. during 1-3 December 2021 (virtual workshop)	December 03, 2021	Geohazards in the Himalaya and their mitigation
Jairam Singh Yadav	42nd Annual Convection and Seminar on Exploration Geophysics organized by WIHG, Dehradun and Association of Exploration Geophysicists Hyderabad, India. during 1-3 December 2021 (virtual workshop)	December 03, 2021	Quantifying surface melt Dynamics for debris-covered Dokriari Glacier Central Himalayas
Sameer K Tiwari	42nd Annual Convection and Seminar on Exploration Geophysics organized by WIHG, Dehradun and Association of Exploration Geophysicists Hyderabad, India. during 1-3 December 2021 (virtual workshop)	December 03, 2021	Geothermal Energy of Himalaya: Trends and potential role of green energy for a sustainable future
M.R. Singh	DM College of Science, Imphal at "Azadi ka Amrit Mahotsav" celebration	December 06, 2021	Advanced Petrology and Geochemistry
Swapnamita Choudhury	Integrated Water Resources Man agement (IWRM) in Uttarakhand State, NIH, Roorkee	December 07, 2021	Integrated Water Resources Management – Understanding Himalayan Geology and Groundwater
Swapnamita Choudhury	ID Refresher Course on Environmental Protection & Disaster Management, held by UGC-Human Resource Development Centre, Gauhati University, Guwahati	December 10, 2021	Revisiting earthquakes in Northeast India, with new insights on past climate and their impacts on pre-historical and historical civilizations
Ajay Paul	Rajkiya Uch Madhyamik Vidyalaya, Pakhi, Garurganga (Chamoli).	December 12, 2021	Earthquake science and preparedness
Swapnamita Choudhury	BFIT Group of Institutes, Sudhowala, Dehradun	December 13, 2021	Himalayan Earthquakes and what we can learn from the past

Devajit Hazarika	3rd International Workshop on "Advanced Seismology, Seismic Hazards & Earthquake Engineering: Theory, Simulation & Observations" held at the Techno College of Engineering Agartala during December 13 -17, 2021(virtual workshop).	December 15, 2021	Earthquake location and Moment Tensor Solution for source mechanism study
Kapesa Lokho	e-Training on "Litho and bio facies analysis of marine succession in NW Himalaya" organized by the RTD., GSI, Northern Region Lucknow. (Virtual mode) during December 13-17, 2021	December 16, 2021	Mesozoic and Cenozoic biostratigraphy of India
M.R. Singh	Mangolnganbi college Ningthoukhong, Manipur at "Azadi ka Amrit Mahotsav" celebration	December 17, 2021	Identification of rocks and minerals
Vikram Gupta	Seminar on Secure Himalaya and safe Himalaya, Shimla (Himachal Pradesh)	December 18, 2021	Landslides in the present day climate change scenario.
Rajesh S.	Govt. Primary School, Sastrinagar, Dehradun at "Azadi ka Amrit Mahotsav" celebration	December 28, 2021	English Language and Poems
Rajesh S.	Prof. Hari Dant Sastri memorial Bhavani Balika Inter College, Dehradun	December 28, 2021	Global Positioning System and its use on our day-to-day life
P. K. R. Gautam	Bhawani Girls Inter College, Ballupur, Dehradun at "Azadi ka Amrit Mahotsav" celebration	December 28, 2021	General awareness of natural disasters
Vikram Gupta	Indian Academy of Highway Engineering, Noida	December 30, 2021	Landslide hazards along the Himalayan Highways.
Vinit Kumar	National Disaster Response Forces Academy (NDRFA), Nagpur,	January 06, 2022	Himalayan Geo-environment & Glacial Lake Outburst Flood
Vinit Kumar	Himalayan Institute Hospital Trust, Uttarakhand	January 12, 2022	Application of remote sensing and other techniques for recharge and sustainability of drinking water resources
Anil Kumar	58th Annual Convention of Indian Geophysical Union (IGU) on "Recent Advances in Earth Sciences with Special Emphasis - Natural Hazards" jointly organized by Indian Geophysical Union and North-Eastern Hill University, Shillong	February 02, 2022	Aggradation, incision, and paleohydrology from the Indus River, Ladakh Himalaya

Kapesa Lokho	DST-GATI -sponsored International Webinar on "Emerging Trends in Geosciences and its Social Impact" organized by the Department of Earth & Atmospheric Sciences, National Institute of Technology Rourkela Odisha, India (Virtual mode).	February 02, 2022	Geology of the Indo-Myanmar Ranges and its social impact
Vikram Gupta	Seminar organized by the HNB Garhwal University, Srinagar on the occasion of one year of the February 2021 Chamoli disaster.	February 07, 2022	Increased incidences of landslides in the Himalaya
Chhavi Pandey	National Science Day, ICFAI University, Dehradun	February 28, 2022	Climate Change and Sustainable Development
Swapnamita Choudhury	International Colloquium of the "Importance, Sacred Landscape and Value -Based Management of the Ahom Moidams of Charaideo in Assam (India)"organized by Directorate of Archaeology, Government of Assam Nazira (Sibsagar), Assam	March 10, 2022	Investigations of the culture, and chronology of the civilizations of the Brahmaputra Valley, Northeast India: a geoarchaeological approach
Santosh K. Rai	Workshop on "Water conservation" at the Tula's Institute Dehradun, conducted by the Uttarakhand Science Education & Research Centre (USERC)	March 22, 2022	Water conservation

MEMBERSHIP

Kalachand Sain	: Member	: Academic Framework Committee, Netaji SCB Univ. of Excellence, Sikkim (2021-2024)
		: High Powered Committees of SERB (DST) (2020-2022)
		: SAC (2020-2023) at GB Pant National Institute of Himalayan Environment, Almora
		: RAC (2020-2023) at Himalaya University, Dehradun
		: NICES-Program Management Council at NRSC (2019-2022), Hyderabad
		: Advisory Committee (2020-2023) for development of Dept. of Earth Sci. at CU, Jammu
	Council Member	: Geological Society of India (2019-2022)
A.K.Singh	: Associate Editor	: Geological Journal (published by Wiley) 2022-2024.
	Associate Editor	: Indian Journal of Geoscience (published by GSI) 2021-2022.
	Lead Guest Editor	: Geological Journal (Special Issue on Geodynamics of Eastern Himalaya and adjoining areas - 2021-2022)
Anil Kumar	: Member	: Association of Quaternary Researchers (AOQR).
	Member	: European Geophysical Union 2022-2023.
Manish Mehta	: Member	: Expert committee National Disaster Management Authority (NDMA), Ministry of Home Affairs, Government of India.
Vinit Kumar	: Member	: Expert committee National Disaster Management Authority (NDMA), Ministry of Home Affairs, Government of India.

PUBLICATION AND DOCUMENTATION

The Publication and Documentation section brought out the (i) 'Himalayan Geology' volumes 42(2) 2021, 43(1A) 2022, and 43(1B) 2022; (ii) Annual Report' of the Institute for the year 2020-21 (bi-lingual); (iii) Hindi magazine 'Ashmika' volume 27 (2021); (iv) Publicity brochures “An Overview of Wadia Institute of Himalayan Geology (bi-lingual) and (v) Flyer “Wadia-Sophisticated Analytical Instrument Facilities (WSAIF) and during the year.

The section was also involved in the dissemination of the publications to individuals, institutions, lifetime subscribers, book agencies, national libraries, indexing agencies, under an exchange program, and maintaining the sale & accounts of publications. Apart from this, works pertaining to the printing of publicity brochures and certificates, 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 of the current volume to the Life Time Subscribers (those who have been given the choice to obtain the volumes in soft copy through online access/email) also has been provided. Out of 491, 165 Life Time Subscribers receive the journal through online access. Journal is indexing in the Thomson Reuters/Clarivate Analytics (US), Elsevier (Netherlands), and Indian Citation Index (India) regularly. The impact factor for 2021 was 1.293 (Source: Clarivate Analytics).

The section also provides the facility and technical support services of printing and scanning to the scientists, research scholars, and other staff of the Institute.

LIBRARY

The Library of Wadia Institute of Himalayan Geology has a special status to its best collection of books, monographs, journals, e-books, etc. on the mountain building process, geological and geophysical phenomena with special reference to the Himalaya. The scientists, researchers, project staff, and students make full utilization of the Library while publishing their research work in reputed peer-reviewed journals. Specialists and professionals across the country also visit our Library to consult thematic and rare collections available at the Library. The Library has more than 4000 selected e-books and about 1300 online journals from different publishers and learned societies on the thrust areas of the research in the Institute.

Acquisition of Documents: The Library has subscription to 60 International, 02 National print Journals and 11 magazines in a year. Total 75 numbers of subject books and 101 Hindi books have been puchased. Binding work of 265 numbers of journal volumes was completed during the year 2021-22.

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's “Earth and Environmental Science and Chemistry” collections. In addition to this, WIHG Library has access to the publications of the American Institute of Physics, American Physical Society,Derwent Innovation Index (with Web of Knowledge), IEEE, NPG: Nature -Main Journal, NPG: Nature Geoscience, Royal Society of Chemistry, Science magazine, Springer Journals, Taylor & Francis, Web of Science, Scopus, Wiley & Blackwell. All these publishers contribute online access to more than four hundred journal titles, apart from our own subscriptions.

***Reprography facility*:** The Library serves as a central facility for the reprography demand of the Institute. This facility is being extended to scientific and administrative sections of the Institute. The facility was also extended on a payment basis to the external users of the Library and a total of 52000 (approx) pages were copied during the year.

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

The Institute library has the following E-resources/Database/software and research tools: 1) Grammarly; 2) Knimbus; 3) iThenticate; 4) ProQuest: Dissertations and Theses; 5) ProQuest: Science and Technology E-books; 6) ProQuest: GeoRef; 7) E-Books; 8) E-Journals; 9) Scopus; and 10) Web of Science.

Institute Library organized a workshop in collaboration with Bridge People Technology Solution, Bangalore in virtual mode. The workshop deals with the improvement of writing skill using Grammarly software. In this workshop, a practical demonstration of Grammarly Software was given. More than 70 participants from WIHG participated and got benefits from this online workshop. The workshop was coordinated by Dr. Balram, WIHG, Dehradun, and Mr. Ratish Iyer from Bridge People Technology Solution, Bangalore.

Prof. S.K. Mehta Vice-Chancellor of University of Ladakh, UT visited WIHG Library

Prof. Ashutosh Sharma, Former Secretary DST, Govt. of India, visited WIHG Library

S.P. NAUTIYAL MUSEUM

The museum is becoming more and more popular every year, and this is reflected by the stream of visitors to the institute. Museum attracts visitors not only from India but also from abroad. To make the educative wing more effective, a new exhibit on continental drift was added.

This year museum observed open days on Founder's Day (October 23, 2021) and National Science Day (February 28, 2022). A large number of students and the general public visited the Museum during these occasions. Guided tours were provided to students and visitors and educative exhibits on Drifting continents, Geological Clock, Structure of Earth, Evolution of Life, Himalaya Glaciers, etc. were shown. One of the major and effective addition was the display of a new exhibit on Continental Drift on the wall of the museum, which depicts the drifting of continents through the ages.

This year museum participated in an outdoor exhibition to celebrate National Science Day during February 22-28 2022 as the glorious week of "Vigyan Sarvatra Pujyate" at Vigyan Dham, Jhajra. During this glorious week, an exhibition was displayed showing the institute's activities and achievements in the form of a stall for the greater benefit of the general public.

In addition, the Museum also organized outdoor exhibitions on various occasions such as:

- Exhibition during December 10-13, 2021 at Panaji, Goa which was organized under the banner of India International Science Festival on the theme 'Celebrating Creativity in Science, Technology and Innovation for Prosperous India'.
- "Rise in Uttar Pradesh 2021" held during December 22-24, 2021 in Ghaziabad, Uttar Pradesh. WIHG stall was awarded the Best Stall in the event.
- Exhibition on the occasion of 'Vasantotsav-2022' was organized in Raj Bhawan during March8-9 2022.

Display on Continental Drift on the wall of the museum

TECHNICAL SERVICES

Analytical Services

The number of samples analyzed by various instruments is listed in the following table:

Laboratory/Instruments	Number of samples analyzed		
	WIHG Users	Outside Users	Total
Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Lab	730	414	1144
Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA- MC-ICP-MS) Lab	Liquid mode: 616 Solid mode: 56 (~3000 U-Pb Ages)	Nil	Liquid mode: 616 Solid mode: 56 (~3000 U-Pb Ages)
Stable Isotope Lab	33	28	61
Luminescence Dating (TL/OSL) Lab	98	23	121
Fission Track Lab	10	22	32
Mineral Separation Lab	45	15	60
Sample Preparation Lab Slide preparation Sample powdering	 590 373	 707 530	 1297 903
X-Ray Fluorescene Spectrometer (XRF) Lab	517	480	997
Scanning Electron Microscope (SEM) Lab	966	128	1094
Laser Micro Raman Spectrometer (LMRS) & Fluid Inclusion Lab	6	10	16
Rock magnetic & Paleomagnetism Lab	80	81	161
Dendrochronology Lab	14 Tree cores	Nil	14 Tree cores
Micropaleontology Lab	250	Nil	250
Laser Particle Size Analyzer (LPSA) Lab	285	0	285
Sedimentology Lab Vibratory Sieve Shaker	 45	 80	 125
Palyonology Lab	20	0	20
Laser Water Isotope Analyzer (LWIA) Lab	600	90	690
Water Chemistry Lab (Ion-Chromatograph)	600	90	690
Total Organic Carbon Lab	400	10	410

Technical Coordination, Planning, Monitoring and Evaluation (TCPME) section

The Technical Coordination, Planning, Monitoring, and Evaluation Group (TCPME), was newly constituted by WIHG to perform the following tasks related to receiving new project proposals, prima facie examination, comments, their submission to the Director, WIHG for consideration, and their onward transmission to funding agencies. The TCPME is involved in scrutinizing the tour programs for scientists and scholars. The section is involved in liaising with different stakeholders for funding including the administrative ministry. TCPME provides scientific inputs to Institue authorities as well as to DST, New Delhi and prepares responses to parliamentary questions as and when required. TCPME is responsible for arranging internal and external reviews of scientists' work for assessment and arranges review of progress for in-house/EMR-funded projects. TCPME also keeps a record of communicated papers and abstracts for publication in journal/book chapters as well as in conferences.

Photography Section

The Photography section of WIHG, Dehradun provides high-Quality images of various functions and activities organized by the institute. These high-quality digital images of important events are useful for the institute's web pages as well as for the preparation of different reports by the institute. During the reporting year 2021-2022, approximately 5000 (150GB) photographs and Videography were taken using a high-resolution DSLR camera to cover the various functions organized in the Institute including Foundation Day, Founders Day, National Science Day, National Technology Day, New Year`s Day, Republic Day, Independence Day, Women's Day, Seminars/Symposia, culture program, and superannuation parties for institute events, Approximately 339 snaps were taken for rocks and fossils in the museum. The majority of scientists have cameras issued permanently to them for use in the field and laboratory, while the remaining scientists form projects 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 thirteen geological maps/structural maps/ geomorphological maps/seismicity diagrams for the scientists and research scholars of the Institute. Besides, the tracing of four topographic sheets/aerial photo maps was carried out along with the preparation of the two 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 laboratory is one of the important labs in the Institute. The main function of this lab is to provide thin/ microprobe/polished sections to the requirements of the Institute Scientists, Research Scholars, and Outside users. During the year 2021-22, the laboratory provided 1297 thin rock wafers and polished sections to various users for carrying out microscopic, fluid inclusion, and Electron Probe Micro Analysis studies. The laboratory also processed crushing/grinding of 903 rock samples for carrying out major, trace, and REE analysis by Inductively Coupled Plasma Mass Spectrometer, X-ray fluorescence, and X-ray Diffraction methods

Computer and Networking Section

WIHG Computer & Networking Section takes care of all the computational requirements of the Institute so as to facilitate the important research work free of any IT-related worries. The role and responsibilities of the Computer Section have increased manifold after the Corona pandemic. The employees of the Computer Section have been working hard to provide uninterrupted IT services to the whole Institute. The pandemic changed the way meeting, seminars, interviews, etc. are conducted, and ever since not only have all the important meetings been conducted online but important Seminars, Conferences, Workshops, and Interviews have also been organized and conducted online successfully. Even the inauguration of the newly built Research Scholars cum Transit Hostel by the Hon'ble Minister was done online.

As a part of celebrating the 75th year of India's Independence, Wadia Institute has been organizing Distinguished Lectures by Eminent Scientists/ Professors around the year. Most of these lectures have been conducted online using MS Teams application and WIHG Computer Section has been instrumental in the successful conducting of these lectures by providing all-around support for the same. Even during the offline events, requisite arrangements as per the requirement were made for the success of the events.

IPv6 is the latest version of IP that was developed to overcome the challenge of a limited pool of IPv4 addresses. In the previous months, conforming to the orders from the Ministry, the IPv6 implementation has been successfully done, and that too in-house.

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. Presentations have been given not only to the Institute employees and research scholars but one of the sessions was dedicated 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 has also been taken. The section has not only maintained a virus and spyware-free environment by adopting centralized anti-virus and anti-spyware solution but has also been adopting the latest preventive security measures in this regard.

Apart from the above, 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 software 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 and the Institute Guest House also and currently the same is being extended to the newly built Research Scholars cum Transit Hostel.
- Provides VPN facility to facilitate the access of Institute resources securely over a 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 software 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 software and solutions.

CELEBRATIONS

National Technology Day

National Technology Day was celebrated in the Institute on May 11, 2021. On this occasion, Dr. O. P. Mishra, Director, National Center for Seismology, MoES, New Delhi delivered the National Technology Day Lecture on the topic “Seismological Research: Advanced tool for inclusive growth and Sustainable Development” in virtual mode.

International Yoga Day

The 7th International Yoga day was celebrated in the Institute on June 21, 2021. About 100 employees and research scholars participated in Yoga during 6-7 AM under the directives and guidance of Yoga Instructors. All COVID-19 protocols were maintained during Yoga.

Foundation Day

The Foundation Day of the Institute was celebrated on June 29, 2021. On this occasion, Hon'ble Dr. V. K. Saraswat, member of NITI Aayog, GoI, and Chancellor Jawaharlal Nehru University delivered the Foundation Day Lecture in hybrid mode.The occasion was also marked by the distribution of several awards. Prof. R. C. Misra awards for the year 2021 were awarded jointly to Dr. Rajeev Kumar Yadav of CSIR-NGRI, Hyderabad, and Dr. Irfan Maqbool Bhat of CSIR-RA, the University of Kashmir for their outstanding contribution in the field of Geosciences. The best research paper award was given to Dr. Kalachand Sain, Director, WIHG, and Dr. Priyadarshi Chinmoy Kumar for the research paper entitled “A machine learning tool for interpretation of Mass Transport Deposits from Seismic data” published in “Scientific Reports”. The best worker awards were given to Shri Rahul Sharma (Assistant Finance& Accounts Officer) and Shri C.B. Sharma (Executive Engineer) for their good work done by them during the year.

Independence Day

The Institute celebrated Independence Day on August 15, 2021. Flag hoisting was followed by a formal address by Dr. Kalachand Sain, Director of the Institute. As a mark of Independence Day Celebrations, various programs were organized such as tree plantation, drawing competition, and games for the Institute's employees and their children. Prizes were distributed to the winners of various events.

Founder's Day

The Institute celebrated October 23, 2021, as 'Founder's Day' in the honour of the Birth Anniversary of Prof. D. N. Wadia. In remembrance of the day, a 'Founder's Day Lecture' was organized which was delivered by Mr. Vishal Shastri, Executive Director-Head of GEOPIC, ONGC on the topic “Energy Scenario and Indian Hydrocarbon Sector”

Vigilance Week

The vigilance awareness week was observed fromOctober 26, 2021, to November 01, 2021. The following programs were organized during this week:

- The observance of the Vigilance Awareness Week

Moments of the Foundation Day celebration with Hon'ble Dr. V. K. Saraswat, member NITI Aayog, GoI in hybrid mode

Flag Hoisting and address by the Director, WIHG as a part of the Independence Day Celebration

Mr. Vishal Shastri, Executive Director-Head of GEOPIC, ONGC, Dehradun during Founder's Day

commenced with the integrity pledge on October 26, 2021, at 11:00 hr at WIHG Auditorium. All the employees and other staff assembled in the auditorium and took the pledge.

- A lecture series was organized on October 27, 2021, in the WIHG auditorium. Five lectures were given in the auditorium by Dr. Santosh Rai, Dr. N.K. Meena, Dr. Gautam Rawat, Mr. Tajender Ahuja and Mr. Yashpal Bisht. A slogan Competition and a Quiz competition were organized on the same day.
- A team from WIHG (Dr. Ajay Paul, Dr. Narendra Meena, Dr. Praveen Kumar, and Sh. Vipin Chauhan Sh. Jawahar Singh Chauhan, Sh.Suresh Rawat, Sh. Devi Chauhan, Smt. Mimo Devi, Smt. Ritu Dhanola, Sh. Balbahadur Thapa, Sh Athiya Ram) visited a village (Gram sabha: Haripur) for a vigilance awareness campaign on October 28, 2021. Nearly seventy villagers attended the vigilance awareness campaign.
- A team from WIHG visited Kendriya Vidyalaya, ITBP, Dehradun on October 30, 2021, for

Mr. Vishal Shastri, Executive Director-Head of GEOPIC, ONGC during his visit to WIHG Museum

delivering a vigilance day lecture to the students and teachers

- Shri R.C.Verma, Chief General Manager, Head Vigilance ONGC delivered a lecture at WIHG on November 01, 2021, on the theme “Independent India @75: Self Reliance with Integrity”.
- Awareness carried out through websites, posters, and social media

Lecture series at Institute

Slogan Competition at Institute

Visit to Gram Sabha Haripur

Invited Lecture by, Head Vigilance, ONGC, Dehradun

Posters in the Institute Premises

Poster inside the Institute Building

Pledge and Vigilance awareness lecture at Kendriya Vidyalaya, ITBP, Dehradun

Republic Day

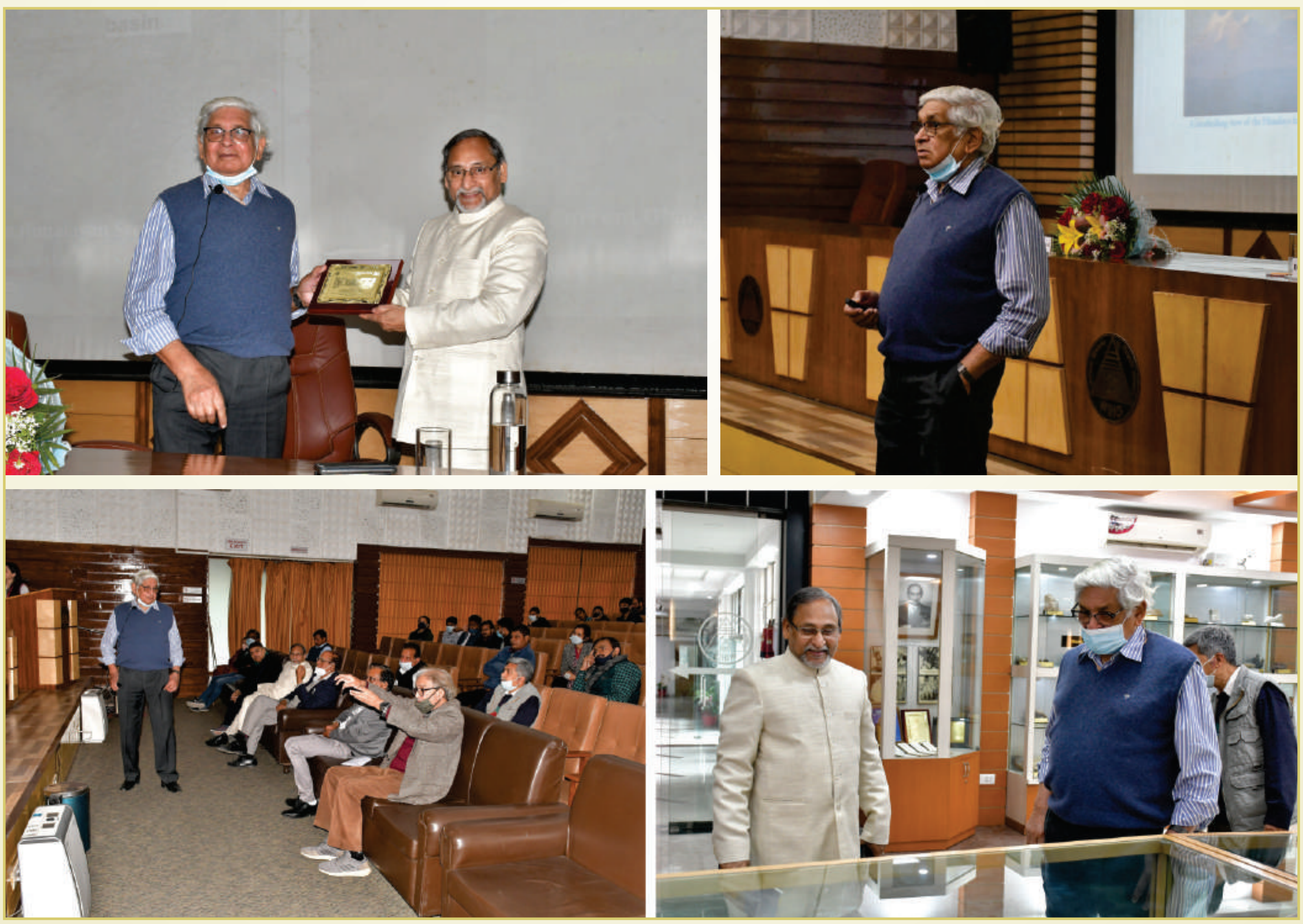
Due to the outbreak of COVID-19, Republic Day was celebrated considering all COVID-19 protocols. Dr. Kalachand Sain, Director WIHG hoisted the National flag on Republic Day, January 01, 2022.

National Science Day

The institute observed February 28, 2022, as 'National Science Day'. Prof. Vinod K. Gaur, Former Secretary, Dept. of Ocean Development (MoES) delivered the 'National Science Day Lecture' on "Engaging with the Grandest Geodynamic Phenomenon on Earth - Vignettes from a Personal Odyssey"

The Institute also observed 'Open Day' on February 28, 2022, wherein laboratories were kept open to students and to the public. A large number of students from schools and colleges, and other public from Dehradun visited the laboratories. Scientists as well as the technical staff and research scholars explained the functioning of the various scientific instruments and their uses to the visitors. The museum was kept open for the visitors, in which various exhibits related to Himalayan glaciers, earthquakes, landslides, the origin of Life, volcanoes, rocks, minerals, fossils, etc., were explained to the visitors.

Republic Day Celebration



Prof. Vinod .K. Gaur delivered National Science Day Lecture

Outreach program

Under the outreach program entitled "भूकंप के लिए तैयारी करने और खतरे की कमी के लिए शिक्षा और जागरूकता कार्यक्रम" ("Education and awareness program for earthquake preparedness and hazard mitigation") WIHG, scientists organized awareness programs for students and common people from different village regarding earthquake disaster and its mitigation.

Outreach programs were organized during 2021-2022 at various schools and villages and nearly 1600 people were benefited from this program. The scientists visited different schools and villages e.g. (i) Kendriya Vidyalaya, ITBP Dehradun, (ii) Village- Haripur, Kalsi, Dehradun, (iii) Jawahar Navodya Vidyalaya, Shankarpur, (iv) Rajkiya Uch Madhyamik Vidyalaya, Pakhi, Chamoli, (v) Rajkiya Kanya Uch madhyamik, Saraswati Shishu Mandir, Saraswati Vidhya Mandir,

Earthquake preparedness talk at Rajkiya Uch madhyamik vidyalaya, Pakhi, Chamoli

Interaction with the villagers at Haripur, Kalsi, Dehradun

Students performing earthquake mockdrill at GIC Gaonla (Uttarkashi)

Students from six school collected at GIC gaonla

Director WIHG, delivering lecture at GIC gaonla

Dr. Ajay Paul Delivering a lecture at GIC geonla

Rajkiya Uch Prathmik, Rajkiya Prathmik, Suman gram Vidyalaya, Living stone, Gyandeep children academy schools, Brahm Khal, Uttarkashi, (vi) Village- Harshil, (vii) Mahindra Sr. Sec. School Karnal, Haryanato educate school children, villagers, and the general public about earthquake disasters and hazard mitigation. Various interactions have been made through online mode at different schools e.g. JNV Sahaspur; SGRR Public school, Dehradun; Central School of Tibetan, Herbrtpur, Dehradun; Ek Lavaya Adharsh Vidyalaya, Kalsi; and Allipurdnar college, West Bengal.

International Women's Day

WIHG, Dehradun celebrated International Women's Day on March 08, 2022 at the WIHG auditorium. Ms. Kusum Kandwal, Chairman, Uttarakhand State for Women Commission was the Chief Guest. She is dedicated to work for the Women Empowerment in Uttarakhand State and spoke on the significant role of women in society. While addressing, she cited the examples of women from the UK state namely Gaura Devi, Tilu Rauteli, and Rani Karnavati who contributed immensely not only in inspiring the women folks for socio-cultural development but also for the elevation of the state in many ways. Dr. Kalachand Sain, Director, WIHG, also stated the contribution of women in difficult areas of Earth Sciences that is mainly based on field studies. He also stated the role of women in bringing up and nurturing children at home, educating the value of humanity and gender differences, fulfilling the dream of a family through sacrifices, inculcating disciplines, punctuality, and morality that shape a person in character building and becoming a leader for the nation. Dr. Suman Lata Srivastava (Co-Convenor) gave a brief introduction of the Chief Guest and Dr. Kapesa Lokho (Convenor) proposed the vote of thanks. The program was attended by all the Scientists and employees of the Institute. The women staff and research scholars were felicitated by the Director of the Institute, and the program ended with a simple lunch.

This year, the National Implementation Committee, chaired by the Hon'ble Home Minister, has inter-alia approved the event 'Women's Day" on March 08, 2022, to be celebrated as part of Azadi ka Amrit Mahotsav. The Ministry of Women and Child Development, Government of India had directed all government departments to observe this day as an opportunity to reflect and amplify on issues that come in the way of women's empowerment and hinder the realization of gender equality. WIHG, Dehradun, held a Panel

Moments of International Women's Day celebration

CELEBRATIONS

Discussion, presided by Director, WIHG, on “Women's Challenges and Achievements in Earth Sciences”, on March 07, 2022, aiming to highlight women's achievements in Earth Sciences, over-coming challenges in personal and professional spheres, and suggestions for future to eliminate gender-based discrimination and violence for bringing about a perceptible change and positive shift towards greater empowerment of women in the field of Earth Sciences. The program for the first time had a sans-gender panel, with participants of Indian geoscientists and geo-faculties from leading Institutes and corporates from India and abroad. The panelists spoke on the requirements of neutral working space, yet complying with special needs as a woman, especially during field tours. Many panelists mentioned how flexible working time helped in their maintaining a career while taking care of the special needs of children. The issue of gender diversity in the management sphere and the need forthe human resource department to instill proper etiquette around women colleagues in the office was also discussed. WIHG was the first to initiate such a discussion to understand genderequality for a sustainable future and was hailed by all the 20 participants

DISTINGUISHED VISITORS TO THE INSTITUTE

- Dr. Shekhar C. Mande, Secretary, DSIR and Director General, Council of Scientific & Industrial Research, New Delhi
- Shri Trivendra Singh Rawat, Former Chief Minister of Uttarakhand
- Prof. Chin Tsan Wang, Director of S & T Division, Taipei Economic and Cultural Center (TECC), New Delhi
- Ms. Ellie Chiang, Assistant Director of S & T Division, Taipei Economic and Cultural Center (TECC), New Delhi
- His Excellency Mr. Gudni Bragason, Ambassador of Iceland


Dr. Shekhar C. Mande, Dr. Sharmila Mande, and Dr. Anjan Ray during the S.P. Nautiyal Memorial Lecture held on June 17, 2021 at WIHG, Dehradun


Former Chief Minister of Uttarakhand Shri Trivendra Singh Rawat visited WIHG, Dehradun on September 13, 2021


Prof. Chin Tsan Wang, Director, and Ms. Ellie Chiang, Assistant Director of S & T Division, Taipei Economic and Cultural Center (TECC), New Delhi were welcomed by Director WIHG during their visit on October 07, 2021

- Prof. Ashutosh Sharma, Former Secretary to the GoI, Dept. of Science and Technology, New Delhi
- Mr. Shrikant N. Chitnis, Executive Director and HoI- KDMIPE, ONGC, Dehradun
- His Excellency Mr. Hans Jacob Frydenlund, Ambassador of Norway to India
- Prof. S. K. Mehta Vice-Chancellor of University of Ladakh, UT

His Excellency Mr Gudni Bragason, Ambassador of Iceland was welcomed by Director WIHG during his visit on November 12, 2021

Prof. Ashutosh Sharma, Former Secretary DST, Govt. of India, delivered the W.D. West Memorial Lecture on November 29, 2021

Mr. Shrikant N. Chitnis, Executive Director and HoI- KDMIPE, ONGC, Dehradun delivered a new year talk at WIHG, Dehradun January 07, 2022

His Excellency Mr. Hans Jacob Frydenlund, Ambassador of Norway to India was welcomed by WIHG on March 25, 2022

STATUS OF IMPLEMENTATION OF HINDI

The Institute follows the policy and guidelines of Rajbhasha Vibhag and regularly submits its quarterly and half-yearly progress reports to Rajbhasha Vibhag, Department of Science and Technology. The Institute also submits the half-yearly and annual reports to NARAKAS, Dehradun. Rajbhasha Implementation Committee is monitoring the implementation of Hindi in the institute. Director of the institute chair the committee. The committee monitors and plans for progressive increment in official language use. The committee takes cognizance of the progress in the Hindi implementation through its regularly organized quarterly meetings.

Rajbhasha Implementation Committee regularly organizes quarterly workshops to promote official language use. In these workshops, a Hindi lecture is also organized to popularise and promote the use of Hindi in scientific research.

Under the banner of the Rajbhasha Implementation committee, Institute celebrates Hindi Pakhwara from September 14 to September 28, 2021. Prof. Sulekha Dangwal, Vice-Chancellor of Doon University inaugurated the opening of pakhwara celebrations through lightning the lamp. Her eloquent opening speech about the Indian cultural heritage and education mesmerized the audience.

An invited Lecture by Mr. Vijay Singh 'Pathik', a prominent and famous story writer, was the main attraction of the celebration. Besides the Invited talks, Institute employees also delivered popular talks on various science topics of general interest. Celebration of Hindi Pakhwara observed various competitions like essay writing, photography competition, etc.

In the closing ceremony of the Pakhwara, Mr. Sunil Uniyal Gama, the Mayor of Dehradun was the chief guest of the closing ceremony of the pakhwara. In his remark, he emphasized the role of the mother tongue in the development of human society. The pakhwara celebration was completed after the prize distribution by the chief guest.

This year the 27th issue of the Annual Hindi Magazine "Ashmika" was published. Authors from various organizations and employees of the Institute contributed articles to the magazine. The articles of the magazines are informative and well appreciated by the readers. The attempt is to get more and more popular science articles in Hindi.

Prof. Sulekha Dangwal, Vice-Chancellor of Doon University inaugurated the Hindi Pakhwara from 14 - 28 September 2021 in the Institute

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 senior scientists/officers, is operational in this institute. During the reporting period, a total of nine grievances were received. Five of them were from the applicants for vacancies advertised, two were from ex-contractual employees and the remaining two were of suggestive nature from the general public. Of these six were received through the Prime Minister's Office (PMO), New Delhi, and three through the Department of Science and Technology (DST). The grievances of the applicants against the posts advertised were related to their disqualified application. All the grievances were replied citing advertisements and rules. Two grievances from ex-contractual employees were replied with reference to their project posts. One grievance was regarding the continuation of glaciology studies in the institute and one related to the maintenance of instruments and logbook. Both these suggestions have already been adhered to in the institute

4. Welfare measures

The Institute has various welfare measures for the benefit of its employees. Various advances likeHouse 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 provide 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

To safeguard the women employees and to enquire into the complaints of sexual harassment of women employees at workplaces in theInstitute, a separate Committee has been constituted. The Committee consists of five members;the Chairperson and four other members of the committee with a female officer from the Wild Life Institute of India, Dehradun. No complaint of sexual harassment of women employees at workplaces was received by the Committee during the year 2021-2022.

6. Status of Vigilance Cases

No vigilance cases are pending in the year 2021-2022

7. Information on the RTI cases

The details of information on the RTI cases during the year 2021-22 are as under:

Details	Opening balance as on 01.04.2021	Received during the year 2021-2022	Number of cases transferred to other public authorities	Decisions where requests/appeals were rejected	Decisions where requests/appeals were accepted
1	2	3	4	5	6
Requests for information	0	68	0	0	68
Firstappeals	0	13	0	0	13

8. Sanctioned Staff strength (category wise)

Group/ Category	Scientific	Technical	Administrative	Ancillary	Total
A	63	0	2	0	65
B	0	4	14	0	18
C	0	60	22	35	117
Total	63	64	38	35	200

9. Sanctioned and released budget grant for the year 2021-2022

Plan : 6099.00 Lakhs

Non- Plan : NIL

Total : 6099.00 Lakhs

STAFF OF THE INSTITUTE

Scientific Staff

1.	Dr. Kalachand Sain	Director
2.	Dr. Rajesh Sharma	Scientist 'G' (Retired on 30.06.2021)
3.	Dr. H.K. Sachan	Scientist 'G'
4.	Dr. Sushil Kumar	Scientist 'G' (Retired on 28.02.2022)
5.	Dr. Vikram Gupta	Scientist 'F'
6.	Dr. Pradeep Srivastava	Scientist 'F' (On Lien to IIT Roorkee)
7.	Dr. Ajay Paul	Scientist 'F'
8.	Dr. R. Jayangonda Perumal	Scientist 'F'
9.	Dr. A.K. Singh	Scientist 'F'
10.	Dr. P.S. Negi	Scientist 'E' (Retired on 31.05.2021)
11.	Dr. K.S. Luirei	Scientist 'E'
12.	Dr. Kapesa Lokho	Scientist 'E'
13.	Dr R.K. Sehgal	Scientist 'E'
14.	Dr. Santosh Kumar Rai	Scientist 'E'
15.	Dr. Jayendra Singh	Scientist 'E'
16.	Dr. B.K. Mukherjee	Scientist 'E'
17.	Dr. Naresh Kumar	Scientist 'E'
18.	Dr. Gautam Rawat	Scientist 'E'
19.	Dr. Devajit Hazarika	Scientist 'E'
20.	Dr. Kaushik Sen	Scientist 'E'
21.	Dr. Satyajeet Singh Thakur	Scientist 'E'
22.	Dr. Narendra Kumar Meena	Scientist 'E'
23.	Dr. Param Kirti Rao Gautam	Scientist 'E'
24.	Dr. Dilip Kumar Yadav	Scientist 'D'
25.	Dr. Manish Mehta	Scientist 'D'
26.	Dr. Aparna Shukla	Scientist 'D' (Tech. Resignation w.e.f. 21.08.2021)
27.	Dr. Rajesh S.	Scientist 'D'
28.	Dr. Swapnamita Choudhuri	Scientist 'D'
29.	Dr. Vikas	Scientist 'D'
30.	Dr. Som Dutt	Scientist 'D'
31.	Dr. Anil Kumar	Scientist 'D'
32.	Sh. Saurabh Singhal	Scientist 'D'
33.	Dr. Narendra Kumar	Scientist 'C'
34.	Dr. Parveen Kumar	Scientist 'C'
35.	Dr. Vinit Kumar	Scientist 'C'
36.	Dr. Aditya Kharya	Scientist 'C'
37.	Dr. Suman Lata Srivastava	Scientist 'C'
38.	Dr. Chhavi Pant Pandey	Scientist 'C'
39.	Dr. Paramjeet Singh	Scientist 'C'
40.	Dr. Sameer Kumar Tiwari	Scientist 'C'
41.	Dr Sudipta Sarkar	Scientist 'C'
42.	Dr. Pinkey Bisht	Scientist 'C'
43.	Dr. M. Prakasam	Scientist 'B'
44.	Dr. C. Perumalsamy	Scientist 'B'
45.	Dr. Pratap Chandra Sethy	Scientist 'B'
46.	Dr. Mutum Rajnikanta Singh	Scientist 'B'
47.	Dr. Rouf Ahmad Sah	Scientist 'B'
48.	Dr. Pankaj Chauhan	Scientist 'B'
49.	Dr. Priyadarshi Chinmoy Kumar	Scientist 'B'
50.	Dr. Chinmay Haldar	Scientist 'B'
51.	Dr. Subhojit Saha	Scientist 'B'

Technical Staff

1.	Shri Sanjeev Kumar Dabral	Sr. Technical Officer
2.	Shri Samay Singh	Sr. Technical Officer (Retired on 31.07.2021)
3.	Shri Rakesh Kumar	Sr. Technical Officer
4.	Shri H.C. Pandey	Sr. Technical Officer (Retired on 31.08.2021)
5.	Shri N.K. Juyal	Sr. Technical Officer
6.	Shri C.B. Sharma	Assistant Engineer
7.	Shri T.K. Ahuja	Technical Officer
8.	Shri S.S. Bhandari	Technical Officer
9.	Shri Rambir Kaushik	Technical Officer
10.	Shri Bharat Singh Rana	Technical Officer
11.	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
12.	Dr. Balram	Librarian
13.	Shri Lokeshwar Vashistha	Sr. Lab.Technician (Retired on 31.10.2021)
14.	Dr. S.K. Chabak	Sr. Lab.Technician (Retired on 31.10.2021)
15.	Shri C.P. Dabral	Sr. Lab.Technician (Retired on 30.11.2021)
16.	Shri R.M. Sharma	Sr. Lab.Technician
17.	Mrs. Sarita	Senior Technical Assistant
18.	Shri Rakesh Kumar	Senior Technical Assistant
19.	Mrs. Sakshi Maurya	Senior Technical Assistant
20.	Mrs. Disha Vishnoi	Senior Technical Assistant
21.	Shri Vipin Chauhan	Technical Assistant
22.	Shri Rahul Lodh	Lab Assistant
23.	Shri Nain Das	Lab Assistant
24.	Shri Prateek Negi	Artist cum Modeller
25.	Shri Nand Ram	Electric-cum-Pump-Operator
26.	Shri Tarun Jain	Draftsman
27.	Shri Pankaj Semwal	Draftsman

28.	Shri Santu Das	Section Cutter
29.	Shri Puneet Kumar	Section Cutter
30.	Shri Amit Bhandari	Junior Photographer
31.	Shri Hari Singh Chauhan	Field-cum-Lab-Attendant
32.	Shri Ravi Lal	Field-cum-Lab-Attendant
33.	Shri Preetam Singh	Field-cum-Lab-Attendant
34.	Shri Sanjeev Kumar	Field-cum-Lab-Attendant
35.	Shri Deepak Tiwari	Field-cum-Lab-Attendant
36.	Shri Ajay Kumar Upadhaya	Field-cum-Lab-Attendant
37.	Ms. Sangeeta Bora	Field-cum-Lab-Attendant
38.	Shri Deepak Kumar	Field-cum-Lab-Attendant
39.	Mrs. Anjali	Field-cum-Lab-Attendant
40.	Shri Ajay Kumar	Field-cum-Lab-Attendant
41.	Shri Vipin Kumar Aditya	Field-cum-Lab-Attendant
42.	Shri Ramesh Chandra	Field Attendant (Retired on 30.06.2021)
43.	Shri M.S. Rawat	Field Attendant (Retired on 30.06.2021)
44.	Shri B.B. Panthri	Field Attendant
45.	Shri Narender Manral	Field Attendant
46.	Shri Aakash Sharma	Field Attendant

Administrative Staff

1.	Shri Pankaj Kumar	Registrar
2.	Shri Manas Kumar Biswas	Store & Purchase Officer
3.	Shri Rahul Sharma	Assistant Finance & Accounts Officer
4.	Shri S.K. Srivastava	Office Superintendent
5.	Mrs. Prabha Kharbanda	Accountant
6.	Shri Ankit Rawat	Senior Personal Assistant
7.	Mrs. Rajvinder Kaur Nagpal	Stenographer
8.	Mrs. Shalini Negi	Stenographer
9.	Mrs. Kalpana Chandel	Assistant
10.	Mrs. Anita Chaudhary	Assistant
11.	Shri Shiv Singh Negi	Assistant (Retired on 31.01.2022)
12.	Mrs. Neelam Chabak	Assistant
13.	Mrs. Seema Juyal	Assistant
14.	Shri Yashpal Singh Bisht	Junior Hindi Translator
15.	Mrs. Suman Nanda	Upper Division Clerk
16.	Shri Kulwant Singh Manral	Upper Division Clerk
17.	Shri Vijai Ram Bhatt	Upper Division Clerk
18.	Shri Girish Chander Singh	Upper Division Clerk
19.	Shri Rajeev Yadav	Upper Division Clerk
20.	Shri Amardeep Kumar	Upper Division Clerk
21.	Shri Ajay Singh	Upper Division Clerk
22.	Mrs. Richa Kukreja	Stenographer
23.	Shri Deepak Jakhmola	Lower Division Clerk
24.	Shri Dinesh Kumar Singh	Lower Division Clerk
25.	Mrs. Rachna	Lower Division Clerk
26.	Mrs. Pushpa Barthwal	Lower Division Clerk
27.	Shri Amit Kumar	Lower Division Clerk
28.	Shri Pintu Kumar	Lower Division Clerk
29.	Shri Naved Khan	Lower Division Clerk

Ancillary Staff

1.	Shri Manmohan	Driver
2.	Shri Vikkee Tomar	Driver
3.	Mrs. Kamla Devi	M.T.S. (Retired on 31.03.2022)
4.	Mrs. Deveshawari Rawat	M.T.S.
5.	Shri S.K. Gupta	M.T.S.
6.	Mrs. Omwati	M.T.S.
7.	Shri Jeevan Lal	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.

Contracutal Staff

1.	Shri Dhanveer Singh	Lower Division Clerk
2.	Mrs. Megha Sharma	Lower Division Clerk
3.	Shri Rezaw Uddin Chaudhary	Driver
4.	Shri Rajesh Yadav	Driver
5.	Shri Bhupendra Kumar	Driver
6.	Shri Vijay Singh	Driver
7.	Shri Rudra Chettri	M.T.S.
8.	Shri Laxman Singh Bhandari	M.T.S.
9.	Shri Kalidas	M.T.S.
10.	Shri Ummed Singh	M.T.S.

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

Governing Body
(till November 2021)

Sl.	Name	Address	Status
1.	Prof. Ashok Sahni	Emeritus Professor, Lucknow University, 98, Mahatma Gandhi Marg, Lucknow-226001, UP	Chairman
2.	Secretary to the Government of India or his/her nominee	Dept. of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016	Member
3.	Prof. Talat Ahmad	Vice Chancellor, Jamia Millia Islamia, Jamia Nagar, New Delhi-110025	Member
4.	Dr. V.M. Tiwari	Director, CSIR-NGRI, (Council of Scientific & Industrial Research), Uppal Road, Hyderabad-500007, Telangana	Member
5.	Prof. Harilal B. Menon	Department of Marine Sciences, Goa University, Taleigoa, Plateau Goa-403206, Goa	Member
6.	Prof. G.V.R. Prasad	Department of Geology, Center for Advance Studies, University of Delhi, Delhi-110007	Member
7.	Dr. Rasik Ravindra	Former Director, National Center for Antarctic and Ocean Research (NCAOR), Headland Sada, Vasco-da-Gama-403804, Goa	Member
8.	Prof. Deepak Srivastava	Head, Department of Earth Sciences, Indian Institute of Technology-Roorkee (IITR), Roorkee-247667, UK	Member
9.	Prof. Pramod K. Verma	Department of Applied Geology, Vikram University, University Road, Madhav Bhavan, Ujjain-456010, MP	Member
10.	Prof. S.K. Dubey	Former Director, Indian Institute of Technology-Kharagpur Kharagpur -721302 (WB)	Member
11.	Financial Adviser or his/her nominee	Dept. of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016	Member
12.	Director, WIHG	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary
13.	Sh. Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Non-Member Asstt. Secretary

(w.e.f. December 2021)

Sl.	Name	Address	Status
1.	Prof. Talat Ahmad	Vice Chancellor, University of Kashmir Hazratbal, Srinagar-190006, Jammu & Kashmir	Chairman
2.	Dr. Srivari Chandrasekhar Secretary to the Government of India	Department of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016	Member
3.	Prof. Shakil Ahmad Romshoo	Vice-Chancellor, Islamic University of Science & Technology, 1-University Avenue, Awantipora, Pulwama-192122, Jammu & Kashmir	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-500046, 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 Chatoopadhyay	Department of Geology 34 Chhatru Marg, University of Delhi (North Campus) Delhi-110007	Member
10.	Prof. Saibal Gupta	Professor & Head, Department 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	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Non-Member Asstt. Secretary

Research Advisory Committee
(till February 2022)

Sl.	Name	Address	Status
1.	Dr. Shailesh Nayak	Director, National Institute of Advanced Studies, Indian Institute of Science campus, Bengaluru -560012	Chairman
2.	Prof. Talat Ahmad	Vice Chancellor, University of Kashmir, Hazratbal, Srinagar-190006, Jammu & Kashmir	Member
3.	Prof. D.C. Srivastava	Department of Earth Sciences, Indian Institute of Technology -Roorkee Roorkee-247667, UK	Member
4.	Prof. O.N. Bhargava	(Ex-Director, GSI) 103, Sector-7, Panchkula-134109	Member
5.	Dr. K.J. Ramesh	D.G., IMD Mausam Bhavan, Lodi Road, New Delhi-110003	Member
6.	Dr. P. P. Chakraborty	Professor, Department of Geology, University of Delhi, Delhi-110007	Member
7.	Prof. N.V. Chalapathi Rao	Department of Geology, Banaras Hindu University (BHU) Varanasi -221005, UP	Member
8.	Dr. Thamban Meloth	Scientist 'F', & Group Director (Polar Sciences) National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Govt. of India, Headland Sada, Vasco -da-Gama, Goa-403804, Goa	Member
9.	Dr. O.P. Mishra	Scientist 'F', Ministry of Earth Sciences, Government of India, Prithvi Bhavan, Opp. India Habitat Centre, Lodhi Road, New Delhi- 110003	Member
10.	Dr. Prakash Chauhan	Director, Indian Institute of Remote Sensing, 4, Kalidas Road, Dehradun - 248001	Member
11.	Prof. Biswajit Mishra	Geology and Geophysics Indian Institute of Technology -Kharagpur, Kharagpur, 721302, WB	Member
12.	Prof. Avinash Chandra Pandey	Director Inter-University Accelerator Centre Aruna Asaf Ali Marg, Near Vasant Kunj, New Delhi -110067	Member
13.	Prof. Ajoy Bhowmik	Associate Professor Department of Applied Geology Indian Institute of Technology (Indian School of Mines), Dhanbad-826004, Jharkhand	Member

14.	Dr. Vandana Prasad	Scientist Birbal Sahni Institute of Paleoscience 53, University Road, Lucknow-226007, UP	Member
15.	Dr. Prantik Mandal	Chief Scientist, Co-ordinator & Professor at AcSIR-NGRI, Theoretical & Computational Geophysics Group, CSIR-NGRI, Uppal Road, Hyderabad-500 007, Telangana	Member
16.	Prof. Anil V. Kulkarni	Distinguished Visiting Scientists Divecha Centre for Climate Change, Indian Institute of Science, Bengaluru- 560012, Karnataka	Member
17.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
18.	Dr. Rajesh Sharma	Scientist 'G' Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

(w.e.f. March 2022)

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	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. Vikram Gupta	Scientist 'F', Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

Finance Committee
(till February 2022)

Sl.	Name	Address	Status
1.	Shri B. Anand	Financial Advisor Department of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi- 110016	Chairman
2.	Dr. Rasik Ravindra	608, Lalleshwari Apart Sector 21 D, Faridabad- 121 001	Member

3.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
4.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
5.	Shri Rahul Sharma	Assistant Finance & Accounts Officer Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

(w.e.f. March 2022)

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	Registrar, Wadia Institute of Himalayan Geology, Dehradun-248001	Member
5.	Shri Rahul Sharma	Assistant Finance & Accounts Officer, Wadia Institute of Himalayan Geology, Dehradun-248001	Member

Building Committee
(till February 2022)

Sl.	Name	Address	Status
1.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	
2.	Shri B. Anand or his/her nominee	Financial Advisor Department of Science & Technology Technology Bhavan, New Mehrauli Road, New Delhi – 110016	Member
3.	Dr. H.K. Sachan	Scientist-'G', Wadia Institute of Himalayan Geology, Dehradun 248001	Member
4.	Representative of Survey of India	Hathibarkala, Dehradun	Member

5.	Shri D.K. Tyagi	General Manager (Civil) Infrastructure Development, Oil & Natural Gas Corporation, Dehradun - 248001	Member
6.	Shri Prashant Singh	Executive Engineer, CPWD,20, Subhash Road, Dehradun- 248001	Member
7.	Mrs. Poonam Gupta	Sr. Principal Scientist CSIR-Indian Institute of Petroleum, Haridwar Road, Dehradun- 248005	Member
8.	Sh. Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
9.	Shri C.B. Sharma	Assistant Engineer, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

(w.e.f. March 2022)

Sl.	Name	Address	Status
1.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248 001	
2.	Shri Vishvajit Sahay or his/ her 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.J. Perumal	Scientist-‘F’, Wadia Institute of Himalayan Geology, Dehradun -248 001	
7.	Sh. Rajesh Kumar	Sr. Principal Scientist, Head ASD, CSIR- Indian Institute of Petroleum Haridwar Road, Dehradun-248005	Member
8.	Sh. Pankaj Kumar	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

P.S.SETHI & CO.
CHARTERED ACCOUNTANTS
Dehradun Off:10, Indraprastha Enclave, Simla By Pass, Po Majra, Dehradun (U.K)
Tel.No. 9837562985, 7579912500 Email: rkguptasre@gmail.com, pssethiddn@gmail.com

Tel.No. 9528173229, 9897226991 *Email: rkgupta091@gmail.com, rkguptarke@yahoo.com*

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, 2022 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.

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, 2022;
b) in the case of the Income and Expenditure Account of the deficit 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 P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
FCA, DISA (ICAI), PARTNER
FRN: 004545C
M.NO: 402349
Date: 31st July, 2022
Place: Dehradun

Action Taken Report on observations of the Chartered Accountant- Annexure-1 to the Consolidated Financial Statement of Audit Report (F.Y. 2021-22)

Sl. No.	Comments/Observations by Chartered Accountants	Replies and Action taken by the Institute
1.	The Institute has not booked the current liability for the retirement benefit of the employees as per Accounting Standard-15 "Employee Benefits" as issued by the Institute of Chartered Accountants of India. The actuary valuation is required for ascertaining the current liability for the retirement benefits of the employees.	The points raised by Audit is noted for compliance.
2.	The physical verification of Fixed Assets and Library for the financial year 2021-22 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 2020-21 has already been completed. Action with regard to the physical verification for the year 2021-2022 is in progress and report will be submitted to the audit shortly.
3.	The contribution towards medical scheme for pensioners is accounted for in pension fund account whereas the payment of actual expenditure is met from the institute account. It is recommended that the expenses should be met from the specific fund only.	The matter has already been submitted to DST for seeking of sufficient grant in pension fund account. Finance Committee of the Institute was decided that till a decision is taken by the MoF/DST on this matter, the status-quo be maintained. The payment of medical reimbursement was made only one time during the year 2022-23 from the institute account which will be refunded after receiving the grant in the pension fund account.
4.	Now Institute is maintaining its financial accounting in the software developed in window base system. To maintain the accounts of institute it is suggested that customization is required for integration of whole store inventories and assets with accounts. It helps to computerization of Assets Registers/Stock Register.	All the accounting reports will be generated through the software. Suggestion for integration of Store and Accounts is noted and action will be taken on the subject shortly. The Institute is in process for obtaining ERP solution.
5.	The review of advances revealed that in many cases employees are overstating the amount of advances submitted any field work and also advances not settled at the end of financial year. This has resulted in drawing of advances in excess to the actual requirement resulting in blockage of government funds, which would have otherwise been utilized for other necessary expenditure. Taking into consideration the facts we are of the opinion that employees who are submitting the request in excess to the expenditure may be imposed penal interest or any other action as the institute may deemed fit.	The matter has already been taken up and the penal interest on delay payment is being initiated. The advances which has not been settled by the employees within the prescribed duration, interest is also being charged as per the rule.

P.S. SETHI & CO. Chartered Accountants

6.	Non disposable of unused furniture & scrap & vehicles, we are recommended that scrap may be enumerated unserviceable and be sold through public auction.	The Process for disposal of the scrap items has been initiated. A copy of tender documents is enclosed for your ready reference.
7.	During the audit it has been noticed that e-Assets register is not properly maintained.	Noted for compliance
8.	During the audit it has been noticed that NPS Register is not maintained. Due to non-maintenance of subscriber wise ledger and broadsheet, it may lead to loss of interest to the subscriber.	The register has been open as per the prescribed format.
9.	Actuary report on Provision not made for pension liability, gratuity and leave encashment.	Noted for compliance
	FOR P.S. SETHI & CO **CHARTERED ACCOUNTANTS** P.S. SETHI & CO. **CA RAKESH GUPTA** **(FCA, DISA (ICAI),**	31/8/22 **(Rahul Sharma)** **AF & AO** 13/9/22 **(Pankaj Kumar Verma)** **Registrar** 13/9/22 **(Dr. Kalachand Sain)** **Director**

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31st MARCH 2022)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	86,11,82,286	69,89,61,057
Reserves and Surplus	2	-	-
Earmaked/ Endowment Fund	3	28,20,394	23,48,394
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	2,11,92,389	1,81,07,322
TOTAL		**88,51,95,069**	**71,94,16,773**
ASSETS			
Fixed Assets	8	36,43,16,605	32,64,29,121
Investments from Earmaked/		-	-
Endowment Funds	9	1,04,043	98,532
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	52,07,74,421	39,28,89,120
TOTAL		**88,51,95,069**	**71,94,16,773**
Significant Accounting Policies	37		
Contingent Liabilities and Notes on Accounts	38		

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

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
(F.C.A, DISA (ICAI))

(RAHUL SHARMA)
A F & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 31st July, 2022
Place : Dehradun

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31st MARCH 2022

(Amt in Rs…)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12	-	-
	Grants/ Subsidies	13	48,49,36,400	37,47,26,411
	Fees/Subscription	14	-	1,34,830
	Income from Investments	15	6,83,880	6,63,675
	Income from Royalty, Publication etc.	16	1,23,782	1,04,255
	Interest earned	17	1,14,33,194	1,07,75,008
	Other Income	18	2,69,25,223	63,11,413
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**52,41,02,479**	**39,27,15,592**
B	**EXPENDITURE**			
	Establishment Expenses	20	33,84,23,026	33,05,92,478
	Other Research & Administrative Expenses	21	9,21,93,882	6,36,04,050
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	61,82,397	60,84,662
	Depreciation Account	8	6,08,84,656	5,21,87,173
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	(1,41,188)	(80,222)
	Loss / (Profit) on sale of Assets	A-19	-	-
	TOTAL (B)		**49,75,42,774**	**45,23,88,141**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		2,65,59,706	(5,96,72,549)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	SURPLUS /(DEFICIT) CARRIED TO CAPITAL FUND		**2,65,59,706**	**(5,96,72,549)**

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

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

P. S. SETHI & CO. Chartered Accountants

CA RAKESH GUPTA
(F.C.A. DISA (ICAI))

(RAHUL SHARMA)
A F & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 31st July, 2022
Place: Dehradun

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WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2022)

(Amt in Rs...)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	16,12,86,247	16,96,65,588
Grants - in - Aids	26	63,24,36,400	43,21,73,411
Grants - in - Aids/Other Receipts (Ear Marked	27	4,72,000	12,73,226
Loan & Advances	28	26,83,65,058	26,22,97,046
Loan & Advances (Ear Marked)	31	-	3,60,369
Fees/Subscription	14	-	1,34,830
Income from Investments	15	6,83,880	6,63,675
Income from Royalty, Publication etc.	16	1,23,782	1,04,255
Interest earned	17	1,43,19,875	1,62,91,998
Other Income	18	2,69,25,223	63,11,413
Investment (L/C Margin Money)	34	2,65,55,293	-
		1,13,11,67,758	**88,92,75,811**
PAYMENTS			
Establishment Expenses	20	33,84,23,026	33,05,92,478
Other Administrative Expenses	21	9,06,63,722	6,36,04,050
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	61,82,397	60,84,662
Loans & Advances	29	27,95,39,089	25,29,56,082
Loans & Advances (Ear Marked)	32	5,511	5,63,826
Investment (L/C Margin Money)	35	4,77,544	3,96,23,765
Fixed Assets	36	10,03,66,848	3,44,91,475
Ear Marked Fund Expenses	33	-	73,226
Grant - in - Aid (Ear Marked) Refunded	30	-	-
Closing Balance	25	31,55,09,620	16,12,86,247
		1,13,11,67,758	**88,92,75,811**

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

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
(F.C.A, DISA (ICAI))

(RAHUL SHARMA)
A F & A.O

(PANKAJ KUMAR VERMA)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 31st July, 2022
Place: Dehradun

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2022

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.

P.S. SETHI & CO 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 : 31th July, 2022
Place: Dehradun

P. S. SETHI & CO
CA
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2022

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

P. S. SETHI & CO. 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. 2021 -22 is as follows:

Remuneration to auditors		
i)	As Auditors	55,000/-
	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, 2022, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2022.

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

(Pankaj Kumar Verma)
Registrar

(Dr. Kalachand Sain)
Director

Date : 30th July, 2022
Place: Dehradun

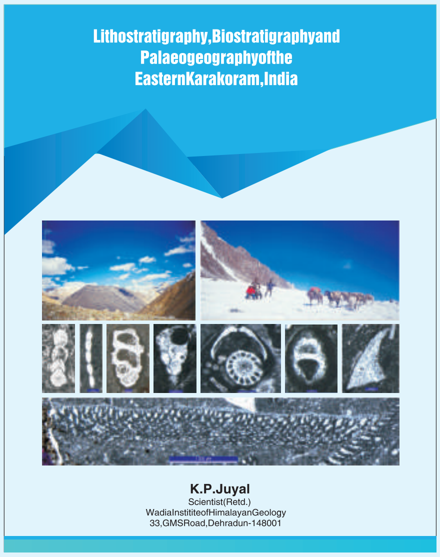
P S SETHI & CO
Chartered Accountants

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

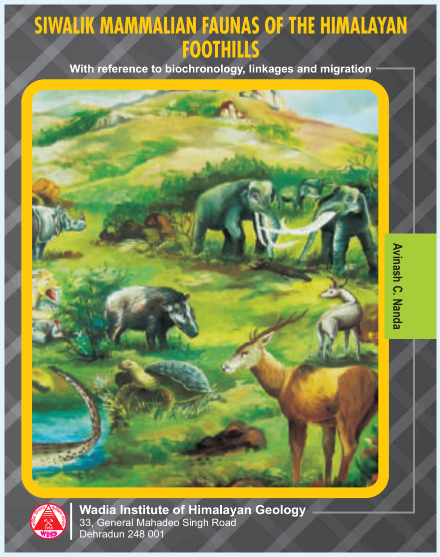
Latest Publications

2018

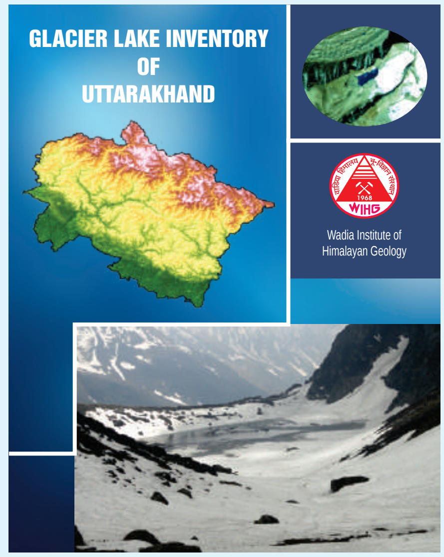


Rs.600/- (India), US$ 50/- (Abroad)

2015

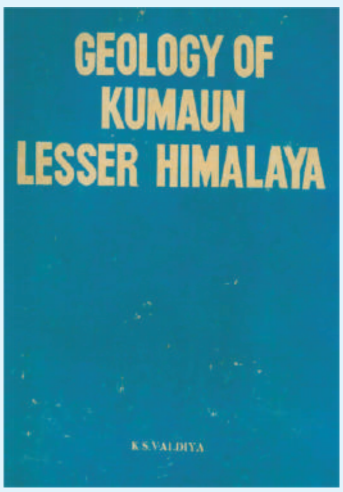


Rs.1200/- (India), US$ 100/- (Abroad)

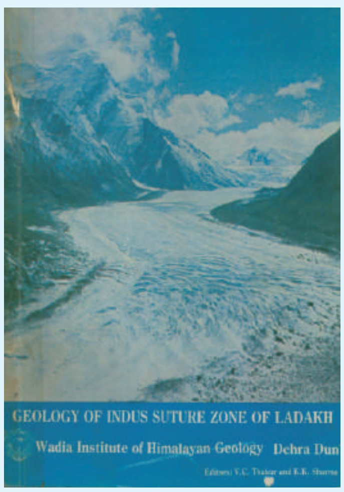


Price: Rs. 500/- (India), US$ 50/- (Abroad)

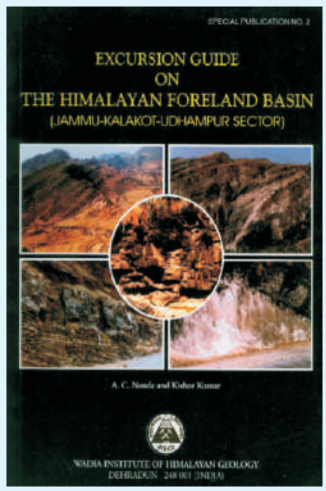
Previous Publications



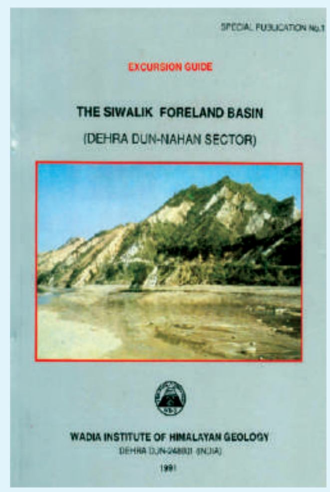
Rs.180/- (India), US$ 50/- (Abroad)



Rs.205/- (India), US$ 40/- (Abroad)



Rs.180/- (India), US$ 15/- (Abroad)



Rs.45/- (India), US$ 8/- (Abroad)

Rs.200/- (India), US$ 15/- (Abroad)

Procurement details:
Corresponding address:
The Director
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun 248001, India
or
Publication Section
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun 248001, India
Phone: +91-0135-2525430, Fax: 0135-2625212
Email: himgeol@wihg.res.in,
Web: http://www.himgeology.com

Cheque/Bank Draft:
Should be in favour of the
'Director, WIHG, Dehradun, India'

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

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Wadia Institute of Himalayan Geology

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33, General Mahadeo Singh Road,
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