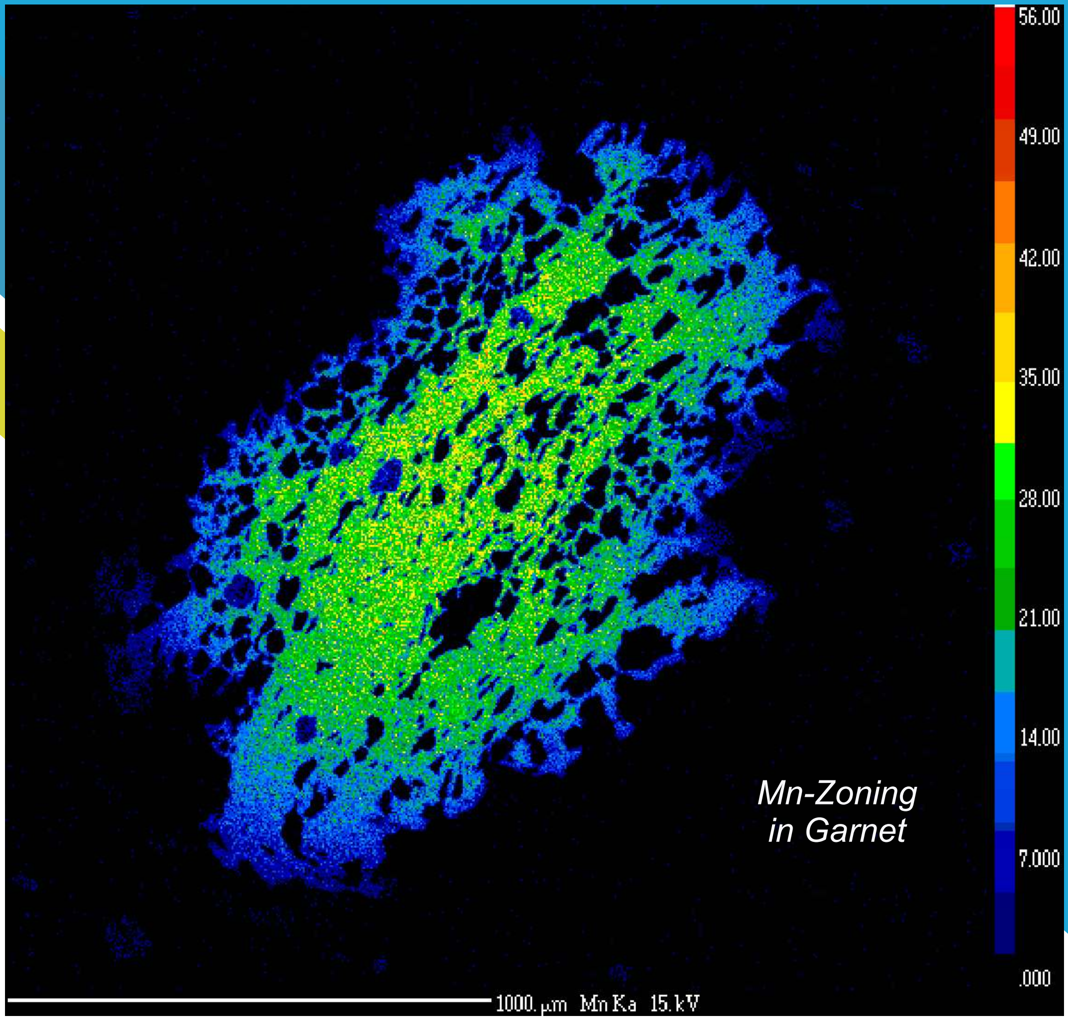
ANNUAL REPORT
2018-19



WADIA INSTITUTE OF HIMALAYAN GEOLOGY
DEHRADUN

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

Cover Photo: X-ray elemental map of Mn content in the Garnet Porphyroblast from the Outer Crystallines of Kullu Area, Beas Valley (NW Himalaya) showing growth with decreasing Mn content from core to rim.

(Courtesy : Dr. Allba Ao)

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WADIA INSTITUTE OF HIMALAYAN GEOLOGY

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WIHG ORGANISATIONAL SET-UP

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DIRECTOR

RESEARCH ACTIVITIES

RESEARCH GROUPS

- Structure & Tectonics
- Igneous Petrology & Geochemistry
- Sedimentology
- Biostratigraphy
- Geophysics
- Geomorphology & Environmental Geology

THRUST AREA THEMES

- Geodynamic Evolution of the Himalaya and Adjoining Mountains
- Indian Monsoon-Tectonic Interaction and Exhumation of the Himalaya
- Earthquake Precursors Studies and Geo Hazard Evaluation
- Biodiversity - Environment Linkage
- Himalayan Glaciers: their role in Indian Monsoon variability and Hydrological changes in the Ganga Basin

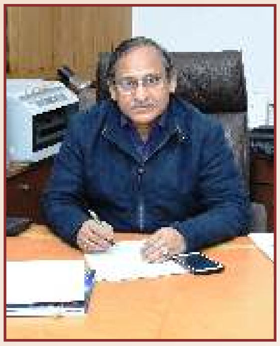
UNITS ANCILLARY TO RESEARCH

- Research Planning & Co-ordination Cell
- Publication & Documentation
- Library
- Museum
- Drawing Section
- Photography Section
- Instrument Maintenance
- Sample Preparation Section

ADMINISTRATION

- Registrar's Office
- Finance & Accounts
- Establishment
- Stores & Purchase
- Works, Building & Maintenance
- Transport
- Guest House

EXECUTIVE SUMMARY



Wadia Institute of Himalayan Geology (WIHG) has the mandate to carry out the basic and applied research related to the geological and geophysical aspects of the Himalayan region, mainly to understand the seismogenesis, geodynamics, geo-hazards related to earthquakes and landslides, glaciological changes, climate variability, natural resources and biotic evolution. The research program that deals with the shallow and deep processes, crust-mantle boundary and lithosphere-asthenosphere interaction across the India-Eurasia plates is grouped into following five broad thrust area themes (TAT):

- TAT - 1: Geodynamic Evolution of the Himalaya and adjoining mountains
- TAT - 2: Indian Monsoon-Tectonic interaction and exhumation of the Himalaya
- TAT - 3: Earthquake precursors studies and Geo-Hazard Evaluation
- TAT - 4: Biodiversity - Environment Linkage
- TAT - 5: Himalayan Glaciers: their Role in Indian Monsoon variability and Hydrological Changes in the Ganga Basin

The excerpts of main works on above TATs, carried out by our scientists during 2018-19, are briefed below:

Geodynamic Evolution of The Himalaya and adjoining mountains

- In the Satluj valley, a network of faults has been mapped at and near the base of the hanging wall block of the South Tibetan Detachment (STD), which is characterized by the presence of mylonitic and brecciated rocks. The analyses of geomorphic features observed particularly in the thrust and fault zones and geomorphic indices suggest that the area is neotectonically active. The seismicity pattern suggests that there are two seismogenic zones in the region -one is associated with the Himalayan Seismic Belt and the other is controlled by the transverse Kaurik - Chango Fault Zone.
- 3D S-wave lithospheric structure suggests thin crust and highly variable Moho in the Satluj valley. A broad low velocity zone (LVZ) has been observed in the middle and lower crust of the Tibetan Plateau and northern part of the Karakoram Fault. This LVZ may be the manifestation of a partial melt or warm zone due to collision tectonics. The high velocities in the southern deeper part indicates that the lower crust and uppermost mantle of the Indian Plate are dense and cold.
- The P-T study of migmatitization in the Satluj valley shows that the migmatitization took place in the P-T range of 650-800°C.The fluid inclusion study of migmatites confirm the presence of carbonic and carbonic-aqueous inclusion. The carbonic inclusions are primary and the carbonic-aqueous inclusions are secondary in nature. Further, the U-Pb ages for zircons present in the migmatites are in the range of 950 - 550 - 25 Ma.
- Garnet porphyroblasts of the Main Central Thrust Zonemetapelites of Alaknanda Valley in the NW Himalaya are characterized by the yttrium zoning with Y-rich core and Y-poor rim. Such zoning is interpreted to have been developed during the prograde metamorphism in the P–T ranges of ~5.3–7.3 kbar and ~500–585ºC.
- The Tethyan metamorphic rocks, exposed in and around the Jaspa Pluton, Bhaga Valley in the NW Himalaya, were re-examined and interpreted to have been attained garnet grade Cenozoic metamorphism as opposed to the earlier interpretation to be chlorite-biotite grade metamorphic rocks.
- The protocol for Apatite and Zircon Fission Track Thermochronology has been developed and multiple age standards have been dated with the inter-laboratory data comparison. Apatite Fission Track (AFT) ages and Zircon Fission Track (ZFT) ages from a vertical transect of the Higher Himalayan Crystalline of Zanskar along the Chenab Normal Fault (CNF) Zone in the NW Himalaya indicate that the ZFT ages does not show any correlation with elevation, whereas the AFT ages decrease as the elevation increases with a regression coefficient of 0.8.Thermal modelling suggests that exhumation rates along the CNF zone were 0.24±0.01 mm/yr during ~21-6.5 Ma which increased to 0.50±0.05 mm/yr during ~6.5 Ma. The increase in exhumation along the CNF zone suggests active normal faulting during ~6.5 Ma, while the reverse age-elevation trend suggests a decrease in relief of the Higher Himalayan Crystallines.

- The geothermal belts along the Goriganga, Kaliganga and Dhauliganga river valleys in the Kumaun region, NW Himalaya were identified and the hydrogen and oxygen isotopic compositions were studied to fingerprint the route of groundwater circulation. The isotopic data of oxygen and hydrogen indicate that geothermal water is depleted, whereas the radiogenic $^{87}Sr/^{86}Sr$ isotopic ratio suggests the deep source of geothermal fluids.

Indian Monsoon-tectonic interaction and exhumation of the Himalaya

- Fluvial records from Zanskar Himalaya indicates sedimentation in the wetter MIS-3. U-Pb based Zircon ages from fill sediments suggested channel connectivity all through aggradation phase. The Pangong Tso record exhibited a sharp lake level fall at ~1.5 ka BP.
- The fluvial stratigraphy from the Ganga Plain suggests a regional hiatus at ~80 ka and peripheral bulge tectonics between 80-54 ka.
- A speleothem record from the Mawmluh cave, Meghalaya indicates highly variable Indian summer monsoon (ISM) strength during the period spanning ~112 BC to 1752 AD. Strong ISM conditions prevailed during ~112 BC to 440 AD and ~570 to 1000 AD punctuated by several dry phases. Abrupt and prolonged weak ISM conditions existed during ~440 to 570 AD and the Maunder Minimum, the earlier interval corresponds to decline of the Gupta Dynasty in the Indian sub-continent. The prolonged weakening of the ISM after ~1000 AD also caused the decline of several long-lasting dynasties in the region.
- Tree-ring chronologies of Himalayan birch and Himalayan pine developed from their respective upper most forest limits in Gangotri glacier forefields showed the role of temperature in modulating growth pattern of trees. A comparison of Himalayan pine chronology with temperature proxies revealed regional and hemispheric scale temperature signal.
- Using tree-ring chronologies, expansion/retreat of the Gangotri glacier was identified and it was established that the Gangotri glacier terminus receded ~1.853 km since the late 16^{th} century (1571 C.E.). The major part of it (~1.79 km) receded since 1935 with the onset of the 20^{th} century warming; the recession got accelerated since 1957 (~1.567 km). With the projected warming in the 21^{st} century in the Hindu Kush-Himalaya, the Gangotri glacier might face accelerated recession on unprecedented rate as ever experienced in past 447 years.
- Stable carbon isotope ($\delta^{13}C$, ‰ VPDB) and total organic content (TOC, wt %) records from palaeolake sediment profile of Chamoli Garhwal were studied to understand the Indian Summer Monsoon precipitation over the past 5,300 years. A high $\delta^{13}C$ values recorded between 5300 and 3230 yr BP indicate reduced moisture condition. This period was followed by a return to moist and humid environmental conditions resulted to progressive increase in grassland as evidenced by increase in TOC (%) from 3230 to 1800 yr BP. This period was briefly interrupted by a centennial scale decline moisture phase from 2,560 to 2,300 yr BP, coinciding with the period of relatively low moist environment. A cold-dry events recorded during ~1800 to 1030 and ~500 to 320 yr BP correspond to the Dark Age Cold Period and Little Ice Age, respectively. However, the intermittent warm and wet period recorded during ~1030 to 500 yr BP corresponds to the Medieval Warm Anomaly, respectively.
- The measurement protocols for determining the isotopic composition of Lithium (^{7}Li) was developed to trace the process of silicate weathering.
- The diatom study of the Renuka Lake indicates that during 1840 - 1900 AD, the lake was not favorable for diatom growth, probably due to low productivity or inability to preserve diatoms. The first appearance of diatoms was recorded since 1903 AD, which seems corresponding to an increased rainfall. In 1940 AD, the population of diatom has increased drastically coinciding with the drastic increase in temperature worldwide. The increased productivity during 1940 - 1972 AD is inferred from the expanded population of *Cyclotella* which prefers warm water condition and eutrophic - mesotrophic lake.
- The observed Equivalent Black Carbon (EBC) concentration near the Gangotri Glaciers is far below the Indian and global limit of the respirable pollutants, i.e. 60 $\mu g/m^3$ and 25 $\mu g/m^3$. The analysis of HYSPLIT backward air-mass trajectories and the active fire spots distribution from the MODIS, meteorological data and ground survey indicate that seasonal cycle of EBC was significantly influenced by the prevailing meteorological conditions and the continental (Mediterranean region) as well as the long range-short range transport (Indo-Gangetic plain) of BC coupled with BC emission at local scale due to burning of biomass (forest-firewood) and fossil fuels.

Earthquake precursors studies and Geo-hazard evaluation

- The source parameters, significant for understanding the dynamic rupture process, for 58 earthquakes ($3.0 \leq M_w \leq 5.0$) occurred during 2007-2015 in the Garhwal Kumaun region have been evaluated. The scaled energy ratio of radiated seismic energy to the seismic moment has also been calculated to determine the dynamic failure. It has been observed that the estimated scaled energy is consistent with global observations, and it increases with moment magnitude. The estimation suggests partial stress-drop.
- Multi-proxy studies provided the first evidences for 1950 A.D. primary surface faulting along the Himalayan Frontal Thrust (HFT), NE Himalaya at Pasighat suggesting that great earthquakes accommodate the convergence between the southern Tibet and stable India along the MHT to the HFT.
- Neotectonic study between the North Almora Thrust (NAT) and the Himalayan Frontal Thrust (HFT) in the SE Kumaun Himalaya suggests the relative movement of rocks along the Tanakpur Fault, which caused sudden swing in strike of the bedrocks in Thuligaon-Pot area of Tanakpur. Further, the tilted Quaternary deposits, soft sediment deformational structures and various geomorphic indices point towards the neo-tectonic activity, particularly along the HFT. These types of evidences so far have not been reported from the immediate hanging wall of the HFT from other parts of the Himalaya.
- The timing of the aggradation and incision of the alluvial fans in the Kota Dun, using quartz OSL dating, establish that the fans aggradation that was initiated before 26 ka and stopped after 11 ka followed by the river incision due to climate change. Holocene tectonic movements in the region have also been identified.
- Non-invasive geophysical techniques, employed across the HFT at Pattapani near Ramnagar and across the Dhikala Thrust at Siyat in the NW Frontal Himalaya, suggest the reactivation of HFT in the recent geological past.
- An inventory of landslides for the Uttarakhand and Himachal Pradesh was compiled in order to understand the distribution that was correlated with various geological and geomorphological factors, geomorphic indices like steepness index (K_s), valley floor width to valley height ratio (V_f), swath profile. It has invariably been observed that tectonics induced-rockfalls are characterized by the higher K_s and lower V_f,whereas debris slides are generally characterized by lower K_s and higher V_f. However this is not true for the man-induced landslides.

Biodiversity - Environment Linkage

- Diverse well preserved organic-walled and biomineralised microfossils have been recovered from the Infrakrol, Krol C- E and chert-phosphorite member of Tal formations. The organic-walled microfossils are mainly filamentous &coccoidal cyanobacteria and sphaeromorphoc and acanthomorphicacritarchs and biomineralised microfossils are mainly sponges.The occurrence of various sponge spicules belonging to class hexactinellida along with *Paradiagonella*, trichimella sponge larva, cyanobacteria and acritarchs indicate that a shallow stromatolitic environment was present at that period which was the most comfortable zone for these microorganisms to thrive.
- The anatomy of *Cambaytherium*, a primitive, perissodactyl-like mammal from the early Eocene Cambay Shale Formation of Western India, has been detailed based on more than 300 specimens representing almost the entire dentition and skeleton. Three species of *Cambaytherium* were recognized: *C. thewissi* (~23 kg), *C. gracilis* (~10 kg), and *C. marinus* (~99 kg). Body masses were estimated from tooth size and long bone dimensions
- Biostratigraphic and isotopic evidence indicate an age of c. 54.5 Ma for the Cambay Shale vertebrate fauna, near or prior to the initial collision with Asia. This constitutes the oldest Cenozoic continental vertebrate assemblage from India. Cambaytheriidae (also including *Nakusia* and *Perissobune*) and Anthracobunidae are sister taxa, comprising the clade Anthracobunia, which is sister to Perissodactyla. They are united in a new higher taxon, Perissodactylamorpha. The occurrence of *Cambaytherium*, the most primitive known perissodactylamorph, in India near or prior to its collision with Asia suggests that Perissodactyla evolved during the Paleocene in India or in peripheral areas of southern or southwestern Asia.
- Study of the faunas of the Himalayan Foreland Basin indicate that the Siwalik- age faunas are not only present in the Himalayan Foreland Basin, but are also known from several localities lying south of the Himalayan ranges and Potwar Plateau of Pakistan. It is inferred that the basin was linked in

the east to the Bay of Bengal through the Bengal Basin and in the west to the Arabian Sea through Rajasthan and Kutch. It is further inferred that the Bugti Basin and Zinda Pir area of Sulaiman Ranges of Pakistan were also part of the foreland basin.

Himalayan Glaciers: their role in Indian Monsoon variability and Hydrological changes in the Ganga Basin

- The study on glaciers in Doda and Suru River basins suggest that the net balance of the Pensilungpa glacier was negative in 2017-2018. It was ~ (-) $6.47x10^6$ m^3 we, while the net accumulation of the glacier was ~ (+) 1.01 $x10^6$ m^3 we. However, the ablation and accumulation gradients of the glacier were ~ (-) 0.120 m/100 m and ~ (+) 0.135 m/100m, respectively. Further, most surface ablation was between altitude 4800 and 5000 m, which encompasses areas covered by thin and patchy debris up to 10 cm thick. This may possibly be due to that thin cover reduces albedo without significantly introducing an insulating layer at the surface. While, lower areas between 4600 to 4800 m reduced the surface ablation due to thick debris covered.
- On the basis of moraine mapping, OSL dates and satellite images, the glacier recession has been categorized into two time frames, i) LIA (1360 ± 180)-1971 and ii) 1971-2017. During the time between LIA (1360±180) and 1971, glacier receded by 2671 ±48 m with an average rate of ~4.3 ±0.08 m a^{-1}, while, between 1971 and 2017, the glacier retreat was 260 ±24 m with an average rate of ~5.65 ±0.5 m a^{-1}. The glacier shows a similar phenomenon between LIA and 2017 and a total retreat of the glacier is ~2931 m, which is lower compared to the other Himalayan glaciers.

Academic Pursuits

The scientistsof WIHG have published 57 research papers both in National and International journals. About 83 research papers are in press / communicated. Six research scholars were awarded Ph.D. degree, while eight theses have been submitted for Ph.D. award. Further, the Institute had also provided the laboratory facilities to various sister organizations, academic institutions, particularly to the students. Besides, the scientists of WIHG has been continually providing the Summer and Winter Training, leading to Dissertations of more than 100 Master students. The Institute has a beautiful Museum. Round the year more than 1000 School Children and College Students visit and our scientists explain how the Himalaya has been evolved in the past and what sort of implications it has on us.

In order to have a close interaction and provide a platform for deliberations of research outcome, the Institute organized a “National Conference on Earth System Science with Special Reference to Himalaya” during May 16-18, 2018. An 'Outreach Program' of the India International Science Festival (IISF) 2018 on September 26-27, 2018 was also organized to instill the scientific temperament among the masses and showcase the contribution in the field of S&T over the years.

The Institute has its own journal entitled 'Himalayan Geology', accredited by the Thomson Reuters. It has brought out the volumes of 39(2) 2018 and 40 (1) 2019 during the 2018-19 calendar year. The institute also brought out the 24th volume of Hindi Magazine Ashmika and Reminiscences of Golden Days - 50 years of Excellence in Himalayan Geology (1968-2018).

Institute's Scientists have been recognized with several awards/honors: Dr R.J.G. Perumal with the National Geoscience Award - 2018 in the field of Natural Hazard Investigations by the Ministry of Mines, GoI, he also received a certificate of Outstanding Contribution in reviewing for Tectonophysics; Dr Aparna Shukla with the 'Women Scientist - 2018' by the Uttarakhand Science Education & Research Centre (USERC), Dehradun, she was also elected as 'The World Academy of Sciences' (TWAS), Young Affiliate - 2018 for the next five years; D.P. Dobhal is nominated as 'National Correspondent' to the World Glacier Monitoring Service (WGMS), Zurich, Switzerland; Dr Rakesh Bhambri - CFG, is selected as the 'Scientific Editor' of the 'Journal of Glaciology'; Dr Nilendu Singh – CFG is awarded the 'B.V. Ramana Rao Best Paper Award – 2018 in Agricultural Meteorology' by the Association of Agrometeorologists, Anand, Gujarat; and Dr. Kalachand Sain is bestowed with the Dr. M.N. Bose Memorial Lecture – 2019 by Birbal Sahni Institute of Paleosciences, Lucknow.

Other Highlights

General order, circulars notices etc were issued in bilingual form to promote the use of Hindi in routine work as well as scientific research. The anuual report of the Institute for the year 2017-18 was translated in Hindi and published in bilingual form. Hindi fortnight was celebrated from 14 Sept to 28 Sept 2018 during which various competitions like essay writing and debate were organized. The staff of the Institute were inspired for the progressive use of Hindi in their work.

Kalachand Sain
Director

TAT 1: GEODYNAMIC EVOLUTION OF THE HIMALAYA AND ADJOINING MOUNTAINS

TAT 1.1

Himalayan Deep Image Profiling (HIMDIP) along Defined Transect

(S.S. Bhakuni, Gautam Rawat, Naresh Kumar, D.K. Yadav, Devajit Hazarika, P.K.R. Gautam and S. Rajesh)

Structural and geomorphological data were collected across the Chail Thrust, Jutogh Thrust, Vaikrita Thrust/Main Central Thrust, South Tibetan Detachment and Kullu-Larji-Rampur window along the Sutlej, Beas and Parvati river valleys, NW Himalaya. The analysis of bedrock structures was linked to know the development of landforms along faults, and their relationship with the recent re-activation of faults and vice versa. It is revealed that there is an intimate relationship between the neotectonic faults and recurrence of landslides or mass movement. In the Sutlej River valley, the NW-SE trending anticlinal Kullu-Larji-Rampur (KLR) window is thrust over by the Chail and Jutogh crystalline thrust sheets. At base of the Jutogh Thrust, the younger brittle thrust faults have rotated foliation planes and increased their dip. Similarly, at top of the footwall block, the normal faults have rotated bedding foliations and reduced their dip. A younger normal fault splay of the Jutogh Thrust is recognized, across which dip of foliation is variable. The surface traces of brittle thrust and normal fault imbrication coincide with the narrow and deeply incised and gorged perennial tributary that indicates the tectonic forcing of channel along the Jutogh Thrust. Development of a number of linear series of slip-circles of mass movements, and closely spaced gullies and spurs formed in the valley-slopes indicates active nature of faults traced along the tributaries. The KLR window has developed towards immediate south of the Jutogh Thrust. It implies that the earlier deformation front associated with the movement of rocks was along the leading edge of the Jutogh Thrust, and now it has shifted toward south to participate in the formation of the KLR window. The published literature shows the locations of hypocentres of shallow swarms of seismic events at 5-10 km beneath the surface trace of the Jutogh Thrust. It is interpreted that the presence of seismically active shallow-level blind thrusts related to faults bounding the tectonic horses associated with the duplex system with in the northern flank of KLR window.

A network of faults is mapped at and near the base of the hanging wall block of the South Tibetan Detachment (STD), which is characterized by presence of the mylonitic and brecciated rocks. Towards north, the basal part of the hanging wall block belongs to the Haimanta Group of rocks of the Tethyan Sedimentary Sequence, whereas towards south the Higher Himalayan Crystallines, Vaikrita Group of rocks form the footwall block of the STD. The northern contact between the Cambro-Ordovician Kinnaur Kailash granite and Haimanta rocks is marked by the presence of a brittle fault. A SW-dipping normal conjugate fault of the STD is delineated in the basal part of the hanging wall block near the STD (Fig. 1). The Miocene leucogranite has injected during extensional tectonics related to normal faulting along the STD. A series of fresh-looking triangular vertical facets, both recent and old/fossilized, developed in the valley slope along the STD-parallel tributary flowing in the hanging wall block, indicates presence of a listric normal fault along tributary. Morphometric analysis was carried out in the STD zone to interpret the morphology of the Sutlej river valley floor. The computed ratio of valley floor width to valley height (Vf) has higher value (0.453) in the hanging wall block while a relatively lower value (0.126) is obtained from the footwall block. These values corroborate to the field observations where there is a relative difference in the width and shape of the Sutlej river valley across the STD. The hypsometric curve shows a young rejuvenated topography that is affected by active tectonics. The values of stream length gradient index (SL), steepness index (Ks) and longitudinal profiles also indicate control of the active tectonics in morphology of the Sutlej river longitudinal profile. SL and Ks peaks and knick points at 6 km and 12 km coincide with the locations of newly mapped faults. The relative small SL and Ks peaks and knick points at the fault zones are as a resultof the active extensional tectonics. The analyses of geomorphic features observed particularly in the thrust and fault zones and geomorphic indices calculated suggest that the area is

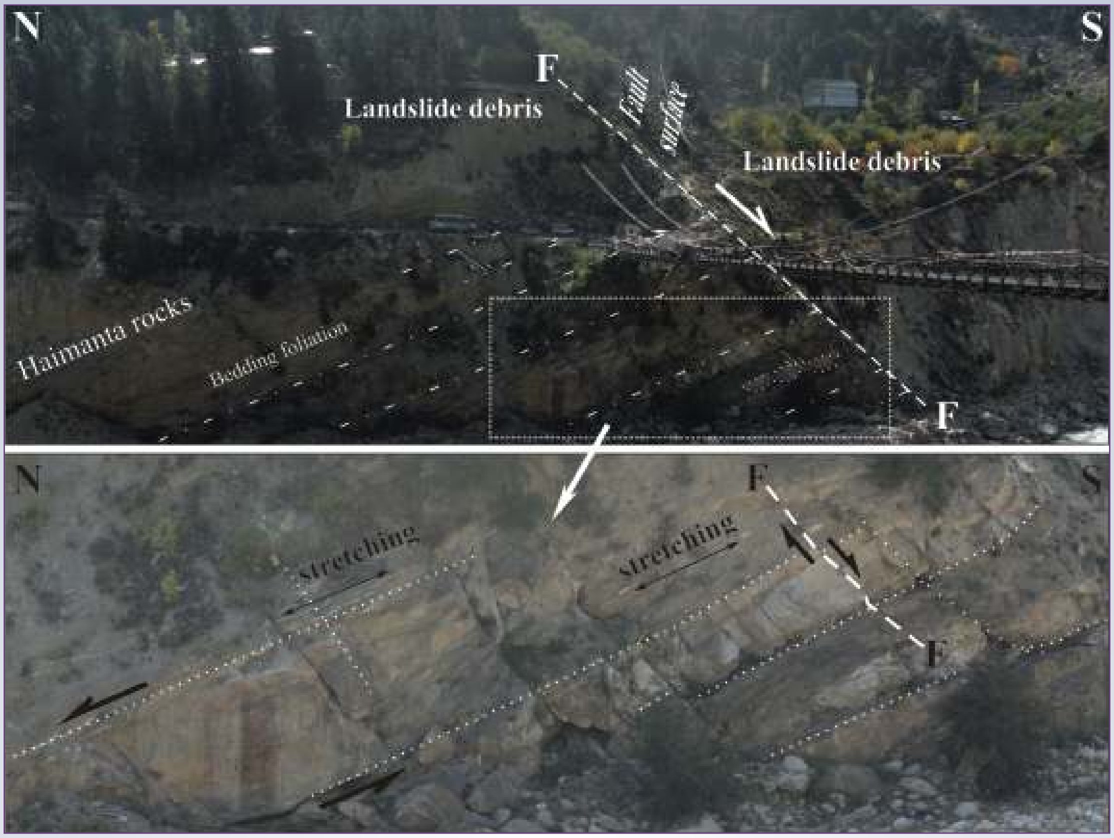


Fig. 1: Active normal fault dipping towards SW developed at base of the hanging wall block of the South Tibetan Detachment (STD). This fault is a part of the conjugate fault system associated with the STD.

neotectonically active. Linear distribution of epicenters of earthquakes across the STD suggests that the seismic activity associated with the transverse Kaurik-Chango fault propagates towards south.

Magnetotelluric (MT) study has also been carried out in the Satluj river valley. A few MT sites were reprocessed to obtain smooth transfer function using different robust approaches. After fixing on transfer functions, the dimensionality and decomposition analyses were executed to understand the regional dimensionality of sub-surface geoelectrical structure. It was verified that the MT response at majority of periods can be modelled as 2D. The MT Tensor decomposition was implemented using Particle swarm optimization algorithm in R. Decomposition for single site was implemented. The strike obtained from phase tensor is used in the decomposition, thereby reducing the number of unknowns. A comparative study between different decomposition methods was done to showcase the efficiency of decomposition using PSO algorithm. Multiple 2D inversion of the rotated MT tensor was carried out for parameter optimization across the Nahan-Leopargil profile. Nonlinear conjugate gradient algorithm was utilized for inverting the transfer functions rotated along the regional structure. In the rotated inverse model, it was also observed that the crystalline rocks of the Jutogh Formation have variable thicknesses, which increase progressively toward north. Different thrust zones are well identified and surface features are well correlated with the known geology of the region in the geo-electrical section. Further seismicity of the region shows that there are two seismogenic zones in the region. One is associated with the Himalayan Seismic Belt (HSB) and another is controlled by the transverse Kaurik-Chango Fault Zone in the Himachal Himalaya. The Kaurik-Chango zone reflects as a resistive feature. The inversion of decomposed transfer function is in progress.

Rayleigh wave dispersion curves, obtained from the moderate and bigger earthquakes ($M \geq 5.0$), were used to investigate the sub-surface lithosphere structure of the western parts of the Himalaya-Tibet region. The data of the NW Himalaya of a dense broadband seismic network was included for the surface wave study. Group velocities for a period range of 660s for the fundamental mode of the Rayleigh wave were extracted at different periods from the dispersion curves. Based on the ray paths of the surface wave from the earthquake epicenters, the spatial variations of the group velocities were obtained through surface wave tomography method. Data of 35 broadband seismographs enabled us to obtain spatial resolution at grids 1° separation. Redefined local dispersion curves were inverted non-linearly to obtain 1D velocity models of the shear wave at 1° up to 90 km depth. Further, these variations at different points were used to construct a 3D image of the S-wave structure of the lithosphere (Fig. 2). The Moho discontinuity is correlated with 4.0 km/s S-wave velocity. The results depict a NE-dipping trend of the Moho depth from ~40 km beneath the frontal part of the Himalaya to up to 70 - 80 km beneath the India-Eurasia collision zone before shallowing substantially to 40 km

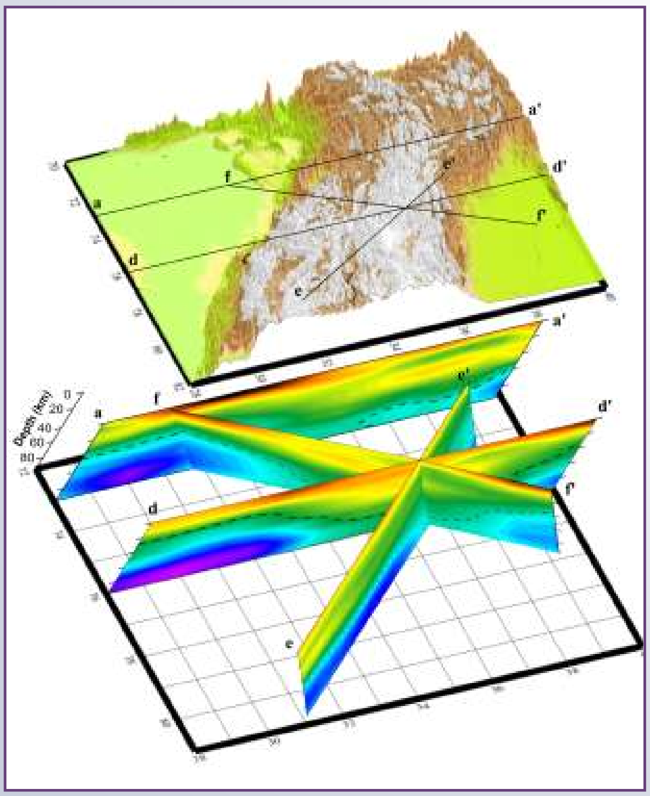


Fig. 2: Shear wave structure obtained for the upper 90 km thick strata of lithosphere along different profiles of the western part of the India-Tibet region and adjoining parts of the Indo-Gangetic plains and Tarim basin. The Moho depth is marked with dotted black lines.

beneath the Tarim basin. In the uppermost crust beneath the IGP in the south and the Tarim Basin in the north, the low values of Rayleigh-wave group velocities and inverted shear-wave velocities suggest the presence of thick deposits of sediments. In these parts, the crust is thin and the assessment of the whole study region indicates a highly variable depth for the Moho discontinuity. The most prominent result is the existence of a broad LVZ in the middle and lower crust in the Tibetan Plateau and northern part of the Karakoram Fault (KF). This LVZ may be the manifestation of a partial melt or warm zone due to collision tectonics. The high velocities in the southern deeper part indicate that the lower crust and uppermost mantle of the Indian Plate are dense and cold.

Recent micro-earthquake and small magnitude earthquake of the Kinnaur Himalaya were used to obtain the spatial variation of coda wave attenuation. Single backscattering model was used for the data of 376 local earthquakes ranging in magnitude from 1.5 to 4.5 (Fig. 3a). Frequency-dependent S-coda wave quality factor, $Qc = 69f^{1.0}$ ($Qc = Q_0 f^n$) was obtained at eight central frequencies between 1.5 and 24 Hz for epicenter distance ≤ 30 km. The Qc, Q_0 and n values were obtained for the data of each station and the results were used to obtain spatial variations (Fig. 3b-c). Q_0 (Qc at 1 Hz) was high in the Higher Himalaya (87 to 109) which matches with already published works of other parts of the Himalaya. It decreases towards NNE, with the lowest value in the Tethyan Himalaya (49 and 55). The 'n' values were found to vary highly, maximum in the tectonically and seismically active High Himalaya, intermediate in the seismically active Kaurik-Chango region, and least in the Spiti valley. To investigate attenuation with increasing depth, the Qc was estimated at eight coda wave window lengths between 20 and 90s. With increasing window length, equivalent to increasing lapse times, the Q_0 increases from 46 ± 3 to 493 ± 34 and n value decreases from 1.07 to 0.58. Further the entire coda wave data was divided into four groups of epicenter distances (0 - 25, 26 - 50, 51 - 75, and 76 - 100 km). The results indicate increasing Qc (and Q_0) and decreasing trends of the n parameters. The obtained Qc relations were estimated to vary as $111f^{0.93}$, $183f^{0.80}$, $264f^{0.73}$, and $296f^{0.71}$, respectively for the above mentioned four groups with increasing epicentral distance. The increase of Qc with increasing lapse time

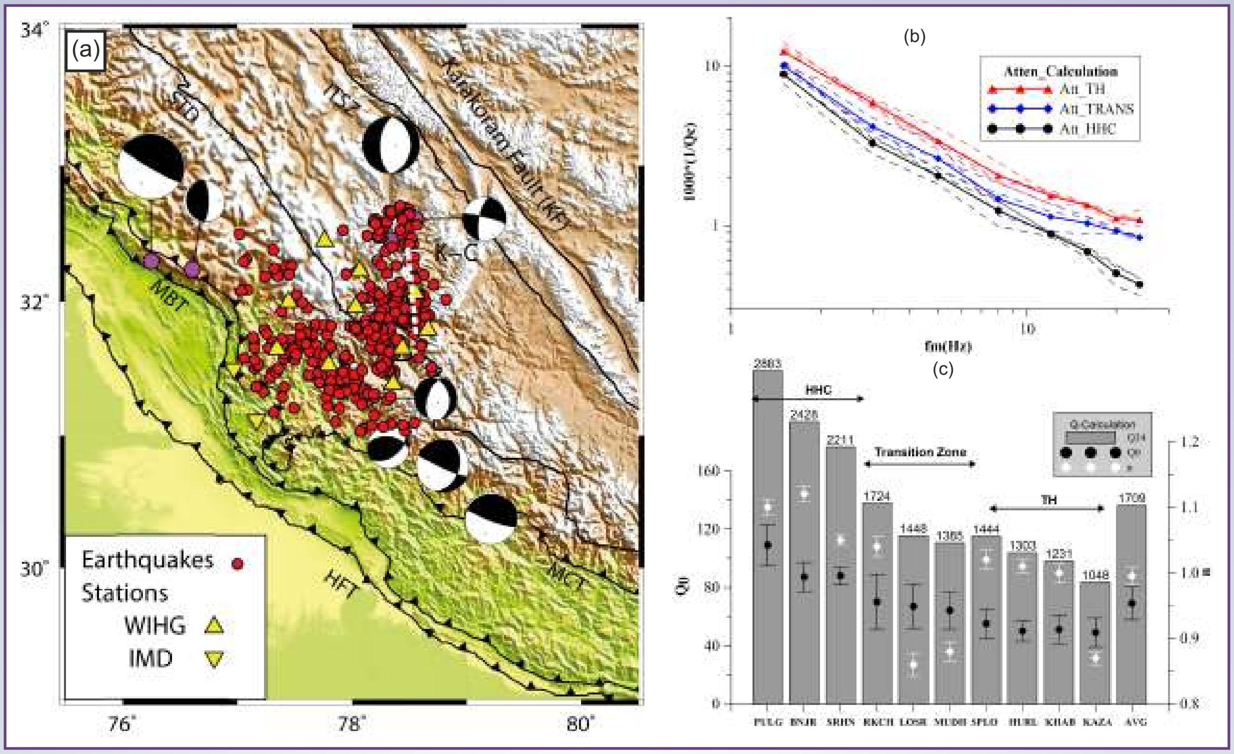


Fig. 3: Coda wave attenuation of the Kinnaur Himalaya based on recent seismic data. (a) Earthquake epicentres (red circle) and seismic stations (yellow triangles), focal mechanism of past big events are shown with lower hemisphere beach-balls. (b) Attenuation (1/Qc) variation with frequency, (Att _TS:- attenuation of the Tethys Himalaya; Att_ HHC:-attenuation of the HHC; Att _ TRANS attenuation of region at the boundary of the TH and HHC. (c) Qc values at 24 Hz frequency (bar height), Q0 Qc at 1 Hz frequency (black circle) and n frequency parameter (white diamond) at different stations.

is interpreted as a decrease of heterogeneity with depth. The data reasonably fit in the power-law decay of turbidity.

Data was collectedfrom a network of six digital broadband seismic stations that was installed along the CHD-AMB ridge region during 2017-2018. The earthquake data from December 2017 to October 2018 are being processed for event extraction and fault plane solutions determinations. We have merged all the six station's waveform data, and local and regional events were extracted using seisan location software. About 698 earthquake events were extractedfor the period. Local and regional earthquake events with magnitudes ≥ 3.0 having good azimuthal coverage, recorded by seismic stations of CHD-AMB Network and by the existing seismic stations of WIHG network in this region, are being used for determination of Fault Plane solutions (FPS) using waveform Inversion technique (i.e. ISOLA). Besides the CHD-AMB Network, we have also combined the corresponding seismic events recorded by other seismic stations of WIHG network to have a better azimuthal control in earthquake location as well as FPS determination. For earthquake events where more numbers of P-wave first arrivals are available, P-wave first motion polarity method were also used for FPS determination, in this way a comparison of FPS using both the above techniques was done. The population of FPS obtained in the region has been used for stress tensor inversion study to get stress pattern existing in the region, the maximum compressional axis ($\sigma 1$, intermediate ($\sigma 2$) and minimum ($\sigma 3$) compressional axis orientations in and around CHD-AMB region of the Himalaya, respectively. These orientation of stress axes shows the direction of forces acting in the region, which are responsible for the occurrence of earthquake activities. In this way the source characterization and stress regime investigation work can be done for the above studied area.

Seismic anisotropy of the upper mantle beneath the NW Himalaya and eastern part of the Ladakh - Karakoram zone (LKZ) has been investigated using shear-wave splitting of the core-refracted SKS waveforms from 122 teleseismic earthquakes recorded at 29 broadband seismic stations. The measurements of anisotropy with the help of the SKS splitting provide insight into the nature of the finite strain field in the lithosphere and uppermost mantle. The SKS Splitting analysis reveals considerable strength of mantle anisotropy ($\sigma t \sim 0.75$-3.0 s) originated primarily in the upper mantle (Fig. 4). The orogen-parallel mantle anisotropy, observed in the frontal part of the Himalaya suggests that a strong localized lithospheric deformation fabric, caused by the India-Asia collision, dominates over the asthenospheric anisotropic signature in this part of the Himalaya. A large portion of the NW Himalaya shows predominantly NE oriented anisotropy direction following the Absolute Plate Motion direction of the Indian plate, which is interpreted as the dominance of the asthenospheric flow in aligning minerals in the sheared lithosphere-asthenosphere boundary layer, masking any compression induced anisotropy. These observations support the view of northward underthrusting of the Indian lithospheric mantle beneath the Himalaya. In the Indus Tsangpo Suture Zone, the anisotropy shows a complex pattern suggesting combined effects of plate motion related anisotropy and anisotropy originated due to lithospheric strain. The anisotropy directions in the Karakoram Fault Zone (KFZ) are parallel or sub-parallel to the strike of the Karakoram Fault. The crustal anisotropy also shows the similar trend indicating that the crust and mantle in the KFZ are mechanically coupled. From the coherent anisotropy directions in the crust and mantle, it can be envisaged that the strike-slip or transpressional deformation in the KF extends up to the lithospheric mantle accommodating the India-Asia collision and facilitating extrusion in the Tibetan Plateau.

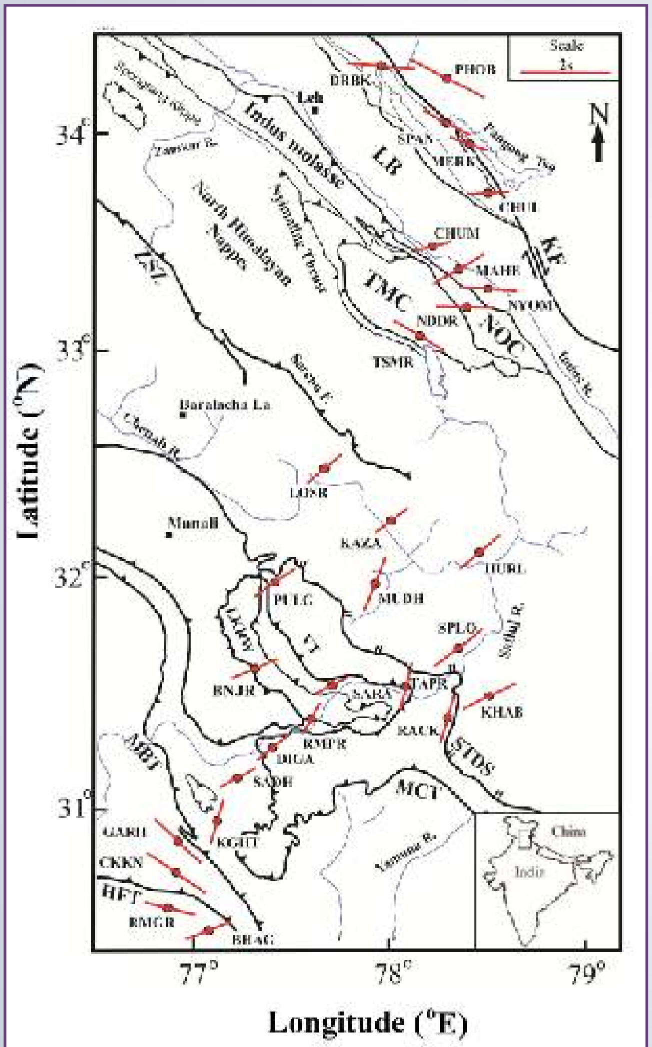


Fig. 4: Simplified tectonic map of the NW Himalaya and Ladakh-Karakoram Zone (modified after Mahéo et al., 2004; Epard and Steck, 2008). Predominant Fast Polarization Direction (FPD) measurements obtained from 29 seismological stations (red dots) are represented. The orientation and length of the bar plotted over the red dots indicate predominant FPDs and splitting delay time (σt), respectively.

Surface deformation along a linear transect from the frontal part of the Nahan salient towards the Main Central Thrust (MCT) has also been studied. GPS data from the Nahan salient station which is situated in the Sub-Himalaya has been processed with other nearby permanent stations data from the Dehradun re-entrant and the Haridwar region. In general the velocity vectors of these stations are oriented along the strike of the Himalayan Frontal Thrust (HFT) with a preferred movement towards southeast. However, the magnitudes of these movements are different which increases from the Nahan station to Dehradun and Haridwar. At Nahan station, the magnitude of surface movement is low, but across and the along the Arc movements toward south and east directions, respectively prevailin a very restricted manner. In comparison with the Dehradun re-entrant, where the predominant movement is along the Arc towards east, the restricted resultant movement in Nahan appears conspicuous and we need to understand further why the resultant velocity in the Nahan salient is relatively less.

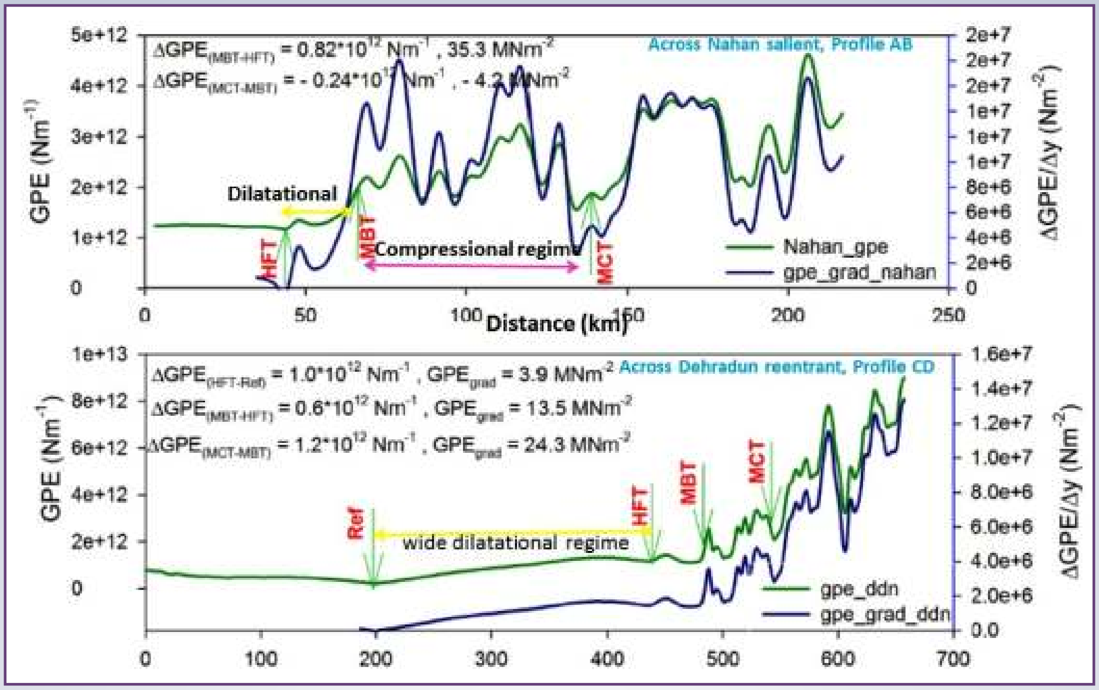


Fig. 5: Gravitational Potential Energy difference and its Horizontal gradient across transects in the Nahan salient and the Dehradun re-entrant.

It has also been observed that across the Nahan salient the topographic gradient is quiet steep in comparison to the Dehradun re-entrant. Moreover, the spatial succession of southern plate boundary thrusts like the Main Boundary Thrust (MBT) and the MCT are quite close and hence possibly cause large gravitational potential energy gradient. Large gravitational potential energy leads to horizontal flow owing to the development of horizontal stress aided by topography. The horizontal stress from the gravitational potential energy by modelling the vertical density contrast for the case of a two layer crust-lithospheric model having a standard thickness of L = 120 km was computed. The analysis of GPE and its gradient results across the Nahan salient were compared to the case of Dehradun re-entrant (Fig. 5). The results show that across the Nahan salient the GPE gradient is quite erratic, especially within the Lesser Himalayan region. Here the negative gradient indicate that the region is under compressive stress. However, in the sub-Himalayan section between the HFT and the MBT, the positive gradient indicate that the region is under dilatational flow, which we observed as a regime of much topographic erosion. However, in the Dehradun re-entrant the GPE gradient is quite steady which increases from the Sub Himalaya to Lesser Himalaya and further to the Higher Himalaya.

TAT 1.2
Fluid-P-T-t evolution of Leopargil Gneissic dome, Himachal Pradesh

(H.K. Sachan, Aditya Kharya and Sauabh Singhal)

Field work was carried out in the Leo – Pargil and Khab area along the Satluj and Spiti river valley. Petrographic study of migmatites collected from the regions have been carried out. The migmatites are located in Satluj valley at the Spiti - Satluj rivers junction. These migmatitesare mainly comprised of melanosome and leucosome. It has been noted that the melanosome is metamorphosed upto garnet grade and it contains plagioclase, amphibole garnet, biotite and quartz, whereas, the leucosome is comprised of quartz and feldspar, amphibole and chlorite. The mineral chemistry of garnet, plagioclase, biotite and amphiboleshave also been carried out.The P-T study of migmatitization of the Satluj valley estimates that the migmatitization took place in the P-T range of 650-800°C. P-T pseudosection modelling of migmatites has also been carried out. It has been noted that the results of empirical geothermobarometry and P-T pseudosection modelling are in the close proximity. Fluid inclusion study of migmatites confirm the presence of carbonic and carbonic-aqueous inclusion. It has been noted that the carbonic inclusions are primary in nature, whereas carbonic-aqueous inclusions are secondary in nature. REE analysis of Zircon has been undertaken to understand the involvement of melt phase. Zircons were also separated from migmatites and U-Pb isotope systematics of zircon mineral were studied.The U-Pb ages for zircons are in the range of 950 – 550-25 Ma.

TAT 1.3

Crust-Mantle interaction in continental subduction zone and their role in Himalayan tectonics

(Barun K. Mukherjee, Koushik Sen, C. Perumalswami, Pratap Sethy and Santosh K. Rai)

In the subduction process, plate interface interaction represent the locus for the mass and energy exchange between crustal and mantle fragments, they are transported downwards and upwards inside subduction channels, it provides avenues for the reaction of fluids and melts, derived from continental and oceanic lithosphere. Their product resides at the higher depth and sometime > 410 km depth, which later on off scrapped through various tectonic processes. They are migrates at the continental subduction channel, leaving behind almost all the primary signature, whereas recycled crustal fragment sometime preserved important remnant signatures. These interaction mechanism resulting, varying extent of metamorphism, deformation and exhumation, can be viewed through tectonic mélange, due to mechanical mixing of crustal and mantle derived rocks. In one of the tuffaceous layer from tectonic melange, the study has revealed the signature of volcanogenic life is well preserved with alteration texture. In order to understand the complete return path of low density continental fragment in the subduction channel, zircon, monazite and rutile has been selected to study and the associated fluid recycling at the down going and uplift processes, Li / B isotopes tracers study is also initiated.

Deep mantle xenolith obtained from the carbonatites of Meghalaya reveal that the Karguelen Plume has upwelled redox volatiles, especially hydrocarbons, from beneath the metal saturation zone. This opens a window to assess the fact if the Karguelen and similar plumes have not only contaminated the Indian craton but also the Tethyan Lithosphere with deep mantle components.

The geochemical and isotopic studies on the southern margin of Ladakh granitiod (LG) in the Indus Suture Zone has also been undertaken. Seventeen samples of different types of granites and host mafic rocks were sampled from the southern margin of Ladakh granitoids between Upshi and Chumathang. Mafic enclaves and different types of granites such as pink granite, porphyritic granite, biotite-hornblende granite, leucogranite and pegmatitic dykes have been observed in the field. Petrographic studies on these samples exhibit different type of textures like graphic, perthitic, rapikivi and myrmekitic in the southern margin of the Ladakh granitoid. These granitoids mostly contain coarse grained quartz, phenocrysts of feldspar, biotite, muscovite, hornblende, epidote and augite. The deformational feature like undulose extinction has been notedin quartz, feldspar and biotite. The feldspar also shows deformational twinning. The sub-grain and grain boundary migration have been observed in quartz. The grain boundaries are in-equigranular and exhibit polygonal to interlobate texture. LOI measurement (< 2 %) indicate that these granitoids have undergone low grade metamorphism and deformation in the southern margin. LG is mostly meta-aluminous innature, transitional between calc-alkaline to shoshonitic magma series and is dominantly I-type. These are formed under partial melting of Tethyan volcanic arc under syn-collisional environment.

TAT 1.4

Tectono-metamorphic, exhumation and mineralization in Himachal, Garhwal and Sikkim Himalaya

(Rajesh Sharma, S.S. Thakur, A.K. Singh, Paramjeet Singh, Aliba Ao, D.R. Rao and Saurabh Singhal)

Yttrium (Y) zoning in garnet and the stability of accessory allanite in metapelites from a greenschist to amphibolite facies inverted metamorphic sequence in the Main Central Thrust Zone (MCTZ) and the overlying Higher Himalayan Crystalline Sequence (HHCS) along the Alaknanda Valley in NW Himalaya have been studied (Fig. 6). Garnet porphyroblasts from the garnet grade MCTZ metapelites commonly show chemical zoning with a Y-rich core (~3311 ppm) and Y-poor rim (b.d.) (Fig. 7; Table 1). Accessory allanite (up to 3.45 wt% Y_2O_3) occurs as inclusion in the rim of garnet porphyroblasts and also in the matrix in most of the MCTZ samples ((Fig. 8). The Y depletion in the rim of zoned garnets from the MCTZ has possibly resulted

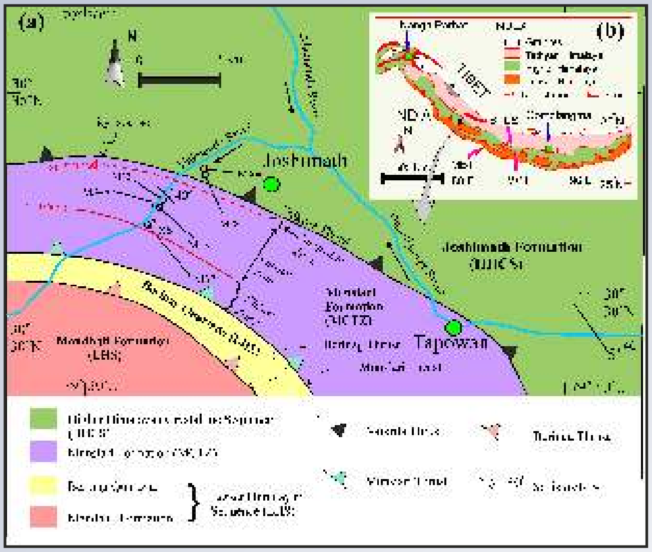


Fig. 6: (a) Geological map of Alaknanda Valley modified after Valdiya (1980), Celerier et al. (2009) and Thakur et al. (2015, 2018). Sample locations are marked by black circles. Inset (b) shows a regional map of the Himalayan orogen. Abbreviations: HHCS = Higher Himalayan Crystalline Sequence; LHS = Lesser Himalayan Sequence; MCTZ = Main Central Thrust Zone.

from sequestration of Y by allanite, which became a stable phase after the formation of the garnet core. Alternatively, the Y zoning has developed by strong partitioning of the element into garnet with the result that it is mostly incorporated in a narrow core and there is little Y available towards the later part of garnet growth. High-Y annulus in garnet occurring in a relatively inclusion-free zone of garnet rim is likely to have resulted from a decrease in the growth rate of the crystal. Garnet porphyroblasts in kyanite grade HHCS metapelites occurring immediately above the MCTZ show weak Y zoning with slightly high concentration of Y at the rim which is attributed to localised resorption of the crystal and back-diffusion of Y. The HHCS garnets contain allanite inclusions both in the core and rim which suggest that allanite was a stable phase throughout garnet growth and sequestered available Y. Allanite shows variation in ΣLREE content and complementary variation in Al which appear to be linked to the modal abundance of garnet in different rocks. Phase diagram modelling for an MCTZ sample shows that the garnet zoning developed during prograde metamorphism in the P–T ranges of ~5.3–7.3 kbar and ~500–585ºC (Fig. 9).

The U-Pb geochronology of zircon was carried out on one sample of the Jispa granite AK-KE7, one samples of Paragneiss AK24 (about 10 Kms west to Manali Himachal Pradesh and one sample of granitic dyke ATS intrusive in Paragneiss. The sample AK-KE7 is The Weighted mean age for sample AK-KE7 has two different clusters at 493.2±6.1 (n=10, MSWD=1.05) and 570±15 (n=8, MSWD=1.7). The U-Pb age for AK24 is distributed from 1200 to 850 Ma.ATS-53 granite is having upper intercept age at 557±27 Ma (n=10 MSWD=4.9). Apart from these 03 samples of Chour granite has also been dated. Sample preparation of remaining 10 sample is under progress and zircons is been separated for these samples.

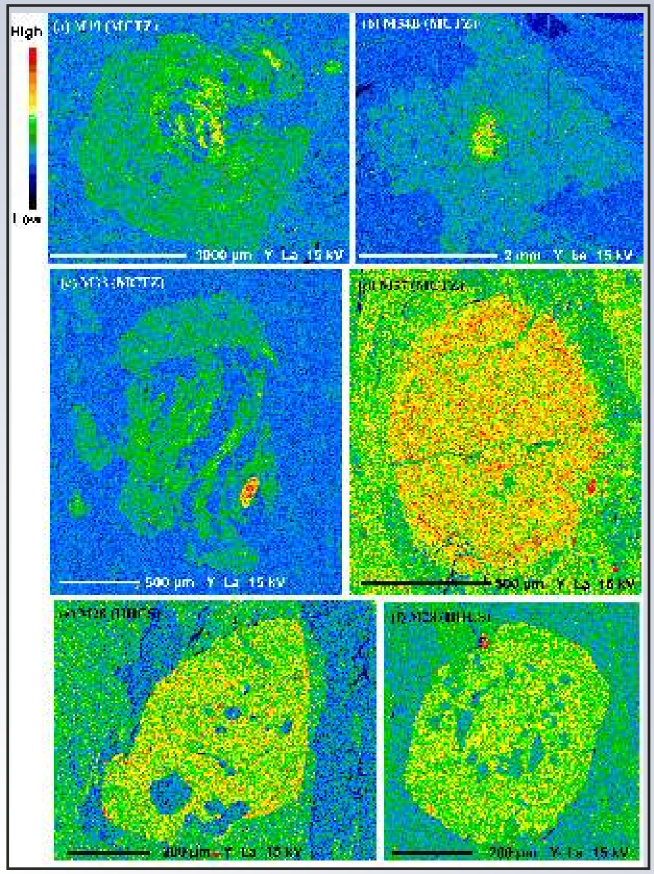


Fig. 7: X-ray elemental maps of yttrium in garnet porphyroblasts from the MCTZ (ad) and HHCS (ef) samples. (a) garnet from sample M19 with Y-rich core with a spiral pattern and Y-poor rim; (b) narrow Y-rich core and wide Y-poor rim in garnet from sample M34b; (c) garnet from sample M33 showing weak Y zoning with higher Y in the core; (d) garnet from sample M37 showing a Y-rich annulus towards the rim; (e, f) garnet porphyroblasts from sample M28 with a slight increase in Y content at the rim (e). 'AB' represents the line along which composition profile was taken.

Table 1: Representative microprobe analyses of garnet. Cations are based on 12 oxygens.

	MCTZ sample							HHCS sample	
	M37	**M19**		**M34B**		**M33**		**M28**	
	core	**core**	**rim**	**core**	**rim**	**core**	**rim***	**core**	**rim**
SiO_2	36.81	36.74	36.97	36.43	37.01	36.56	36.51	37.44	37.29
TiO_2	0.05	0.07	0.09	0.10	0.08	0.07	0.05	b.d.	0.02
Al_2O_3	20.60	20.49	20.69	20.28	20.55	20.65	20.64	20.91	20.82
FeO	33.58	31.38	32.14	33.46	34.00	33.74	34.56	30.12	30.55
MnO	2.42	2.59	1.17	2.50	1.41	2.24	1.00	1.28	1.39
MgO	1.67	1.86	2.08	1.48	2.23	2.02	2.49	3.79	3.49
CaO	4.18	4.90	5.47	3.53	3.43	3.94	3.46	5.65	5.48
Na_2O	0.05	0.07	b.d.	0.07	0.02	0.04	0.02	0.03	b.d.
Y (ppm)	398	2444	143	3311	b.d.	1116	n.a.	562	435
Total	99.41	98.41	98.62	98.27	98.73	99.40	98.73	99.29	99.10
Si	2.994	3.009	3.010	3.009	3.022	2.970	2.978	2.991	2.993
Ti	0.003	0.004	0.006	0.006	0.005	0.004	0.003	0.000	0.001
Al	1.975	1.978	1.985	1.974	1.978	1.977	1.984	1.969	1.970
Fe^{3+}	0.037	0.000	0.000	0.000	0.000	0.074	0.057	0.051	0.039
Fe^{2+}	2.247	2.149	2.188	2.311	2.322	2.219	2.300	1.962	2.012
Mn	0.167	0.179	0.081	0.175	0.097	0.154	0.069	0.087	0.095
Mg	0.203	0.226	0.252	0.182	0.272	0.245	0.303	0.451	0.417
Ca	0.365	0.430	0.478	0.313	0.300	0.343	0.302	0.484	0.471
Na	0.008	0.011	0.000	0.012	0.004	0.007	0.003	0.004	0.000
Y	0.002	0.014	0.001	0.018	0.000	0.006	n.a.	0.003	0.002
Total	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
X_{Mg}	0.08	0.10	0.10	0.07	0.10	0.10	0.12	0.19	0.17
X_{alm}	0.75	0.72	0.73	0.78	0.78	0.75	0.77	0.66	0.67
X_{prp}	0.07	0.08	0.08	0.06	0.09	0.08	0.10	0.15	0.14
X_{grs}	0.12	0.14	0.16	0.10	0.10	0.12	0.10	0.16	0.16
X_{sps}	0.06	0.06	0.03	0.06	0.03	0.05	0.02	0.03	0.03

b.d. = below the detection limit; n.a.= not analysed
Detection limit (in ppm): Si = 116, Ti = 168, Al = 95, Fe = 355, Mn = 172, Mg = 73, Ca = 112, Na = 197, Y = 47
**analysed at accelartion voltage of 15 kV, beam current of 20 nA and beam diameter of 1 micron.*

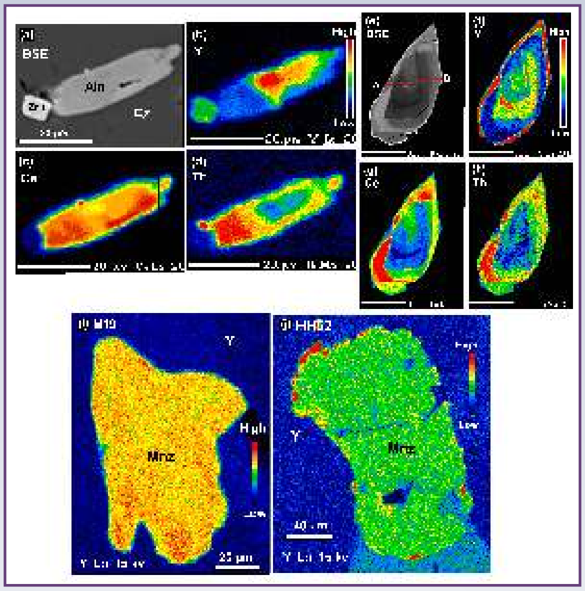


Fig. 8: BSE image and X-ray elemental maps of Y, Ce and Th, respectively of allanite in the MCTZ sample M19 (ad) and HHCS sample M28 (eh). Y X-ray map of monazite in the MCTZ sample M19 (i) and HHCS sample HH52 (j).

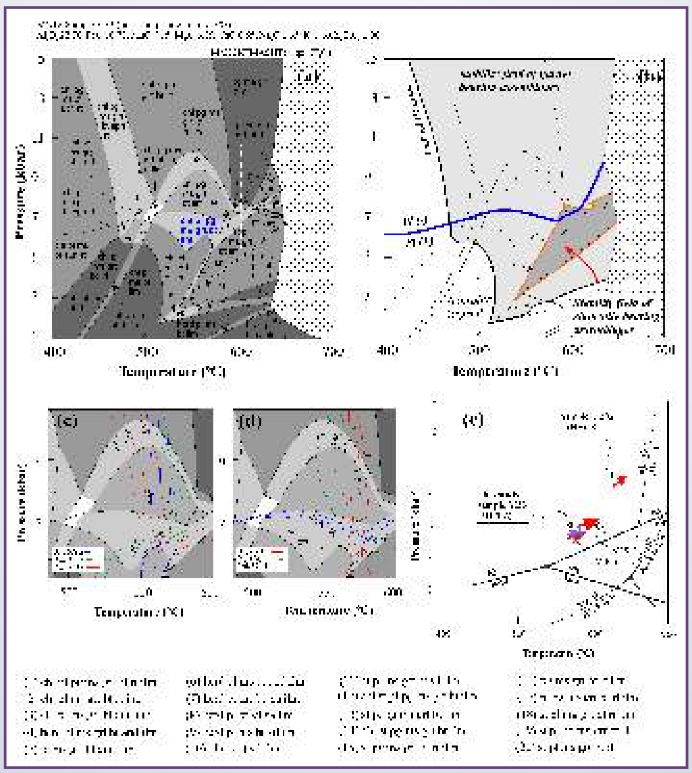


Fig. 9: Phase diagrams (a–d) constructed for fixed bulk rock composition in the MnNCKFMASHT system (+ qz + H_2O) and P–T plot (e) for the MCTZ sample M33. (a) Stability field of the assemblage grt–bt–chl–pl–pg–ms–qz is marked in bold letters.The dotted area in the right side of the phase diagram represents melt-bearing assemblages; (b) Stability field of all garnet-bearing assemblages is shown in light grey shade, while that of a staurolite-bearing assemblage is shown in dark grey shade; (c) compositional isopleths of X_{prp}, X_{sps} and X_{grs} corresponding to the measured core composition of garnet intersect at P–T condition 6.5 kbar and 566°C; (d) compositional isopleths of X_{grs} in garnet rim and X_{Mg} in biotite, and modal abundance of plagioclase intersect at point corresponding to P–T condition of 6.5 kbar and 576°C; (e) P–T path for sample M33; P–T paths for samples M19, M34B and M30a are from Thakur et al. (2015).

In order to study the tectonometamorphic evolution of NW Himalaya, metamorphic rocks exposed along the Beas valley, Himachal Himalaya was chosen because of excellent exposure of the crystalline rocks and lack of well-constraint metamorphic P-T data from the region. Here we report the petrography and geochemistry of pelitic schists that was exposed between Mandi and Larji section of the Beas Valley, NW Himalaya. Bulk-rock geochemistry of these rocks are suggestive of pelitic composition. The mineral association in these rocks are represented by: garnet + quartz + muscovite + biotite + chlorite + ilmenite ± tourmaline. Based on the absence of staurolite and/or alumino silicate minerals (kyanite/sillimanite/andalusite), the rock is interpreted to have attained peak metamorphism up to garnet-grade. This is also in conjunction will reports from previous studies. A general trend of increase in garnet grain-size is also observed with increasing structural height, with the garnet size as small as ~ 100 micron at the base of the crystallines up to ~ 1.5 cm in the topmost section of the selected traverse. Detailed study a pelitic rock from the top most section reveals garnet grains upto ~ 1.5 cm in length with highly resorbed grain boundaries (Fig. 10a). X-ray mapping and element profiling across the garnet gain reveals distinct chemical zoning with a decrease in MnO and CaO and an increase in FeO content from core to rim (Fig.10). These evidences indicate preservation of growth zoning garnet profile. A P-T pseudosection modelling approach is currently underway to decipher the peak P-T conditions of metamorphism of these rock that will give important insights into the tectonomorphic evolution of the terrain. For understanding the exhumation history of the Himachal Himalaya, traverse from Mandi to Manali along the road section (Beas Valley) were taken. Total 30 bedrock sample have been collected including a vertical profile in Kulu area. Out of these, 25 bedrock samples has been selected for Fission Track Thermochronological work. In order to obtain Fission Track dating data, our Mineral separation (apatite and zircon) and slide preparation work has been completed. The Polishing, etching and sample packing for thermal irradiation work are in process.

Uchich in the Parvati valley of Himachal Himalaya lies at the northwester extension of Larji-Kulu-Rampur window. The area is covered by the Proterozoic rocks of Banjar and Kulu Formations/Chail Formation, wherein the rocks of Chail Formation are thrusted over Manikaran Quartzite of Banjar Formation along Chail/Kulu Thrust. The contact zone of Chail and Banjar Formation mainly along the hanging wall side on the right bank of Parvati River and south of the Uchich village, is marked by the presence of polymetallic sulphide mineralization. The mineral assemblage include pyrite, arsenopyrite, galena and minor chalcopyrite. SEM-EDS data is largely consistent with major Fe and S with usual presence of 2 to about 15% As in pyrite. Sn is also noticed in one analysis. Presence of scorodite, an alteration product of arsenopyrite, has also been verified by the Micro Raman data. It is evident that the mineralogy of the ore assemblage is complex and unusual, as non-stoichiometric ore minerals are also noticed in Raman results. The fluid inclusion

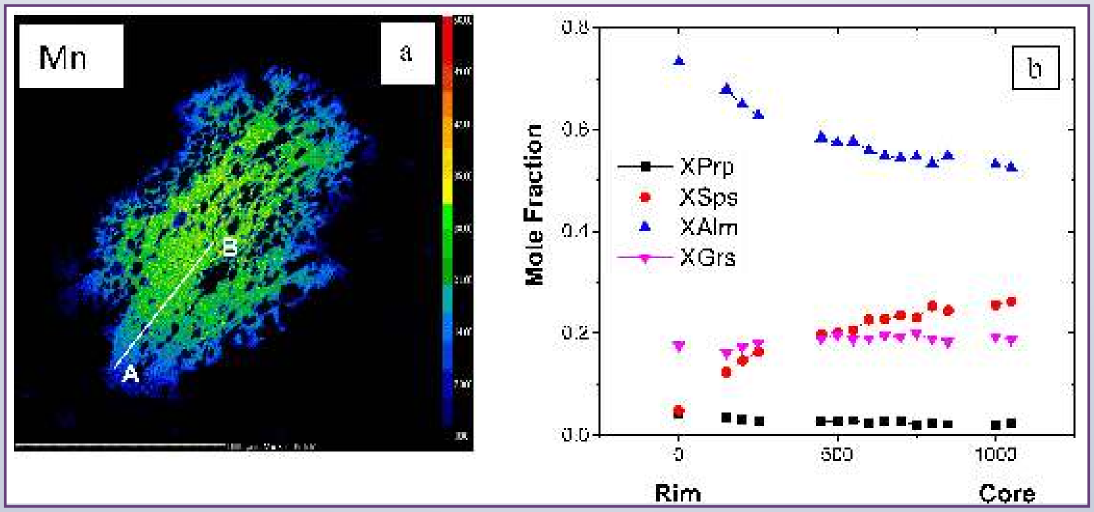


Fig. 10: (a) X-ray element image of garnet from Mandi-Larji section, NW Himalaya. (b) Garnet composition profile from core to rim along as shown in (a).

distribution pattern is indicating a syn- to post-ore nature of the fluid in these inclusions. In the aqueous-carbonic inclusions the liquid – liquid meniscus at room temperature is common, suggesting low density of the carbonic fluid. Together with monophase carbonic inclusions, the proportion of carbonic and aqueous phase widely varying from 60:40 to and 20:80, points to immiscibility in fluid. The ore mineralization is interpreted to be result of the unmixing of carbonic-aqueous fluid, and the high saline fluid was in limited flux. Late aqueous inclusions are linked to recrystallization of vein quartz characterized by the presence of incipient neograin and annealing texture. Further, the copper sulphide mineralization of Dewaldhar hosted within the platformtype Deoban carbonates during Meso-Neo- Proterozoic timeare also investigated. No details work is available on these sulphides. The ore petrography, micro Raman spectroscopy and the fluid inclusion studies are carried out on the ore assemblage which is present in quartz-calcite veins filling the fractures of the carbonate rocks. The ore assemblage consists of chalcopyrite as dominant ore minerals with subordinate covellite and pyrite. Under microscope the sulphide ore minerals are seen filling the fractures as well as present as inter granular fillings. Chalcopyrite and pyrite are coeval. The characterization of fluid inclusions in mineralized quartz was carried out using microthermometry and micro Raman spectroscopy, which suggest that the inclusions are filled with aqueous fluid with no signature of carbonic fluid. The initial melting temperatures of the biphase fluid inclusions from -25 to -44^{o}C signifies that the ore fluid composition was H_2O-NaCl-KCl±$MgCl_2$. The composition of the fluid and salinity range can be interpreted to suggest that a basinal hydrothermal fluid with long circulation and fluid-rock interaction period was responsible for the mineralization.

TAT 1.5

Exhumation History of Higher Himalayan Crystallines of Zanskar, NW India

(Vikas Adlakha)

The protocol for Apatite and Zircon Fission Track Thermochronology has been developed in the Wadia Institute of Himalayan Geology, Dehradun. Multiple age standards have been dated and inter-laboratory data comparison has also been carried out.

During the year six new Apatite Fission Track (AFT) ages and five new Zircon Fission Track (ZFT) ages have been obtained from a vertical transect of the Higher Himalayan Crystalline of Zanskar along the Chenab Normal Fault (CNF) Zone in the NW Himalaya. AFT ages range from 5.5±1.6 Ma to 7.4±1.3 Ma,while ZFT ages range from 20.3±1.7 Ma to 23.3±2.3 Ma. Interestingly, the ZFT ages does not show any correlation with elevation, while AFT ages decrease as the elevation increases with a coefficient of regression as 0.8. Thermal modelling suggests that exhumation rates along the CNF zone were 0.24±0.01 mm/yr during ~21-6.5 Ma which increased during ~6.5 Ma to 0.50±0.05 mm/yr. This increase in exhumation along the CNF zone suggest active normal faulting during ~6.5 Ma, while the reverse age-elevation trend suggest a decrease in relief of the HHC along the CNF zone in the NW Himalaya.

For the 23 samples of apatite and 19 samples of Zircon of Gianbul Dome of HHC of Zanskar, the analytical procedure of slide preparation of Fission Track Thermochronology were completed and subsequently has been sent for thermal neutron irradiation.

TAT 1.6

Isotopic aqautic (major & trace elements) gerochemistry and morpho-tectonic studies of geothermal systems (geothermal springs) of Kumaun West - Central Himalaya India: Implications for their source of origin and orogenic CO_2 degassing

(Sameer K. Tiwari, A.K.L. Asthana and Aditya Kharya)

Towards understanding of carbon dioxide (CO_2) degassing processes through orogenic belts like young mountain chain of the Himalaya, geothermal belts of the northwest Himalaya were studied. The major emphasis was aimed to understand the process of degassing through the isotopic and geochemical proxies of springs. Magnitude and rate of degassing of metamorphic CO_2 and its contribution in the atmosphere along the major Himalayan tectonic zones are important to understand the global carbon cycle. Therefore, it is important to address the degassing of orogenic CO_2 in the Indian Himalaya for a better and representative estimate of the process. During the year work has been done to identify the geothermal belts along the river valleys of Goriganga, Kaliganga and Dhauliganga of the Kumaun region in the northwest Himalaya. Water samples of geothermal springs and associated river were collected for the pre - monsoon season to study the recharge source of the geothermal springs (Fig. 11). Various physical parameters like pH, EC, and surface temperature of these springswere measured. Post-monsoon study has also been undertaken to identify the temporal variation in physical parameters of the springs and also to understand any monsoonal effect on the recharge source of the same.

Stable isotopes study of the collected sampleshas been carried out. The study reveals that in the study area there is a relationship between the formation mechanisms of the recharge source of geothermal springs. Given the diverse hydrogen and oxygen isotopic compositions of various water sources, stable oxygen and hydrogen isotopic ratios ($\delta^{18}O$ & $\delta^{18}D$) are a tremendous way to fingerprint the route of groundwater circulation, including recharge, runoff, and discharge (Fig. 12). The isotopic data of oxygen and hydrogen indicate that geothermal water is depleted and accordingly the altitude variation and no positive oxygen isotope shift has been observed, whereas the radiogenic $^{87}Sr/^{86}Sr$ isotopic ratio suggests the deep source of geothermal fluids.

Fig.11: Field photograph of Kimilkhet Geothermal field located in the Goriganga river, Kumaun Himalaya.

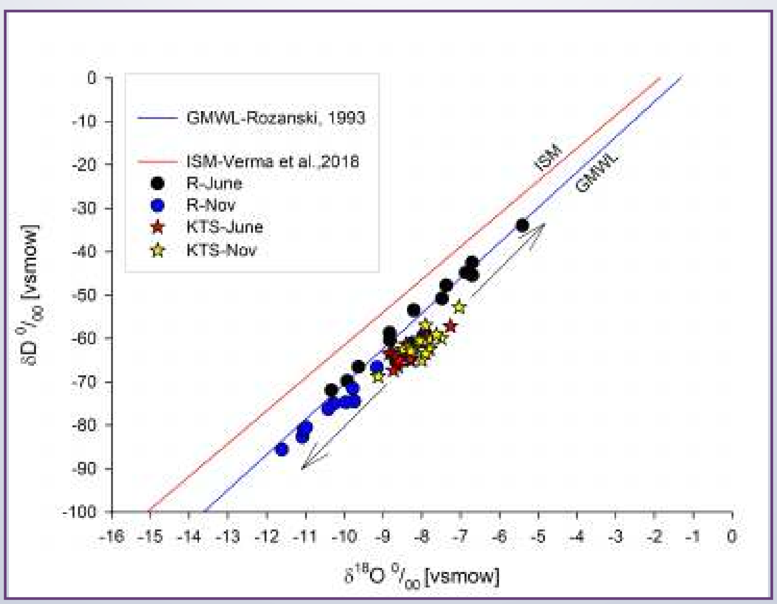


Fig. 12: X - Y plot between the stable isotopes of oxygen and deuterium indicating the affinity of recharge source towards the meteoric origin in the geothermal springs of Kumaun Himalaya.

TAT - 2: INDIAN MONSOON-TECTONIC INTERACTION AND EXHUMATION OF THE HIMALAYA

TAT- 2.1

Paleoclimatic records from Himalaya and its foreland and their hydrological impacts

(Pradeep Srivastava, Anil Kumar, Santosh K. Rai, Suman Lata Rawat, Jayendra Singh, Som Dutt, Prakasham M., Saurabh Singhal and Pinky Bisht)

Fluvial records from Zanskar Himalaya (Fig. 13) indicated sedimentation in wetter MIS-3, 1. U-Pb based Zircon ages from fill sediments suggested channel connectivity all through aggradation phase. The Pangong Tso record exhibited a sharp lake level fall at ~1.5 ka BP. The fluvial stratigraphy from the Ganga Plain suggests a regional hiatus at ~80 ka and peripheral bulge tectonics between 80-54 ka. Paleoflood record from Ladakh Himalaya indicates clusters in Early- and Mid-Holocene. The U-Pb Zircon chronology of flood deposits indicates a hotspot of erosion in Zanskar and Indus Headwaters.

In order to understand the climatic variability during the Holocene, 80 sediment samples from Himalayan foreland have been analysed for stable carbon isotopes. Eight stalagmite samples have been collected from the Meghalaya.

A speleothem record from the Mawmluh cave, Meghalaya indicates highly variable Indian summer monsoon (ISM) strength during the period spanning ~112 BC to 1752 AD. Strong ISM conditions prevailed during ~112 BC to 440 AD and ~570 to 1000 AD punctuated by several dry phases (Fig. 14). Abrupt and prolonged weak ISM conditions existed during ~440 to 570 AD and the Maunder Minimum, the earlier interval corresponds to decline of the Gupta Dynasty in the Indian sub-continent. The prolonged weakening of the ISM after ~1000 AD also caused the decline of several long-lasting dynasties in the region. Variations in northern Hemisphere temperature and northward/

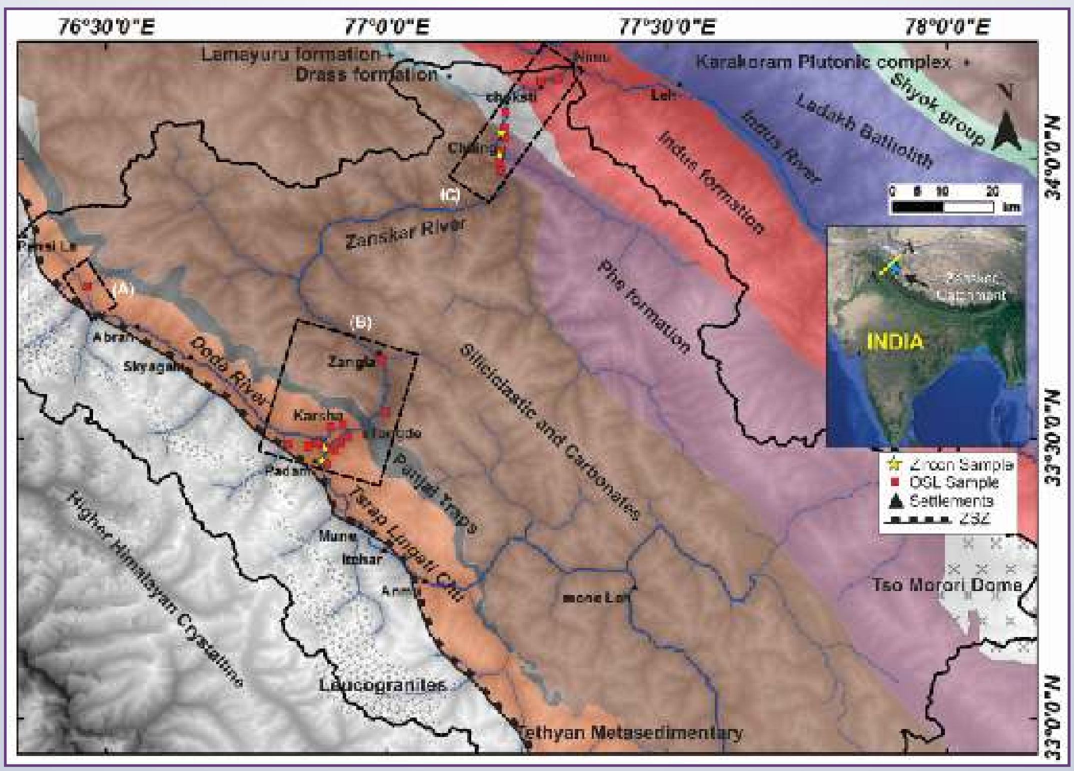


Fig. 13: Geological map of the Zanskar basin (modified after Thakur, 1981, Dèzes et al., 1999), showing studied sections as black dotted boxes- (A) Doda section, (B) Padam sections, (C) lower Zanskar sections; also locations of OSL and U-Pb zircon samples and the Zanskar Shear Zone (ZSZ). Inset is a map of India showing the location of the Zanskar basin.

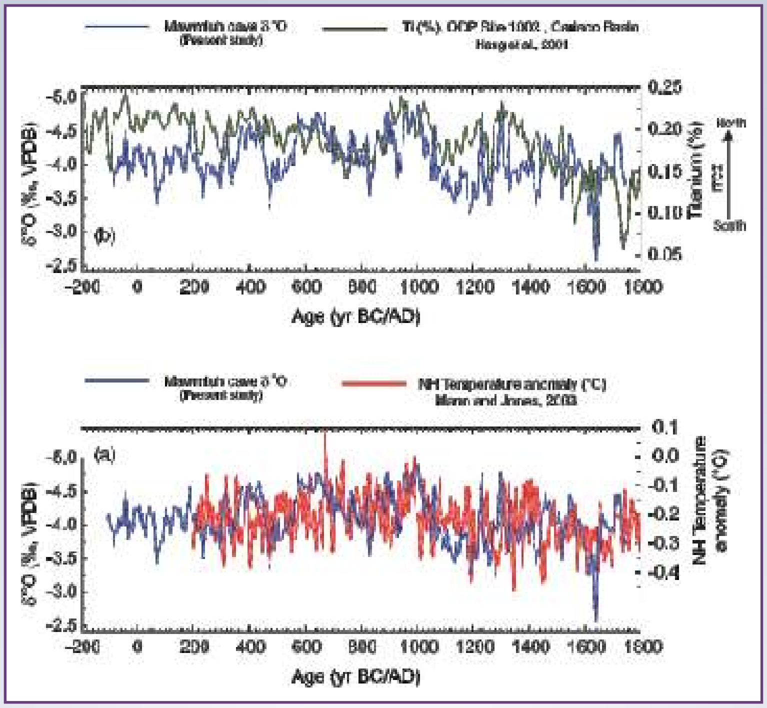


Fig. 14: (a) δ18O record of ISM variability from the Mawmluh cave for the interval 112 BC to 1752 AD compared with Northern Hemisphere Temperature Anomaly, and (b) δ18O record of ISM variability from the Mawmluh cave for the interval 112 BC to 1752 AD compared with Ti (%) record of ITCZ migration from ODP Site 1002, Cariaco Basin.

southward shifting of Inter-Tropical Convergence Zone played a major role in modulating the strength of the ISM over the last two millennia. Another study indicates a general agreement about the weakening of the ISM driven by 4.2 ka drought event. It has been observed that the duration of dry phase varied greatly across different parts of the Indian subcontinent, lasting ~1000 yrs in the western Himalaya, central Himalaya, western and northwestern India and southern India, whereas 200-300 yrs in northeastern and northern India. The strengthening of El Niño-Southern Oscillation at ~4.3 kyr BP and southward positioning of the Inter-Tropical Convergence Zone could be one of the most important factors driving such a prolong weakening of the ISM in the Indian subcontinent across the 4.2 ka event.

Tree-ring chronologies of Himalayan birch and Himalayan pine developed from their respective upper most forest limits in Gangotri glacier forefields showed role of temperature in modulating growth pattern of trees. A comparison of Himalayan pine chronology with temperature proxies revealed regional and hemispheric scale temperature signal. Using tree-ring chronologies, expansion (retreat) of the Gangotri glacier during cool (warm) phases was indicated and using tree colonization pattern, it was established that the Gangotri glacier terminus receded ~1.853 km since the late 16th century (1571 C.E.), major part of which (1.79 km) receded since 1935, that got accelerated since 1957 (1.567 km) with the onset of the 20th century warming. With the projected warming in the 21st century in the Hindu Kush-Himalaya, the Gangotri glacier might face accelerated recession on unprecedented rate as ever experienced in past 447 years.

Tree-ring based temperature reconstructions from the Himalayan region were also analysed and it has been observed that temperature reconstructions available so far have largely demonstrated consistency on decadal and inter-decadal scales. However, there existed glaring anomalies especially in case of the extreme years coinciding with the volcanic eruption associated cooling and suggested that the tree-ring chronologies showing direct relationship with temperature should be used in temperature reconstructions.

Besides, tree-ring δ18O based June-July rainfall reconstruction (1743-2015 CE) developed from Dingad valley, Uttarakhand were also analysed. The reconstruction was found consistent with instrumental records and proxies from different regions. Such consistency revealed the capture of regional scale rainfall features in reconstructed data testifying its utility in understanding of Indian summer monsoon rainfall variability in long-term perspective. Decreasing rainfall trend since 1743 CE is also consistent with other monsoon rainfall proxies from a large part of the south Asian monsoon region (India, Nepal, Bhutan, Myanmar and Tibet Plateau).

Growth rings of 150 cores of *Abies spectabilis* and 67 cores of *Cedrus deodara*were dated to the level of calendar year of their formation. The growth rings of Juniper and Rhododendron species growing on the Dokriani glacier moraines were also dated.

Stable carbon isotope ($\delta^{13}C$, ‰ VPDB) and total organic content (TOC, wt %) records from palaeolake sediment profile of Chamoli Garhwal divulge common response to Indian summer monsoon precipitation over the past 5,300 years. $\delta^{13}C$ values vary between -24.32 and -26.89 ‰ with an average of -25.54 ‰ and hence, suggested that the region is dominated by the C_3 type vegetation. A high $\delta^{13}C$ values recorded between 5300 and 3230 yr BP indicate reduced moisture condition. This period was followed by a return to moist and humid environmental conditions in the Chamoli region resulting in progressive increase in grassland as indicated by the increased TOC (%) from 3230 to 1800 yr BP. This period was briefly interrupted by a centennial scale decline moisture phase from 2,560 to 2,300 yr BP. This phase coincides with the period of relatively low moist environmental conditions and also recorded in other regions of the Garhwal Himalaya. A cold-dry events recorded during ~1800 to 1030 and ~500 to 320 yr BP correspond to the Dark Age Cold Period and Little Ice Age, respectively. However, the intermittent warm and wet periods recorded during ~1030 to 500 yr BP correspond to the Medieval Warm Anomaly, respectively.

TAT -2.2

Aquatic geochemistry and morpho-tectonic studies in the Indus River system: Implications to denudation process and evolution of land forms in the Northwest Indian Himalaya

(Santosh K. Rai and A.K.L. Asthana)

Major ions and stable isotopes were used to infer about the process of silicate weathering occurring in the Indus river system that could be mediated through CO_2 or H_2SO_4. Co-variation of [HCO_3+SO_4] with [Ca+Mg] hints that the alkalinity in these rivers may be originated with silicate weathering mediated either by H_2SO_4 or dissolution of Halites. Therefore, the study makes a case for the possibility of silicate weathering mediated by the H_2SO_4 which consumes no CO_2 from the atmosphere. Further, the measurement protocols for determining the isotopic composition of Lithium (^{7}Li) was also developed to trace the process of silicate weathering. In addition a time series analyses of $\delta^{18}O$ & δD in Himalayan snow was used to track the changes in the moisture pattern in the Indus catchment. Strong variation in the *d-excess* (δD- 8*$\delta^{18}O$) values (33-7) suggests about the multiple sources of moisture contributing to the precipitation in the northwest Himalaya covering annual cycle. A field work was conducted in the Beas river system covering Himachal Pradesh and Ladakh region to understand the hydro-morphological features of the river. The study area of Beas river basin is situated between Latitude 31^{0}45'N to 32^{0}25'N and Longitude 77^{0}00'E to 77^{0}25'E covering an area of ~1,500 km^2. The seventh order upper Beas basin in the study are a shows that the network has developed through along period of time and is well knitted. It also brings out the strong relationship of lithological control on drainage network development. Higher order trunk stream has greater ramification and larger aerial extent of the drainage basin. The bifurcation ratio serves a very useful purpose in enumerating the stream order. The decreasing value of bifurcation ratio and length of the stream with increasing order represents a well-developed mature stage of drainage network system. The morphometric analysis of the river Beas basin in the study are a has been done in three main aspects i.e. linear, aerial and relief aspect of morphometric parameters.

TAT 2.3

Past 2 ka climatic variability in Himalaya using multiproxy and multi-archival records

(Narendra Kumar, Narender K. Meena, Sudipta Sarkar and M. Prakasam)

Fieldwork was carried out in Himachal Pradesh and Uttarakhand to collect samples from Chitkul and Sangla (HP) and from Koti - Kanasar (Uttarakhand) and were studied for paleoclimatic reconstruction. Environmental magnetic data suggests four wet and warm events in the Chitkul peat deposit, whereas samples from Koti - Kanasar are being studied.

Renuka Lake: Nine sediment core samples from Renuka Lake (HP) northwestern Himalaya were studied for AMS ^{14}C age-dating at IUAC, Delhi, and seventy sediment core samples were analyzed for nitrogen stable isotope at Stable Isotope Laboratory in the Institute. One short core collected from ~1.3 m below the lake floor was analyzed for multi-proxy paleoclimatic study during the period 1840 – 2010 AD (Fig. 15). Geochemical and clay mineralogical studies of the core revealed ENSO - Indian Ocean Dipole (IOD) interplay that affects the intensity of Indian Summer Monsoon (ISM). As a consequence, the negative ENSO and IOD resulted into weak ISM. Chemical index of weathering (CIW) data shows strong coherence with solar irradiance during 1840 - 2010 AD (Fig. 15). The diatom proxy during this period responds to the 20^{th} century global warming and climate change in the Himalaya. The study points that during 1840 - 1900 AD, the lake was not favourable for diatom growth, probably due to low productivity or inability to preserve diatoms. The first appearance of diatoms was recorded since 1903 AD, which seems to correspond to an increase in rainfall in this region (Sirmour at Nahan, HP). In 1940 AD, the population of diatom has increased drastically which coincides with "the great acceleration of the 1940s", when the drastic increase in temperature was recorded worldwide. The increased productivity during 1940 - 1972 AD is inferred from the expanded population of *Cyclotella* which prefer warm water condition and eutrophic - mesotrophic lake.

One long core extracted from ~8 m below the lake has also been analyzed for multi-proxy paleoclimatic study representing a time span of 100 - 2000 AD. Warm and wet climate prevailed during 890-1350 AD which coincides with Medieval Warm Period (MWP). The cold period during 1500-1800 AD corresponds to the Little Ice Age (LIA). The percentage of 'Al' shows good agreement with the Solar data. The post 18^{th} century warming shows similar pattern with the climate data of Central India. Thus, the last 2 ka multi-proxy climate records from the Renuka Lake responded to the major climatic events - MWP and LIA.

Rewalsar Lake: Five sediment core samples from Rewalsar Lake, located near Mandi in HP were studied for AMS ^{14}C age dating at IUAC, Delhi. The results show ~2800 yr old sediment records.

Sediment samples from around eleven meters depth of lake were analyzed for stable carbon isotope from the Rewalsar Lake. The carbon isotope values ranges from -26.81‰ to -17.17‰ (VPDB), which display the record of C_3 and C_4 vegetational changes and its related state of the climate. Enriched $\delta^{13}C$ during ~ 1000 to ~ 1975 AD suggests relatively drier climatic conditions during this period.

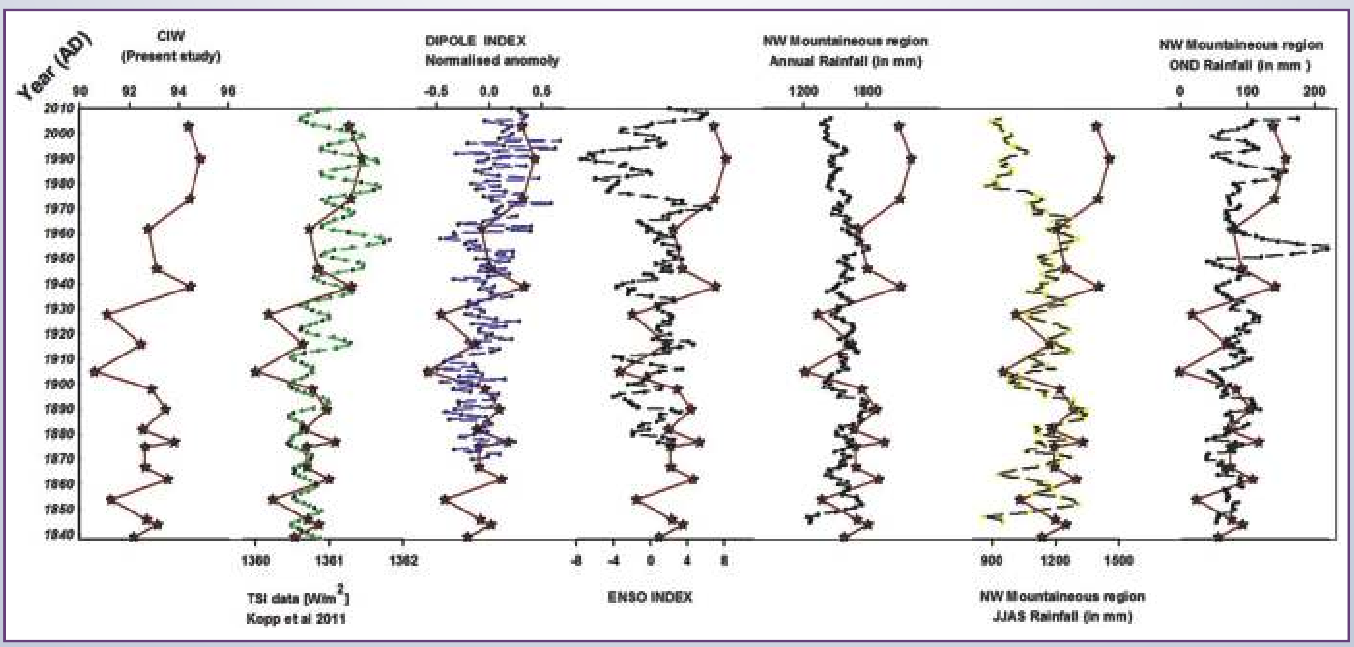


Fig. 15: Paleoclimatic record from the Renuka Lake, HP during 1830 - 2010 AD

TAT 2.4

Black Carbon monitoring in north-west Himalaya

(P.S. Negi and Chhavi P. Pandey)

In order to monitor the ambient Equivalent Black Carbon (EBC) concentration in the alpine ecosystem, especially in the Gangotri Glacier valley, EBC monitoring stations were established at Bhojbasa (3800 m asl) and Chirbasa (3600 m asl), near to Gangotri Glacier during previous years. Data was collected and analysed to understand the potential source of BC origin and its seasonal variability besides its potential interlinkage with regional meteorology and ground conditions including natural as well as anthropogenic factors. Due to inhospitable working conditions, baseline data on EBC is not available from most of the glaciated Himalayan region. This work provides the first real time and all weather measurement of ambient EBC mass concentration near the Gangotri glacier which is one of the largest glaciers in the Indian Himalayan cryosphere. EBC data has been corrected, processed and analysed and it has been noted that there is a significant variation in EBC concentration ranging from 0.01µg/m^3 to 4.62µg/m^3 during the preceding year. The diurnal variation ranges from 0.1µg/m^3 to 1.8µg/m^3.

The monthly mean concentration of EBC varies from a minimum of 0.087±0.046 µg/m^3 in August to a maximum of 0.823 ± 0.711 µg/m^3 in May. The monthly and seasonal variation in EBC mass concentration is depicted in figure 16.

Comparison with BC mass concentration recorded over other high altitude monitoring sites in India and adjoining countries has also been carried out. Being a pristine locality, the observed EBC concentration is far below from the Indian and global limit of the respirable pollutants, i.e. 60 µg/m^3 and 25 µg/m^3. However, observed BC concentration is likely to change the radiation budget that onward influences the ecosystem characteristics and associated natural resources. The analysis of HYSPLIT backward air-mass trajectories and the active fire spots distribution from the MODIS, meteorological data and ground survey indicated that seasonal cycle of EBC was significantly influenced by the prevailing meteorological conditions and the continental (Mediterranean region) as well as the long range-short range transport (Indo-Gangetic plain) of BC coupled with BC emission at local scale due to burning of biomass (forest-firewood) and fossil fuel.

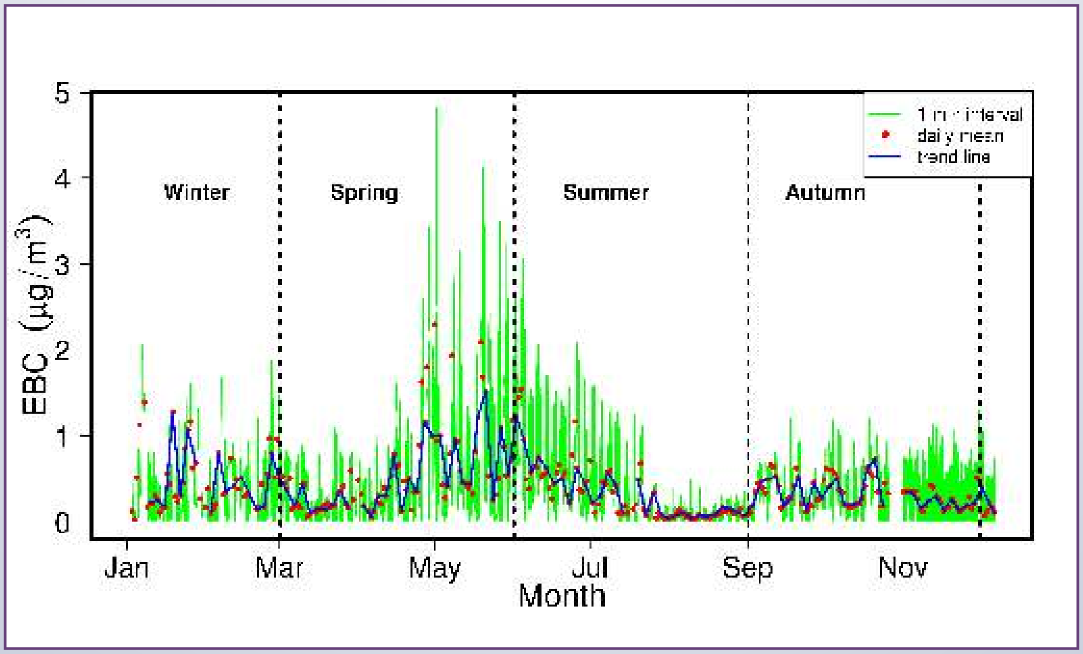


Fig. 16: Plot depicting the seasonal variation in EBC mass concentration

TAT 2.5

Late Quaternary summer monsoon variability and its connection with erosion in the western Himalaya from Site U1457, Arabian Sea

(Anil Kumar and Som Dutt)

The multiple proxy data from grain size characterization, environmental magnetic parameters, elemental ratios and clay mineralogy has been used to understand the defined objectives of the project. Grain size and bulk magnetic susceptibility provided sedimentation history in the Indus Fan, Arabian Sea. The transportation of coarser fraction to the distal Indus Fan is controlled by sea-level change (Fig. 17).

The high fluctuation in coarse silt concentration and End Member 3 (EM3: represent high hydrological conditions) content suggests significant instability in the hydrologic energy conditions. The abrupt fluctuations in the coarse silt and EM3, as well as χlf, suggest a rapidly changing erosional flux, possibly linked to climatic conditions. Weakening in monsoon precipitation as well global cooling is marked from reduction in the atmospheric carbon dioxide (CO_2), enrichment in the $\delta^{18}O$ from speleothem records of the Bittoo cave (NW India), and a drop in the Mg/Ca values indicator of sea surface cooling in the Indian Ocean.

These observations require an explanation as to why higher coarse silt and χlf are associated with a cold and dry climate during falling sea-level and deteriorating climate. Globally, sea-level fell during ~200–130 ka, suggesting ice-volume increase in the northern hemisphere. The falling base level would have driven incision and an increase in the coarse silt fraction into the deep water. The increase in coarse silt and EM3 implies sediment transport by erosion of the delta and shelf areas, as well as the Indus canyon. Low sea-stand caused incision in the delta, canyon and fan area. Magnetic properties suggest prior to ~ 130 ka, the major sediment contributor to the distal Indus Fan (drilling site U1457) was the Narmada River system. The $^{87}Sr/^{86}Sr$ ratio (varying from 0.7154 to 0.7255) and εNd (varying from -12.9 to -9.5) imply a mixing of sediments derived from not only the Indus River but also the rivers draining the Deccan Traps. The variations in the smectite/(illite + chlorite) ratio combined with Sr/Nd isotopes permit the reconstruction of past changes in the relative proportions of sediments derived from the Indus River.

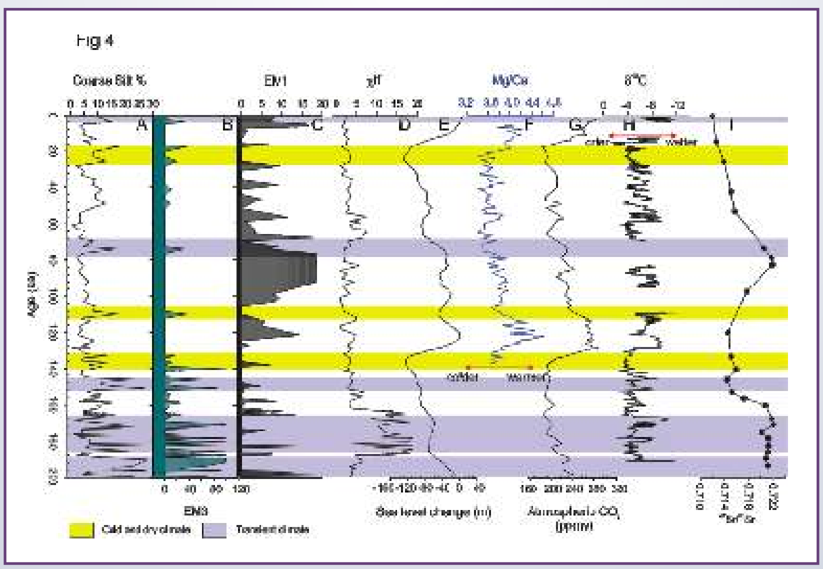


Fig. 17: (A) Variation in the coarse silt fraction, (B) End Member 3 (EM3), (C) EM1, and (D) magnetic susceptibility (χlf) values from the Site 1457 Laxmi Basin, Arabian Sea. These dataset is correlated with (E) the Global sea-level fluctuation, (F) sea surface temperature in the Arabian Sea reconstructed from Globigerina ruber (white) Mg/Ca ratio (in blue line). (G) Global atmospheric carbon dioxide (CO_2) from Vostok Ice Core, Antarctica, (H) monsoon precipitation record from speleothem samples, Bittoo cave, NW India and (I) detrital $^{87}Sr/^{86}Sr$ isotopic ratio from Site U1456, Laxmi Basin, Arabian Sea to delineate the source of the sediment. The purple bar represents the transient climate from the warmer to the cold and yellow bar cold climate and least sea-level.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEO HAZARD EVALUATION

TAT 3.1

Seismological, seismotectonic and subsurface related studies hazard evaluation from the NW Himalaya, Ladakh & Jammu & Kashmir regions

(Sushil Kumar, Ajay Paul, P.K.R. Gautam, Narendar Kumar, Chhavi P. Pandey and Parveen Kumar)

The Himalaya continues to rise as plate tectonic activity drives India into Eurasia. The compression from this collision results in severe seismic activity along the facade of the range. Stress builds continually along faults in the region, until it is released through earthquakes. Tectonic earthquakes are the most common of all natural earthquakes. Each one of them is associated with faulting in rocks, a fault being a shear fracture in which rocks on its two sides undergo relative slip parallel to the discontinuity surface. Although some of them may be associated with formation of fresh faults in rocks, most tectonic earthquakes occur due to renewed slip on pre-existing faults. The understanding of earthquake source processes and the medium characteristics provides the basic tools for the assessment, mitigation and reduction of seismic hazards. To obtain these objectives, Institute is operating a regional seismic network in the NW Himalaya and adjoining regions (Fig. 18) to address the seismotectonics and the evolution of stress pattern of the region.

Source parameters and moment tensors Studies of the February 06, 2017 Mw5.7 Garhwal Himalaya Earthquake

The Garhwal Himalaya lies in the central seismic gap (CSG) zone between 1905 Kangra earthquake (Mw 7.8), India and the 1934 Bihar-Nepal earthquake (Mw 8.0), India-Nepal border. The strain energy stored in the CSG is enough for a great earthquake in near future. The

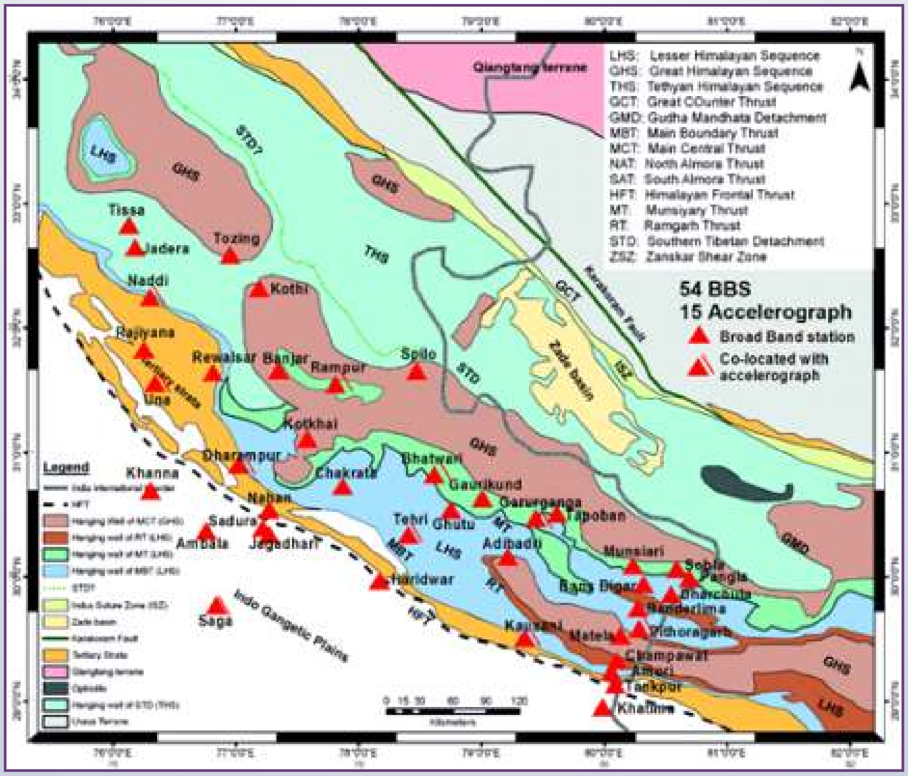


Fig. 18: Seismic Network of the Wadia Institute of Himalayan Geology (Stations located in the Ladakh and Jammu & Kashmir regions are not shown in this map)

two recent moderate earthquakes in Garhwal region are Mw 6.5 Uttarkashi earthquake (1991) and Mw 6.6 Chamoli earthquake (1999). After the Chamoli earthquake, the largest earthquake occurred in this region is the moderate earthquake Mw 5.7, which occurred in the Garhwal Himalayan on 6th February, 2017 (17H: 03M: 04S UTC). Further this earthquake is important and draws attention as it occurred at about 24 km northwest of the epicentral location of the 1999 Chamoli earthquake. This earthquake is very well recorded at seismic array operated by WIHG and it has provided an opportunity to constraint on the elements of seismotectonic model with better accuracy. Its epicentre (30.586°N, 79.104°E) is positioned on the Munsiari Thrust which is a part of the Main Central Thrust (MCT). The centroid depth calculated utilizing the grid search with a fixed epicenter inversion approach placed the hypocenter at the down dip edge of the Main Himalayan Thrust (MHT) plane at 10 ± 2.2 km depth which coincides further with the ramp part of the flat ramp flat geometry of the plane in the region. The source parameters computed shows a 225°N oriented northwest-southeast strike direction and a dipping of 19° towards northeast and a rake of 4°. This clearly signifies an oblique thrust movement along the footwall of MCT resulting from dipping of the MHT along the Mid Crustal Ramp (MCR). The present study signifies the seismic hazard in the region with emphasis to current seismotectonic scenario prevailing in the Garhwal Himalaya, India (Figs. 19 & 20).

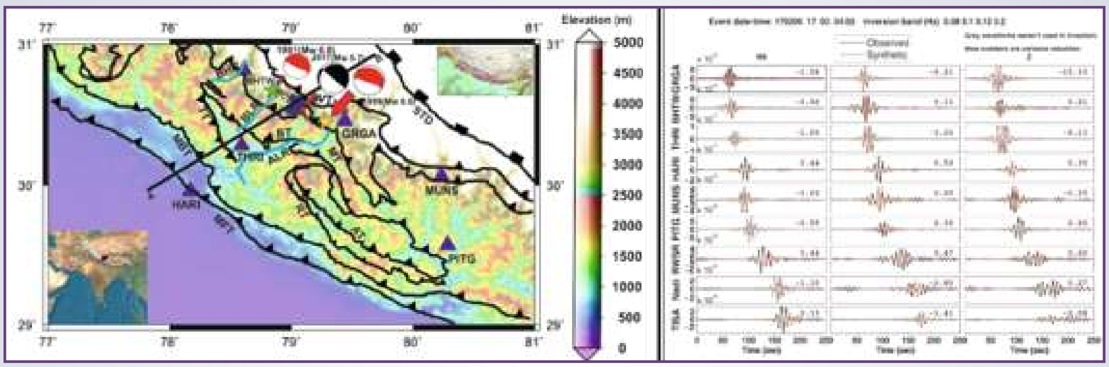


Fig. 19: Topographic map of the Garhwal Himalaya boxed in the inset map of India (below left panel) showing the locations of 12 aftershocks (blue solid circles) reported by Wadia Institute of Himalayan Geology, Dehradun (WIHG).

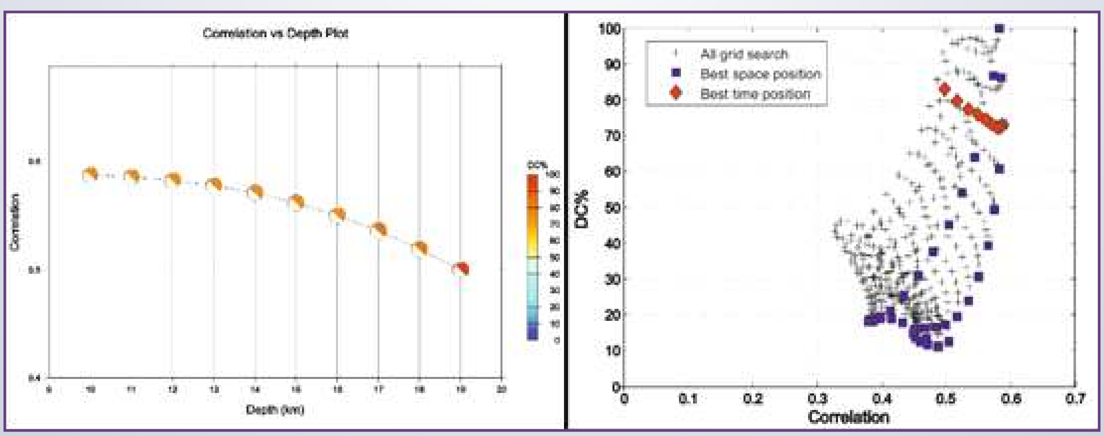


Fig. 20: Figure shows the normalised correlation plot between observed and synthetic wave form data. The observed seismograms were represented by black lines, whereas the synthetic waveform data were represented by red lines. The correlation factor between observed and synthetic data is represented at the upper right corner of each component inside the box. The seismograms were filtered in the frequency band of 0.05 Hz to 0.09 Hz and tapered between 0.04 Hz to 0.05 Hz and 0.08 Hz to 0.09 Hz. Stations Haridwar (HARI), Munsiari (MUNS) and Pithoragarh (PITG) were used in inversion. Other Figure signifies for the best time and source position with maximum correlation relationship for various source and time position utilizing the grid search method.

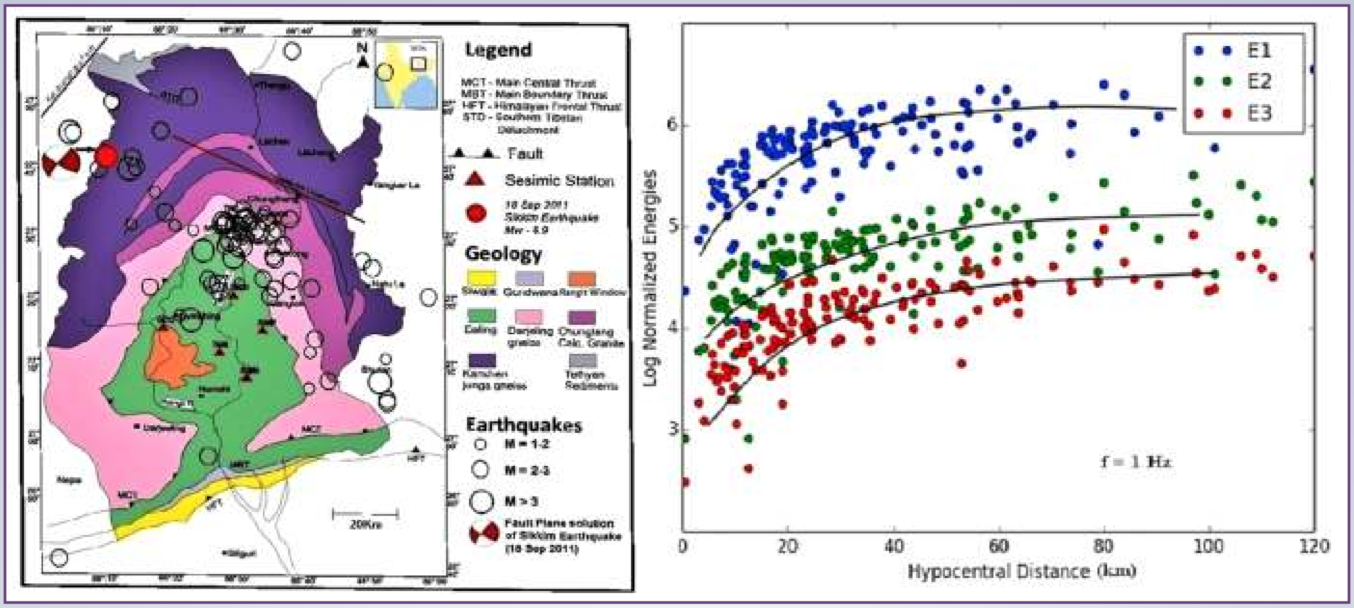


Fig. 21: (a) Plot of the earthquake's epicentres recording stations and other tectonic features on the geological map of Sikkim Himalaya and adjoining area and (b) Variation of Observed Log Normalized energies E1, E2, E3 with frequency centred at 1Hz for 0-10s, 10-20s, 20-30s, respectively with hypocentral distance is shown. The best fit curve used for estimating attenuation parameters is shown in black.

Source parameters of earthquakes are significant for understanding the dynamic rupture process. In a similar study on earthquakes of Garhwal-Kumaun region, the source parameters for 58 earthquakes ($3.0 \leq Mw \leq 5.0$) occurred during 2007-2015 have been evaluated. The scaled energy ratio of radiated seismic energy to the seismic moment is evaluated to determine the dynamic failure process of the events. The estimated scaled energy is consistent with global observations and it increases with moment magnitude. The estimation suggests the partial stress drop mechanism in the region.

Scattering and intrinsic attenuation studies in the Sikkim Himalayan region

An earthquake of 6.9 Mw occurred on18 September 2011 in the Sikkim region. WIHG deployed 8 temporary broad band seismometers and recorded 283 aftershocks with a magnitude distribution ranging from 1.02 to 5.0 (Fig. 21). The aftershocks have been analysed for the relative contributions of scattering attenuation and intrinsic absorption. It is estimated by multiple lapse time window analysis under the hypothesis of isotropic scattering and a uniform distribution of scatters in the crustal part of the study area. The coda wave attenuation was also estimated using single backscattering method. All of the attenuation parameters are estimated as a function of frequency in the range 1-16 Hz. The results show that scattering attenuation is greater than intrinsic absorption for all of the frequencies. The relative contribution of scattering attenuation decreases with increasing frequency. Around the 1-4 Hz frequency band, scattering attenuation primarily contributes to seismic wave attenuation in the Sikkim region. The estimated values of seismic albedo ranges from 0.65 to 0.79; as seismic albedo is higher than 0.5 for all frequencies, it is concluded that the medium in the Sikkim Himalaya is highly heterogeneous and is tectonically active. From this study, the knowledge of the attenuation mechanism of the Sikkim region is enhanced by the application of the multiple lapse time window analysis method, and results can be useful for the hazard assessment.

TAT - 3.2

Seismotectonics and subsurface structure investigation in the Siang Valley of the Eastern Himalaya, Northeast India

(D.K. Yadav, Devajit Hazarika, Naresh Kumar and A.K. Singh)

The northeastern part of India is seismically very active region and falls in zone V of seismic zoning map of India. Seismotectonics and subsurface structure of the eastern Himalayan syntaxis is poorly understood, so it is crucial to understand the geodynamics of the region. In

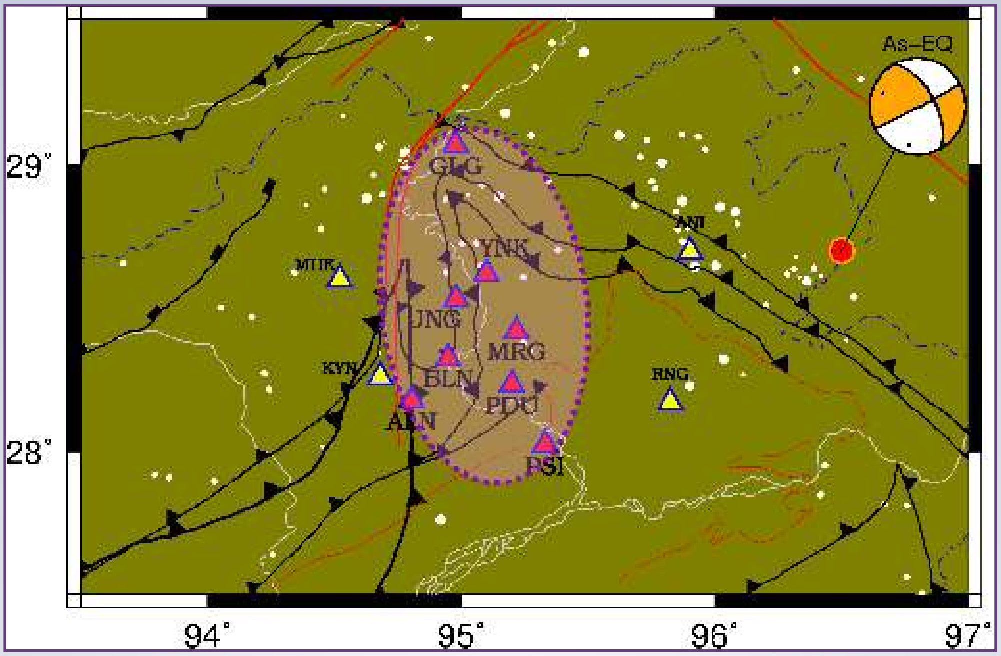


Fig. 22: Map showing major tectonic features of the Eastern Himalayan syntaxis northeast, India. The broadband seismological stations Network along Siang river valley is shown by pink triangles inside dotted ellipsoid, the yellow triangles are the proposed seismic stations in and around Siang Valley network of Arunachal Pradesh. The white circles with different size shows seismicity with earthquake magnitudes 5.0 and above (ISC- Bulletin) recorded during the period 1976-2018. Fault plane solution of the great Assam earthquake of 1950 was shown by orange beachball with Strike slip type of faulting.

this connection, two field visits were undertaken in the Siang valley. In the first visit, site selection for seismic network consisting of 8 Broadband Stations (BBS) was performed (Fig. 22). These were mainly chosen on the basis of local geology and tectonic setting and also at remote and approachable place with good signal to noise ratio (SNR). Six BBS were installed at the following locations:-

1. Pasighat, East Siang District, Arunachal Pradesh.
2. Boleng, Siang District, Arunachal Pradesh.
3. Along, West Siang District, Arunachal Pradesh.
4. Padu, Upper Siang District, Arunachal Pradesh.
5. Mariyang, Upper Siang District, Arunachal Pradesh.
6. Jengging, Upper Siang District, Arunachal Pradesh.

TAT 3.3

Timing, size, and lateral extent of earthquake ruptures along the Himalayan Frontal Thrust, Dauki-Dapsi and Naga Thrust, Schuppen Thrust Belt

(R.Jayangondaperumal Pradeep Srivastava and Swapnamita Vaideswaran)

The tectonic framework of NW Himalaya is different from that of the central Himalaya with respect to the position of the Main Central Thrust and Higher Himalayan Crystalline and the Lesser and Sub Himalayan structures. The former is characterized by thick-skinned tectonics, whereas the thin-skinned model explains the tectonic evolution of the central Himalaya. The boundary between the two segments of Himalaya is recognized along the Ropar–Manali lineament fault zone (Fig. 23). The normal convergence rate within the Himalaya decreases from c. 18 mm a^{-1} in the central to c. 15 mm a^{-1} in the NW segments. In the last 800 years of historical accounts of large earthquakes of magnitude Mw $\geq$ 7, there are seven earthquakes clustered in the central Himalaya, whereas three reported earthquakes are widely separated in the NW Himalaya (Fig. 24). The earthquakes in central Himalaya are inferred as occurring over the plate boundary fault, the Main Himalayan Thrust. The wedge thrust earthquakes in NW Himalaya originate over the faults on the hanging wall of the Main Himalayan Thrust. Palaeoseismic evidence recorded on the Himalayan front suggests the occurrence of giant earthquakes in the central Himalaya. The lack of such an event reported in the NW Himalaya may be due to oblique convergence.

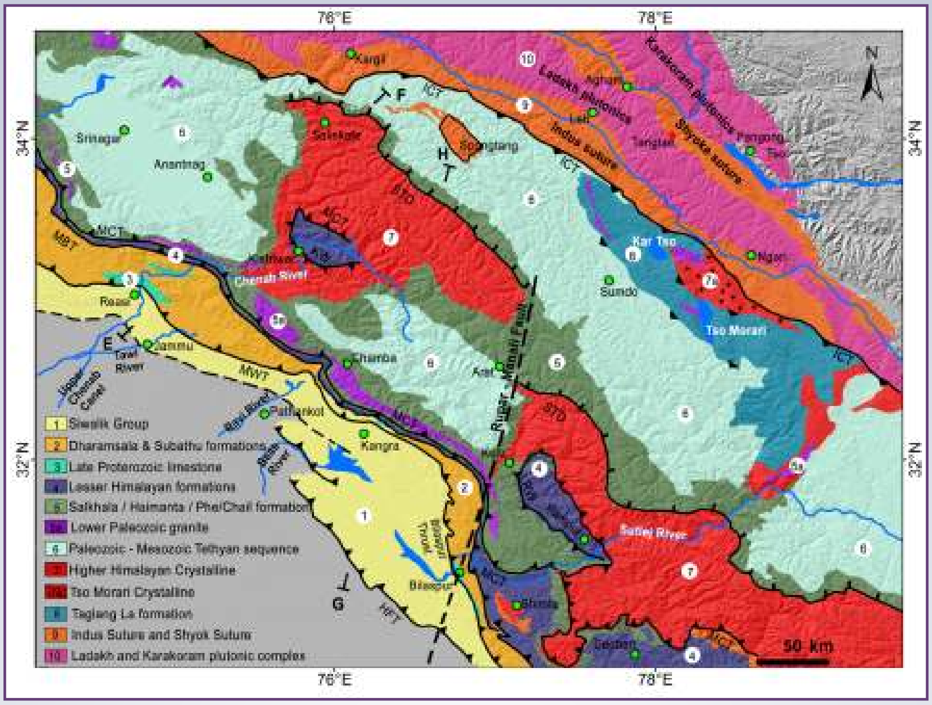


Fig. 23: Geological map of NW Himalaya (Thakur 1992). Distinctive features: HFT is non-emergent west of Beas in the Jammu region of Kashmir. Medlicott Wadia Thrust (MWT) separates the lower Tertiary belt of Murrees/Dharamsalas, Subathus and Late Proterozoic limestone from the main Siwaliks. Narrow lesser Himalayan Thrust sheet between the MBT and the MCT. The late Precambrian Jurassic sequence of Kashmir and the Chamba sequence correspond to the southern extension of the Tethyan zone. RoparManali Fault, earlier recognized as a lineament, is a dextral strike-slip fault, and appears to be an active fault.

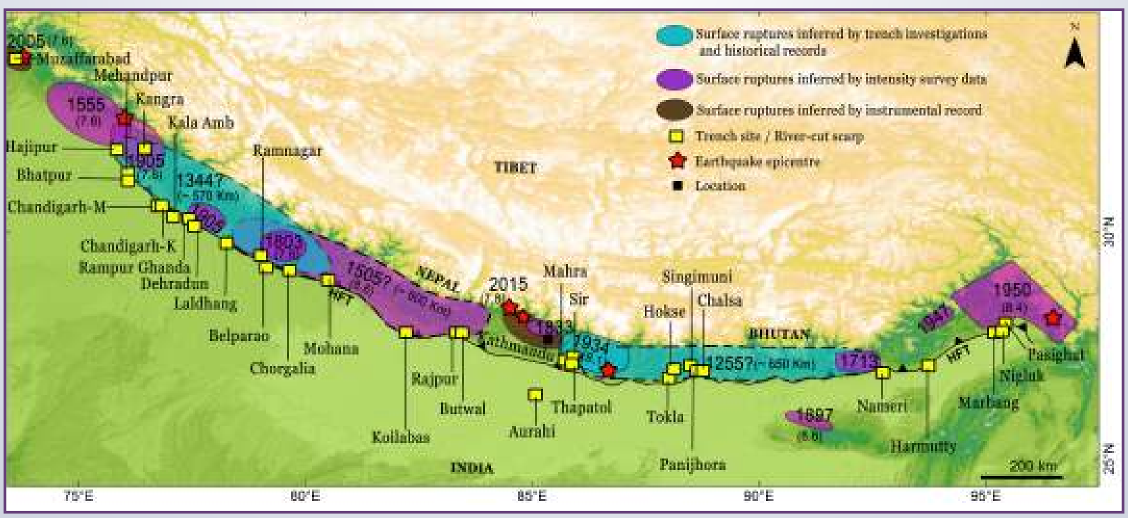


Fig. 24: A simplified map of the Himalaya and adjoining regions with demarcation of the Himalayan frontal fault (HFT/MFT) shows inferred rupture extent of large to great earthquakes derived through intensity data and historical record, instrumental recorded microseismicity, and palaeoseismological investigations along the Himalaya front (after Jayangondaperumal et al. 2017b). Palaeoseismological trenches are depicted in yellow squares: Hajipur, Malik et al. (2010a, b); Bhatpur, Kumahara & Jayangondaperumal (2013); Chandigarh (M), Malik et al. (2008); Chandigarh (K), Rampur Ghanda, Laldhang, Dehradun, Belparao, Chourgalia trench sites, Kumar et al. (2006); Mohanna, Yule et al. (2006); Botechaur, Upreti et al. (2000); Koilabas, Mugnier et al. (2005); Mahar Khola, Lave et al. (2005); Sir Khola, Sapkota et al. (2013); Chalsa, Nameri, Harmuty, Kumar et al. (2010); Marbang, Jayangondaperumal et al. (2011); Panijhora, Mishra et al. (2016); Pasighat, Priyanka et al. (2017); Nigluk, unpublished data.

TAT 3.4

Neotectonics between North Almora Thrust (NAT) and Himalayan Frontal Thrust (HFT) of Kumaun Himalaya: Implication to morphotectonic evolution

(Khayingshing Luirei and S.S. Bhakuni)

Neotectonic study was carried out between the North Almora Thrust (NAT) and the Himalayan Frontal Thrust (HFT) in the southeast Kumaun Himalaya. It is observed that as a result of relative movement of rocks along the Tanakpur Fault there is a sudden swing in strike of the bedrocks in Thuligaon-Pot area of Tanakpur (Fig. 25a). Around the fault, the strike became NNE-SSW in western part and NNW-SSE in eastern part of fault. The Kali River cuts across the steeply-dipping Siwalik bedrocks (>70°) where the shape of the valley is V-shaped. The Main Boundary Thrust (MBT) separates the sandstone of the Siwaliks from the highly crushed volcanics of the Bhimtal volcanic rocks. The MBT is also a morphogenic structure where breaks in the topography including hill and valley slopes are observed. Linear trace of fault parallel to the MBT is also observed in the MBT zone, e.g. the Ladhiya river, a major tributary of Kali River, flows almost along the Ladhiya Fault which is parallel to the MBT. Along the fault, the river valley is very wide in Chalthi and towards upstream also, and maximum width of the valley varies between 0.8 and 1.0 km. The bedrock is made up of highly crushed quartzite of the Nagthat Formation and the highly crushed nature of the rocks points towards repeated crushing events during the movement along the Ladhiya Fault. A broad synclinal structure is observed between the Himalayan frontal Thrust (HFT) and MBT. In the core region of syncline, normal faults related lakelets have been farmed by faulting. Linear trend of paleolakelets suggests a normal fault lineament. In the HFT zone at Senapani the uplifted strath terrace is made up of black shales of pre-Siwalik rocks which are highly sheared and is overlain by highly sheared sandstone of Siwaliks which in turn is capped by Quaternary deposits (Fig. 25b). The tilted Siwalik bedrock is overlain by 2 m thick deposit of tilted conglomerates which in turn is overlain by a sand deposit of more than 26 m in thickness (Fig. 25c). The bedrocks dip 47°-60° towards NW (305° to 345°) while

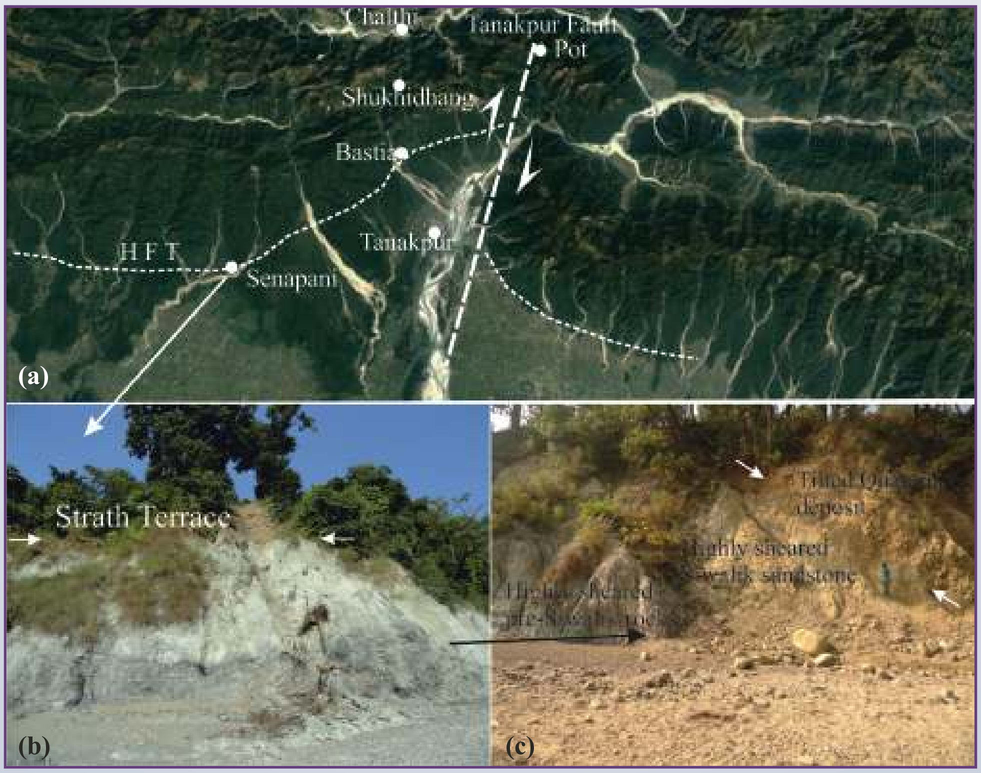


Fig. 25: (a) Google earth image showing displacement of the mountain front as a result of Tanakpur Fault. (b&c) Strath terrace that result from the uplift along the HFT, the bedrock and the overlying Quaternary sediments are tilted moderately towards northwest.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEO HAZARD EVALUATION the Quaternary deposits are tilted 44° towards 357° while the topmost layer of the terrace (sand) is tilted 10° towards 345°. The tilted Quaternary deposits points towards tectonic activity after the deposition of the terrace. Further towards the upper part of terrace soft sediment deformational structures are observed, which indicate later phase of tectonic activity along the HFT. These types of evidences so far have not been reported from the immediate hanging wall of the HFT from other parts of the Himalaya.

Transverse Topography Symmetry Factor (T) has been computed from the eastern part of the outer Kumaun Lesser Himalaya. The Lohawati river basin has been considered for the computation of this index and has catchment area in the Lesser Himalayan province. A total of 529 transverse topography symmetry factors (T) have been generated from the topographic map and these are subdivided into two i) Axial river of the Lohawati river and ii) tributaries of the Lohawati river. The T values range from 0 to 0.9, with maximum migration towards 271-360°. The average T value for 379 data for the tributaries sub-basins is 0.3788 and mean migration is towards 206°; while the average T value for 150 data for the Axial Lohawati river is 0.334 towards 132.76°. In the axial river, the migration is towards NE excepting a few migrating towards the NW and SE. The maximum data (0.9) suggests that in some cases streams have migrated much distance indicating tectonic tilting that led to the migration. The average T value for the entire Lohawati basin is 0.336 and the mean migration is towards 185.72°. From the obtained T values, it is observed that out of the 529, total values of T, 134 fall in 1st quadrant, 156 fall in 2nd quadrant, 41 fall in 3rd quadrant and 198 fall in 4th quadrant, representing 25.33%, 29.48%, 7.75% and 37.42%, respectively. This shows that maximum migration direction is towards NW followed by migration towards the SE. Tilting of the blocks may be as a result of m various reasons, e.g. lithological contrast, drainage densities, joints and structure of the underlying rocks. The ratio of valley floor width to valley height is an important parameter to know the relative tectonic activity of the area. For this study Vf of Lohawati river has been calculated from near it source to near its confluence with the Kali River. Vf of 40 valleys, the cross-sections have been computed with equal distance apart. The average Vf is 1.928 that suggests that the valley carved out by the narrow Lohawati river, which suggest down-cutting by the rivers. Down-cutting by stream or rivers is an indication where the area is rapidly uplifting. In stable region stream/river action is characterized side wise erosion while in an active area it is characterized by down-cutting. The Vf values range from 0.454 to 7.625. Lower average of 1.165 is observed towards the confluence section of the basin with the Kali River. The Lohawati river does not cut across major intracrustal boundaries such as the South Almora Thrust and the Ramgarh Thrust. Higher values of Vf are observed in the headward region, which in the field is supported by a relatively broad flat stable area of the Champawat, which suggests a major topography that reflected by broad stream and river valleys. The lower values near the confluence may be due to higher erosion by the Kali River than the Lohawati river.

TAT 3.5

Late Quaternary landform evolution and active tectonics in the selected segments of northwestern Sub Himalaya between Kali-Ganga-Beas rivers

(G. Philip, N. Suresh, Gautam Rawat, S. Rajesh and P.K.R. Gautam)

Field work was carried out in the Sub-Himalayan region between Ramnagar and Haldwani (between rivers Kosi and Gaula) to study Quaternary landforms and document signatures of active tectonics. Topographic maps and Google Earth images were used to delineate the geomorphic and tectonic features. Alluvial fans, river terraces and up warped areas were identified and dated in the Kota-Pawalgarh duns, along Himalayan frontal Thrust and along the Kosi River. Timing of the aggradation and incision of the alluvial fans in the Kota Dun has been established using quartz OSL dating. The fans aggradation were initiated before 26 ka and stopped after 11 ka followed by river incision due to climate change. Holocene tectonic movements in the region have been identified. At the proximal part of the fans, the Lower Siwalik Subgroup rock is riding over the fan sequences along the NW-SE trending Dhikala Thrust. The multiple displacement of the fan head sediments along Dhikala Thrust suggests recurring tectonic movements since 11ka. At the frontal hills along HFT, separating the Duns from Indo-Ganga Plain, vertical scarp have been observed between Gaibua and

Kaladhungi stretch. The HFT is segmented and lateral shifts were observed along transverse faults. At places, drainage deflection and abandoned channels were also recognized. The Dabka River has abandoned its course and deflected to the west and also show knee-bend deflection in the downstream. In addition, signature of active tectonics was documented between Ramnagar and Tanakpur areas in the Sub-Himalaya.

Electrical resistivity across HFT at Pattapani and Dhikala Active Fault

Non-invasive geophysical techniques were employed across the HFT at Pattapani near Ramnagar and across the Dhikala Thrust at Siyat in the northwestern Frontal Himalaya to understand shallow subsurface geological structures and their nature in relation to active tectonics. At Pattapani 155 meter length of ERT profile is covered using 32 electrodes at 5m electrode spacing. Schulmberger and Wenner configurations are utilised for recording electrical potential and induced potential. Apparent resistivity is calculated using these observed potentials. These apparent resistivities are inverted for 2D resistivity section. Iterative Incomplete Gauss newton method were used to solve the least square equations of inversion scheme. Smoothness constraints were applied on model resistivity values as well as model perturbation vectors also. The final inversion is achieved in 5 iterations with absolute error 5.8 of convergence. The inverted resistivity model has lateral and vertical resistivity variations according to lateral and vertical extent of different depositional units in the area. Presence of north dipping fault at 45m distance from zero electrode position towards south clearly distinguishes two separate zone of lithology. The fault imaged in the ERT profile appears to be the splay of the HFT and suggest the reactivation of HFT in the recent geological past (Fig. 26). The study in correlation with other segments of the HFT indicates that the tectonic front of the Himalaya has been repeatedly active in the recent geological past. The timing and the slip rate can be estimated only after the trench excavation which is already scheduled in this area.

At siyat in Kota Dun. Kumaun Himalaya a 294m long profile is covered with 43 electrodes using 7m electrode spacing. Schulmberger and Wenner configuration is utilised for recording electrical potential and induced potential. The Dhikala thrust which is dipping towards north 40^{o} is imged in the profile. The thickness of the overburden (Quaternary alluvium) in the hanging wall of the Dhikala Thrust is estimated to be 25m. The ERT imaging reconfirms the Quaternary tectonic activity in the Kota dun. The slip rate and the chronology of the tectonic events can be assessed only after a trench excavation survey in the across the thrust.

Geodetic studies

One of the objectives in the project is to correlate the long (Geological) and short (Geodetic) term deformations related with the frontal HFT and the associated Active faults in the study area. HFT is the southernmost Plate boundary fault and situated right over the southern trailing portion of the locked zone of the Main Himalayan Thrust (MHT). Palaeoseismological investigations had identified numerous active fault systems that appear sub-parallel and umbilically linked with the HFT. So far there were no instrumental (GNSS) observations along these active fault systems in the frontal Himalaya and hence we do not know the interplay of strain distribution between these Active fault systems vis. a. viz with the HFT. This necessitates the need to monitor active fault systems in conjunction with the HFT in order to unravel the slip rates and other deformation parameters through the correlation of Geological and Geodetic methods.

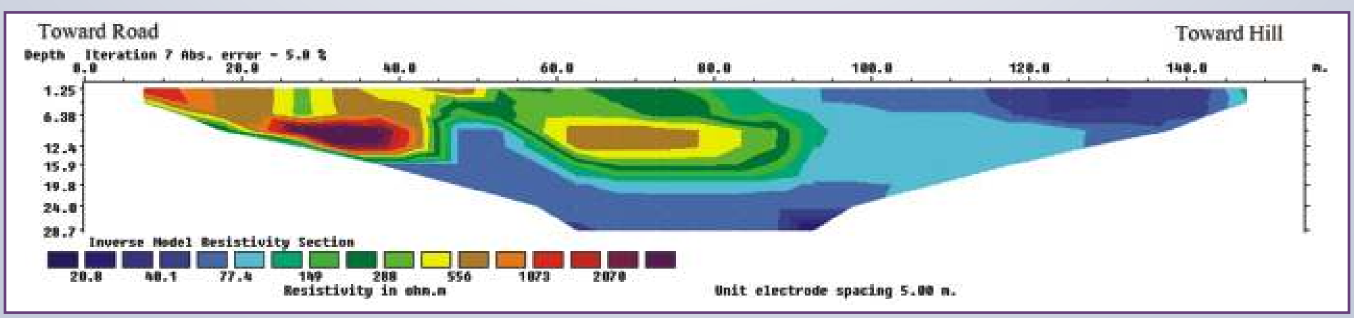


Fig. 26: ERT profile across the HFT at Pattapani showing the subsurface structure

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEO HAZARD EVALUATION

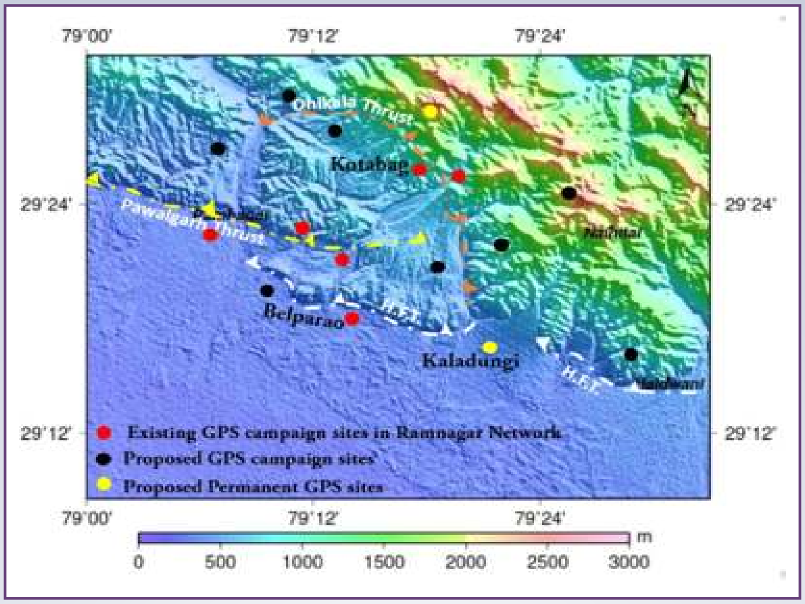


Fig. 27: Location of GNSS based Active Fault Deformation monitoring at Pawalgarh and Dhikala Thrust in the Ramnagar-Haldwani area

Accordingly, two active fault systems; namely, the Pawalgarh and the Dhikala thrust in the Ramanagar - Haldwani area have been selected as a test case, where a close network of GNSS stations was installed for the periodic survey. The network comprises six stations covering both these faults and semi-permanent GNSS antenna fixing points were constructed for the repeated observations at locations shown in figure 27. First set of data at all these points were acquired during a campaign held in the month of March 2019 and the data is currently under pre-processing.

Apart from the Ramnagar network, we have simultaneously developed a parallel network (Haridwar network) close to the Ganga Tear by adding two more repeated GNSS observation points at the Mansa and Chandi Hills, where geological uplift and subsidence rates were earlier reported. In the Haridwar network the results from two permanent GNSS stations re-confirms the surface displacement predominantly along the Arc of the HFT with a minor displacement across the Arc component. The preliminary observations suggest that the deformation of HFT that situated right over the trailing locked portion of the HFT is getting accommodated along the Arc rather than across the Arc of the HFT. However the challenge is to comprehend a distinct picture on this style of accommodation happening everywhere along the HFT. In such case it is important to understand how this accommodation is influenced by the feeder active faults. Perhaps this can be answered by augmenting more data to be acquired by two more periodic observations from the above network.

TAT 3.6
Evaluation of Geomorphic Hazards in the selected transacts of Uttarakhand and Himachal Himalaya

(Vikram Gupta and Ajay Paul)

Landslide hazard has been studied in different river valleys in the state of Uttarakhand and Himachal Pradesh. Besides, an inventory of active landslides have also been compiled for both the states. The main emphasis has been in the Satuj river valley in the Himachal Pradesh and Yamuna and Kali river valleys in the Uttarakhand. In order to understand the spatial distribution of landslides in these valleys vis-à-vis various geological and geomorphological factors, geomorphic indices like steepness index (K_s), valley floor width to valley height ratio (V_f), swath profile have been computed. These indices have invariably been used to represent the tectonic regime of the region. Usually, higher K_s represents high uplift region and low K_s to low uplift zones. The higher V_f values generally characterize broad, flat-floored valleys, and lower V_f characterize 'V' shaped valleys. The 'V' shaped valleys are usually associated with areas undergoing rapid uplift and valley incision. It has invariably been noted that tectonics induced rockfall are characterized by the higher K_s and lower $V_{f,}$, whereas debris slides are generally characterized by lower K_s and higher $V_{f,}$. However this is not true for the man-induced landslides.

Besides, an isolated landslide, near village Khotila in Dharchula region in the Kumaun Himalaya has been studied for its geological and geotechnical characterization as this is posing serious threat to the local habitants of the village and also the habitants of Bangabagar village located in Nepal opposite to the landslide face.

The peak ground accelerations (PGA) have also been evaluated in the Garhwal-Kumaun region. This region is sandwiched between the epicenter two great earthquakes (i) 1934 Bihar-Nepal earthquake and (ii) 1905 Kangra earthquake. The analysis include (i) checking the consistency of the attenuation relation and (ii) calculating PGA values to draw its contour map. The PGA contours drawn for the 2007 - 2015 seismicity show that the trends of peak values following the trend of MCT and there is a narrow zone of microseismicity that prevails in the region. The peak values of 21.5 gals and 13.7 gals were obtained for the Uttarkashi and Chamoli regions. These values are far too low as compared to the observed PGA values of the two moderate earthquakes of recent past in this region (i) 268 gals at Uttarkashi for Mw6.8, 1991 Uttarkashi earthquake and (ii) 262 gals at Gopeshwar for Mw6.6, 1999 Chamoli earthquake.

TAT - 4: BIODIVERSITY - ENVIRONMENT LINKAGE

TAT 4.1

Paleobiological study of the Neoproterozoic-early Cambrian sequence of Carbonate belt, Lesser Himalaya and their interpretation in terms of palaeo- environment and correlation of evolutionary trend with global bioevents.

(Meera Tiwari)

Diverse well preserved organic- walled and biomineralised microfossils have been recovered from Infrakrol, Krol C- E and chert phosphorite member of Tal formations. The organic walled microfossils present are mainly filamentous & coccoidal cyanobacteria and sphaeromorphoc and acanthomorphic acritarchs and biomineralised microfossils are mainly sponges. Newly discovered microfossils in the Krol Fprmation are *Eomicocoleus* sp., *Archaeophycus yunnanensis*, *Gloediniopsis lamellosa*; *Sphaerophycus medium*; *Eogloeocapsa bella*; *Huroniospora psilata*; *Leiosphaeridia minutissima*; *L. jacutia*; *Schizofusa* sp. *Tianzhushania spinosa; T.polisiphonia; T.sp., Papillomembrana compta; Granitunica mcfaddina*. The Chert- phosphorite member of the Tal Formation contain *Paleopleurocapsa wopfernii; P. fusiforma; S. medium; Obruchevella parva; Glodiniopsis lamellosa; Archaephysis yunnanensis; Huroniospora sp.; Leiosphaeridia minutissima; L.jacutia; Micrhystridium tornatum*. The sponges are mainly siliceous and are represented by isolated and clustered monactins and hexactins. Their presence within the assemblage is important as sponges are considered as primitive metazoans based on the study of their molecular phylogenetic analysis and have been suggested to diversewith each other and with oxeas and hexactines around 750 -635 ma. The Precambrian sponges could not get fossilized easily as they were soft bodied and the spicules were scattered within the mesohyle. The sponge *Paradiaginella* has irregularly arranged sub quadrules consisiting of ranked stauractines. *Paradiagonella*can be easily differentiated from protospongiids having regular meshes of hexactines. Though it has ranked the obliguily oriented stauratines that are slightly similar to those of *Diagonella*, but it does not possess regularly arranged principal stauractines with parallel arrangement of stauractines of different rank like *Paradiagonella*. The occurrence of various sponge spicules belonging to class hexactinellida along with *Paradiagonella*, trichimella sponge larva, cyanobacteria and acritarchs indicate that a shallow stromatolitic environment was present at that period of time which was the most comfortable zone for these microorganisms to thrive.

TAT 4.3

Biotic investigations of Early Tertiary successions from NW Sub-Himalaya and western India with reference to India-Asia collision and faunal dispersals

(K. Kumar - till Sept. 2018)

The study of Eocene vertebrates from the Himalayan and peninsular sections and their palaeogeographic implications was continued. The dentition of *Cambaytherium* was investigated in terms of dental wear, tooth replacement and enamel microstructure. The postcanine tooth row shows a significant wear gradient, with flattened premolars and anterior molars at a time when the last molars are only little worn. This wear gradient, which is more intensive in *Cambaytherium thewissi* than in *Cambaytherium gracilis*, and the resulting flattened occlusal surfaces, may indicate a preference for a durophagous diet (Fig. 28). The tooth replacement (known only in *C. thewissi*) shows an early eruption of the permanent premolars. They are in function before the third molars are fully erupted. During the dominant phase I of the chewing cycle the jaw movement is very steep, almost orthal, with a slight mesiolingual direction and changes into a horizontal movement during phase II. The enamel microstructure shows Hunter-Schreger-bands (HSB) in the inner zone of the enamel. In some teeth the transverse orientation of the HSB is modified into a zig-zag pattern, possibly an additional indicator of a durophagous diet.

The anatomy of *Cambaytherium*, a primitive, perissodactyl-like mammal from the early Eocene Cambay Shale Formation of Western India, is detailed based on more than 300 specimens representing almost the entire dentition and skeleton. *Cambaytherium* combines plesiomorphic traits typical of archaic

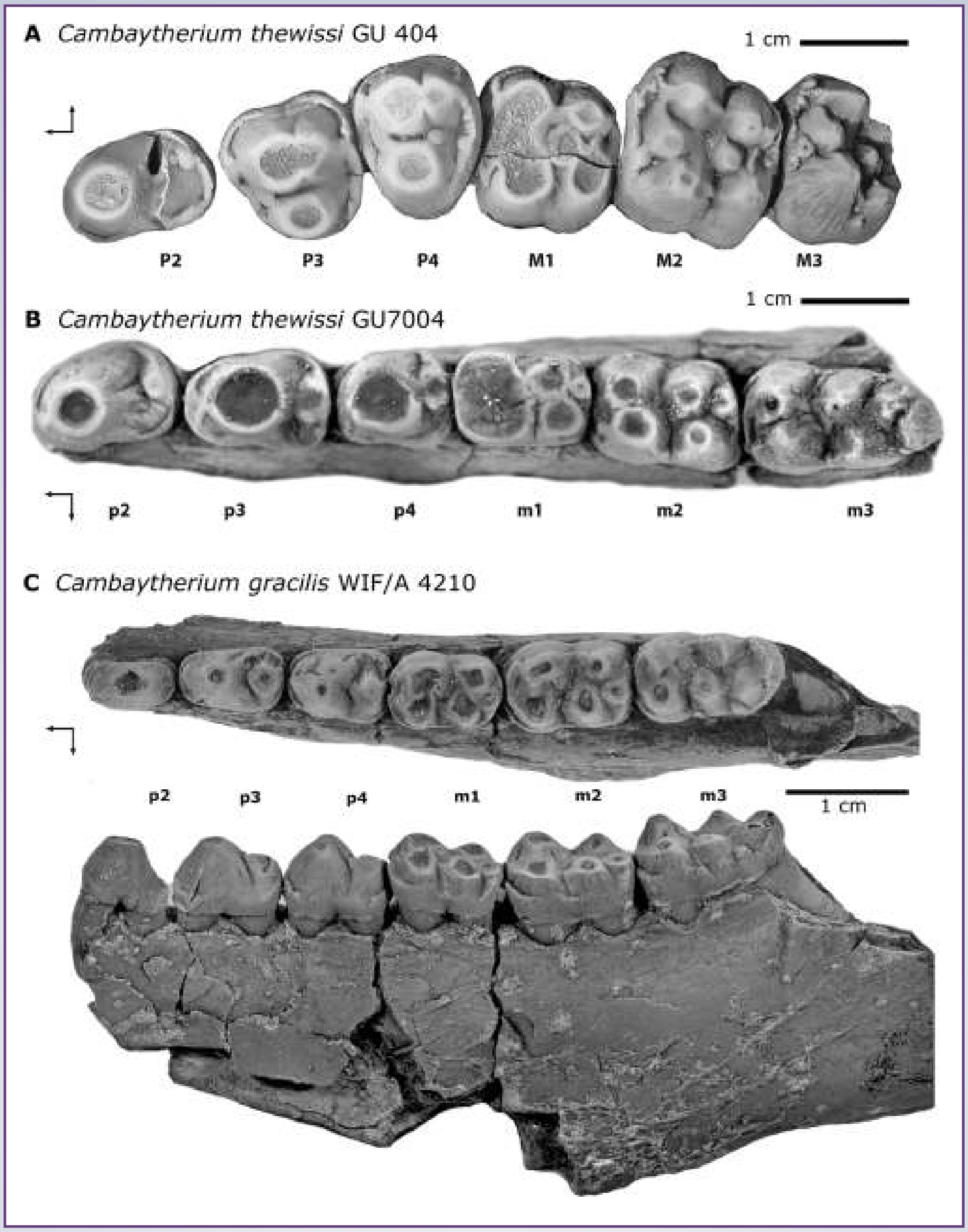


Fig. 28: Differential wear in Cambaytherium. A Cambaytherium thewissi (GU404) left maxilla with P2-M3. B Cambaytherium thewissi (GU7004) right dentary with p2-m3. CD Cambaytherium gracilis (WIF/A 4210) left dentary with p2-m3. Note the different wear gradient in the two species. In C. thewissi the premolars show heavy wear at an individual age when M3/m3 are not fully erupted, whereas in C. gracilis the premolars are less flattened although them3 has distinct facets. Thus, C. thewissi shows a distinctly higher wear gradient and a later eruption of the M3/m3. Photos: PM 1A-B, KR 1C.

ungulates like phenacodontids with derived traits characteristic of early perissodactyls. *Cambaytherium* was a subcursorial animal better adapted for running than phenacodontids but less specialized than early perissodactyls. The cheek teeth are bunodont with large upper molar conules, not lophodont as in early perissodactyls; like perissodactyls, however, the lower molars have twinned metaconids and m3 has an extended hypoconulid lobe. A steep wear gradient with heavy wear in the middle of the tooth-row suggests an abrasive herbivorous diet. Three species of *Cambaytherium* are recognized: *C. thewissi* (~23 kg), *C. gracilis* (~10 kg), and *C. marinus* (~99 kg). Body masses were estimated from tooth size and long bone dimensions.

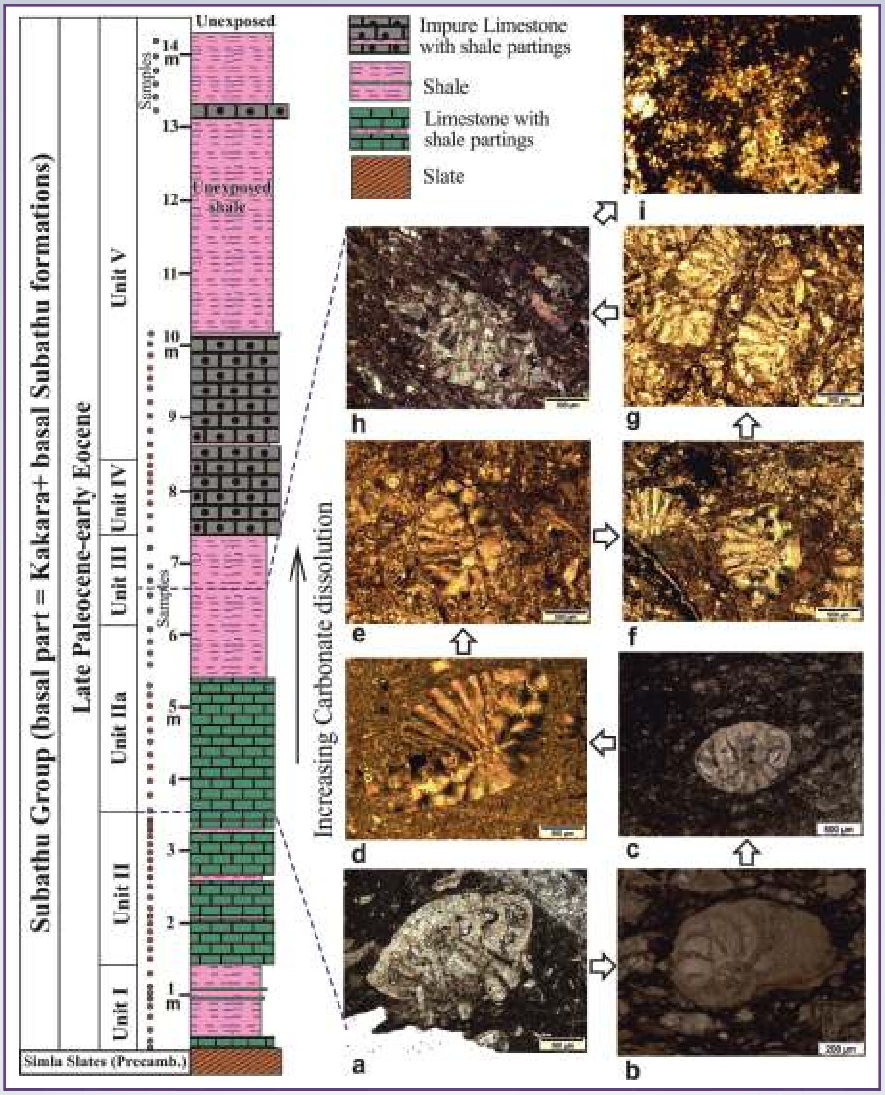


Fig. 29: Photomicrographs of thin sections of limestone samples from successively younger units (Unit II to Unit III) of the basal part of the Subathu succession exposed in the Kurla section showing progressive deterioration (increasing carbonate dissolution) in preservation of larger benthic foraminiferids. (ad) very well preserved larger foraminiferids with distinctly visible outlines from the Unit II; (e) less well preserved larger foraminiferids showing corroded boundaries or outlines from the lower part of the Unit IIa; (f) badly preserved larger foraminiferids with a few solution channels from further up in the Unit IIa; (g, h) broken largerforaminiferids with corroded boundaries and many solution channels from the top part of the Unit IIa; (i) larger foraminiferids completely missing probably due to their complete dissolution from units III, IV and V.

Biostratigraphic and isotopic evidence indicate an age of c. 54.5 Ma for the Cambay Shale vertebrate fauna, near or prior to the initial collision with Asia. This constitutes the oldest Cenozoic continental vertebrate assemblage from India. Cambaytheriidae (also including *Nakusia* and *Perissobune*) and Anthracobunidae are sister taxa, comprising the clade Anthracobunia, which is sister to Perissodactyla. They are united in a new higher taxon, Perissodactylamorpha. Occurrence of *Cambaytherium*, the most primitive known perissodactylamorph, in India near or prior to its collision with Asia suggests that Perissodactyla evolved during the Paleocene in India or in peripheral areas of southern or southwestern Asia.

The Paleocene–Eocene Thermal Maximum (PETM), one of the most pronounced and widely documented global warming events in the geological

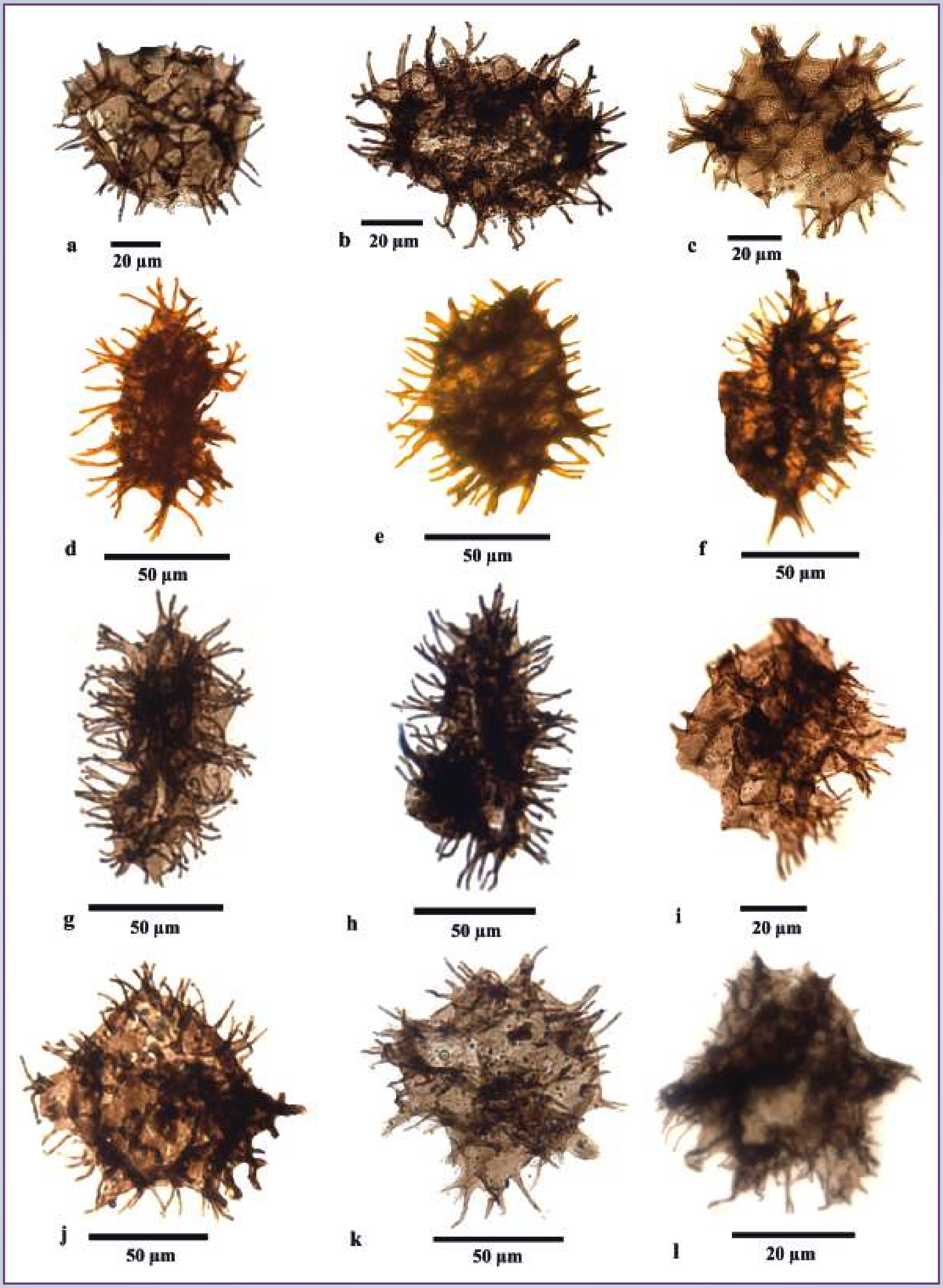


Fig. 30: Apectodinium species from the lower part of the Subathu Group (sample number KUR 18) of the Kurla section. (ac) A. homomorphum (WIMF/A 44844486); (df) A. ?parvum (WIMF/A 4487a, 4487b, 4488); (gi) Apectodinium sp. (WIMF/A 44894491); (j, k) A. quinquelatum (WIMF/A 44924493); (l) Apectodinium sp. (WIMF/A 4494).

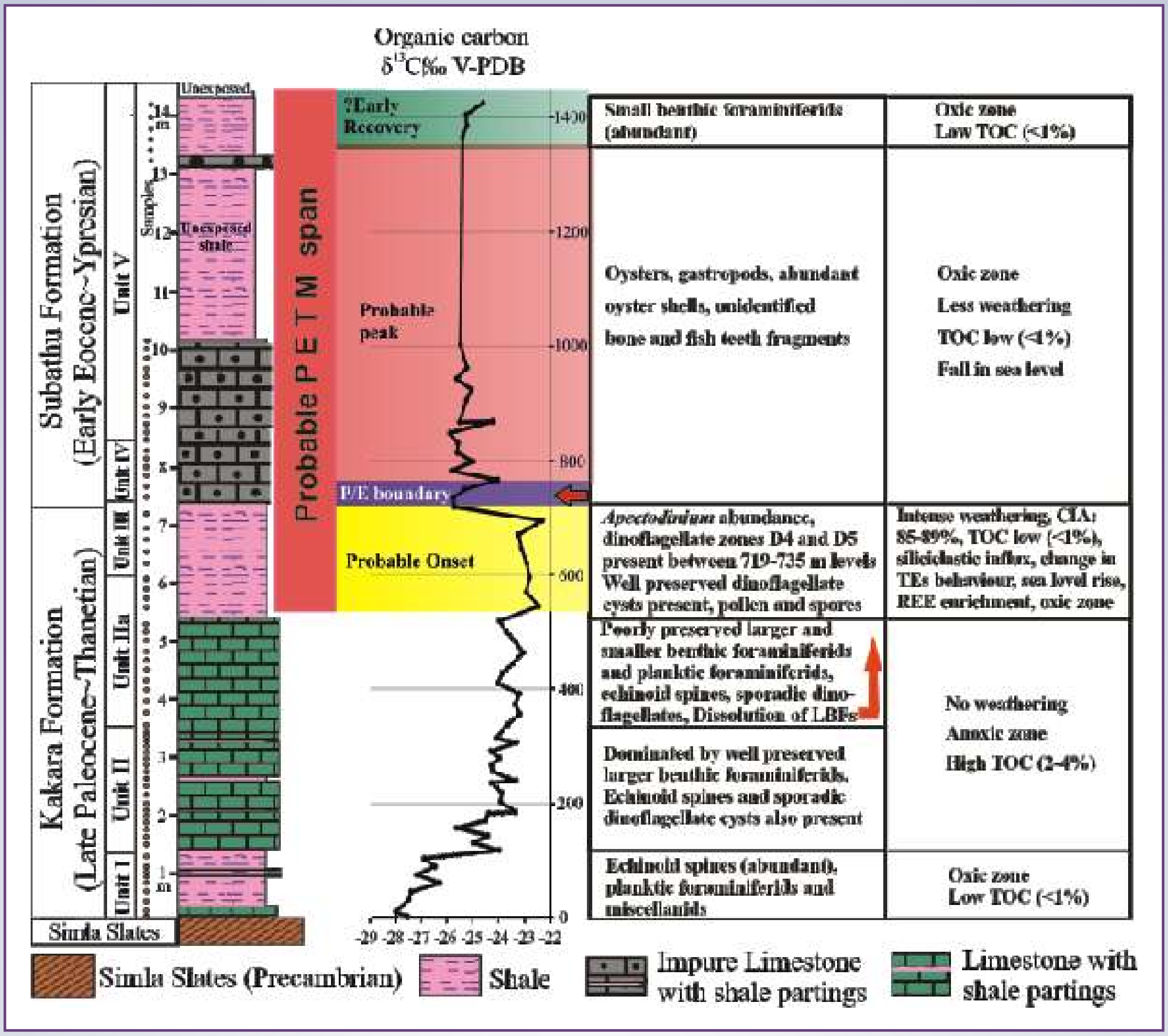


Fig. 31: Paleocene/Eocene boundary and various phases of the probable PETM span in the Subathu Group of the Kurla section, Delgi (Subathu) inferred using mainly geochemical and limited paleontological data.

history occurred at the beginning of the Eocene (~ 56 Ma) causing substantial changes in biota and geochemistry. It is marked worldwide by a negative isotopic excursion of $\delta^{13}C$, bloom of the dinoflagellate *Apectodinium*, turnover of larger foraminiferids, diversification of planktic foraminiferids, and carbonate dissolution of calcareous test shells, decrease in carbonates and increase in abundance of silicates and phyllosilicates, etc. There has been no attempt to identify the PETM in the Himalaya even though some Himalayan sections are known to have Paleocene–Eocene transition beds. To fill this lacuna, the basal part of the late Paleocene–middle Eocene Subathu Group exposed at the village Kurla near Subathu in Himachal Pradesh (NW sub-Himalaya) was investigated for biotic, mineralogical, and geochemical signatures of this abrupt warming event. The significant results of this study include carbon isotope excursion (CIE) of 3.4‰, occurrence of index dinoflagellate genus *Apectodinium*, and carbonate dissolution of the larger benthic foraminiferids. The mineralogical changes noted across the Paleocene−Eocene transition include increase in quartz and phyllosilicates and decrease in carbonates. The geochemical changes include (i) increase in SiO_2, Al_2O_3, K_2O, and Fe_2O_3, (ii) decrease in $CaCO_3$, (iii) decreasing trend of Si/Al, Fe/Al, and Mg/Al ratios, (iv) increasing trend of K/Al, Ti/Al, and Zr/Al ratios, (v) changes in trace element abundance, (vi) maximum chemical index of alteration (CIA) of 85–89%, and (vii) increase in abundance of

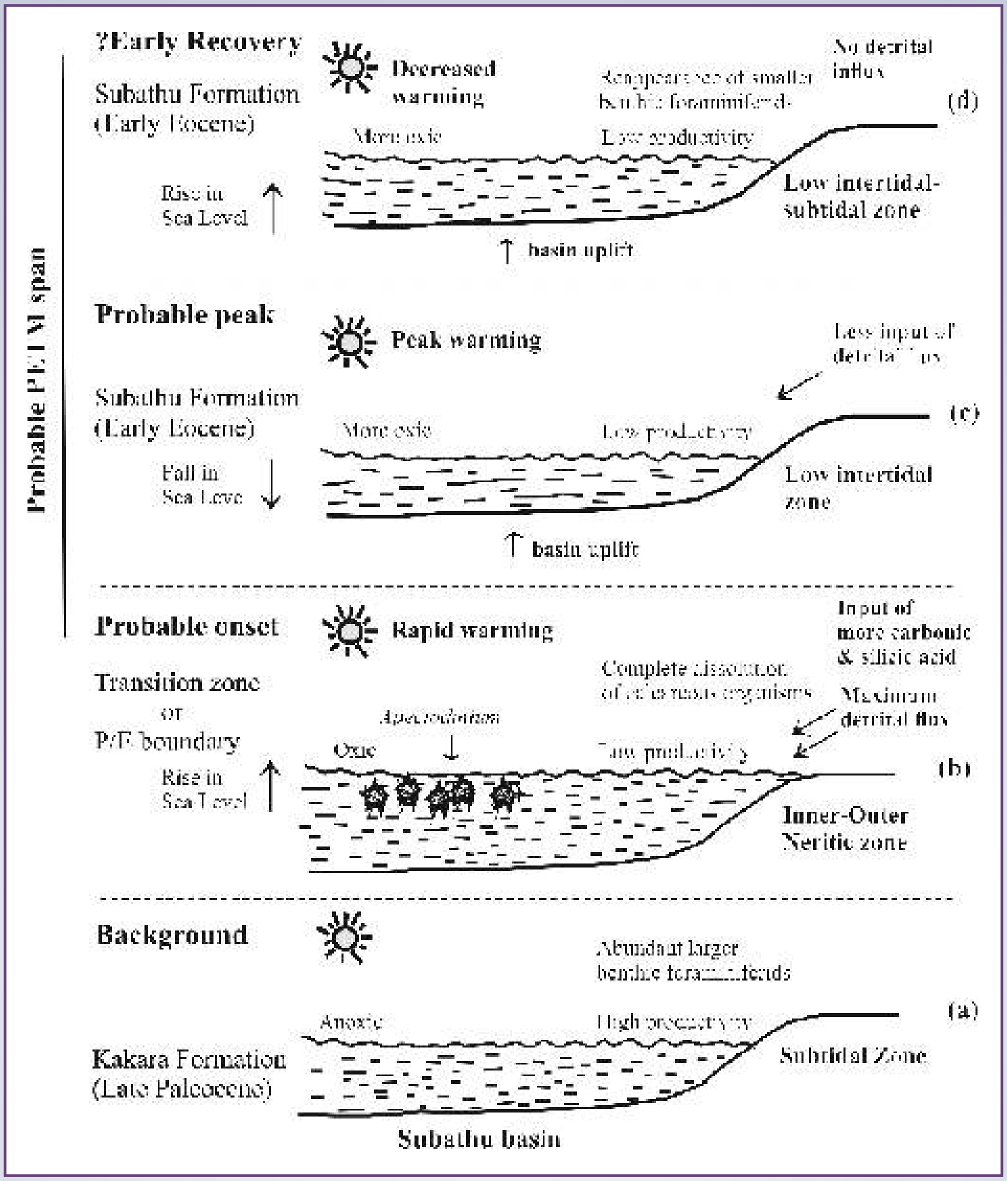


Fig. 32: Conceptual model of environmental changes across the probable PETM span in the basal part of the Subathu Group of the Kurla Section. (a) Background conditions, (b) probable onset of the PETM, (c) probable peak phase of the PETM, (d) probable early recovery phase of the PETM (based on Schulte et al., 2011). [to be printed in full page width].

rare earth elements (Figs. 29-32). The aforementioned dataset is clearly very close to the PETM and even reflects its probable onset and peak phases, however, it is insufficient to definitively identify the PETM in the studied section. Nevertheless, since this study is the first from a Himalayan section and brings out considerable new information, all results and interpretations are presented and discussed.

TAT 4.4
Characterization of Tertiary fauna and flora from the NE India vis-à-vis NW Himalaya in light of India-Asia collision and global bioevents

(Kapesa Lokho, Kishor Kumar and M. Prakasam)

Fieldwork was carried out to in the Himachal Pradesh, Northwestern Himalaya and in the Northeastern Himalaya. The visit to NW Himalaya was undertaken to get introduced to the Subathu Formation of Paleocene and Eocene sediments. Rock sampling was carried out for the geochemical and paleoenvironmental studies. Whereas the visit to NE Himalaya was aimed to collect rock samples from different locations of NE India and field re-verification of the fossil horizons.

Although the recovered trace fossils are limited, these are important for deciphering the broad paleoenvironmental setting in association with the observed sedimentary structures of the Laisong Formation in Naga Hills. We interpret that the Oligocene Barail trough in the Assam-Arakan orogen originated at the active margin of the Indo-Burmese plate convergence and therefore was a zone of coarse-grained turbidite system with hyperpycnal flow condition. As the Barail trough formed in an active margin with narrow shelves and coastal plains, the braided submarine channels formed at the base of the slope. These braided submarine channels are of low sinuosity and site for the turbulent hyperpycnal flow in coarse-grained turbidite setting. The fine to coarse grained sandstone with subtle parallel lamination, rare combined-flow ripples, ball and pillow structures, gutter cast, plant remains, gradual change in grain size and alternating coarsening- and fining upward intervals, and flattened rip-up clasts indicate flow-fluctuation (waxing and waning flows) and progressive increase in fluvial discharge due to hyperpycnal flow. A low diversity trace fossils dominantly comprises of *Ophiomorpha, Thalassinoides* and subordinate traces of *Chondrites, Palaeophycus,? Gyrolithes,* and *Planolites* (Fig. 33) and lack of graphoglyptids in the Laisong Formation of the Naga Hills supports proximal part of the hyperpycnal-deltaic lobes of delta-fed marine coarse grained turbidite system. *Ophiomorpha-Palaeophycus* ichnofabric in these deposits indicate short-term colonization of opportunistic organisms like crustacean (e.g. decapods) in submarine channels and terraces. The associated plant remains also support the proximal part of the hyperpycnal-deltaic lobes.

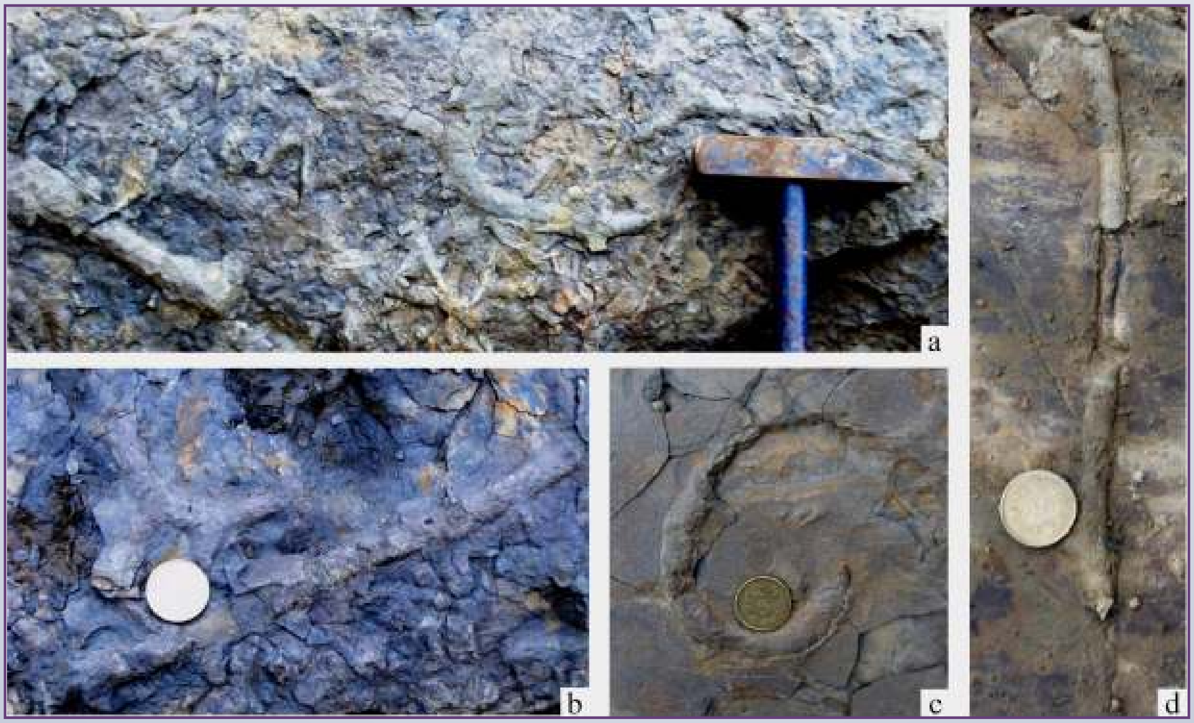


Fig. 33: Trace fossils from the Laisong Formation. (a) Thalassinoides isp., (b) Planolites isp.; (c) ?Gyrolithes isp., and (d) Palaeophycus tubularis. Scale bar=2 cm.

TAT 4.5

Biostratigraphy and paleoecology of the Neogene terrestrial Siwalik Group of NW India: a combined study of vertebrate fossils and stable isotopes

(R.K. Sehgal and Aditya Kharya)

A comprehensive study of the faunas of the Himalayan Foreland Basin was attempted. It is noticed that the Siwalik- age faunas are not only present in the Himalayan Foreland Basin, but these are also known from several localities lying south of the Himalayan ranges and Potwar Plateau Pakistan. It is inferred that the basin was linked in the east to the Bay of Bengal through the Bengal Basin and its western part was connected to the Arabian Sea through Rajasthan and Kutch, Gujarat. Further, it is noticed that the Bugti Basin and Zinda Pir area of Sulaiman Ranges of Pakistan were also part of the foreland basin. It is also inferred that the faunal succession in the Irrawaddy Valley may have geologically and biogeographically belonged to the Himalayan foreland basin in the past. The Himalayan foothills have long been known for yielding rich mammalian fossil occurrences and significant localities in the Indian Siwaliks include Kalagarh, Ramnagar, Haritalyangar, Chandigarh and Jammu regions. The Bugti Basin and Zinda Pir area of Sulaiman Range of Pakistan were also part of the foreland basin, as Lower and Middle Siwalik fossils are known from the Vihowa and Litra formations, respectively. The Marwat Formation of Bhittani and Marwat Ranges, Pakistan have also yielded Pinjor-age vertebrate fossils. The Middle and Upper Siwalik-age fossils are also known from the Irrawaddy Formation of Myanmar, where older Pegu beds have also yielded scanty Lower Siwalik-age fossils. This faunal succession in the Irrawaddy Valley may have geologically and biogeographically belonged to the Himalayan Foreland Basin in the past. Additional mammalian fossils having an affinity with the Lower and Middle Siwaliks are known from the Khari Nadi Formation of Kachchh. The Bokabil Formation of Tripura also yielded scanty Lower to Middle Siwalik fossils. A younger Siwalik late Miocene assemblage is known from Piram Island of Gujarat. These areas are also part of the foreland basin. Most recently, a late Miocene suid species was discovered and reported from near Baripada, Odisha. A detailed interpretation of the faunal lists of the respective region was attempted.

A detailed study of the ravines in the Ganga Plain was also carried out. It was noticed that the gravel channel facies are invariably associated with mammalian fossils and the same were collected from Musanagar section (Marginal Ganga Plains), as moderately preserved specimens of isolated upper and lower dentitions. Two mammalian groups are present in the collection viz. perissodactyl and artiodactyl. The former is represented by an extinct species of *Equus* (horse) and the latter belongs to bovids. The *Equus* specimen is the last, right molar, the dental morphological features are fairly well preserved and distinctly identifiable up to species level. The fossil specimens belonging to bovids are isolated upper and lower molars in which the dental morphology is not sufficient to decide their species, as the bovids can be better identified on the basis of skull characteristics and horn cores. The molars in the present collection resemble the dental morphology of *Bos* and *Bubalus.* The palaeo-biogeography of the fauna was also discussed and it is inferred that the fauna represents the post-Siwalik fauna.

Besides, the analytical studies pertaining to Carbon ($\delta^{13}C$) and Oxygen ($\delta^{18}O$) values of pedogenic nodules and fossil dental enamel from three sections (Ghaggar River Section; Khetpurali Section and Markanda valley Section) of the Upper Siwalik subgroup of NW Himalaya were carried out, and it was interpreted that C-4 type vegetation dominated the region at that period of time.

A sample belonging the Hominoid was found. This sample was described and a taxonomic revision of the Ramnagar hominoids was attempted. Although, Hominoids have been known from Ramnagar (J & K, India) since the early 1920s, and over the last nine decades, up to 5 genera and 8 species have been recognized by different researchers working in the region. Our recent analyses have treated the Ramnagar hominoids and those from the Chinji-level of the Potwar Plateau (Pakistan) as a single population, and it has been demonstrated that this combined population is no more variable than other well-established Asian fossil hominoid taxa. However, statistical comparisons between Ramnagar and Potwar specimens were never explicitly made (or reported) before combining the samples for a larger comparative analysis. A new hominoid specimen - a lower right M_3 - from Ramnagar was described and explicitly tested the distinctiveness of the Ramnagar hominoid sample compared to the Chinji-level sample on the Potwar Plateau. Multiple indices of premolar and molar size and shape were compared and results indicate no statistical differences between the two populations. It was inferred that, the Ramnagar and Chinji-level Potwar specimens should be considered conspecific at this time, and *Sivapithecus indicus* is the available name with taxonomic priority. In addition, the digitization of the mammalian faunal collection from Ramnagar (J & K) was initiated in collaboration with researchers from USA.

TAT- 5: HIMALAYAN GLACIERS: THEIR ROLE IN INDIAN MONSOON VARIABILITY AND HYDROLOGICAL CHANGES IN THE GANGA BASIN

TAT 5.1
Status of glaciers in Doda and Suru River basins, Ladakh, Western Himalaya
(Manish Mehta, Aparna Shukla, Vinit Kumar and S.K. Bartarya)

During the reporting year, fieldwork was carried out to monitor the glaciers in Doda and Suru River basins. The measurements made on the ablation-stake network suggest that the net balance of the Pensilungpa glacier was negative in 2017-2018. During the measurement periods 2017/18 the net ablation of the glacier was ~ (-) $6.47 x 10^6$ m^3 we, while the net accumulation of the glacier was ~ (+) $1.01 x 10^6$ m^3 we. However, the ablation and accumulation gradients of the glacier were ~ (-) 0.120 m/100 m and ~ (+) 0.135 m/100m, respectively. The results also suggested that during same period the Equilibrium Line Altitude (ELA) of the glacier situated at the height of the 5225 m asl. Further, our result shows that most surface ablation was observed between altitude 4800 and 5000 m, which encompasses areas covered by thin and patchy debris up to 10 cm thick. We suggest that a thin cover reduces albedo without significantly introducing an insulating layer at the surface. While, lower areas between 4600 to 4800 m reduced the surface ablation due to thick debris covered.

On the basis of moraine mapping, OSL dates and satellite images, we have categorized the glacier recession in two time frame, i) LIA (1360 ± 180)-1971 and ii) 1971-2017. During the time between LIA (1360±180) and 1971 glacier receded 2671 ±48 m with an average rate of ~4.3 ±0.08 m a^{-1}, while, between 1971 and 2017 glacier retreat 260 ±24 m with an average rate of ~5.65 ±0.5 m a^{-1}. The glacier has shown a similar between LIA and 2017 and a total retreat of the glacier is ~2931 m, which is lower compared to the other Himalayan glaciers.

An inventory of glaciers in the Suru sub-basin (~4429 km^2) for the year 2017 has been prepared. The sub-basin has 240 glaciers, with 126 glaciers located in the GHR and 114 in the LR. The overall glacierized area is ~11 %. Based on size distribution, small, medium and large glaciers occupy 47%, 15% and 38% of the glacierized sub-basin. As per the debris-cover classification the glaciers in the sub-basin can be categorised as:clean glaciers (CG: 43%), partially debris covered glaciers (PDG: 40%) and heavily debris covered glaciers (HDG: 17%). Majority of the glaciers in the sub basin are north facing (N/ NW/NE: 71%), followed by south (S/ SW/ SE: 20%), with very few oriented in other (E/ W: 9%) directions. The mean elevation of the glaciers in the Suru sub-basin varies from 4368 ±96 to 5828 ±59 masl. Mean slope of the glaciers varies from 13.6 ±37° to 39.8 ±77° and 16.2 ±71° to 41 ±66° in the GHR and LR, respectively. While, percentage distribution of glaciers shows that nearly 80 % of the LR glaciers have steeper slope (20-40°) as compared to the GHR glaciers (57%).

The glacial history of the Suru basin and its sub valleys (Achambur, Kangriz, Shafat and Pensilugnpa), southern Zanskar range, western Himalaya is characterized by using geomorphic mapping and Optical Stimulated Luminescence (OSL) dating (Fig. 34). At least six glacial advancement stages are evident in the Suru basin. The glaciation episodes (oldest to youngest) belong to the MIS 3 to 4 to Little Ice Age (LIA), respectively. These glacier advancement episodes are dated between 33±6 ka, and 0.66 ± 0.18 ka. It was also observed that the mean ELA during oldest stage was lowered to 4836 m asl compared to the present level of 5374 m asl. This implies an ELA depression of ~538 m from the maximum extent of glaciers (down valley) to present day (snout positions). The glacier reconstructions for the Suru basin

TAT 5.2
Hydrogeology of Himalayan Spring
(S.K. Bartarya)

Springs, a manifestation of groundwater on the surface, are the source of water supply to ~53 million inhabitants of Indian Himalaya, sustain the lean flow of several groundwater fed rivers in the mountain. Direct infiltration of rainwater through joints, fractures and weathered zones is the main cause of recharge to these springs. Numerous NW-SE, N-S and NE-SW, and E-W trending thrusts, faults, fractures and joints are developed very pronouncedly in all the geological formations. Most of the fractures/joints are developed

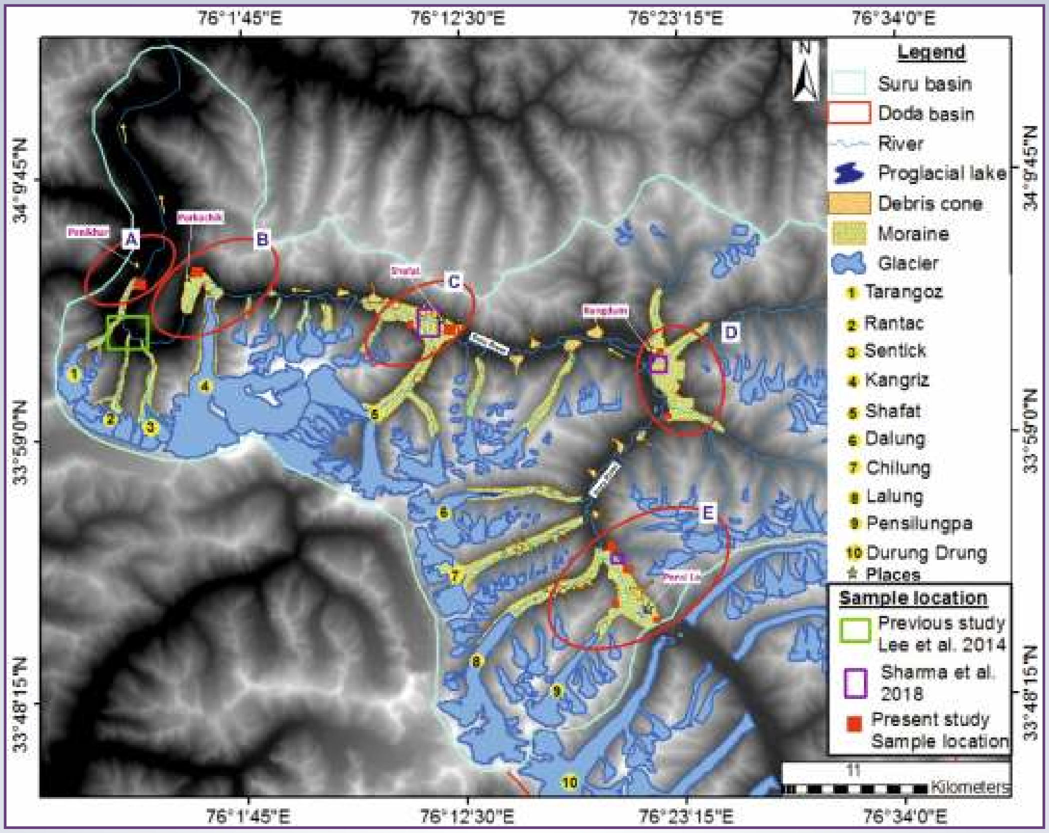


Fig. 34: Reconstructed glacier history of Suru River basin. Map showing the past glacier evidences like moraine, debris cone etc. The red circle indicating the area where the sample was collected and red small square boxes showing the sample locations.

either parallel or perpendicular to the regional strike of the major thrust plane. The dominant structurally weak zones are identified on satellite data as major lineaments in the area of study. At places, streams flow along these lineaments/joints. These fracture-joints and lineaments are serving as easy conduits for infiltrating water and its further movement. The groundwater flow and yield are therefore attributed to these lineaments. Incidentally, the zones of faulting and closely spaced joints are more susceptible to weathering and serve as potential water-bearing zones. Further, the springs also contribute significantly to the base flow of streams and this can be substantiated by a hydrograph of small streams during the rainy season which clearly demonstrates that base flow in the streams is supported by subsurface flow or springs. The drying up of springs and the factors responsible for the reduction in their discharges in the Lesser Himalayan region has been highlighted during the last 3 decades through isolated studies, unpublished reports and observations of Non-Government Organisation (NGO's) and local inhabitants. Some of the studies have generated baseline data and provided opportunities for assessment of factors responsible for the reduction in spring discharges. Most of the observations are based on limited data and qualitative assessment and observations, particularly on a temporal scale. Drying up of springs has resulted due to collective impact of activities related to indiscriminate exploitation of Himalayan resources, enhancement of climate variability, a general rise in atmospheric temperature and at large negligence of springs as a vital water resource or lifeline of the mountain community.

Improved management of springs is required to ensure water security for people in the mountain region, as well as downstream communities in the plains. In response to the crisis, a participatory approach to spring management is being adopted in many parts of the country by several NGO's (e.g., DHARA VIKAS, Sikkim, AQUADAM, CHIRAG, PSI). It combines the hydro-geological investigations with the local knowledge and their participation to map the catchment area - the springshed, for targeted treatment such as restoration or conservation. Results have been generally positive in terms of increased spring discharge and better water quality. The springshed management approach can be upscaled with public investment and local governance due to easy/people friendly schemes and revival of traditional knowledge. This dwindling resource of Himalaya require more focussed in-depth studies for understanding and quantifying the spring hydrogeological processes, database of springs, dissemination of knowledge among affected communities and stakeholders. The rejuvenation of springs should also be undertaken alongside with more scientific inputs for providing water security in the mountain region at large and the Himalaya in particular.

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MoES Sponsored Project

Multi-Parametric Geophysical Observatory for Earthquake precursory research at Ghuttu, Garhwal Himalaya

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

Earthquake precursory is a very hard to achieve due to very insignificant success during the last 60 years of research. Multi-Parametric Geophysical Observatory (MPGO) at Ghuttu in the Garhwal Himalaya was established under the ambit of National programme of earthquake precursory research to study the earthquake precursory using multiple geophysical parameter at a single site in the highly seismic active zone. The project involves the continuous measurement of eleven parameters mainly, seismic waves velocities and acceleration, crustal deformation, gravity, geomagnetic field variations, observation of radon in soil and water, water table and some meteorological parameters like air temperature, pressure and rainfall measurements.

Strong motion record

A digital accelerograph was installed at MPGO, Ghuttu for the observation of strong motion data. This data will help to determine the significant event of earthquakes for further study. The peak ground acceleration (PGA) plot of vertical component, along with magnitude and epicentre distance is shown in figure 35.

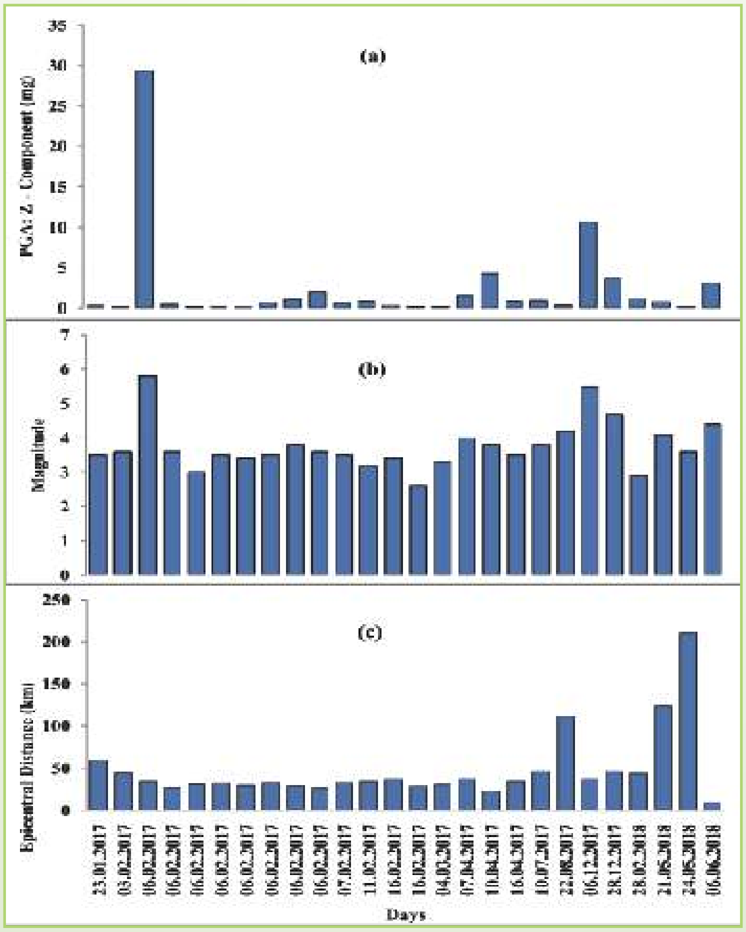

Fig. 35: Earthquake data recorded by strong motion at MPGO, Ghuttu. (a) Peak Ground Acceleration (PGA) of vertical component (b) Epicentre distance (c) magnitude and date of occurrence.

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GPS data Measurement

GPS measurement at MPGO Ghuttu has a long time series of over 12 years. The continuous data of this station along with 27 sites has been processed for evaluation of crustal deformation in the Garhwal–Kumaun Himalaya (Fig. 36). The results suggest that the convergence rate in this part of the Himalaya is about 18 mm/yr which is leading to strain accumulation in the region. The displacement rates of these sites are also used to obtain seismic coupling derived from the slip deficit rate. The Main Himalayan Thrust (MHT) in the frontal part of the Himalaya under the Outer and southern Lesser Himalaya is strongly coupled for a width of about 85 km. The mid crustal ramp where earthquakes of Himalayan seismic belt occur exhibits low coupling. Strong coupling on the MHT beneath the Outer and Lesser Himalaya is homogeneous except in the very shallow updip part of the MHT. Subduction of sediments of the Indo-Gangetic plains or the Delhi Haridwar ridge does not seem to influence the coupling. No great earthquake has reported in the Garhwal–Kumaun region of NW Himalaya in the past 500 years or more and high rate of strain accumulation has continued on a strongly coupled MHT makes this as one of the most earthquake-vulnerable segments of the Himalayan arc.

Radon and other parameters Measurement

Continuous temporal data of various parameters during 2018 recorded in a 10 m depth borehole is presented in figure 37. This include the earthquakes (≥ 3.0) occurred around MPGO Ghuttu (Fig. 37a), the temporal variation of radon emanation in soil (Fig. 37b) along with rainfall (Fig. 37c) air temperature (Fig. 37d), and probe temperature (Fig. 37e). The data indicate a very small amount of anomaly in the soil radon which is mainly due to rain precipitation during the monsoon period, whereas, during other period, no significant radon anomaly has been observed related to nearby moderate to small earthquake occurrence. During the monsoon period between July to August, a high precipitation adds water within uppermost crust charging the ground water table. Atmospheric temperature and atmospheric pressure have very high daily fluctuations interlinked

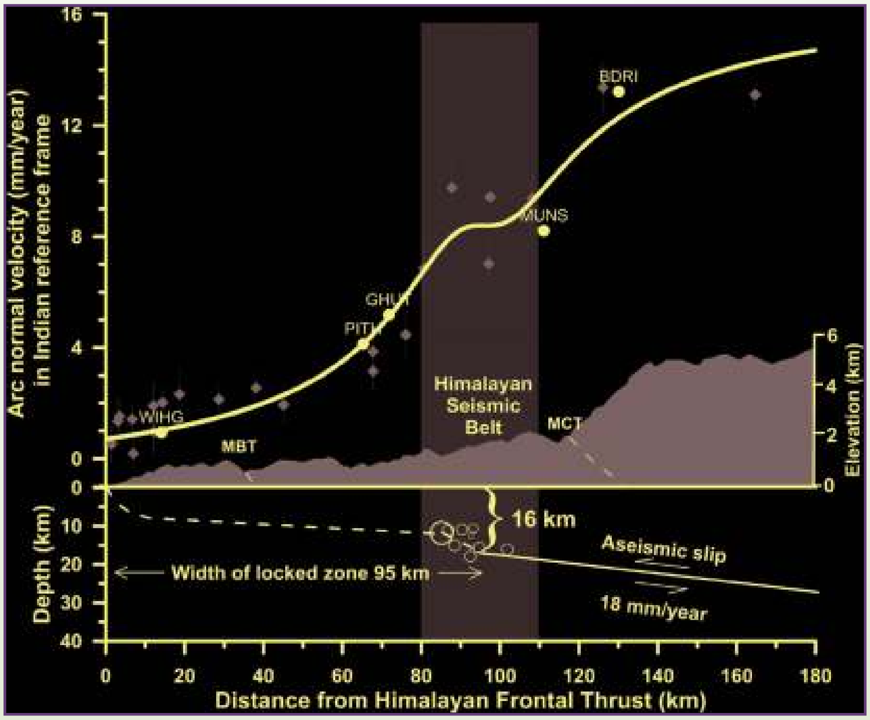

Fig. 36: Arc normal site velocity along a composite profile in the direction along N30. The continuous curve simulates the effect of locking of a 95 km wide Main Himalayan Thrust (MHT) under the Outer and Lesser Himalaya. The slip deficit rate at the MHT is 18 mm/year. Grey diamonds denote the campaign mode GPS sites of Banerjee and Bürgmann (2002).

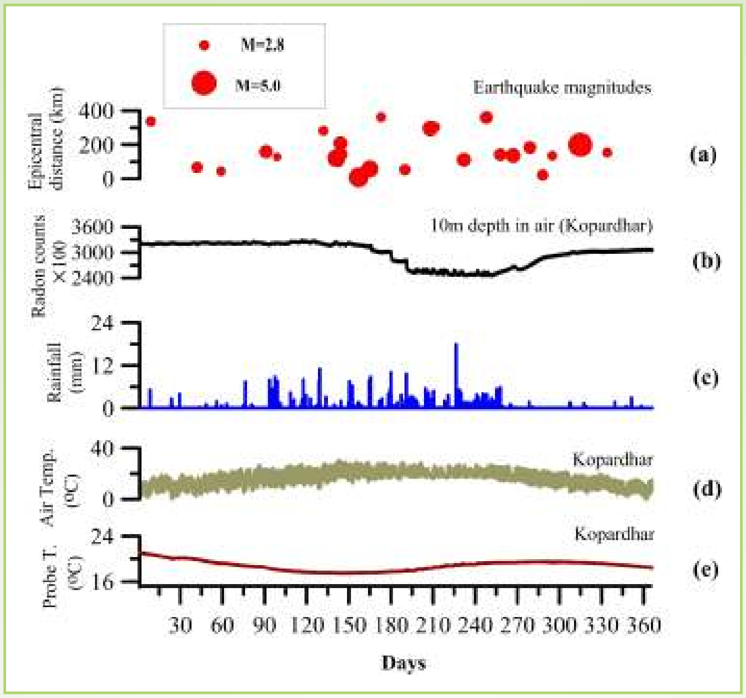

Fig. 37: Temporal variation of various parameters measured at Kopardhar during 2018 at 10 m depth (a) Earthquake magnitude and epicentre distance - the size of red star denotes magnitude of earthquake events while y-axis represents epicentral distance from MPGO(b) Soil radon at 10 m depth (c) rainfall (d) atmospheric temperature (e) temperature at 10 m depth.

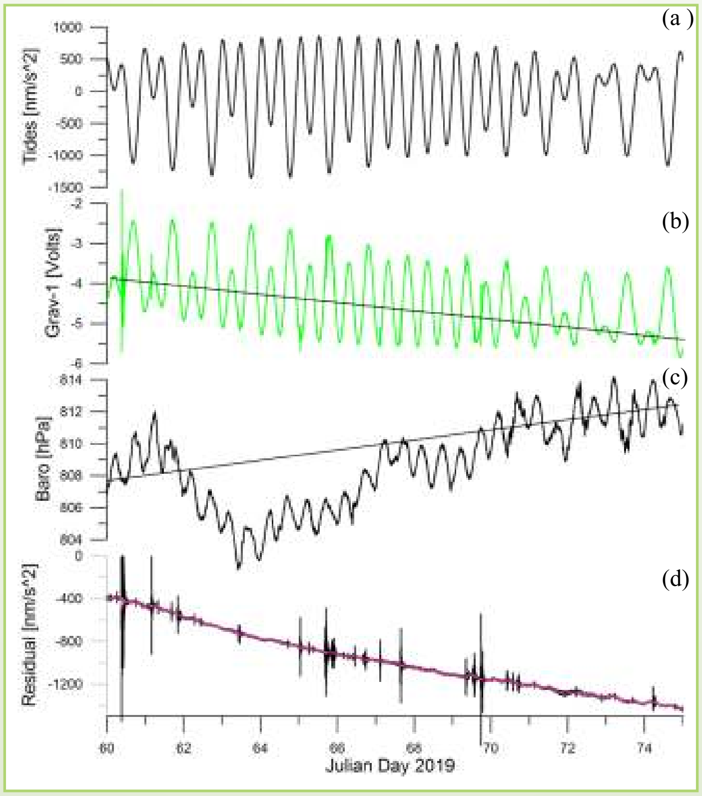

Fig. 38: Temporal changes of gravity observed through Superconducting Gravimeter during March 2019. (a) Solid earth theoretical tides (b) Recorded raw gravity data atmospheric pressure (d) Gravity residual obtained after removal of solid earth tides and the atmospheric pressure effects.

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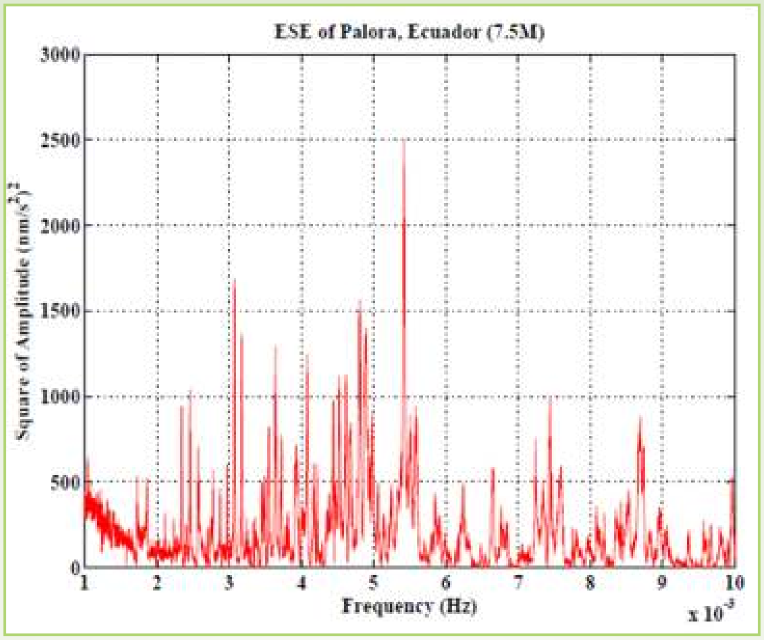

Fig. 39: Amplitude spectrum (1-10 mHz) of SG data corresponding to the latest earthquake (M7.5) of 22 February 2019

with each other and influenced by the solar radiations. It has been noted that the increasing depth decrease the amount of temporal change in the temperature.

Gravity data Measurement

The Ghuttu Superconducting Gravimeter (SG) was re-installed during January-February 2019. The superconducting state was achieved by cooling down the temperatures of Dewar and liquefaction of Helium gas. The instrument started recording data since 02nd February 2019, however, the data recorded with 50% of helium level could be useful for study. The SG data recorded during March 2019 is plotted in figure 38.

The records of temporal variation of gravity compared with solid earth tides (Fig. 38a) at Ghuttu indicate a strong influence (~300 microgal) of the tidal forces. The atmospheric pressure also induces effects on gravity which is ~3.0 Nm/s^2 based on the past long duration data at this site. The regression analysis used to remove these effects give end result of gravity residual (Fig. 38d) which shows a decreasing trend of gravity and high oscillation during the time of occurrence of moderate and bigger earthquakes. The decreasing trend of gravity is correlated with the depletion of ground water level in this part of the year. Therefore, gravity variation has a strong hydrological effect. Precursory signals are not observed in this data set however, a few Free Earth Oscillations (FEO) are observed during the time of occurrence of Mw 7.5 a distant Peru-Ecuador border earthquake on February 22, 2019 (Fig. 39).

DST Sponsored Project

Centre for Glaciology

(Director-WIHG, D.P. Dobhal, Rakesh Bhambri, Indira Karakoti, Amit Kumar, Akshaya Verma, R.S. Ahluwalia and Nilendu Singh)

The Centre is currently monitoring eight glaciers in the Uttarakhand and Himachal Himalaya. These are namely Gangotri & Dokriani in the Bhagirathi River basin, Chorabari in the Mandakini River basin; Dunagiri & Bagni in the Dhauliganga River basin, Pindari in the Pindar River basin, Panchi Nala &Patisou glacier in the Bhaga River basin. Full-fledged research station facilities are being developed at these glaciers for capturing high resolution data on different aspects of the glaciological studies. During this period, high quality time series data on glacier dynamics, meteorology, glacial-hydrology, sediment transport, melt-water smaplling have been collected. Besides, in-situ measurements, the study on glacier surface changes, snow cover assessment and glacier lakes have been documented using vigorous high resolution space based observations and datasets.

Evolution of debris flow and moraine failure in the Gangotri Glacier

A debris flow had occurred in the foreland of Gangotri Glacier along its tributary, Meru (Bamak) Glacier between 16 and 19 July 2017. This invent of debris flow was investigated using pre- and post-event field observations and with remote sensing assessments and hydro-meteorological data. A large volume of sediments (-7.9×10^{6} m^{3} $\pm$ $0.1\times10^{6} m^{3}$) was moved from the Meru Bamak and adjoining Neela Taal (4380 m a.s.l) during the debris flow, depositing 6.5×10^{6} m^{3} $\pm$ 0.1×10^{6} m^{3} of sediments in the frontal region (4050 m asl) of the Gangotri Glacier. This event transported sediments up to 1.5 km downstream, as a debris flow fan-type feature. During the event, ~18% of the sediments were transferred by the melt water stream. The stream of the Meru Bamak completely dissected and exposed the ice-cored left lateral moraine of the Gangotri Glacier. This has comprehensively reworked the morainic material and entirely changed the morphology of the pro-glacial area. A small pro-glacial lake, having an area of ~ 5075 $m^{2}$was also observed at the snout of the Gangotri Glacier because of the blockage by morainic material and sediments (Fig. 40).

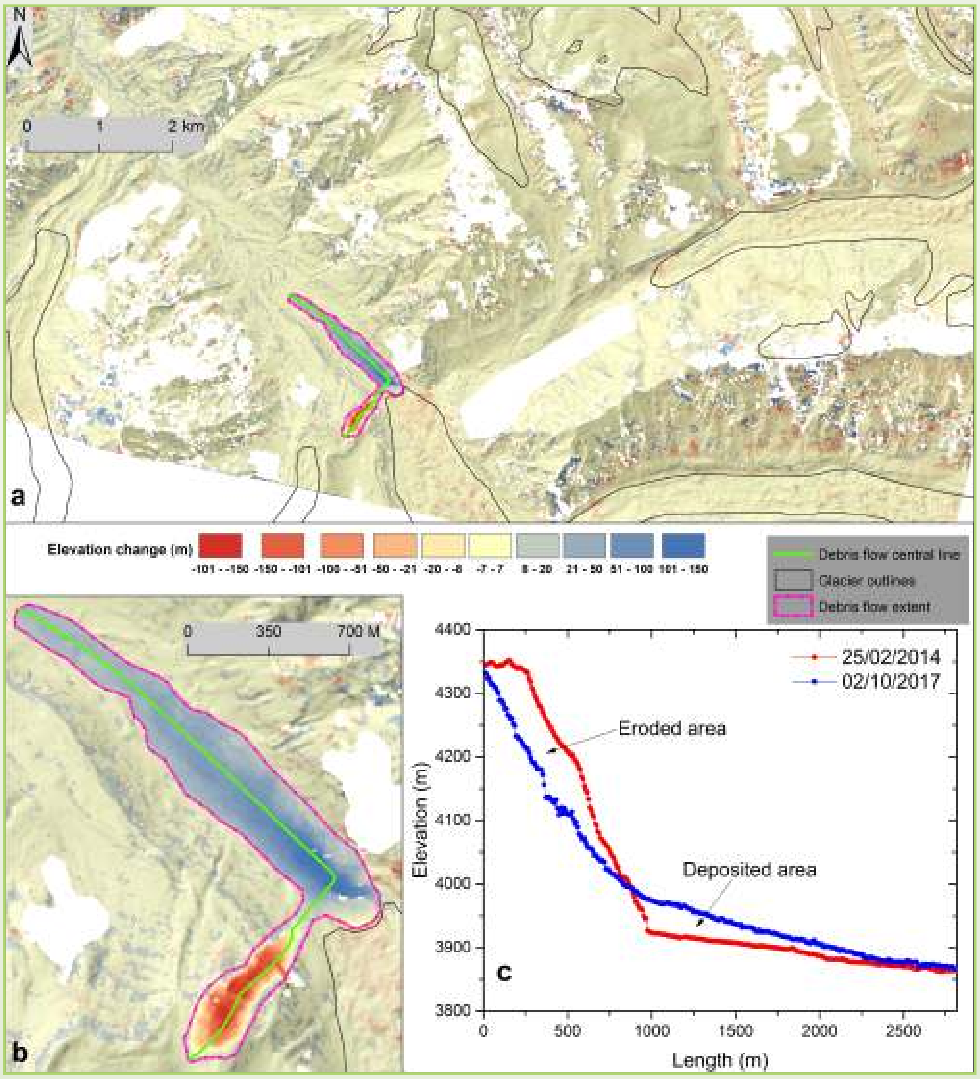

Fig. 40: (a) Elevation change of frontal part of Meru Bamak and Gangotri Glacier using HMA DEM (2014) and Cartosat 1 DEM (2017) after the coregistration; (b) closer view of elevation change of frontal part of Meru Bamak and Gangotri Glacier, red and blue color represents eroded and deposited sediments respectively by the debris flow event; (c) elevation change profile of debris flow area from 2014 and 2017 DEMs which shows eroded and deposited sediments.

A sharp increase in the concentration of suspended sediments (SSC), reaching 11,370 and 10,605 mg/l on July 18 and 19, respectively was recorded at Bhojwasa (~3 km downstream). Multiple factors such as recession of Gangotri Glacier, degraded ice-cored moraine, loose sediments at the front of the Meru Bamak, and continuous rainfall created favourable conditions for the debris flow. Therefore, geomorphic hazards associated with glacial retreat need to be investigated intensively in the Himalaya especially, in areas where significant glacial retreat is observed, lateral moraines are exposed and the unstable slopes are occupied by the tributary glaciers.

Assessment and review of hydro-meteorological aspects for cloudburst and flash flood events

In the Indian Himalayan Region (IHR), well distributed hydro-meteorological records (contemporary and historical) that facilitate the understanding of processes driving extreme weather events are scarce or rarely available. However, the capacity to observe, measure and quantify precipitation on regional scales has increased tremendously over the last three decades. Topography of the IHR provides favourable conditions for the cloudburst phenomenon which lead to frequent flash floods and landslides, killing hundreds of people every year. Understanding the exact mechanism of the driving processes of cloudbursts such as orographic lifting, precipitation distribution, precipitation thresholds and its source or origin are still uncertain. Keeping in view that cloudbursts have been increasing in both their frequency and intensity, they are likely to intensify in the near future. Present study analyzes and critically summarizes facts and impacts of cloudburst events through compilation of hydro-meteorological records and analysis of available data in the IHR (Fig. 41). Results indicate that natural climate variability has played a much greater role in driving these extreme events than earlier thought. There is a general consensus about the role of climate change,

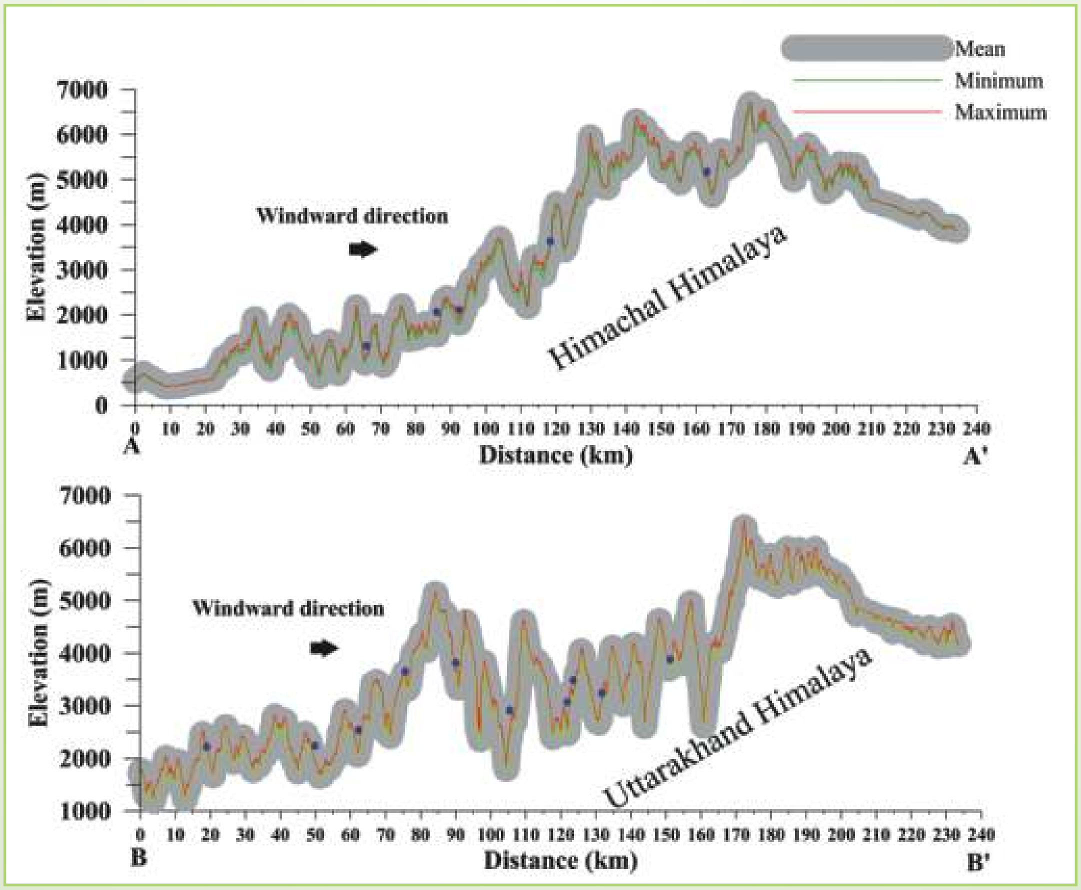

Fig. 41: Spatial distribution of cloudbursts and associated hazards over the longitudinal swath profiles extracted from the DEM in the IHR. (Blue dots represent the locations of cloudbursts and associated hazards)

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large atmospheric circulations, tele-connections and land use - land cover changes in driving the extreme events. Therefore, in light of such challenges and potential research gaps, an attempt to produce actionable knowledge in the IHR for climate modellers and policy planners has been made.

Black Carbon and Aerosol concentration in glacierised area

BC plays a crucial role in the global as well regional climatic change process, contributing significantly to atmospheric warming. An investigation on real-time monitoring of BC aerosols mass concentration at the Dokraini Glacier has been carried out. The data from Nov 2015 to July 2016 using a seven channel Aethalometer (AE-33) installed at a height of 3900 m a.s.l was analyzed. The results show high mass concentration of BC in April, May and June with a peak value of 1694 ng/m^3 in May while due to wet removal mechanism, BC concentration is low during monsoon season in July (454 ng/m^3). A mean annual mass concentration of 777 ng/$m^3$is recorded at the glacier sit. In snow, average BC concentration is found to be 135.23µg/kg. A positive correlation of BC with temperature, wind speed, wind direction and incoming shortwave radiation has been noticed while BC is negatively correlated with the rainfall for the studied period (Fig. 42). The BC aerosols present in the atmosphere absorb solar radiation causing atmospheric heating. In the Dokriani Glacier valley, annual mean heating rate of 0.015 K/day was noticed which might play an important in the acceleration of glacier melting.

A comparative study of BC aerosols between two valleys of Bhagirathi river basin: Dokriani and Gangotri glacier valleys have also been made. The results reveal that in spite of being pilgrims' place, Gangotri Glacier valley shows slightly lower concentration of BC (691ng/m^3), indicating that BC in Dokriani is transported from nearby localized rural and urban areas through upslope valley wind.

Ice mass loss in central Himalaya

Uncertainty prevails about state and dynamics of the glaciers in the Himalaya that obscure reliable future projections. An attempt is made to study the mass balance dynamics of monsoon-affected central Himalayan glaciers based on $\delta^{13}C$ records in regionally dominant trees since the 1743 CE. Annually resolved mass balance time-series based on two different plant functional types indicate accelerated ice-mass loss since the 1960s. The reasons have been ascribed to anthropogenic climate change and concurrent alterations in atmospheric circulations including weakening of Indian summer monsoon. Our reconstructed mass balance time-series provides a long-term context for recent glacier dynamics variability that is critically needed for modelling, projection, and attribution (Fig. 43).

Isotopic studies on Patsio Glacier, Himachal Pradesh

Patsio glacier is a valley type glacier in the Bhaga River basin in Himachal Pradesh. Its snout is situated at an elevation of 4820 m asl and is covered by debris cover. Two discharge sites and three sampling sites were established on Patsio glacier and Bhaga river for measuring the discharge and collection of river water samples. A Rain-gauge was also installed near the camp site of Patsio glacier. For isotopic study, total number of

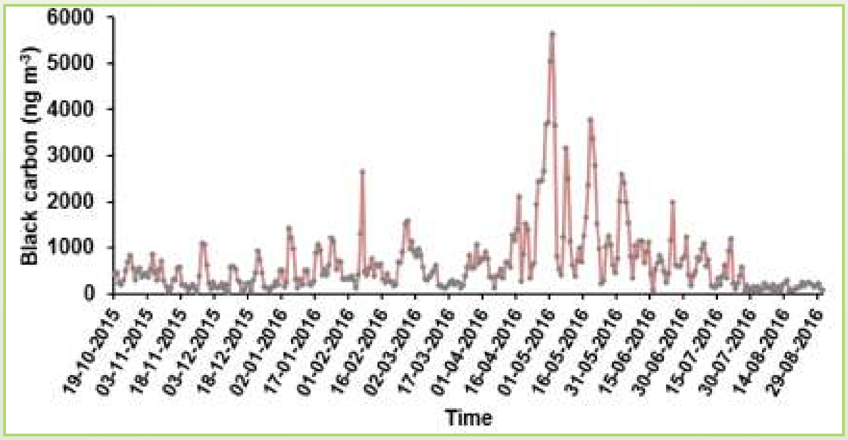

Fig. 42: Diurnal to seasonal behaviour of BC concentration in Dokriani Glacier valley

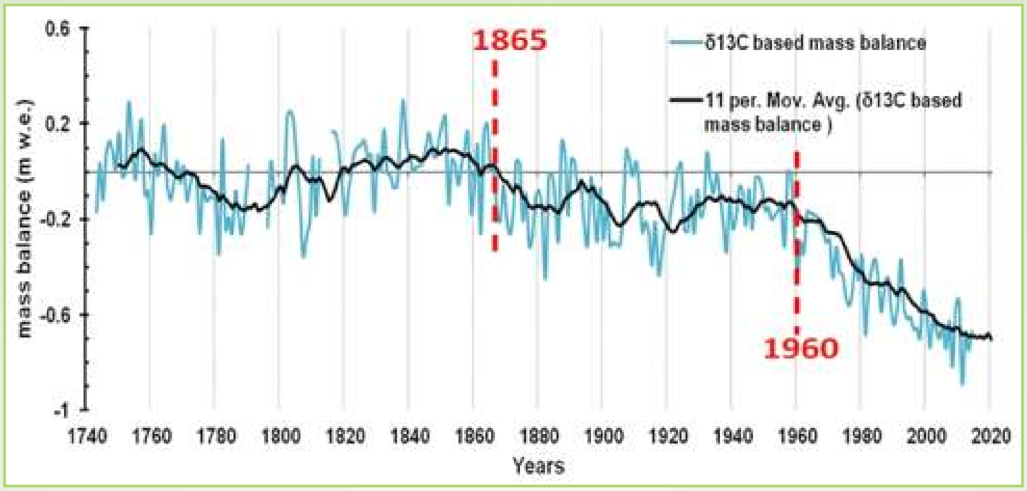

Fig. 43: Tree-ring C-isotope based mass balance reconstruction of the central Himalayan Glaciers since the little ice age: reconstructed mass balance is based on regionally dominant $\delta^{13}C$ chronology of two different species. Strong negative trend of mass balance since the 1960s is perceptible.

200 samples of snow/glacier melt water, ground water and river water were collected at glacier during the course of study. Initial results of isotope signature ($\delta^{18}O$) shows the variation from -14.0 ‰ to -9.67 ‰ for snow melt runoff, variation for ground water runoff is noticed between -10.7 ‰ and -8.9 ‰, whereas the isotope signature ($\delta^{18}O$) for Patsio runoff varied - 14.9 ‰ to -10.2 ‰.

MoES Sponsored Project

Quaternary Landform Evolution along the Himalayan Frontal Thrust of India: Insight to the patterns of strain release along a Continental Convergent Plate Boundary.

(R.J. Perumal and P. Srivastava)

The Assam Seismic Gap has witnessed a long seismic quiescence since the great Assam earthquake of A.D. 1950. Though a need of proper knowledge on the status of active faults in the area is inevitable for the assessment of paleo-earthquake repetition, and hazard of the area, very few studies have been focused till date. Recent geodetic measurements in the eastern Himalaya using GPS document a discrepancy between the geologic and geodetic convergence rates. West to east increase in convergence rate added with shorter time span earthquakes like the 1697 Sadiya, 1713 Bhutan and 1950 Tibet-Assam, makes this discrepancy more composite and crucial in terms of seismic hazard assessment.

To understand the scenario of paleo-earthquake surface rupturing and deformation of youngest landforms between the meizoseismal area of 1934 and 1950 earthquakes, the area between the Manas and Dhanshiri Rivers along the Himalayan Frontal Thrust (HFT) was studied in details (Fig. 44). Preliminary mapping along with the published literature suggests that, in the eastern Himalayan front the deformation is taking place largely by the thrust sheet translation without producing fault-related folds, unlike that of the central and western Himalayas.

MoES Sponsored Project

Pedological, sedimentological and thermochronological records of climate change during the evolution of Siwalik succession, Punjab re-entrant”

(N. Suresh and Rohtash Kumar -Retd)

This is a multi-institutional collaborative project involving WIHG, Delhi University and Kurukshetra University and was initiated in August 2018. The major objective of the project is to evaluate the role of climate change and tectonics during the evolution of late Cenozoic fluvial successions (12Ma - 5Ma) from western part of Panjab re-entrant. Our component mainly include sedimentological studies of the Panjab re-entrant and also provide basic support of sedimentological attributes to other investigators. Fieldwork was carried out in the eastern part of Kangra Basin and the Ranital-Kangra section along Dodan Nala was visited for sample collection. Stratigraphy of Siwalik succession was divided into three Subgroups – Lower, Middle and Upper Siwalik. In the Kangra Basin, the Siwalik succession is divided

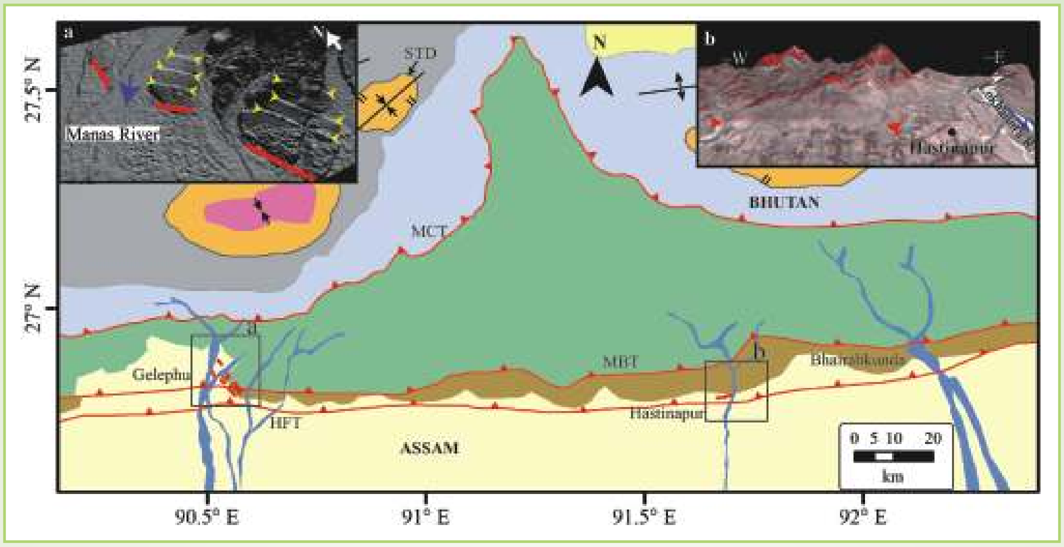

Fig. 44: Showing geological map between Manas and Dhansiri river in the eastern Himalaya. Inset a) DEM generated through cartosat showing multi-levels fault scarps line ending with arrows, b) orthro-perspective DEM view of fault scarp along the range front. Locations are shown by rectangles with alphabet.

into the northern and southern belt by Jawalamukhi Thrust (JMT). All the three Subgroups, Lower Siwalik, Middle Siwalik and Upper Siwalik are well exposed in the northern belt. The Lower Siwalik rocks are mudstone dominated and consist of alternating fine-grained sandstones and siltstones; the Middle Siwalik rocks is dominated by fine-medium- to coarse-grained sandstone and up section increase of conglomerates whereas, the Upper Siwalik rocks are mainly composed of conglomerates interceded with sandstones and some siltstones. In addition, a reconnaissance survey in the Bilapur area was also carried out to identify new litho-section for the measurement and an attempt was made to understand the source rock lithology along the Satluj River.

ISRO/IIRS Sponsored Project:

Geodynamics and Seismicity Investigations in the Northwest Himalaya

(G. Philip, Naresh Kumar, S. Rajesh, N. Suresh, D.K. Yadav, Ajay Paul, Devajit Hazarika and P.K.R. Gautam)

Monitoring of current seismicity in the gap areas

The seismic energy budget of the NW Himalaya evaluated through recent seismic catalogue suggests a high concentration of seismicity around the surface trace of Main Central Thrust (MCT). Correlation with Earth surface relief indicates a relation of the seismicity with heterogeneities of Earth crust resulted due to tectonic deformations in the inter-plate region. Seismic catalogue is further compiled for its unification, elimination of duplicate events and calibration of different magnitude scales. The uniform seismic catalogue of 1991-2017 is used to obtain the spatial variation of the catalogue completeness and the b-value (Fig. 45a). The spatial distribution of seismic events of $M \geq 5.0$ is also plotted along with b-value. During this period, mostly the study region has a magnitude threshold of 3.0 and therefore the data of events of $M \geq 3.3$ divide the NW Himalaya and the adjoining Indo-Gangetic Plains (IGP) into three parts with variable b-values (Fig. 45b).

In general, the b-value is close to 1.0 and its deviation indicates heterogeneous stress pattern of the region. The study region has high variation of b-value between 0.6 and 1.6.The Garhwal-Kumaon region has low b-values mostly below 0.9, the Kangra-Kinnaur region has intermediate values between 0.8 - 1.3 while the b-value exceeds 1.2 for the region of IGP. This data set along with the concentrations of different size earthquakes utilised to divide the study region into three zones (Fig. 45b) as Kangra-Chamba-Kinnaur (R1), Garlhwal-Kumaon (R2) and Indo-Gangetic Plains (R3) for further analysis of hidden periodicities. The division of NW Himalaya into three zones (R1, R2 and R3) is also supported on the basis of different tectonic units, geological features, seismic pattern and sub-surface crustal/lithosphere structures.

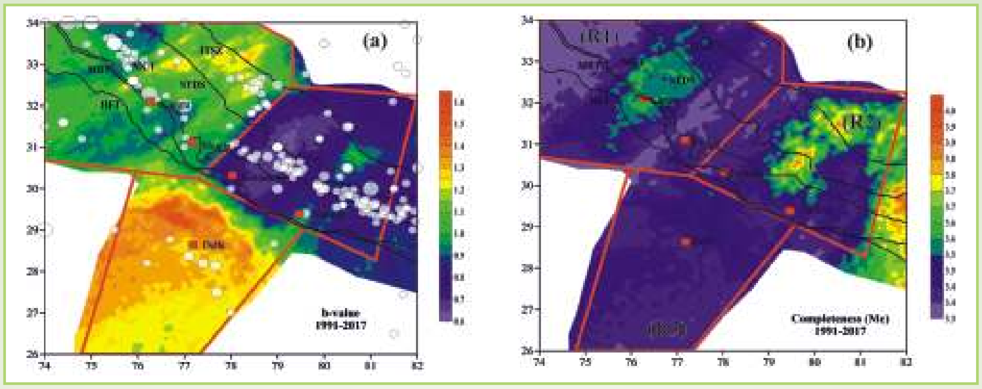

Fig. 45: Spatial variation obtained based on seismic data for the period 1991-2017 for (a) the magnitude completeness and (b) the b-value.

Based on the spectral analysis of point processes of the earthquake sequences, time-dependent models of seismicity to evaluate hidden pereiodicities were developed. Events of M 4.3 for the period from1963 to 2017 for the regions R1 and R2 and M 4.3 for the R3 for the period 1991 to 2017 were used to perform the time-frequency analysis by computing the log-likelihood with moving time window of 1461 days (4 years) and mutual shift of 25 days. The time marks on the diagrams represent the right-hand coordinate of the moving time windows (Fig. 46). This mode of time marking is helpful to observe the precursory signal if it existed on the basis of earthquake occurrence periodicity. The plot for the Kangra-chamba-Kinnaur (R1) region for the period 1963 to 2017 (Fig. 46) highlights some anomalous changes in the earthquake occurrence sequence before M 6.5 Kinnaur earthquake of 1975. We obtained time-frequency diagrams of log-likelihood increments evolution for these three regions separately. In addition, for each diagram a corresponding sequence of main shocks is presented by a bar, whose length is proportional to the magnitude of the event. The plots highlight the periods of quiescence (more amplitude) or enhanced seismicity for the investigating region.

Temporal scaling of differential Total Electron Content (DTEC)

Changes in Ionospheric Total Electron Content (TEC) associated with Great Magnitude earthquakes had observed in the past through ground based Ionosonde as well as space based GPS measurements. Global Navigational Satellite Systems (GNSS) based continues observation on ionosphere TEC revealed how this parameter changes during the inter-seismic, co- and post seismic phases of a Great Magnitude earthquake (e.g. 2011, Mw 9.0 Tohoku-Oki earthquake). In this work weattempted to scale the GPS measured differential TEC anomalies with time in terms of number of pre- and post-seismic days from the co-seismic day of Major Magnitude earthquakes occurred at Mexico, Japan and Nepal during the period 2014 to 2017. Major Magnitude earthquakes occurred in the Mexico and Japan regions were in the oceanic regime while the 2015 Gorkha-Nepal earthquake was along the Nepal Himalaya continent-continent convergence zone. Sixty days of continues GPS data from these three networks have been acquired; such that for the case of each earthquake, minimum thirty days of prior and post event data window has been maintained to get the continuity of TEC anomalies. Data from multiple stations (Mexico event: 20 stations, Japan event: 7 IGS stations and for the Nepal event 6 stations) distributed at various radial distances ranging from 50 to 1000 km from the respective epicenters were considered. For the case of Nepal network the selected six stations are very close and less than 200 km from the epicenter of the Gorkha-Nepal event.

Results on the radial distribution of differential TEC from the respective epicentres of major earthquakes occurred from 2014 to 2017 in the aforementioned networks have been analyzed with the number of days prior and post to the main event. We got clustered distribution of positive and negative differential anomalies at specific day windows before the main event irrespective of the geographic locations of the networks and the same is shown here for the case of Mexico earthquake as depicted in figure 47. We modelled one such positive cluster or the first order positive differential TEC anomaly and obtained a

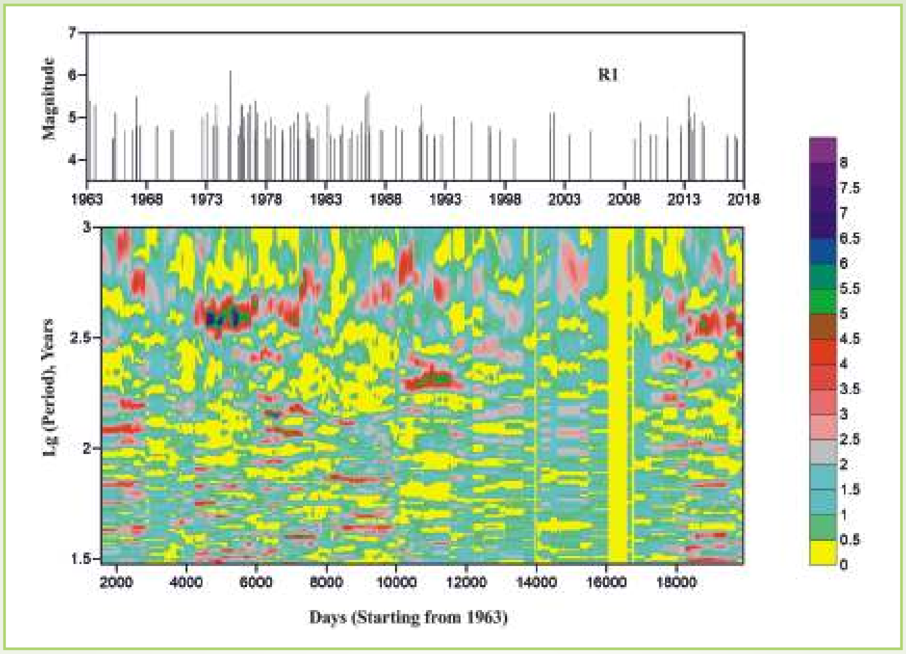

Fig. 46: Time-evolution of the periodic components (log-likelihood functions) in the flow seismic sequences with M ≥ 4.5 in the spatial region R2 within moving time windows of the length 1461 days (4 years) with 25 days shift. The upper panel shows bar diagram of earthquake occurrences wherein length of the bar is proportional to the magnitude of the events.

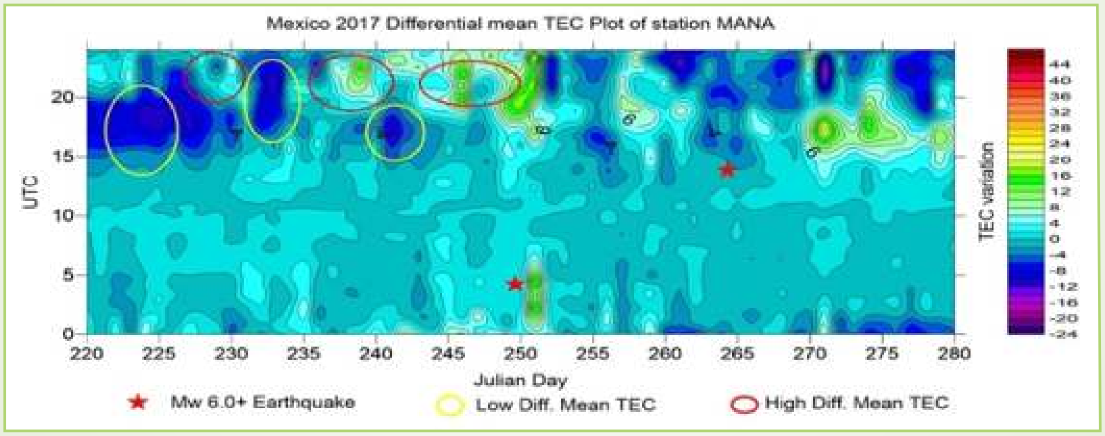

Fig. 47: Clusters of positive and negative differential TEC anomalies (shown as encircled) prior to the 2017 Mexico earthquake

parabolic relation with number of days prior to the Mexico, Japan and the Nepal main events. Scaling relationships show that the saddle point or the low amplitude in the differential TEC of the positive cluster was formed 5.1 and 6.3 days before the main Mexico and Japan events. Interestingly, isolated sharp clusters of negative deviation of differential TEC from the mean TEC are also observed within day windows of 8-10 days, 16-18 days and 26-28 days for the case of Mexico, while the same is 4-6 days and 8-10 days for the case of Japan events. Similarly, the 2015 Nepal event also show clustering of negative differential TEC on day windows of 8-9 days, 13-18 days and 23-30 days even though the region had witnessed only a single Major main event on 25th April 2015. Nevertheless, in all these cases 8-10 day window was found to be common. In this work although we addressed scaling of TEC anomalies using global Major earthquakes, but also put forth a methodology to quantify and temporally scale differential TEC with days prior to any future such events that may occur in the Himalayan plate convergence zone.

Active fault mapping in selected sectors around MCT and HFT

The integrated non-invasive geophysical survey was carried out along the Singhauli nala, which cut across the HFT in the north and exit to the Indo-Ganga alluvial plain in the south. The combination of high-resolution Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT)techniques with different acquisition parameters and Multi-channel Analysis of Surface Waves (MASW) have been employed in the present study.Since the location of the fault trace was already established through satellite image interpretation and trench excavation survey, the profiles of the GPR, ERT and MASW surveys were also very much focused to the fault trace/extension for a distance varying from 45-160 m. The technique is used for imaging shallow sub-surface structures from electrical measurements made at the surface with an electrode array where the electrode is used alternately as a potential and current electrode. The potential measurement are directly related to the electrical properties of the sub-surface materials. Repeat surveys comprising of different arrays were carried out using Lippman 4point light hp earth resistivity meter across the HFT at Singhauli. GPR profiles were obtained with sensors using IDS system equipped with 100, 200 and 600 MHz shielded antennas and GRED 3D viewer. A transmitter antenna radiates very short pulses into the subsurface while from boundaries, with electromagnetic property contrasts, the pulses are reflected back to a receiver antenna at the surface. A series of signals are captured as the mounted antennas are moved along a pre decided trajectory and form a display profile of the subsurface features. To ensure parallel and comparable observation, all the geophysical surveys were carried out along the same traverse line and also along the same orientation in the Singhauli Nala. With this all the profiles also remained parallel to the trend of the trench excavated earlier. Repeated ERT surveys comprising of different resistivity arrays were carried out across the HFT at Singhauli using Lippman 4 point light hp earth resistivity meter consisting of 40 electrodes. GPR (IDS system) was employed with 100, 200 and 600 MHz dual frequency antennas. MASW (DMT-Summit) seismic data (using roll along technique) was acquired at shot stations evenly spaced along a continuous transect using 48 channel geophones. MASW methods is an emerging technique to use the surface waves for investigating shallow subsurface structure, exclusively the structural features characterized by lateral seismic velocity changes. The raw seismic data, which contains dispersive ground roll, is used in swept-frequency format to obtain the phase velocity and frequency relationship. The dispersive nature of the Rayleigh waves can be used for characterization and imaging the near surface physical properties. To achieve the accurate estimation of shear wave velocity using fundamental-mode of Rayleigh wave, 48-channel geophones were used at an interval of 2.5 m to ensure the minimum noise to measure the ground roll wavelengths.

ISRO-Space Application Centre Sponsored Project

Detection and monitoring of major active faults in the selected segments of Himalaya for seismic hazard vulnerability assessment

(G. Philip and Gautam Rawat)

To better comprehend the extension and geometry of the fault, the geophysical imaging along the established active fault systems using Electrical Resistivity Tomography (ERT) has been carried out (Fig. 48).

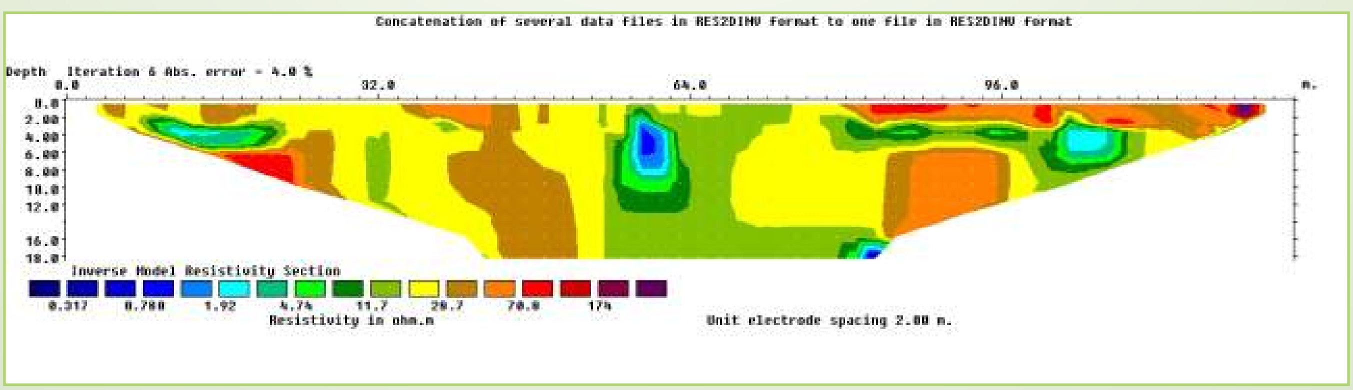

Fig. 48: ERT section across the Nalagarh Active Fault.

Dependence of ground resistivity upon mineral content, porosity, degree of water saturation in the rock and fluid content makes it ideal for imaging and understanding the subsurface. ERT being most non-invasive and effective geophysical tool in understanding the subsurface and its characterization, the resistivity contrast along the lithology imprinted due to displacement of lithology enable tracing of the faults. The study areas for ERT were selected based on previous trench excavation surveys. The displacements and variation in resistive features could be correlated with the structures delineated in the trench log. ERT 2D profile survey was conducted along two profiles in Nalagarh region near trench site. In this survey total 128 meter length of profile is covered with 48 electrodes having 2 meter electrode spacing. Schulmberger and Wenner configuration is utilised for recording electrical potential and induced potential. The 2D inverted resistivity section display subsurface geology in terms of variation in resistivity. The inverted resistivity model is having lateral and vertical resistivity variations according to lateral and vertical extent of different depositional units in the area. The presence of north dipping fault at 32 meter distance from zero electrode position toward south clearly distinguishes two separate zone of lithology. The study is in progress and new sites of active faults are being investigated using ERT, GPR and MASW techniques.

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 and Koushik Sen)

Protocol for Apatite and Zircon Fission Track Thermochronology has been developed in the Institute. Multiple age standards have been dated and inter-laboratory data comparison has also been carried out. During the reporting year, field work has been carried out to map the geological features and the major shear zones using structural data in the Lohit valley region of Arunachal Pradesh. Bedrock samples have been collected for geochronology and thermochronology. The laboratory analysis included the mineral separation and slide preparation work for Fission Track Thermochronology of 13 samples of apatite and 11 samples of zircon from Higher Himalayan Crystallines (HHC). The slide preparation for thermal neutron irradiation of the samples is under process. Mineral separation work for samples from the Lohit batholith is ongoing.

SERB Sponsored Project

Project Title: Exhumation History of the Karakoram Fault Zone, India using Fission Track Thermochronology

(Vikas Adalakha)

The spatial-temporal variations in exhumation rates in the northern undeformed domains of the Karakoram Fault using bedrock apatite fission track (AFT) and zircon fission track (ZFT) thermochronology has been obtained. In addition, data gaps have been filled by providing the first ZFT age record across the Karakoram Transpression Zone, along with new AFT ages. The published data from the Ladakh block has been compiled to assess and compare exhumation histories across the India-Asia margin. AFT and ZFT ages represent the duration of rock cooling since the minerals achieved the effective closure temperatures of ~116ºC and ~232ºC, respectively. Exhumation rates were estimated by applying an eroding half-space model to the obtained thermochronometric ages because exhumation is mainly erosional in the undeformed domains of Karakoram and Ladakh batholiths and advection is dominant due to partial melting in the transpressional domain.

The ZFT ages yield faster exhumation rates since ~8-10 Ma in the KTZ (~0.87 mm yr^{-1}) than in the Ladakh and northern Karakoram blocks (~0.25 and ~0.52 mm yr^{-1}, respectively). In contrast, the AFT ages record faster exhumation rates of ~0.80 mm yr^{-1} in the Karakoram block but consistent rates in the Ladakh block and KTZ. Calculations of the temporal variations in exhumation suggest that the exhumation rates during the middle to late Miocene were as high as ~1.07±0.4 mm yr^{-1} in the KTZ but as low as ~0.28±0.1 and ~0.42±0.2 mm yr^{-1} in the southern Ladakh and northern Karakoram blocks, respectively. Furthermore, the compilation of published Ar-Ar hornblende, Ar-Ar muscovite, and Ar-Ar biotite thermochronological data and ZFT and AFT ages suggests that the cooling rates in the KTZ were spectacularly high (~116-148 ºC/Ma) at ~10 Ma. The high cooling and exhumation rates in the KTZ suggest that rapid rock uplift due to contractional shortening in the transpressional domain facilitated erosional exhumation. This correlation between transpression and exhumation in the data suggests that variations in erosion across tectonically deformed regions occur over even short horizontal distances and indicates a link between tectonics and erosion in active orogens. In contrast, the exhumation rates in the transpression zone abruptly decreased to ~0.73±0.4 mm yr^{-1}, while the rates in the undeformed domains of the northern Karakoram block doubled to ~0.83±0.55 mm yr^{-1} during the late Mio-Pliocene. However, during this time period, the exhumation rates in the Ladakh block were 0.2±0.1 mm yr^{-1}, i.e., one-fourth those in the Karakoram block.

Morphometry analysis has also been carried out across the Karakoram Fault Zone. The correlation between the morphometric indices and millennial-scale exhumation rates suggest that the topography of the Karakoram block was established by the late Mio-Pliocene.

The granites and granite gneisses from a tectono-metamorphic complex exposed along the Shyok Valley in Karakoram region have been subjected to mineralogical, geochemical, and U-Pb zircon geochronological investigations in order to constrain the petrogenetic and geodynamic evolution of the Karakoram terrane through time. Outcrop-scale observations reveal the presence of pre- and syn-kinematic leucogranite bodies intruded within the granites and granite gneisses. Biotite composition and whole-rock elemental geochemistry equivocally suggest subduction- related metaluminous (I-type) calc-alkaline nature for most of the host granites and gneisses, and generation of peraluminous (S-type) leucogranites through crustal anatexis mechanism of pre-existing rocks. The obtained U-Pb zircon ages vary widely from ca 160 Ma to 14 Ma for the granites and granite gneisses, having specific geochemical and structural characteristics, which reveal: (a) the initiation of subduction of the Tethyan oceanic crust beneath the southern Asian Plate at least ~160 Ma ago, and (b) existence of continuous deformation along ~1000 km long lithospheric scale dextral Karakoram Fault (KF) during ~27-14 Ma. The presence of deformed leucogranite dikes are characteristics of dextral shear sense in a wide metamorphic complex suggesting that a ~30-40 km broad dextral strike-slip shear zone as Karakoram Fault (KF) zone exists in the Ladakh Trans-Himalaya.

SERB Sponsored Project

Holocene centennial to millennial scale changes in Indian summer monsoon: a multi proxy record from high altitude regions of Uttarakhand Himalaya

(Sumal Lata Rawat)

Fieldwork was carried out in the palaeo-glaciated valley, above the treeline, in Auli, Alaknanda basin. In order to understand the modern vegetation and climate relationship 30 surface samples have been collected from the study area. The pollen extraction from these sediments has been completed and the microscopic analysis is under progress. For the high resolution centennial to millennial scale Holocene vegetation and climate reconstruction, a 2.5 m deep pit was dug and sample was collected at every cm interval for multi proxy analysis. The data generation of TOC, environmental magnetism and chemical treatment of lake sediments for pollen analysis is under progress. The sediment profile shows seven distinct charcoal layer at various depth intervals. This dark black organic rich layers may have deposited due to rapid accumulation of organic matter in warm and wet climatic conditions. Further, radiocarbon AMS ^{14}C analysis of this profile is under progress.

SERB Sponsored Project

Geo-Thermochronological investigation of Lesser Himalayan Crystallines of Garhwal Region, NW-Himalaya: Implication to Extrusion and Duplexing model

(Paramjeet Singh)

The transact along Kotdwar-Lansdown-Srinagar-Ukhimath-Gorikund road section encompassing sub-Himalaya, Lesser Himalaya and Higher Himalaya has been studied under the present project (Fig. 49). A total of 45 bed rock samples have been collected for Fission Track Thermochronology from different tectonic units, including sampling from Siwaliks, Lesser Himalayan metasedimentary zone, Lesser Himalayan Crystalline zone and Higher Himalayan Crystallines (Fig. 49). Sampling has also been done for the U-Pb dating and structural data like dip, strike, lineation, foliation shear sense indicators etc essential to reconstruct the tectonic history of the area have been collected. The further processing of the samples are underway for the Fission Track Thermochronology.

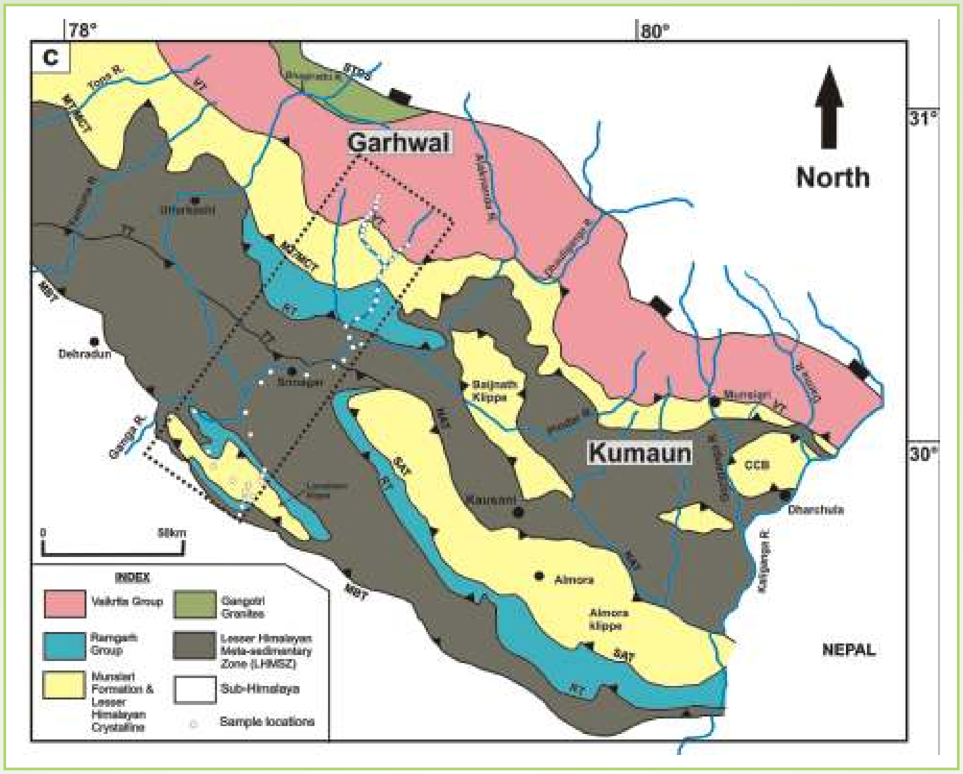

Fig. 49: Geological setting of the Kotdwar-Lansdown-Srinagar-Ukhimath-Gorikund road section and adjoining area along with the sampling locations

SERB Sponsored Project

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

(Pankaj Chauhan)

The project involves the applications of remote sensing as well as field based real time monitoring of meteorological data and glacial stream discharge measurement with the objectives to (i) compute the evapo-transpiration at daily to interannual timescale (ii) analysis and quantification of discharge of the Pindari and Kafni glaciers (iii) calculate the seasonal and inter-annual water balance (iv) delineation and characterization of snow& ice melt and rain from the Pindari and Kafni glaciers using stable isotopes and separation of hydrograph through isotopic methods (v) estimate the suspended sediment concentration and suspended sediment load.

The Pindari and Kafni glaciers lie in the Pindar valley of Alaknanda basin in the Kumaun, Central Himalaya and are located in the Bagehswar district of Uttarakhand has been studied (Fig. 50). The total length of Pindari Glacier is ~5.9 km and the covered area is ~ 9.6 km^2 and the Kafni glacier has occupied about ~ 3.3 km^2 area with 4.21 km glacier length. The valley lies between latitudes 30˚12′15″-30˚ 19′10″N and longitudes 79˚59′00″-80˚01′55″E. The entire Pindar basin occupies ~173 km^2 area of which ~9.2 km^2 is the glacierized area.

During the year, handheld AT-RH meter, Open PAN evaporimeter and rainfall event logger have been installed at Dwali site (Fig. 51a-c). A meteorological observatory/ automatics weather station (AWS) containing sensors for monitoring air temperature, relative humidity, wind speed, wind direction, rain gauge and soil temperature have also been installed at Kafni glacier zero point during (Fig. 51d). Hydrological suspended solid analyzer was utilized to estimate the sediment budget of the glacier valley (Fig 52a-f).

Two discharge sites (20m long and 20m wide) have been constructed, one at Pindari stream ($30^0$10'41"N; $79^0$59'39"E; Elevation 2631 m above msl) and second at Kafni stream ($30^0$70'36"N; $79^0$59'40"E; Elevation 2590 m above msl). Both sites are located near the Dwali station and are constructed before the confluence of Pindari and Kafni streams (Fig. 50).

SPONSORED PROJECTS

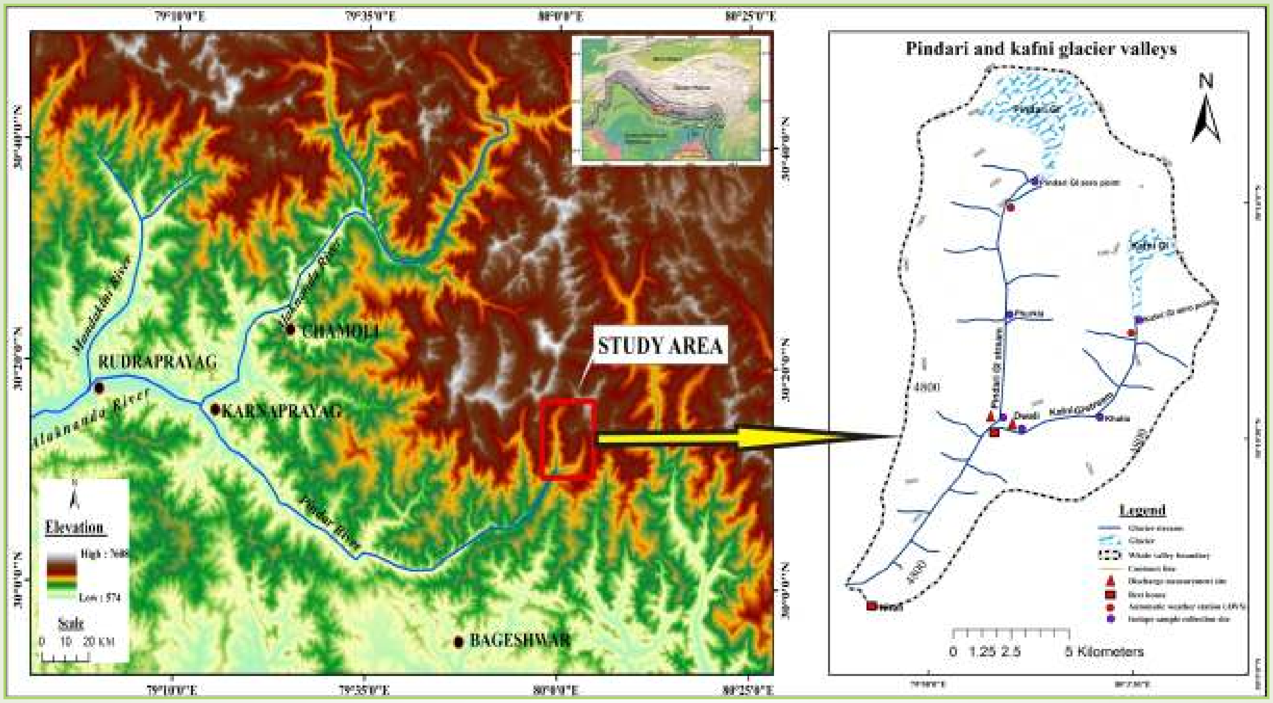

Fig. 50: Location map of the Pindari and Kafni glaciers

Fig. 51: (a-c) AT-RH meter, rain gauge and Evaporimeter installed at Dwali station. (Fig. d) meteorological Observatory/ AWS established at Kafni glacier zero point.

Fig. 52: (a-b)show construction of discharge site, measurement of stage and cross sectional area of the stream. (c-d) display collection of samples for isotopic analysis, (e) sediment filtration process to quantify the SSC and SSL and (f) testing semiautomatic suspended solid analyzer.

200 samples of surface, ground and snow melt water have been collected for isotopic studies; 100 samples have been analysed in the laboratory. Suspended sediments concentration (SSC) and the suspended sediments load (SSL) for two years (2017-18) have been quantified. The results are presented in Fig.53(a-p). It has been noted that the maximum percentage of discharge and sediments are in the months of July and August in both years (2017-18). It has also been observed that discharge has good correlation with SSC and SSL.

SERB - NPDF Scheme

Stable carbon and oxygen isotopic studies of the Paleocene-Eocene sequences of Kachchh, western India and their implications on the paleoenvironment of the western Indian shelf

(Vineet Kumar Srivastava)

The Paleocene lateritic bauxite deposits of Kachchh Basin are mineralogically dominated by gibbsite with Al_2O_3 content ranges between 78.5 - 29% that allows them to fall into an economical grade deposits. Such lateritic bauxite deposits are formed in-situ over Deccan Basalt parent through deferruginization and destruction of kaolinite under moderate to strong lateritization in an oxidizing environment and the gibbsite-kaolinite-hematite-anatase mineral assemblage suggests warm and humid climatic conditions. Furthermore, the low values of $(La/Sm)_N$ and ΣREE along with slight negative Eu anomaly suggests its development from young undifferentiated volcanic arc. The higher CIA values (>84%) and mineralogical assemblages revalidate the complete isolation of Indian plate and its movement over the southern equatorial climatic belt during Paleocene.

In addition, a 16 m thick late middle Eocene dolostone succession is reported for the first time from Panandhro region of Kachchh and based on its sedimentological and geochemical characteristics, a meteoric-marine mixing model of dolomitization is proposed that is corroborated with the isotopic data as well (Fig. 54). The petrographic and geochemical investigations (including stable C and O isotopes) suggests its development during early diagenetic phase in a shallow water marginal marine environment where mixing of fresh water was feasible. The slightly negative to positive $\delta^{18}O$ values (-0.99 to 1.70‰) indicates semi-closed lagoonal environment where dolomitization was mediated by evaporated seawater as well freshwater influx. While, the highly negative $\delta^{13}C$ values (-25.98 to -38.83‰) are attributed to the

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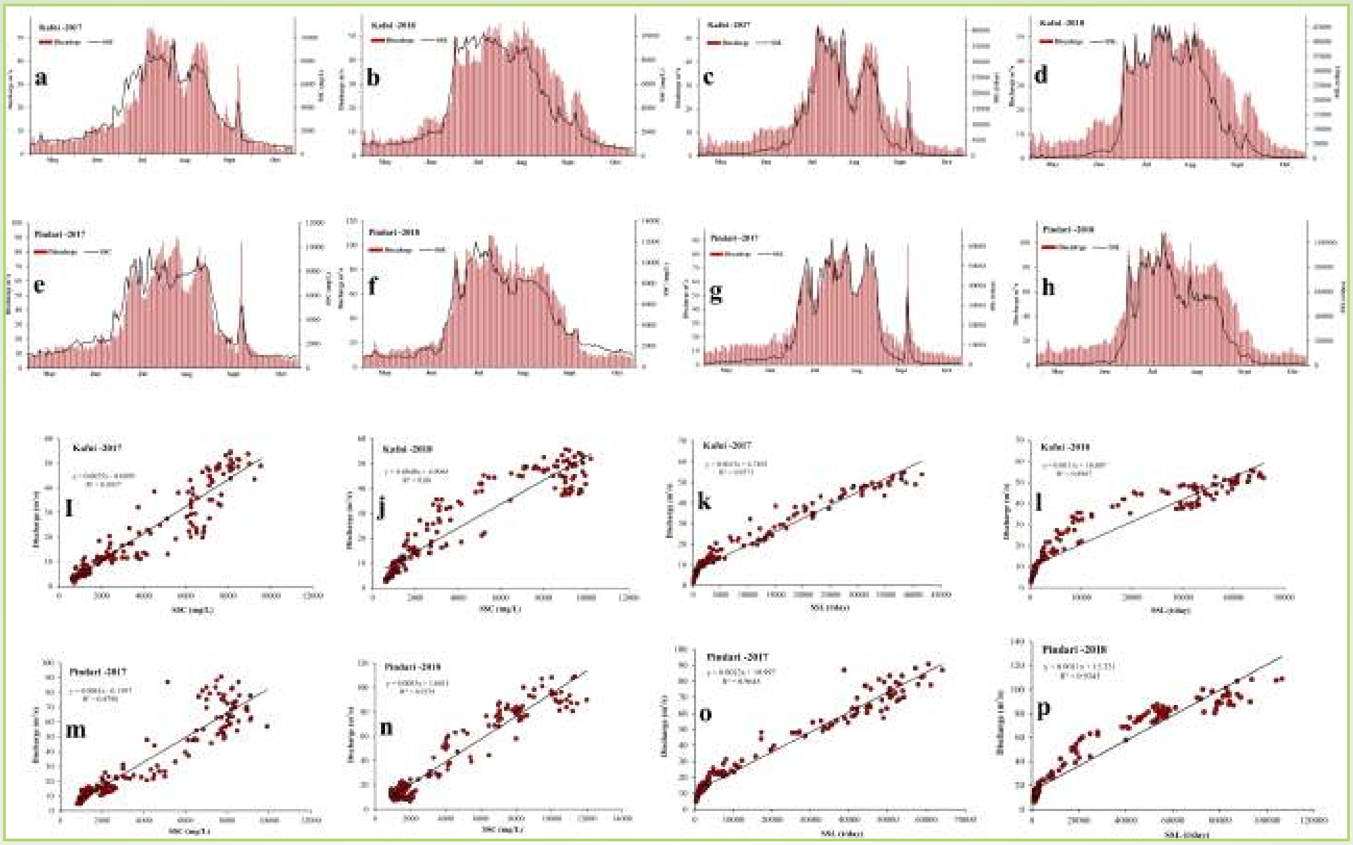

Fig. 53: (a-h) the behaviour of the discharge with SSC and SSL of the Kafni and Pindari Glacier (i-p) shows the relationship between SSC and SSL between discharge of the Kafni and Pindari glaciers.

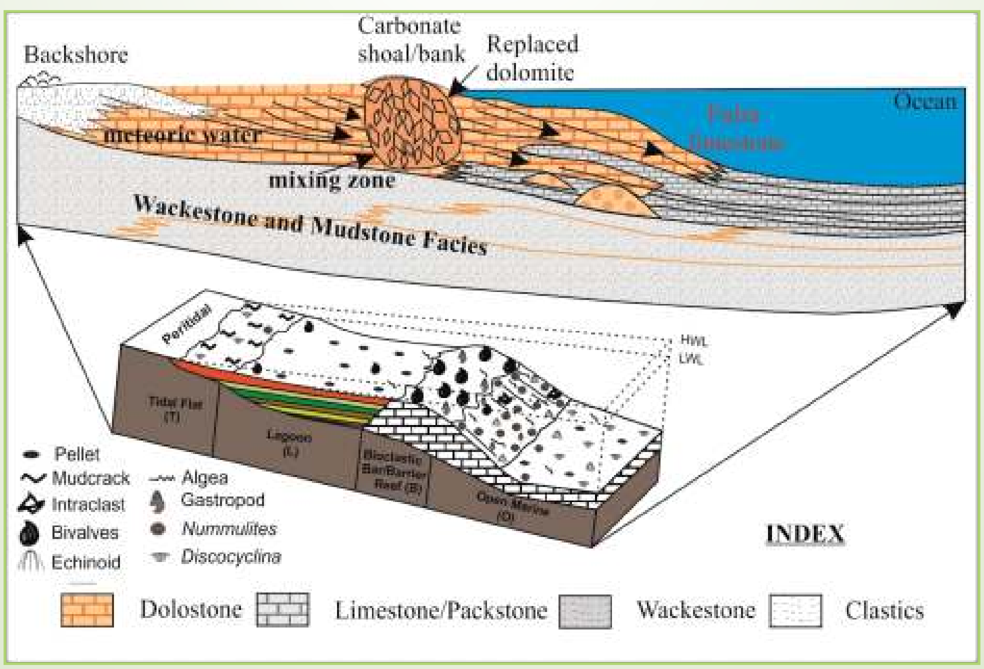

Fig. 54: Cartoon exhibiting the depositional realm of the Middle Eocene dolostones of Kachchh basin, western India (modified after Flügel, 2010).

combined effects of anaerobic microbial degradation of organic matter and decomposition of biogenic methanes by sulphate reducing bacteria.

SERB Sponsored Project

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

(Parveen Kumar)

The frequency dependent shear wave quality factor ($Q_\beta(f)$) relationship and site effect are estimated for the Garhwal region from the inversion of strong motion data. The strong motion data of eighty two events recorded at seven stations are used for this work. Numerous experiments are executed to check stability of inversion algorithm, which confirm the reliability of the solution of adopted algorithm. The acceleration records corrected from the site effect are used to develop attenuation relations at each station. The attenuation relation are obtained at Chamoli, Bhatwari, Garurganga Tehri, Uttarkashi, Barkot and Gopeshwar stations as (92±4.0)f(1.10±0.13), (112±4.2)f(1.0±0.08), (99±3.0)f(1.0±0.12), (101±4.5)f(1.1±0.15), (110±3.2)f(0.9±0.12), (95±4.0)f(1.10±0.11) and (103±4.6)f(0.9±0.10), respectively. The close resemblance of these attenuation relations with each other and almost similar site effects at all stations confirm the existence of same type of rocks at these stations. A regional regression relation of the form $Q_\beta(f) = (102 \pm 3.9)f(1.0\pm0.12)$ is established for the Garhwal Himalaya, which represents the high level of tectonic activity and large heterogeneities of this area.

DST INSPIRE Faculty Project

Metamorphic evolution and fluid-rock interaction at the slab-mantle interface:constraints from Nagaland Ophiolite Complex, NE India

(Aliba AO)

The Nagaland Ophiolite Complex (NOC) is the largest exposed section of dis-membered and tectonized site of ophiolite rocks that are part of a ~ 3000 km long, nearly north-south trending, arcuate ophiolite belt from the eastern Himalayan syntaxis in the north through Indo Burmese ranges (IBR) in the middle to the Andaman Nicobar island in the south. The NOC is the one of the largest exposed ophiolite sequences that occurs all along the IBR. Recent metamorphic studies suggests an intra-oceanic subduction system for the formation of the NOC. Study of high-pressure (HP) rocks which are typically associated with the ophiolites have proved invaluable in understanding the dynamic evolution of rocks in a subduction zone setting. Previous studies have indicated the preservation of high-pressure (HP) rocks from the NOC. Based on the identification of HP rocks, selected samples were processed for detailed metamorphic study. Rock thin sections for EPMA analysis were prepared and selected samples were again powdered and analysed in X-ray fluorescence (XRF) spectrometer for major and trace element whole-rock bulk geochemistry. Trace element analyses of the bulk-rock composition was also carried out using Inductively Coupled Mass Plasma Spectrometry (ICP-MS, ELAN DRC-E, PerkinElmer). Mineral analyses of representative samples were also carried out with a CAMECA SX-50 electron microprobe.

The HP rocks have the following mineral association of glaucophane/magnesioriebeckite + magnesiokataphorite/winchite + phengite + titanite + chlorite ± garnet ± epidote. Garnetiferous amphibolite rocks are rare and preserved with the following mineral association: garnet + magnesiokataphorite/winchite + glaucophane/magnesioriebeckite + quartz + epidote + phengite + titanite + chlorite + apatite. Metamorphic peak mineral assemblage in this rock is garnet + hornblende + phengite + epidote and a post-peak assemblage of garnet + glaucophane + epidote + phengite with an intermittent reaction involving retrogression of hornblende to magnesiokataphorite/ winchite is preserved. Based on P-T pseudosection modelling using PERPLEX program, the minimum peak P-T of metamorphism at amphibolite facies condition was constrained at ca. 11 kbar and 570 ºC (Fig. 55).

WoS-A Scheme DST

Palaeobiology and Palaeoenvironmental Reconstruction of the Eastern Krol Belt, Himachal Pradesh

(Rajita Shukla)

The Krol Belt of Lesser Himalaya is exposed as a series of synclines from Himachal Pradesh in the north-west to Uttarakhand in the east and represents the transition from Precambrian to Cambrian time. Kamlidhar, Nigalidhar and Korgai synclines in Himachal Pradesh, Lesser Himalaya form the study area for the project.

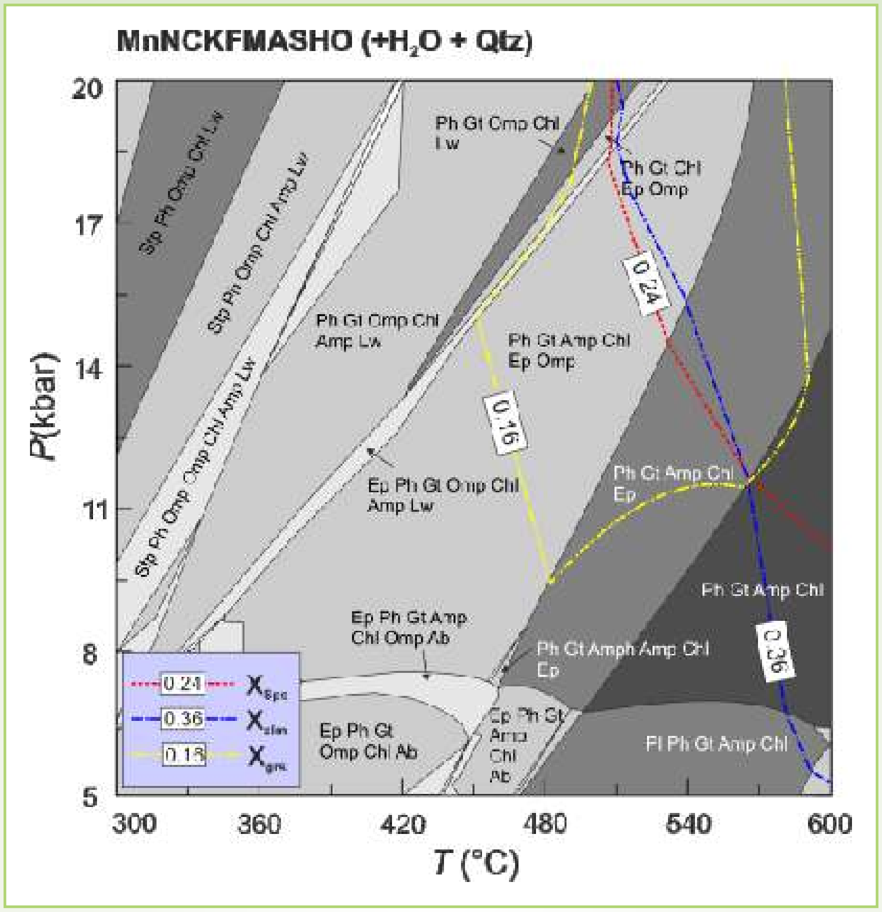

Fig. 55: MnMCKFMASHO P-T pseudosection calculation of HP garnetiferous amphibolite rock from the Nagaland Ophiolite Complex.

Complete sequence of all lithological units of the Krol Belt (i.e. Blaini, Infrakrol, Krol Sandstone, Krol and Tal sequences) is present within these three synclines. These synclines have thus been selected to generate data from new sections for understanding the palaeobiological changes and deposition across the Krol Belt.

The focus of the project is the study of palaeobiological entities, namely microfossils and trace fossils, from the Krol Belt of Kamlidhar, Nigalidhar and Korgai synclines, H. P., with the objective of filling the existing gaps in the evolutionary chain during Precambrian-Cambrian time.

Thin sections of chert collected during the previous field work have revealed a microfossil assemblage which is not as well preserved as reported from coeval successions in other synclines of the Krol Belt. Filamentous forms are predominant, coccoidal microfossils are few while acritarchs are not observed so far. Few species of *Siphonophycus*, a filamentous genus are the most prominent biotic entities observed so far. This genus is the most common constituent of the Neoproterozoic microfossil assemblage and is indicative of low energy, intertidal environment of deposition. A few unknown forms are seen and their biogenecity is being tested. Another field work was carried out recently and thin section studies for microfossils have been initiated on those samples.

Trace fossils have been recorded from the Nigalidhar Syncline near Koti Dhaman. *Palaeophycus, Planolites, Skolithos* are a few of the commonly occurring trace fossils observed, which have been published earlier. Further field work in the current year has revealed many more trace fossils which are being documented for detailed study and interpretation. Total Organic Carbon (TOC) studies have also been carried out on a few shale, carbonate and chert samples. These studies so far reveal poor organic carbon content that is reflected by the thin section studies which are showing paucity and poor preservation of microfossils.

DST-INSPIRE Faculty program

Lake sediments-a natural laboratory to study the past climate variability

(Praveen Kumar Mishra)

The study on the past climate variability focuses from the lake sediments from the Indian sub-continent. Based on the multiproxy approach like elemental and isotope geochemistry, hydrochemistry and biological proxies, the study aims to (i) understand the present sedimentation pattern in lake basins by surface sediment sampling, sinking particles, and water column investigations; (ii) increase the spatial coverage of the palaeo-data for obtaining a better understanding of the past climate variability, and (iii) understand the monsoonal relationship with different teleconnections (e.g. ENSO, IOD, Active-break cycle).We have largely utilized various factors including fluvial, tidal or human affecting the modern processes in Estuarine sequence, reconstruction of past climate variability in terms of south-west and north-east monsoon, and a review work focussing on the Holocene climate variability and the cultural dynamics in the region for the present study.

Geochemical and *end-member mixing analyses (EMMA*) of the grain-size distribution were conducted on modern surface sediments from Ashtamudi Estuary, Southern India to understand the hydrodynamic factors that influence recent depositional processes in the region. The study reveals that the sediment deposition in Ashtamudi Estuary is largely governed by the fluvial input (from the North), tidal activity (in the south) and the human influence (especially in the eastern and southern end of the estuary. This integrated geochemical analyses and EMMA provides advancement in the knowledge of the transportation mechanisms and regional sediment dynamics from the estuarine system in Southern India.

The work on Ashtamudi Lake, focusing on past 2 millennia climate variability in the region, have also been initiated (Fig. 56). The palaeoclimatic study will help to understand the past interaction between fluvial versus marine system in the region. Core sediment sampling have been carried out and are being analysed.

terms of south-west and north-east monsoon, has also been studied using multi-proxy approaches like geochemistry, clay mineralogy and end member mixing analyses of the grain size parameters. The proxy data shows that the increasing precipitation in the region during the later part of the late Holocene is in contrast to the records from the core monsoon zone and shows an inverse relationship between Indian summer monsoon (ISM or SW monsoon) and north-east (NE) monsoon strength. The result is also corroborated with increasing

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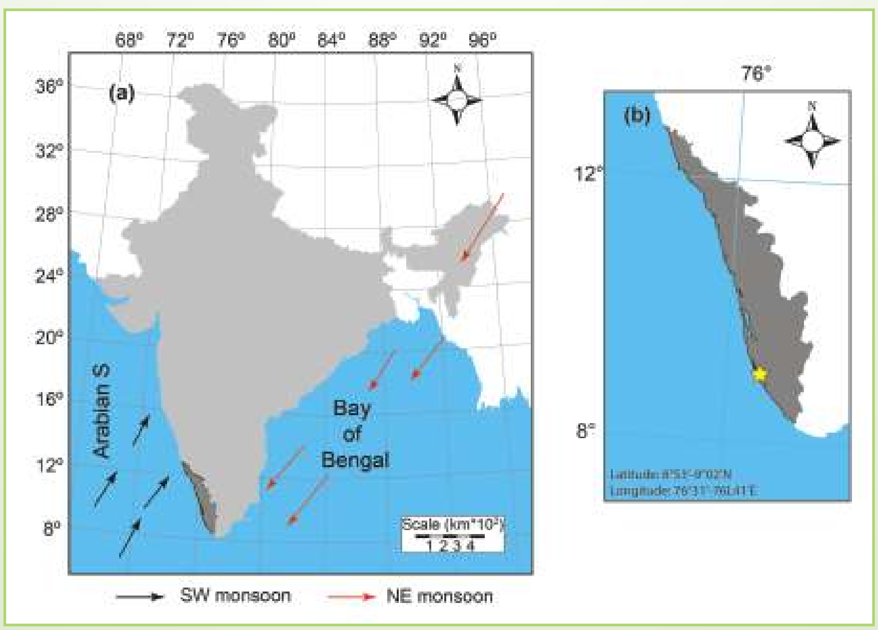

Fig. 56: (a) Location of the study area (b) map of Ashtamudi basin with sampling locations of the sediments. (indicated with a 'yellow star').

ENSO variability and shifts in the Intertropical Convergence Zone.

MoES Sponsored Project

Landslide Hazard Assessment in NE India along the Gangtok-Tsomgo/Changu Lake and Gangtok/Chungthang-Lachen Corridors

(Vikram Gupta)

This is a joint Indo-Norwegian project involving Geological Survey of Norway, Trondheim (Norway), Norwegian Geotechnical Institute, Oslo (Norway), Indian Institute of Technology, Kharagpur (India) and Wadia Institute of Himalayan Geology, Dehradun (India).

During the year, landslide inventory has also been prepared for the entire state of Sikkim, and more detailed emphasis have been given to the distribution of landslides along the Teesta river. The landslides along the river valley were correlated with geological, geomorphic indices such as steepness index, valley floor width to valley flood height, dissection index, and knick points along the river. Daily rainfall data for three different stations have also been analyzed to understand the temporal occurrence of landslides in the area. The distribution of landslides have been correlated with various geological and geomorphological features. All the data were prepared in the GIS environment for easy overlaying of one parameter with another.

Further Dzongu landslide that has occurred along the tributary of Teesta river, and has blocked the river, been studied in detail. The slopes has been scanned with the Terrestrial Laser Scanner (Fig. 57) and the Drone mapping has also been carried out for the preparation of DEM and thus the large-scale map. Geotechnical characterization of the soil and rocks constituting the slopes were carried out, and finally the modelling were attempted to know the condition of slope before its failure.

Fig. 57: Terrestrial Laser scanning of the Dzongu landslide that has blocked the tributary of the Teesta river and created a reservoir.

DST Sponsored Project

Status of geo- resources and impact assessment of geological (exogenic) processes in NW Himalayan Ecosystem under National Mission of Sustaining Himalayan Eco-system (NMSHE)

(WIHG Director, Rajesh Sharma, D.P. Dobhal and Vikram Gupta)

This National Mission project on Sustaining Himalayan Eco-system mainly pertains to establishing database and information system about geological resources (groundwater, springs including geothermal springs, mineral resources and snow cover) and exogenic geological processes (mass - movements including GLOF) along the major valleys, to facilitate policy decision about the sustainable development of Himalayan Ecosystem taking into account the work of existing knowledge.

As a part of the program, one Task Force Partner Himachal Pradesh Council for Science, Technology and Environment (HIMCOSTE), Shimla was selected for the data collection and compilation on various aspects. During the reporting year, using high resolution LISS III and LANDSAT satellite data, they have carried out data generation on various aspects of geological resources, like ground water, springs, snow cover, Quaternary deposits and mass movements for the Kangra, Hamirpur, Una, Mandi, Kullu, Sirmour, Solan and Bilaspur districts of Himachal Pradesh and for Shimla district the data collection is underway. Besides, the inventory of the lakes, and the possibility of the GLOF

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for the Spiti river basin, located in the Kinnaur district of Himachal Pradesh has been prepared.

In continuation of preceding years, the preparation and updation of the inventory of landslides for Indian states of Himachal Pradesh, Uttarakhand, Sikkim Himalaya and parts of Jammu & Kashmir were done. It has been observed that there are 3303 and 850 active landslides in the Uttarakhand and Himachal Pradesh, respectively. Further, it has been noted that the concentration of landslides in the Uttarakhand is higher (~66%) in the Lesser Himalaya, whereas in HP the landslides are equally distributed in various zones. Further these landslides are reported to lie between 400 and 3000 m above msl, where ~90% of the population resides, thus posing greater risk and vulnerability to the society.

For some of the river valleys, like Satluj valley (HP), Yamuna valley, Bhagirathi valley, Alaknanda valley, Goriganga valley, Kali valley (Uttarakhand), and Teesta valley (Sikkim), detailed studies on the relationship on landslides with various geological, geomorphological and climatic proxies were carried out to understand the spatial distribution of these landslides in the area. The studied parameters included litho-tectonic set up, quantification of river gradient, steepness index, valley floor width to valley height ratio and normalized difference vegetation index (NDVI). Besides the scaling relationship of landslide area-volume relation havebeen established. In order to understand and demarcate, various landslide susceptibility zones, landslide susceptibility mapping using various techniques and methods like frequency ratio, weight of evidence, Yule's coefficient have been carried out.

MoES Sponsored Project

Seismicity monitoring and evaluation of active faults in Garhwal Himalaya and adjoining Shimla hills region in Himachal Pradesh

(Ajay Paul)

A broad band seismic network is continuously recording the earthquake events in the Garhwal and adjoining Shimla Hills region of Himachal Pradesh. This study region lies in the Central Seismic Gap. The data has been acquired from seismic stations Adibadri, Chakrata, Tapovan, Ghuttu, Gaurikund, Nahan and Kotkhai. The analysis has been carried out for 812 earthquake events (2018-2019). The analysis of a total of 2723 events (2007 to 2018) acquired for this region indicate that majority of earthquakes are occurring in a narrow zone, south of MCT in the magnitude range between 1.8 and 5.5 with focal depths of 12 to 25 km . The events have low stress drop values and one of the reasons could be that the crust of the region is not able to sustain accumulated energy and is being released regularly in the form of micro earthquakes. It has been observed that there are two major clusters of seismicity. One near Uttarkashi and the other near Chamoli. The presence of fluids and low coefficient of friction are two major characteristics of the Chamoli region, which need to be monitored, in order to ascertain this region as probable for a future great earthquake.

The spectral analysis of SH-wave for local earthquakes ($3.0 \leq M \leq 5.0$ M) that occurred in the Garhwal-Kumaun region have been carried out to infer the source parameters and scaling relation. The correction for the path attenuation is done by estimating the quality factors $Q_\beta(f)$ using frequency-dependent coda normalization method. The decrease in observed shear wave attenuation from the Kinnaur to Kumaun region indicates a variation in lateral heterogeneity. Therefore, the $Q_\beta(f)$ values for each station have been estimated and applied for different frequencies to eliminate any bias in the determination of source parameters. The correction for near site effect is done by using spectral decay parameter κ obtained from the decay of acceleration spectra at high frequencies. Then, the estimated corner frequency and stress drop were corrected for the finite-bandwidth effect using the analytical solutions for an omega-square source model. The estimated radiated energy (E_s) was also corrected for the finite band width limitation. Finally, after evaluating the parameters with no tight constraint on finite-bandwidth effect, five scaling relations have also been established,

$\log(M_O) = 39.58\text{-}3.12 \log(fc)$; $\log(\Delta\sigma) = 0.41 * \log(M_O)\text{-}14$; $\log(Es) = 1.32 * \log(M_O)\text{-}21.58 \log(\sigma a) = .77 * \log(\Delta\sigma)\text{-}0.025$; $\log(Es) = (1.9 \pm 0.06) *$; $Mw + (3.04 \pm 0.21)$ where, Mo, f_c, $\Delta\sigma$, E_s, σ_a and Mw are seismic moment, corner frequency, stress drop, seismic radiated energy. Apparent stress and moment magnitude respectively. Fig. 58 shows the effect of finite bandwidth on $\Delta\sigma$ estimates.

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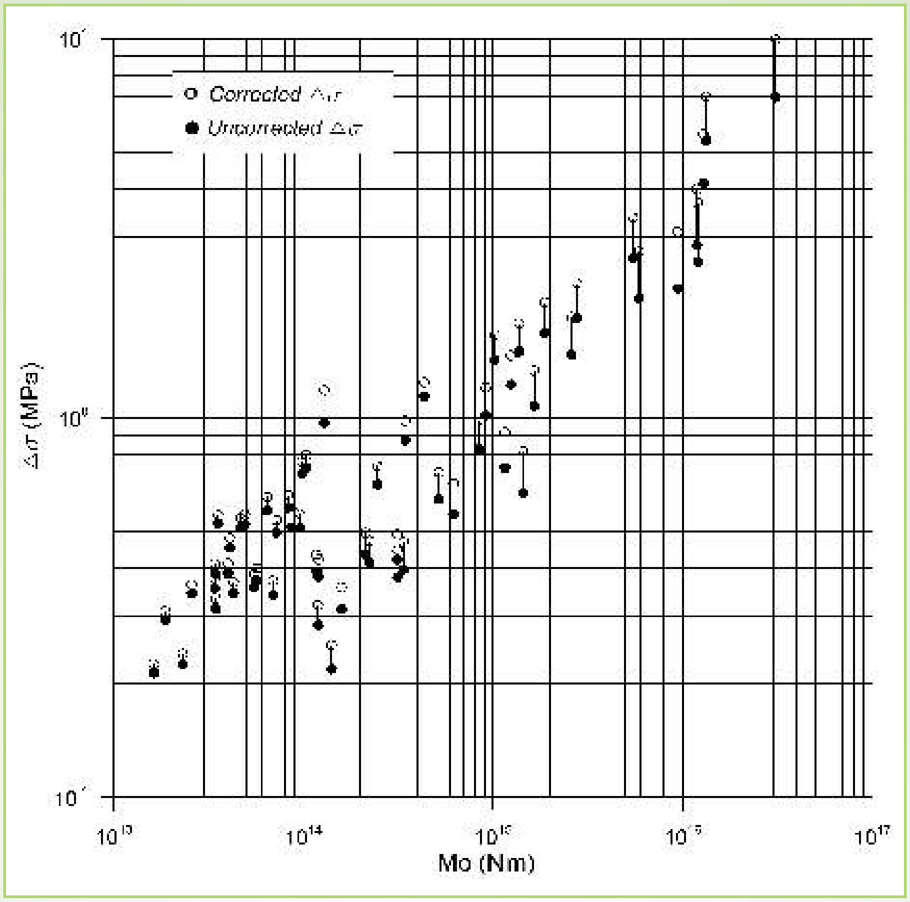

Fig. 58: The variation of seismic moment (Mo) and stress drop (Δσ). The uncorrected and corrected estimates are shown with closed and filled circles, respectively. Both the estimates are connected with small line segment. The length of line segment indicates change in the estimates after correction applied.

SERB Sponsored Project

Evaluating tectonics of the Indian lithosphere and sub-Moho dynamics with respect to exhumation and present day configuration of the Indian Continental margin in the Indus Suture Zone, Laddakh: An Integrated Magnetotelluric, Seismological and Structural Approach

(Gautam Rawat, Devajit Hazarika and Koushik Sen)

Different dimensionality analysis and decomposition scheme applied to MT tensor in order to find regional geo-electrical co-ordinates. A Fortran code developed and provided by Matri et al. (2009) is utilized for WALDIM analysis. The code read edi files and calculate different invariants based on WAL dimensionality criteria. These set of eight invariants are correlated with points and rotation along represented Mohr circle (Lilley, Part-I & Part II. 1998). The classification is based on a set eight rotational invariants (WAL invariants), out of which seven rotational invariants ($I_1, I_2, I_3, I_4, I_5, I_6$, *and* I_7) are independent and one (Q) is dependent parameter. The most important aspect of this classification is that by inspecting the value of I_7, one can infer the dimensionality of the regional structure. Although in the presence of noise, these parameters will never be zero. A threshold value of 0.1 (equivalent to 6% of error in relation to 90°) is suggested (Weaver et al. 2000) and below which values are assumed to be zero. Selecting this threshold value is critical for the classification of regional dimensionality. Fig. 59 displays the classification of background regional dimensionality of our data sets using WALDIM code.

Further Phase tensor parameters are calculated using Matlab script of Unsworth (2009), using singular value decomposition, as specified in Caldwell et al. 2004. Phase tensor parameters Φ_{max} and Φ_{min} are converted into their related phases ϕ_{max} and ϕ_{min}. These

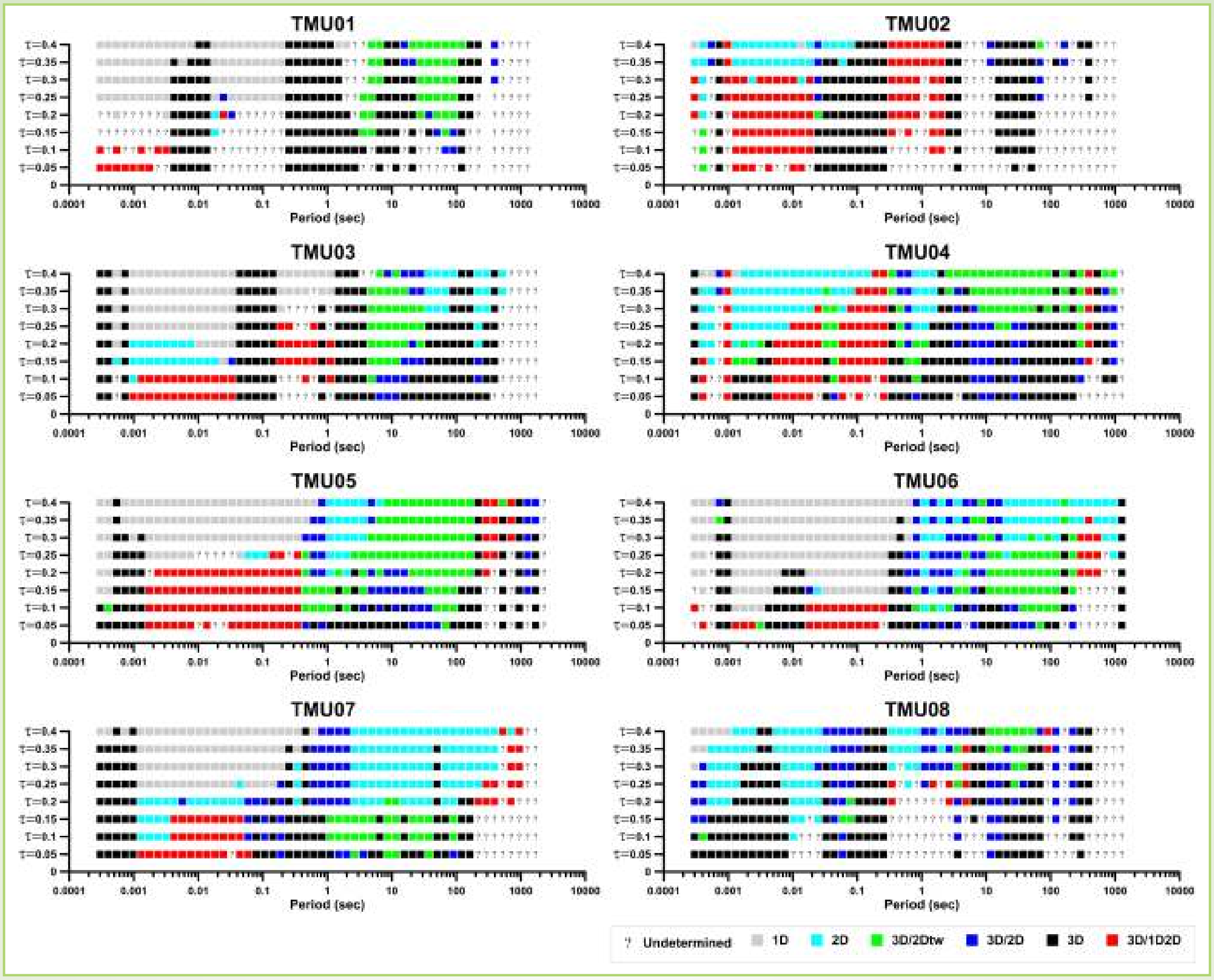

Fig. 59: Dimensionality obtained after WALDIM analysis

phases are then expressed in first quadrant taking into account that one of these is actually $\phi - 180^0$. Figure 60 is the pseudo-section of ϕ_{max} and ϕ_{min} Observing ϕ_{max} variation with period along the profile it is quite clear that phase is increasing with period indicating a conducting structure at depth throughout the profile. Similar behavior is also observed for ϕ_{min} variation except at long periods where phase is decreasing. It can be visualized that the difference of $|\Phi_{max} - \Phi_{min}|$ is non zero.

The contour plot of skew of phase tensor (Fig. 60c) shows that except for periods greater than 100 sec, β with low values confined to the limit of ± 3o, and can be considered to be zero. Non-zero $|\Phi_{max} - \Phi_{min}|$ and β tending to be zero across the profile permit to conclude that regional structure can be modeled as 2-Dimensional. Bandwise averaged angle (α-β) for all MT sites.

MoES Sponsored Project

Present day subsurface configuration and geodynamics of the Kumaon Himalaya: an integrated geophysical and geological investigation

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

Expansion of Seismological network along Kali river valley

In order to achieve high resolution image of the crust and for precise estimation of hypocentral parameters of local earthquakes, the seismological network in the Kali river valley has been expanded by establishing five broadband seismological (BBS) stations in addition to

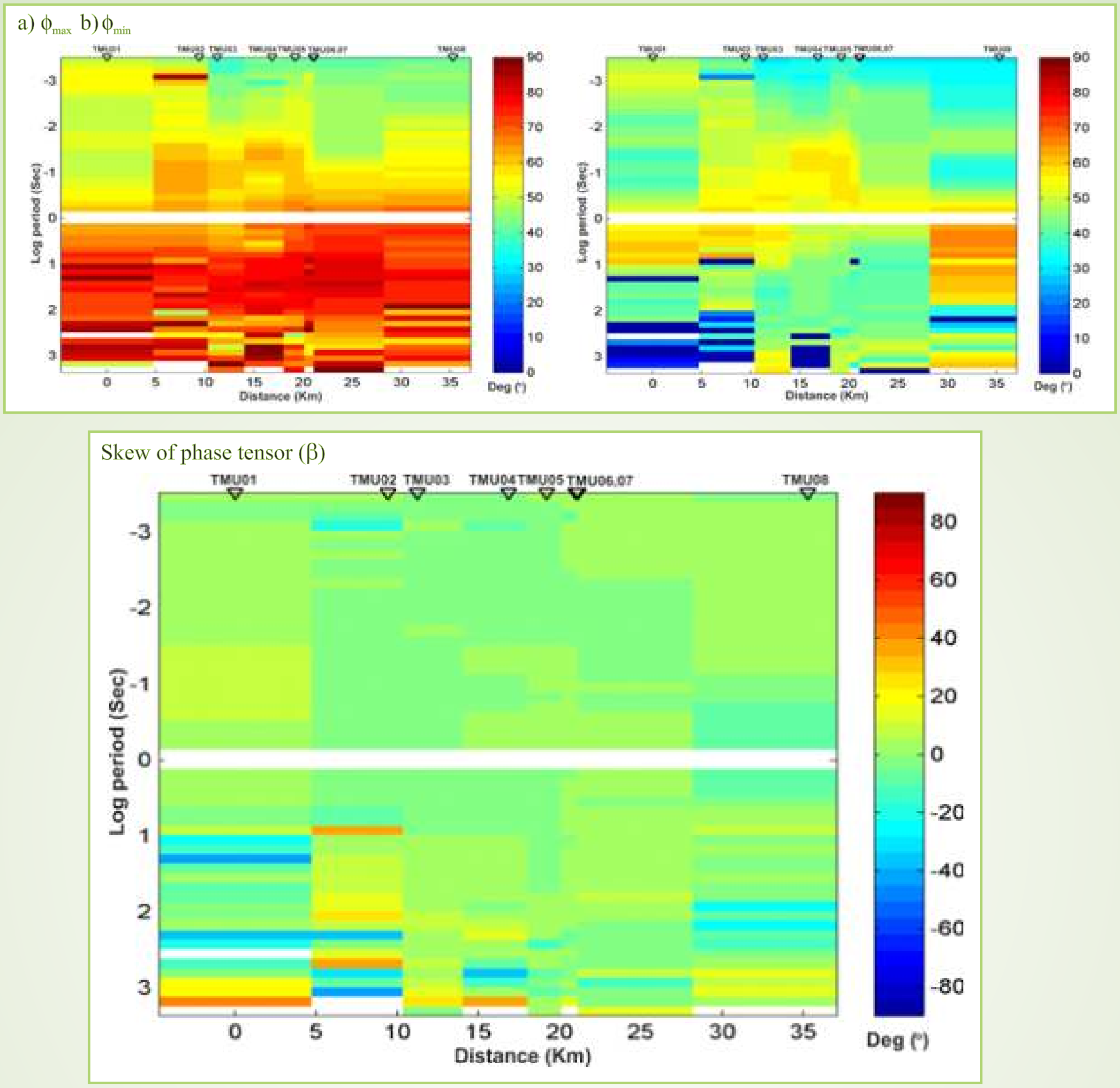

Fig. 60: ϕ_{max} and ϕ_{min} obtained after phase tensor decomposition.

existing 10 BBS stations installed under this project (Fig. 61). Out of total 15 stations of Kali river profile, 10 stations (KAHT, BAST, AMRI, CHAM, MTLA, BNDL, BANS, DHAR, SBLA, and PNGL) were established during May 2016, additional 3 stations (CHDN, LGHT and DHAM) were established in June 2017 and another 2 stations (TAWA and GARB) were established during the reporting period. The linear profile covers about 200 km along the Kali river valley. In order to analyse local earthquake data, it is essential to have a suitable azimuthal coverage of the recording stations. To achieve azimuthal coverage, the data recorded by broadband seismological stations operated by Kumaun University, Nainital and Ghuttu station of WIHG, Dehradun were also collected (shown by black triangles whereas Ghuttu station is shown by pink triangle in figure 61).

Crustal structure investigation through modelling of receiver function

The receiver function (RF) analysis has been carried out for ~ 250 teleseismic earthquake data (magnitude ≥ 5.5 and epicentral distance range 30^o-90^o) recorded by seismological stations along the Kali river valley. The iterative deconvolution method of Ligorria and Ammon (1999) has been used. Shear wave velocity structures beneath 13 seismological stations of WIHG, Dehradun have been obtained with the help of modelling of RFs.

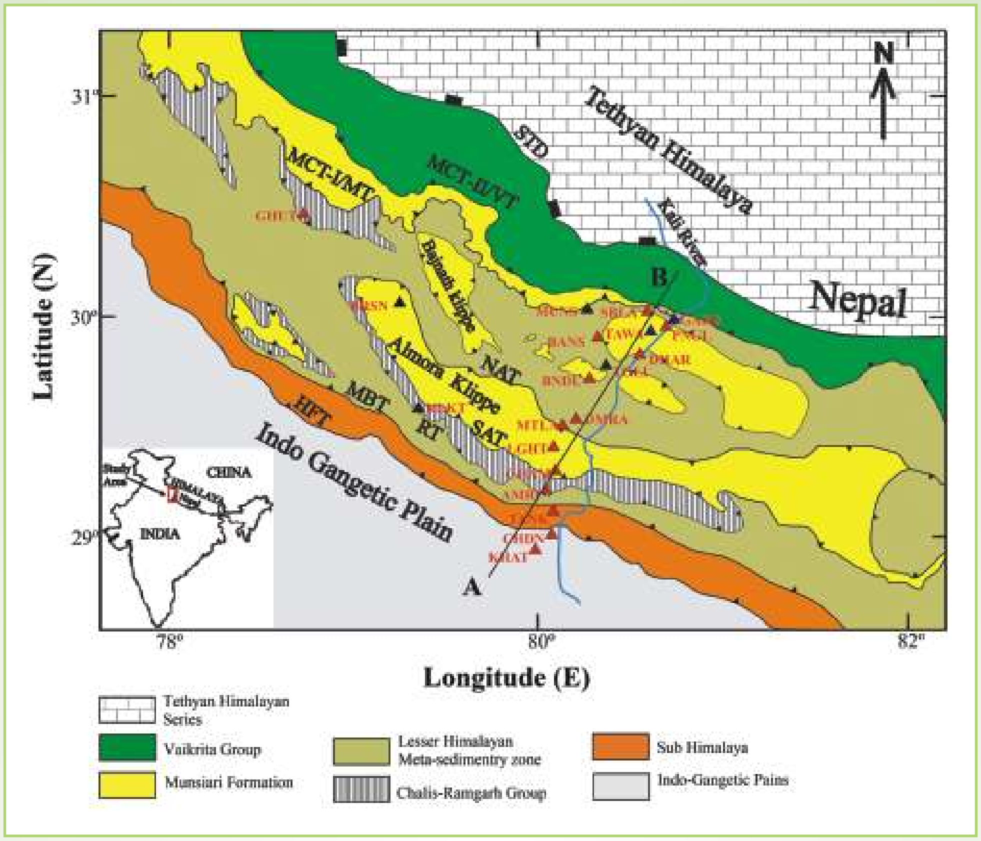

Fig. 61: Geological map of the Kumaon Himalaya with major tectonic features (modified after Srivastava and Mitra, 1994). Seismological stations used in the present study are shown by the triangles. The red triangles shows stations established under this project. The blue triangles are additional stations established for strengthening the profile. The black triangles are BBS stations of Kumaun University. The tectonic features from south to north are IGP - Indo Gangetic plain, HFT - Himalayan Frontal Thrust, MBT -Main Boundary Thrust, RT- Ramgarh Thrust, SAT-South Almora Thrust, NAT-North Almora Thrust, MT- Munsiari Thrust, VT-Vaikrita Thrust and STD South Tibetan Detachment.

The Neighborhood Algorithm (NA) of Sambridge (1999) has been adopted for RF modelling. The NA algorithm is a class of global search approach that is fully non-linear and derivative free direct search technique. During the implementation of this technique, we consider subsurface to be composed of six layers, viz. sediment, basement, upper crust, middle crust, lower crust and upper mantle. Each layer is represented by four parameters: (i) layer thickness, (ii) *Vs* at top of the layer (iii) *Vs* at bottom of the layer and (iv) *Vp/Vs* ratio. The four parameters for six different layers produce 24-dimensional parameter space for modelling. This large parameter space allows a wide range of velocity models to search for the best fit model. The minimum and the maximum *Vs*are used to define velocity gradient of a particular layer. The values of minimum and maximum *Vs*, layer thickness and *Vp/Vs* ratio are chosen in such a way that model parameterisation is as flexible as possible. The major discontinuities in the subsurface can be identified by velocity contrast in the inverted velocity model obtained by the NA method. It produces velocity gradients between the discontinuities. The inversion scheme uses a wide variation of *Vp/Vs* values, within a range 1.65-2.60, which is an advantage to this method. Usually, RFs with narrow epicentral distance and BAZ bins are stacked and inverted using the NA method. We stacked RFs with epicentral distance and BAZ bins less than 25° for modelling. In case of seismological stations, where BAZ variation is insignificant, the stacking bin is broadened to improve the signal to noise ratio. Each inversion run involves 1000 iterations that generate 40,020 velocity models. The different velocity model parameterizations and incident angles for obtaining stable inversion results have been tried.

The RRF data of the AMRI station (Fig. 61) is used for demonstrating the modelling procedure (Fig. 62*a*). An initial model required by the modelling scheme is constructed using results of earlier geophysical investigations in and around our study area. The inversion procedure involves computing synthetic RRFs for 40,020 alternative 1-D models (Fig. 62). During each iteration, synthetic and observed waveforms are compared and 1000 best fit models are chosen (colored section in Fig. 61b). The red and white lines shown over the 1000 best models in Fig. 62b indicate best fitting and the average *Vs,* respectively. The separate red line shows estimated *Vp/Vs* ratio. Synthetic RF obtained from the NA inversion with ±1 standard deviation (S.D.) bounds is shown in figure 62c. The Moho and intra-crustal phases at each individual station are identified from the velocity-depth section. The Moho discontinuity is marked at a depth where significant velocity gradient with *Vs* ~4.6 km s^{-1} or higher is observed. The modelling at AMRI station shows comparatively low *Vs* at the surface (~2.0 km s^{-1}), which increases to ~ 3.8 km s^{-1} at a depth of ~3 km. A LVZ is observed at 4-10 km depth with an average *Vs*~2.8 km s^{-1}. The *Vs* increases to ~3.6 km s^{-1} at ~10 km depth and attains its maximum value ~4.3 km s^{-1} in the lowermost part of the crust. The step in velocity at ~40 km depth corresponds to the positive arrival at ~5.0 s and is marked as the Moho discontinuity.

This illustrated modelling procedure has been applied for data recorded at 13 seismological stations of WIHG and RF modeling for rest of the stations are in progress. The preliminary investigation suggests that the crustal thickness beneath the Indo-Gangetic Plain (IGP) is ~38 km which gradually increases up to ~42 km at the northernmost station located in the Higher Himalaya. A prominent Intra-Crustal Low Velocity Zone (IC-LVL) is detected at a depth range of ~25-30 km beneath the Chiplakot Crystalline Belt (Dharchula region) where micro-to-moderate magnitude earthquakes form a cluster.

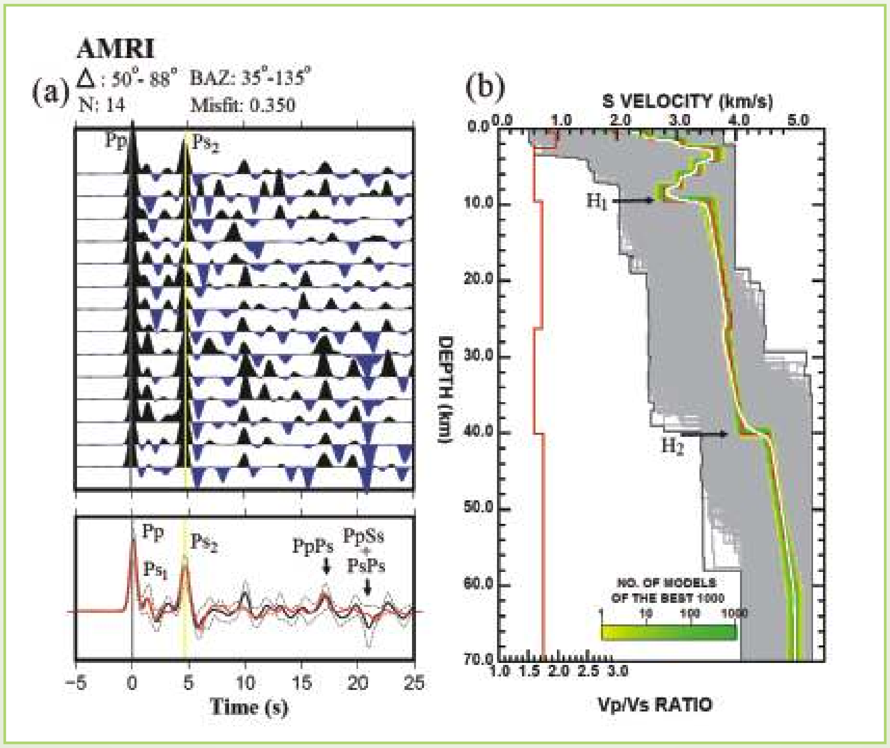

Fig. 62: Illustration of the inversion scheme using neighbourhood algorithm (NA) for the AMRI station. (a) Selected RRF are shown in the upper left panel , (b) The grey area indicates the range of models (40,020 models) searched to find the best model, the green area indicates the best 1000 models with a minimum error between observed and computed receiver functions. The best fitting and average model are indicated by the red and white line, respectively. The best fitting Vp/Vs model (red line) is shown on the left side. (c) Stacked observed RF (blue waveform) and Synthetic RF (red waveform) obtained from the NA inversion with ±1 standard deviation bounds (black dashed line).

Seismicity Distribution

A seismicity map has been prepared by combining ~300 local earthquake data recorded by 21 broadband seismological stations recorded during 2016-2018 as well as data from ISC-EHB catalog (duration 1950-2008) of International Seismological Centre (ISC). The seismicity shows distinctive characteristics in the study region. Usually, seismicity in the NW Himalaya is largely concentrated in the Himalayan Seismic Belt (HSB), a narrow belt (~30–50 km width) straddling the northern Lesser Himalaya and the southern Higher Himalaya. In contrast to the other parts of NW Himalaya, the seismicity in the region is largely concentrated in the Lesser Himalaya. However, the seismicity in the Higher Himalaya is comparatively less. The seismicity appears to be scarce in the outer Lesser Himalaya as well as in the IGP. This is in accordance with the strain distribution reported by GPS studies in the Kumaun Himalaya. GPS study shows strain accumulation around the MCT to be 6-8 x 10^{-7} strain/y, as compared to 0-4 x 10^{-7} strain/y in the Sub and outer Lesser Himalaya. Correspondingly, deformation up to 15 mm/year is recorded between the North Almora Thrust (NAT) and the Higher Himalaya. The depth distribution of seismicity is shown in (Fig. 63). Both the clustered seismicity in the inner Lesser Himalaya, as well as high Poisson's ratio and presence of IC-LVL in its vicinity could be attributed to the effect of fluids/partial melt in the region in the crust. The brittle-ductile transition zone facilitates a suitable environment for the generation of earthquake activity.

Ambient noise data analysis for sub-surface structure investigation

Persistent vibration of earth's ground generate seismic noise due to different aseismic sources of the environment on the surface of earth. The noise consists of low frequency waves mainly surface wave vibrations referred as 'microseisms and microtremors'. This seismic noise recorded through continuous monitoring for 6-12 months has widely been used to characterize the sub-surface structure of the earth. The Empirical Green Functions (EGFs) between station pairs has been obtained. The pre-processing steps include the removal of mean, trend and instrument response from the continuous individual record of each station. In this process, only the noise data is required and therefore the data recorded during earthquakes occurrence is also removed using temporal normalization and spectral

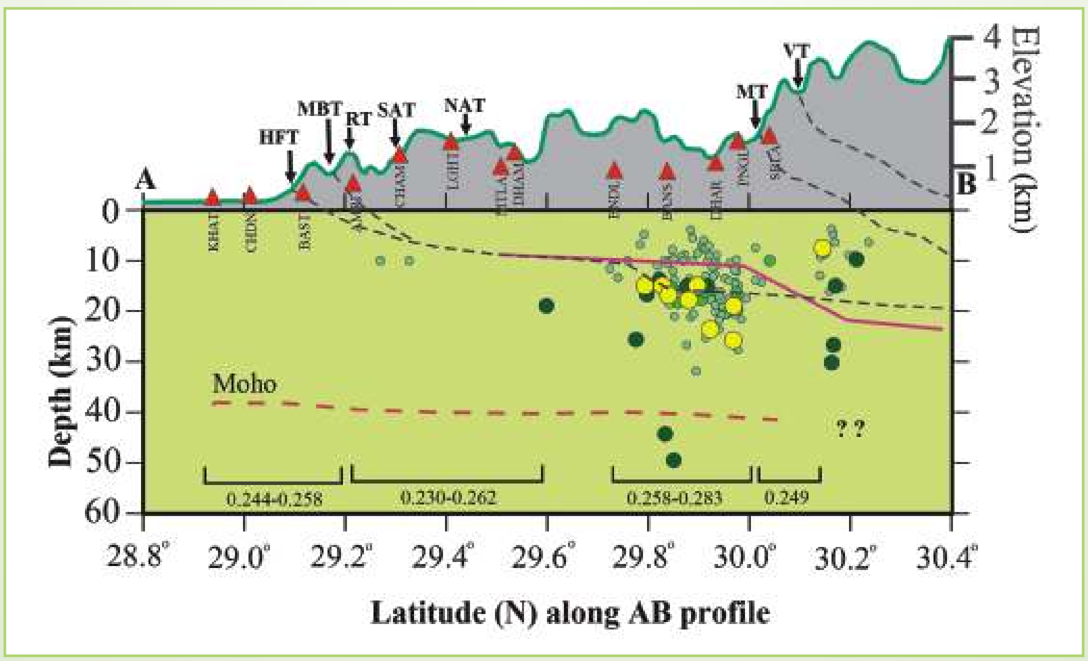

Fig. 63: Depth distribution of seismicity along the seismological profile (AB profile, Fig. 60). The red dashed line in the depth section shows the variation of Moho along the profile. The ranges of Poisson's ratio value are marked. The green and blue lines show the MHT following Caldwell et al., (2013) and the MHT marked by Srivastava and Mitra (1994). The topographic variations is shown at the top. The station locations are shown by red triangles along with the other tectonic features.

whitening techniques. A day-length individual component of time series between pairs of stations have been cross correlated. This gives the daily correlation data of a pair of stations for the individual component to obtain the dispersion characteristic of Rayleigh wave using vertical and radial component and the Love wave using transverse component. Daily cross-correlations for at least six months duration of 2016-2017 were stacked to improve the signal to noise ratio and prepare representative Green's functions of a particular component. Thereafter, Multiple-filter techniques was applied to compute the fundamental mode group velocity dispersions at different periods depending on the distance between stain pair. The dispersion curve of the MTLA-SBLA station pair is shown in figure 64 for the vertical component records. Based on the distance of these stations, the high signal-to-noise ratio fundamental mode group velocity can be used for the period < 10 s. For this period range the group velocity is more than 3.0 km/s, with an increasing trend for the initial part of the curve and then decreasing trend at 7.0 s period. This characterize the shear wave velocity structure of the uppermost crust. Similarly, the dispersion curves were obtained for the other components for all the station pairs.

To quantify the results in terms of S-wave velocity for the upper crust, the obtained dispersion curves of particular path were non-linearly inverted. To obtain a probable solution, inversion was performed using initial model and selection of appropriate resulted model was adopted based on statistical approach. Many iteration were performed to obtain the final solution and for each iteration the S-wave velocity is computed and the P-wave velocity was updated using Vp/Vs ratio of initial model. As the inversion methodology shows some dependence on the initial model, to account for this dependence and non-uniqueness, the inversions using 28 different starting models, were repeated. The obtained results for three paths of station pairs MTLA-SBLA, KHAT-BANS and KHAT-PNGL are shown in figure 65.

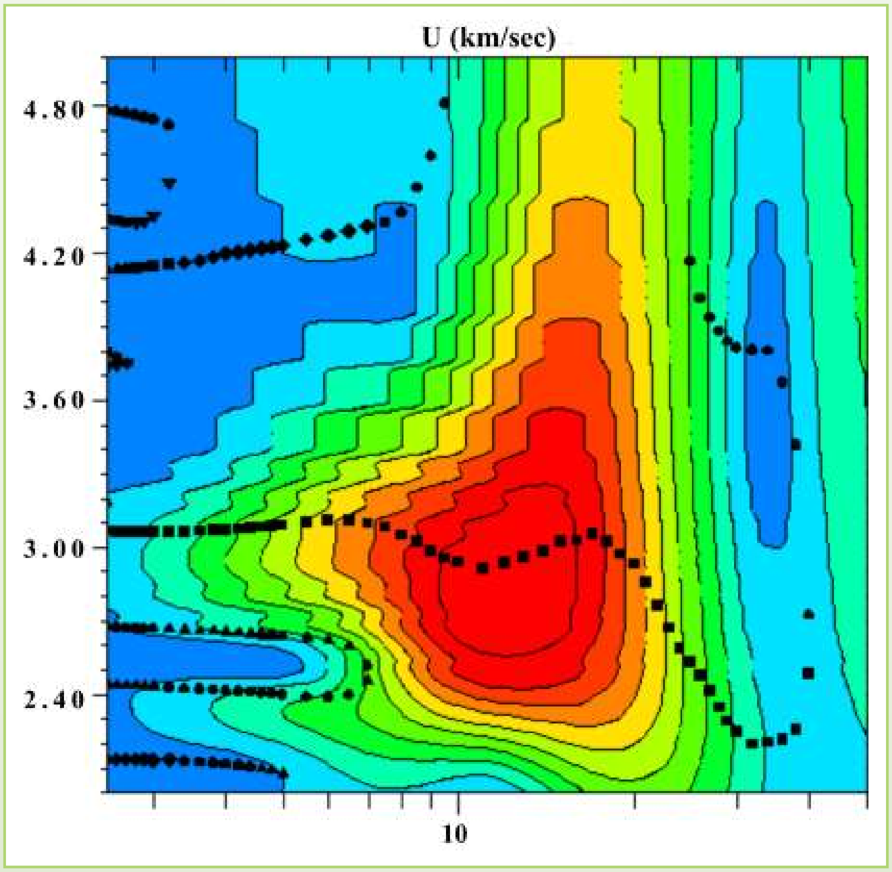

Fig. 64: Dispersion curve of the fundamental group velocity obtained through the broadband seismic data recorded in 2017 at the station pair MTLA-SBLA.

SPONSORED PROJECTS

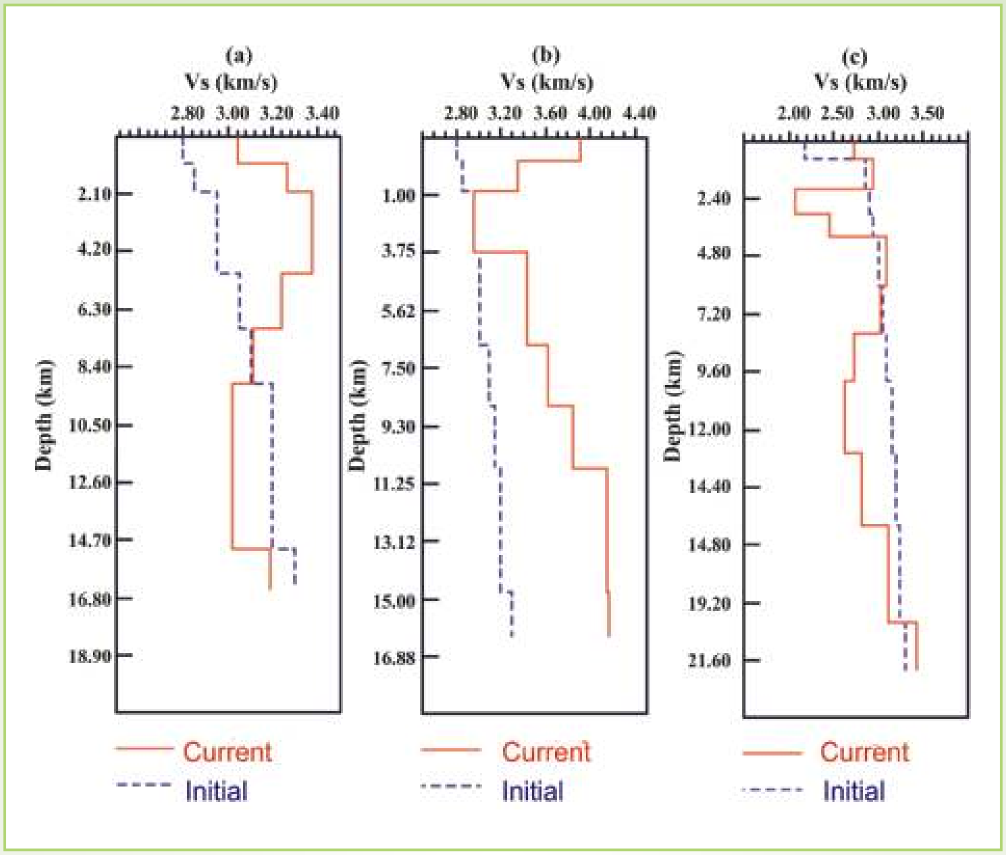

Fig. 65: Shear Wave velocity structure obtained for the uppermost crust through the dispersion data inversion along the paths of station pairs of (a) MTLA-SBLA (b) KHAT-BANS (c) KHAT-PNGL.

The initial and final *S*-wave velocity models for the upper crust are shown with blue dotted line and red solid line, respectively.

Geological Analysis

Geological investigations have been carried out in the Chiplakot Crystalline Belt. Detailed structural, piezometric and fractal dimension analysis of recrystallized quartz grains indicate that the Central Chiplakot Thrust has played a pivotal role in brittle stage exhumation of the Chiplakot Crystalline Belt. The southern Boundary of the Chiplakot Crystalline Belt has remained comparatively inactive during that period. The Chiplakot Belt and the Munsiari Formation are of similar age (~1.9 Ga) and are product of active subduction along the north Indian continental margin during the Paleoproterozoic. The Chiplakot Belt has no lineage with the Greater Himalayan Sequence and is an *in situ* structure rather than thrust transported klippen.

CSIR-Emeritus Project

Regional variability in climate over the past two millennia using multi-proxy tree-ring records and climate change impact on high elevation plant species in Himalaya

(R.R. Yadav)

During the reporting year tree-ring materials of Himalayan cedar (*Cedrus deodara*) collected from six different moisture stressed sites in Kishtwar, Jammu and Kashmir have been analysed and ring width chronologies were prepared. Steps were taken in adopting the methods in tree-ring standardization process to maximize low frequency variations in the mean chronologies. Comparison of ring width chronologies with observational climate variables (temperature, precipitation) revealed strong signature of precipitation in the chronologies. In view of the existence of strong relationship between ring-width chronologies and precipitation the chronologies were used to analyze if there existed any relationship with river discharge. The chronologies showed strong relationship with river discharge records of Jhelum available from 1990 onwards. Previous years October to current years August Jhelum discharge extending back to A.D. 1612 was reconstructed. The reconstruction revealed low discharge values in early 17^{th} century and high in the early 19^{th} century in context of the whole series. The detailed analyses of data are being finalized to prepare the manuscript for publication.

Colonization pattern of *Betula utilis* in Gangotri glacier forefield was also studied to understand glacier snout dynamics. The colonization pattern revealed accelerated snout retreat since late 20^{th} century.

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19. Kannaujiya, S., Philip, G., Champati-Ray, P.K. & Pal, S.K. 2019: Integrated Geophysical Techniques for Subsurface Imaging of Active Deformation across the Himalayan Frontal Thrust in the Northwestern Frontal Himalaya, India. Journal of Engineering Geology (Communicated)

20. Kar, A. & Kumar, A. 2019: Evolution of arid landscape in India and likely impact of future climate change. Episodes (Accepted).

21. Karakoti, I., Shukla, T. & Dobhal, D.P. 2019: Ground monitoring and characteristics of Black Carbon Aerosol over the glacier of central Himalaya: A case study of Dokraini Glacier. Journal of Atmospheric Research (Communicated).

22. Karakoti, I., Kesarwani, K., Mehta, M. & Dobhal D.P. 2019: Surface ablation modelling (spatiotemporal scale) of the debris-covered Dokriani Glacier (Central Himalaya, India) using interpolated hypsometric meteorological variables. Regional Environmental Change (Communicated).

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24. Kharya, A., Sachan, H.K., Santosh, M., Singh, S.K. & Tiwari, S.K. 2019: Isotopic fingerprinting of fluid circulation at the terminal stage of Himalayan orogeny: An example from Himalayan forarc basin, Indus Tsangpo Suture Zone, Ladakh India. Journal of Earth System Sciences (Communicated).

25. Kumar, A., Bhambri, R., Tiwari, S.K., Verma, A., Gupta, A.K. & Kawishwar, P. 2019: Evolution of debris flow and moraine failure in the Gangotri Glacier region, Garhwal Himalaya: Hydro-geomorphological aspects. Geomorphology (In press).

26. Kumar, A., Ray, Y., Ghosh, R., Bandyopadhyay, S., Singh, V. & Srivastava, P. 2019: Late Quaternary sedimentation history of the Himalaya and its foreland. Episodes. (Communicated).

27. Kumar, A., Dutt, S., Saraswat, S. Gupta, Anil K., Clift, Peter D., Pandey, D.K., Yu, Zhaojie & Kulhanek, D.K. 2019: A Late Pleistocene Sedimentation in the Indus Fan, Arabian Sea, IODP Site U1457 Geological Magazine (In press).

28. Kumar, N., Aoudia, A., Guidarelli, M., Babu, G.B., Hazarika, D. & Yadav, D.K. 2019: Delineation of lithosphere structure and characterization of the Moho geometry under the Himalaya-Karakoram-Tibet collision zone using surface-wave tomography. GSL Special Publication (In press).

29. Kumar N., Kumar, N. & Singh, A.K. 2019: Petrology and Geochemistry of acid volcano-plutonic rocks from Riwasa and Nigana areas of Neoproterozoic Malani Igneous Suite, Northwestern peninsular India: An understanding approach to magmatic evolution. Geochemistry International (In press).

30. Kumar, P., Mahajan, A.K. & Meena, N.K. 2019: Evaluation of trophic status and its limiting factors in the Renuka Lake of Lesser Himalaya, India. Environ Environmental Monitoring and Assessment (In press).

31. Kumar, P., Devi, S., Monika, Srivastava, A., Sandeep, Joshi, A. & Kumari, R. 2019: Site response study based on H/V method using S-wave: A case study in the Kumaon Himalaya, India, Himalayan Geology (In press).

32. Kumar, P., Meena, N., Diwate, P., Mahajan, A.K. & Bhushan, R. 2019: The heavy metal contamination history during ca 1839-2003 AD from Renuka Lake of Lesser Himalaya, Himachal Pradesh, India. Journal of Environmental Earth science (Communicated).

33. Lokho, K., Aitchison, J., Whiso, K., Lhoupenyi, D., Zhou, R. & Raju, D.S.N. 2019:Eocene foraminifera from the Upper Disang Formation, Naga Hills of Manipur, Indo-Burma Range (IBR). Marine Micropaleontology (Communicated).

34. Lokho, K., Singh, B.P. & Bhandari, A. 2019: A synoptic review of Eocene-Miocene faunal records of the Indo-Burma Range (IBR), NE India and coeval northwestern Himalaya: paleoenvironmental and tectonic inferences. Journal of the Paleontological Society of India (In press).

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36. Manas, M. & Mukherjee, B.K.2019: Volcanogenic microfossils imprint in suture zone rock: a study from western Ladakh, Himalaya, India. Geological Magazine (Under review).

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38. Mahima, Karakoti, I., Hemwati, Nandan H. & Pathak P.P. 2018: A comprehensive study of ground measurement and satellite derived data of global and diffuse radiation. Environmental Progress and Sustainable Energy (In press).

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41. Misra, A., Kumar, A., Bhambri, R., Haritashya, U.K., Verma, A., Gupta, A.K., Dobhal, D.P., Gupta, G. & Upadhyay, R. 2019: Topographic and climatic influence on seasonal snow cover over Chorabari Glacier, Garhwal Himalaya, India. Geomorphology (Communicated).

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Microseismicity, tectonics and seismic potential in the Western Himalayan segment, NW Himalaya, India, Journal of Asian Earth Sciences (In press).

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51. Rawat, G., Philip, G., Suresh, N., Medha & Rekha 2019: Electrical Resistivity Tomography along the Himalayan Frontal Thrust in the northwestern Frontal Himalaya for Active Tectonics Studies. Modelling of Earth System and Environment (Accepted).

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55. Saravanan, P., Gupta, A.K., Panigrahi, M.K., Tiwari, S.K., Rai, S.K. & Prakasam, M. 2019: Response of shallow-sea benthic foraminifera to environmental changes off the coast of Goa, eastern Arabian Sea during the last ~6,100 cal yr BP. Geological Magazine (Under review).

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59. Shukla, A., Rana, R., Sharma, S. & Bisht, P. 2019: Glacial response to climate variability since MIS-2 in the Southern Ladakh Range, NW Himalaya, India. Palaeogeography, Palaeoclimatolog, Palaeoecology (Communicated).

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RESEARCH PUBLICATIONS

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67. Singh, N. & Parida, B.R. 2019: Environmental factors associated with seasonal variations of night-time plant canopy and soil respiration fluxes in deciduous conifer forest, western Himalaya, India. Trees, 33(2) (In press).

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69. Singh, N., Singhal, M., Chhikara, S., Karakoti, I., Chauhan, P. & Dobhal,D.P. 2018: Radiation and energy balance dynamics over a rapidly receding glacier in the central Himalaya. International Journal of Climatology (Accepted).

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72. Sundriyal, S., Kumar, S., Dobhal, D.P. & Bhan, U. 2019: Variability in the major ions chemistry of melt water draining from Dokriani Glacier, Central Himalaya, India. Journal of the Geological Society of India (Communicated).

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77. Thena, T., Mohan, K., Prakasam, M., Saravanan, K. Vijaya&Lakshmi, C.S. 2019: Northern Pacific intermediate and deep water changes over the last 50,000 years. Geo-marine Letters (Under review).

78. Yadav, J.S., Pratap, B., Gupta, A.K., Dobhal, D.P., Yadav, R.B.S.& Tiwari, Sameer. K. 2019: Spatio-temporal variability of near-surface air temperature in the Dokriani glacier catchment (DGC), central Himalaya. Theoretical and Applied Climatology (In press).

79. Yadav, R.R. & Singh, J. 2019: Tree-ring-width chronologies from moisture stressed sites fail to capture volcanic eruption associated extreme low temperature events. Current Science (Communicated).

80. Yadav, R.R., Negi, P.S. & Singh, J. 2019: Communicated as an invited paper for book being released by INSA. 2018 Climate Change and Plant Biodiversity in Himalaya, India. Book being published by INSA (Communicated).

81. Yousuf, B., Shukla, A., Arora, M.K. & Jasrotia A.S. 2019: Glacier facies characterization using optical satellite data: Impacts of radiometric resolution, seasonality, and surface morphology. Progress in Physical Geography (In press).

82. Zack, S., Rose, K.D., Holbrook, L.T., Kumar, K., Rana, R.S. & Smith, T. 2019: An enigmatic new family of ungulate-like mammals from the early Eocene of India. Palaeontology (Accepted).

SEMINAR/SYMPOSIA/WORKSHOP ORGANIZED

Golden Jubilee -National Conference on Earth System Science with Special Reference to Himalaya (May 16-18, 2018)

Institute organized the “National Conference on Earth System Science with Special Reference to Himalaya” during May 16-18, 2018 as part of its Golden Jubilee Celebration. The conference was aimed for close interaction and deliberations on the recent geo-scientific research in the Himalaya, and assessing the risk related to Earthquakes and Landslides. With better evolved models and concepts on the Himalaya, the conference was designed to cover the themes like Crustal Evolution and Tectonic Framework, Climate Change and Geological Processes, Geological Resource Potentials, Science of Natural Hazards, Sedimentary basins and the Geophysical studies in the Himalaya. However, the geodynamic evolution and the societal aspects, such as mitigation of natural hazards, management of water and energy resources, economic minerals, climate change and ecosystem etc. were the main focus.

The Inauguration function of the conference was held on May 16, 2018. Dr K.K. Paul, Hon'ble Governor of Uttarakhand was the Chief Guest, and the 'Waterman of India', Shri Rajendra Singh was the Guest of Honour. Drs Rajesh Sharma and Pradeep Srivastava were the convener and co-convener respectively.

There were 6 technical sessions on above subjects. A plenary session with four special talks by eminent researchers was organized. Besides, there were five keynote presentations by senior scientists. All these led to knowledge sharing and vibrant interaction by the young researchers and participating delegates. There were 30 contributory oral and more than 100 posters presentations. The pan-India participants were from National and State Institutions, IITs, Central and State universities. In order to encourage the young researchers, three best presentation prizes were awarded to them. A post workshop field trip on 18^{th} May to HFT-MBT-Krol-Tal section across the Moh and Mussoorie area was also organized. Overall, this conference provided an integrated data set for comprehensive understanding of the Himalayan geoscience on a single platform.

SEMINAR/SYMPOSIA/WORKSHOP ORGANIZED

The Inauguration function: Chief Guest, Hon'ble Governor of Uttarakhand Dr. K.K. Paul, Guest of Honour, the 'Waterman of India', Shri Rajendra Singh along with Director In-Charge Dr (Mrs) Meera Tiwari, Dr Rajesh Sharma and Dr Pradeep Srivastava were on the Dias.

Glimpses of the Inauguration function

Jury discussing the research results presented in the posters

Outreach Program of India International Science Festival 2018 (September 26-27, 2018)

Institute organized 'Outreach Program' of the India International Science Festival (IISF) 2018 on September 26-27, 2018. The prime objective of the IISF was to instil scientific temperament among the masses and showcasethe contribution in the field of S&T over the years. The relationship between Science and Society has always led to the development of new frontiers of growth both scientifically and economically. IISF over the years has established itself as a unique platform for connecting science, technology & innovation with the masses be they students, entrepreneurs, teachers or the general public.

During the two days Outreach Program of IISF 2018, Institute organised many programs to interact with the students and general public. Students from various schools and colleges from Dehradun and its vicinity were invited. Many students participated in competitive science based programs. A debate on the Science & Technology for the sustainable development




Glimpses of students from different schools interacting with the scientists

of the society was organised. A Geoscience Quiz was also organised for the graduate and postgraduate students.

An Open Day for the students and general public was observed on 27th Sept. The main attraction of the Day was the direct interaction of the Institute Scientists with the public at the entrance of the Institute wherein, a booth was organized to educate the common public on the geoscience for the society and about the earthquake awareness. Regular lectures in the auditorium on the earthquake preparedness were delivered and mock drills were organised. An exhibition focussing on the Institute research work was also organised and all the Laboratories in the Institute were kept open for the public and students. Guided tours to the museum and labs were organised for the school/college students. The two days program was also enriched with a popular lecture by the Chief Guest Dr S.S. Negi, Chairman, Uttarakhand State Environment Assessment Authority. The Guest of Honour of this program was Dr Mahesh Bhatt, a well-known surgeon and President of the Vigyan Bharati, Uttarakhand. About >1000 students from schools and colleges attended this Outreach Program.


Dr S.S. Negi, Chairman, Uttarakhand State Environment Assessment Authority delivering the popular lecture and Dr Mahesh Bhatt President of the Vigyan Bharati, Uttarakhand presenting the introduction of the IISF

AWARDS AND HONOURS

- Dr R.J.G. Perumal has been conferred with National Geoscience Award - 2018 in the field of Natural Hazard Investigations. The award was conferred by the Ministry of Mines, Government of India. He also received a certificate of Outstanding Contribution in reviewing for Tectonophysics.
- Dr Aparna Shukla was chosen as the 'Women Scientist' for the year 2018 by the Uttarakhand Science Education & Research Centre (USERC), Dehradun. She was also elected as 'The World Academy of Sciences' (TWAS), Young Affiliate - 2018 for five years.
- Dr D.P. Dobhal has been nominated as 'National Correspondent' of the World Glacier Monitoring Service (WGMS), Zurich, Switzerland.
- Dr Rakesh Bhambri - CFG, has been selected as the 'Scientific Editor' of the 'Journal of Glaciology'.
- Dr Nilendu Singh CFG has been awarded 'B.V. Ramana Rao Best Paper Award in Agricultural Meteorology' for the year 2018 by the Association of Agrometeorologists, Anand, Gujarat.
- Dr. Kalachand Sain has been bestowed with the Dr. M.N. Bose Memorial Lecture Award for the year 2019 by Birbal Sahni Institute of Paleosciences, Lucknow.

VISITS ABROAD

- Dr. Praveen Mishra visited University of Konstanz, Germany to attend Stable Isotope Summer School during April 15-19, 2018.
- A.K. Singh visited Honolulu, Hawaii, USA to attend 15th Annual Meeting Asian Oceanic Geosciences Society (AOGS) during June 03-08, 2018.
- Dr Prakasam M. visited Cambridge, UK to participate in the 'Ocean Circulation 3, Workshop during Sept. 06-09, 2018.
- Dr Naresh Kumar visited Lausanne, Switzerland to attend '33rd Himalaya-Karakoram-Tibet Workshop' during Sept. 10-12, 2018. He also visited Trieste, Italy under the Regular Associateship of the International Centre for Theoretical Physics (ICTP), during 13 Sept. to 13 Oct. 2019.
- Sh Vipin Kumar and Ms Imlirenla Jamir visited Chengdu University of Technology, Chengdu, China to attend 'iRALL School 2018' during Oct. 13 - 27, 2018
- Dr D.P. Dobhal visited Integrated Mountain Development (ICIMOD), Kathmandu, Nepal to attend a workshop Cryosphere, Glacier Melting and Mountain Economy in the HKH Region, during Sept.17-18, 2018.
- Dr Pinky Bisht and Dr Pankaj Chauhan visited International Centre for Integrated Mountain Development (ICOMOD), Nepal to attend HUC-IHCAP Glacier Monitoring Training Program during Nov. 11-16, 2018.

PH.D. THESES

Name of Student	Supervisor	Title of the Theses	University	Awarded/ Submitted
Ms Deepa Arya	Prof. Santosh Kumar Dr Rajesh Sharma	Geochemistry and phase petrology of mineralized and barren granitoids of Malanjkhand Region, Central India	Kumaun University, Nainital	Awarded April 2018
Sh Mahesh Prasad Parija	Dr Sushil Kumar Dr V.M. Tiwari Dr V.L. Narasimham	Seismological and Gravity field studies on NW Himalaya: Tectonic implications	University of Petroleum and Energy Studies, Dehradun	Awarded Aug. 2018
Sh Tanuj Shukla	Dr D.P. Dobhal Prof. H.C. Nainiwal	Late Quaternary Glacial and Climatic Records from Dokriani and Chorabari Glaciers of Uttarakhand Himalaya Using Optically Stimulated Luminescence and Stable isotope Techniques	HNB Garhwal University, Srinagar	Awarded Oct. 2018
Ms Rupa Ghosh	Dr Pradeep Srivastava Prof. Umakant Shukla	Late Quaternary Geological Evolution of Yamuna River Valley, Marginal Ganga Plain in the Himalayan Foreland setup	BHU, Varanasi	Awarded Nov. 2018
Sh Pawan Kumar	Dr N. K. Meena Prof. A. K. Mahajan	Hydro-geochemistry and contamination history of western Himalayan lakes in Himachal Pradesh, India	Central University of Himachal Pradesh, Dharamshala	Awarded Feb. 2019 Awarded
Sh Vinit Kumar	Prof. Ajai Mishra	Study of Temporal Variations of Snout and Geomorphology of Dunagiri Glacier, Garhwal Himalaya, Chamoli District, Uttarakhand	University of Lucknow, Lucknow	March 2019
Ms Divya Thakur	Dr S.K. Bartarya Prof. H.C. Nainiwal	Hydrogeological studies of Inter-mountain basin of Una district, H.P., with special reference to impact assessment of Environmental Change	HNB Garhwal University, Srinagar	Submitted Aug. 2018
Ms. Manju Negi	Dr S.K. Rai Dr Udai Bhan	Petrographic and Isotopic Studies of the Precambrian Lesser Himalayan Clastic Sediments: Implication for their Provenances	University of Petroleum and Energy Studies, Dehradun	Submitted Oct. 2018
Sh Arun Prasath R.	Dr Ajay Paul Prof. Sandeep Singh	Seismotectonics of Garhwal Himalaya between Alaknanda and Yamuna Valleys	IIT Roorkee	Submitted Oct. 2018
Ms Priyanka Singh Rao	Dr R.J.G. Perumal Prof. A.K. Sharma	Surface Rupture Investigations of the 1950-Meisoseismal Zone of Assam Earthquake along Himalayan Foothill Zone, Arunachal Pradesh-Assam Himalaya	Kumaun University, Nainital	Submitted Dec. 2018
Sh Purushottam Kumar Garg	Dr Aparna Shukla Prof. A.S. Jasrotia	Assessment of variable response of Himalayan glaciers to climate change using geospatial techniques	University of Jammu, Jammu	Submitted Jan. 2019

Ms Poonam Chahal	Dr Pradeep Srivastava, Prof. Y.P. Sundriyal	Late Pleistocene Landscape of Zanskar River Valley (Ladakh Himalaya): Implications to sediment storage and river connectivity	HNB Garhwal University, Srinagar	Submitted March 2019
Sh Vipin Kumar	Dr Vikram Gupta Prof. Y.P. Sundriyal	Landslide Susceptibility Zonation and slope stability analyses between Moorang and Rampur, Satluj Valley, Himachal Pradesh	HNB Garhwal University, Srinagar	Submitted March 2019
Ms Imlirenla Jamir	Dr Vikram Gupta Prof. G.T. Thong	Slope Stability Analysis in part of the Yamuna Valley, Garhwal Himalaya	Nagaland University, Kohima	Submitted March 2019

PARTICIPATIONS IN SEMINARS / SYMPOSIA / MEETINGS

Jammu & Kashmir Science Congress at University of Kashmir, Srinagar, during April 02-04, 2018
Participant: Shukla, A.

26th meeting of CED - 39 Committee of BIS at New Delhi on April 13, 2018
Participant: Sushil Kumar

5th International Conference on 'Science and Geopolitics of Himalaya-Arctic & Antarctic' held at New Delhi during February 26-27, 2019
Participant: Rakesh Bhambri

Workshop on 'Mainstreaming Climate Change in Disaster Risk with special reference to Glacial Lake Outburst Flood (GLOF) and Forest Fire in the Himalaya' held at Gangtok, Sikkim during May 08-09, 2018
Participant: D.P. Dobhal

National Conference on Earth System Science with special reference to Himalaya: advancement and challenges organized by WIHG, Dehradun (16-18 May, 2018)
Participants: Most of the scientists and research scholars of the Institute

ICSU Future Earth Committee meeting at INSA, New Delhi on July 23, 2018
Participant: R.R. Yadav

IODP Proposal Nurturing Workshop held at NCAOR, Goa during Sept. 17-18, 2018.
Participants: Prakasam M.

National Seminar on 'Advance in Mantle Petrology' held at Banaras Hindu University, Varanasi during Oct. 04 - 06, 2018
Participants: A.K. Singh and Tania Saha

4th India International Science Festival (IISF) for the Women Scientists' and Entrepreneur Conclave at Lucknow during Oct. 05 – 08, 2018.
Participants:Kapesa Lokho, Aparna Shukla and Suman Lata Rawat

National Conference on 'Aerosols, Air Quality, and Climate Change (AAC-2018) on Himalayan Region of Uttarakhand' held at HNB Garhwal University, Srinagar, during Oct. 21-23, 2018.
Participants: P.S. Negi and, Chhavi Pandey

International Conference on 'Climate Change and Disaster Risk Reduction' at H.N.B. Garhwal University, SRT Campus, Tehri during Oct. 26 - 28, 2018
Participant: Chhavi Pandey

5th Expert Committee meeting of DST on 'Climate Change' held at New Delhi during Nov. 19-20, 2018,
Participant: Rajesh Sharma

Consultation Meet on 'Climate Change & Sustainable development at Dehradun on Nov. 14, 2018
Participant: P.S. Negi

Meeting on 'National Mission for Sustaining the Himalayan Ecosystem (NMSHE)' at National Institute of Hydrology (NIH), Roorkee on Nov 22, 2018
Participant: R.S. Ahluwalia

Joint TWAS-DCCC Workshop on 'Climate Change' held at Indian Institute of Science, Bangalore during Dec. 05-07, 2018.
Participant: Prakasam M.

National Symposium on 'Advancements in Geospatial Technology for Societal Benefits' held at Space Applications Centre (SAC), ISRO, Ahmedabad during Dec. 05-07, 2018.
Participant: Yousuf, B.

55th Annual Convention of Indian Geophysical Union (IGU) on Changing Water Cycle & Water Resources at Rabindranath Tagore University, Bhopal during Dec 5-7, 2018.
Participant: Choudhary, S.

Workshop on 'Space based Information Support for Decentralized Planning' held at Uttarakhand Space Application Center, Dehradun on Jan. 15, 2019.
Participant: A.K.L. Asthana

2nd International Conference on 'GEM-2019'at Christ College, Thrissur, during Jan. 17-19, 2019.
Participant: Prakasam M.

Meeting of the 'Research and Academic Institution and other user Department in the field of water' held at the IIT, Roorkee on Feb. 20, 2019.
Participant: S.K. Rai

National Workshop on Advances in stratigraphy and geochronology of Indian sedimentary basins and road ahead organized by Department of Geology, University of Delhi during Feb. 27, 2019
Participant: Vineet Kumar Srivastava

IIRS Academia Meet -2019 at Indian Institute of Remote Sensing, Dehradun on March 14, 2019
Participants: G. Philip, Vikram Gupta and A. Shukla

National Symposium on 'Luminescence Dating' held at BSIP, Lucknowduring March 29-30, 2019
Participant: Pinky Bisht

LECTURES DELIVERED BY INSTITUTE SCIENTISTS

Name of Scientist	Venue	Date	Topic
Vineet Srivastava (National PDF)	WIHG	13.04.2018	Depositional environment, provenance and geological significance of the late Paleocene Matanomadh Sandstones, Kachchh Basin, Western India
Praveen Mishra (DST INSPIRE Faculty)	Univesity of Konstanz, Konstanz (Germany)	18.04.2018	Lake sediments- a natural laboratory to study past climate variability
Indira Karakoti (CFG)	NESTER Education, Society, Dehradun	22.04.2018	Melting Glaciers and Rivers Life
P.S. Negi	HESCO, Dehradun	22.4.2018	Eco-system crises in Himalayan Region
S.S. Thakur	Kumaun University, Nainital	17-26.08.2018	Series of lectures on 'Metamorphic Geology' to the M.Sc. (Geology) Students.
Anil Kumar	Archaeological Survey of India, Dehradun	21.08.2018	Luminescence dating and its application in Geoscience
Rajesh Sharma	NIT, Hamirpur, H.P.	08.09.2018	Geological Proxies and Resilience in the Himalayan Ecosystem.
R.K. Sehgal	Indian National Science Academy, New Delhi	10.09.2018	WIHG collections - history, policy on collections from the Himalaya
Vikram Gupta	Disaster Mitigation and Management Center (DMMC), Dehradun	24.09.2018	An overview of landslides in the Garhwal Himalaya
Chhavi Pandey	Gurukul Kangri Vishwavidyalaya, Haridwar	29.09.2018	Electronic Devices & Data Science
Sushil Kumar	Central Board of Irrigation and Power (CBIP), Dehradun	09.10.2018	Slope Stabilization Challenges in Infrastructure Projects
Akshaya Verma (CFG)	Dolphin PG Institute, Dehradun	28.11.2018	Himalayan Glaciers and experiences from Antarctica
Rajesh Sathiyaseelan	Indira Gandhi National Forest Academy, Dehradun	17-18.12.2018	Geological structures and their topographic expression
Kapesa Lokho	Indira Gandhi National Forest Academy, Dehradun	17-18.12.2018	Fossils and Geologic Time Scale

Aparna Shukla	Indira Gandhi National Forest Academy, Dehradun	19-20.12.2018	i) Fundamentals of Remote Sensing and Applications in Forestry ii) Geospatial techniques for multiparametric assessment of the Himalayan Cryosphere.
S.S. Thakur	Indira Gandhi National Forest Academy, Dehradun	21.12.2018	Study of solid Earth: Petrology and Mineralogy
Pradeep Srivastava	HNB Garhwal University, Srinagar	28.12.2018	Evolution of Himalaya
Vikram Gupta	NCESS, Thiruvananthapuram, Kerala	10.01.2019	Landslide Hazard in the Garhwal Himalaya
Pradeep Srivastava	National Institute of Oceanography, Goa	13.01.2019	Neotectonic Evolution of Himalaya
R.J.G. Perumal	Christ College, Cochin, Kerala	17.01.2019	Earthquakes and Geological Structures along Himalayan Arc
Vikram Gupta	Indian Academy of Highway Engineering, Noida	31.01.2019	Landslide, hazard, risk and vulnerability in the context of Himalayan terrain
Manish Mehta	Geological Survey of India (GSI), Dehradun	04.02.2019	Quaternary glacial Advances in Himalaya
Pradeep Srivastava	Geological Survey of India (GSI), Dehradun	04-05.02.2019	i) Quaternary landscape of Himalaya: climate and tectonic forcing, ii) Palaeo flood records of Himalaya
Sushil Kumar	Central Board of Irrigation and Power (CBIP), Bhopal.	7-8.02.2019	i) Seismological Investigations of Hydropower Projects ii) Basics of Earthquake Analysis of Structures iii) Seismic Evaluation and Remediation Strategies and Case Studies
S.K. Rai	Punjab University, Chandigarh	09.02. 2019	Remnants of the Paleo-channels of the River Sarasvati (Haryana) and its possible affinity with Vedic civilization
S.K. Rai	Indira Gandhi National Centre for the Arts, New Delhi	10.02.2019	River Sarasvati
Pradeep Srivastava	Geological Survey of India (GSI), Dehradun	04.03.2019	Neotectonic Evolution of Himalaya
S.K. Rai	Uttarakhand State Disaster Management Authority (USDMA), Dehradun	18.03.2019	Flood Risk Management
Rajesh Sharma	Kumaun University, Nainital	26.03. 2019	Application of Raman spectroscopy in Gemology

MEMBERSHIPS

Rajesh Sharma	• Member - Expert Committee ASEAN-India collaboration program, SERB-DST
Vikram Gupta	• Member - Committee constituted by the Ministry of Environment, Forest and Climate Change, for the formulation of guidelines for muck disposal in hilly areas of Uttarakhand and Himachal Pradesh • Member - Oversight Committee of the Hon'ble National Green Tribunal
S. K. Rai	• Member - Geochemical Society, America

POPULAR LECTURES DELIVERED IN THE INSTITUTE

Golden Jubilee Year – 'Lecture Series'

The Institute celebrated the Golden Jubilee Year, which started from June 30, 2017 and culminates on June 29, 2018, the Foundation Day of the Institute. As part of the *Golden Jubilee Year Celebrations*, the Institute had initiated '*Golden Jubilee Lecture Series'* from 30th June 2107 by the eminent scientists of India. Following lectures were delivered during the reporting period:-

- Dr. Rasik Ravindra, Ex-Director of NCAOR delivered lecture on "Adventure in Science: India's first expedition to South Pole" on April 26, 2018
- Dr S.K. Ghosh, Ex-Scientist of Wadia Institute, delivered lecture on "Detrital modes and their geological significance" on May 01, 2018
- Dr Rohtash Kumar, Ex-Scientist of Wadia Institute delivered lecture titled "Spatio-temporal variation in sedimentation pattern during late Cenozoic Himalayan foreland basin between rivers Ganga and Ravi: causative factors" on May 09, 2018
- Dr. Ashok Singhvi, Former Chairman of the RAC of our Institute delivered lecture on "Societal Relevance of-and Scientific Challenges for-Geosciences as Services" and "Land-Sea-Ice Correlations: How real are they?" on June 12 and 13, 2018, respectively.

- Padmashree Prof. D. Balasubramanian Former President of Indian Academy of Sciences, and Director of Research at the Prof. Brien Holden Eye Research Centre of L.V. Prasad Eye Institute, Hyderabad delivered a lecture on June 28, 2018 "You do not have to have a science degree to practice science"

National Technology Day Lecture

Dr Harish Bahuguna, Director GSI and presently at Uttrakhand Jal Vidyut Nigam Ltd. (UNVNL) Dehradun delivered National Technology Day Lecture titled 'Technological Intervention in Development of Water Resources of Uttarakhand' on May 11, 2018

Other Lectures / Interaction

Other Popular - cum - Technical lectures delivered in the Institute area:-

- Dr. J. S. Mehta, Dy Director General, Geological Survey of India (GSI), New Delhi on the "GSI Role and Contributions in the Field of Geosciences" on July 23, 2018.
- Prof Ram Sagar, Senior Scientist, Indian Institute of Astrophysics (IIA), Bangalore on the "Global importance of recently installed Asia's largest (4 meter) size optical telescopes" on July 25, 2018
- Sh Vijaya Dhingra, State teacher and coordinator of 'The Art of Living' delivered a talk on 'Stress Free Life', including the practical demonstration of meditation/yoga and breathing techniques on August 10, 2018.
- Dr Jayant Narlikar, the famous Indian Astrophysicist and recipient of Padama Vibhushan visited the Institute on August 10, 2018 and interacted with the researchers and elucidated the experiments he was involved with about the 'possibility of existence of life in space'.
- Padmashri Dr. Harsh Gupta, Former Director, National Geophysical Research Institute (NGRI), Hyderabad on the "Triggered Earthquakes at Koyna, India" on August 20, 2018
- Dr. Chris J. Spenser, School of Earth & Planetary Sciences, Curtin University, Australia on the "De-convolving the pre-Himalayan Indian margin-Tales of crustal growth and destruction" on October 11, 2018
- Prof. Andrew Meigs, Oregon State University, Oregon, USA on the "Late Cenozoic mountain building of the Northwest Himalaya" on October 24, 2018

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section during the year brought out the (i) Journal Himalayan Geology volumes 39(2), and 40(1) (ii) Annual Report' of the Institute for the year 2017-18 in Hindi and English (iii) Hindi magazine 'Ashmika' volume 24 (iv) Reminiscences of Golden Days - 50 years of Excellence in Himalayan Geology (1968-2018).

The section also provides the facility & technical support services of printing and scanning to scientists, research scholars and other staff of the Institute. Section was also involved in dissemination of the publications to individuals, institutions, life time subscribers, book agencies, national libraries, indexing agencies, under exchange program and maintaining the sale & accounts of publications. Apart from this, works pertaining to printing of brochures and certificates etc are also taken-up.

Himalayan Geology (journal) website http://www.himgeology.com is functioning with online enquiry, online prepaid subscription order, and online manuscript submission facility under this section. All information regarding the journal including contents and abstracts is up-dated time to time on the website. Online access of current volume to the Life Time Subscribers (those have given the choice to obtain the volumes in soft copy through online access/email) also has been provided. Journal is indexed in Thomson Reutors (US), Elsevier (Netherlands), and in Indian Citation Index (India). Six new members got registered under the Life Time Subscriber Scheme (LTSS) Membership for Himalayan Geology journal bring the total registered number to 482.

LIBRARY

The Library of Wadia Institute of Himalayan Geology has a special status owing to its best collection of books, monographs, journals, and e-books on the mountain building process, geological and geophysical phenomenon with special reference to the Himalaya. Also the collection and services offered makes it one of the best libraries in the country in the field of earth sciences. The scientists, researchers, projects staff and students make full utilisation of the Library while publishing their research work in the reputed peer-reviewed journals. Specialists and professionals across the country also visit our Library to consult thematic and rare collections available in it.

The Library has subscribed to 71 International and 38 Indian Journals. The Library has purchased 09 reference books, while 68 books are received as gratis. In addition, 133 books have been added to the Hindi Collections. The Library has > 4000 selected e-books from different publishers and learned societies on the thrust areas of the research in the Institute.

In order to get the easy access and exclusive publications of the research work by WIHG, digitization of research publications have been carried out by incorporating them into the Institutional Repository (IR) which is essentially developed using DSpace (OSS). The repository consists of 98 full PDF text of Prof D.N. Wadia's publications and 2011 PDFs of WIHG Scientist's publications, which are placed on the intranet within the Institute.

The Library is a member of National Knowledge Resource Consortium (NKRC) and continue to receive support of Consortia towards online access to Elsevier's “Earth and Planetary Science collection”, Wiley's “Earth, Space & Environmental Sciences”, Springer “Earth and Environmental Science and Chemistry” collections. In addition to this, the Library has access to the publications of American Institute of Physics, American Physical Society,Springer Journals, Taylor & Francis, Web of Science, Wiley & Blackwell, Derwent Innovation Index (with Web of Knowledge), Emerald Group Publishing, IEEE, NPG, Nature, Nature Geoscience, Royal Society of Chemistry and Science Magazine. In all > 400 online access to journals are available.

The Library has the small hub of computers for the users for accessing the e-books, e-journals and other e-resources available, either 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 Library serves as central facility for the reprography demand of the Institute. The reprographic facility was also extended to the external users of the Library on payment basis and a total of 84122 pages were copied during the reporting year.

S.P. NAUTIYAL MUSEUM

The Institute's Museum named after Prof. S.P. Nautiyal is a major axis of education, and is increasingly becoming popular every year. This year, the annual foot-fall in the museum was ~10,000 including visitors from all walk of life, such as school children, university students, general public, IFS probationers, ITBP personals, Forest rangers, Teacher trainees etc., besides the tourists from various countries. A number of students visit the museum to complete their project work, mainly on the evolution of the Himalaya, assigned to them by their respective school teachers.

Like every year, Museum observed Open Days on National Technology Day (11th May), Foundation Day (29th June), Founder's Day (23rd October) and National Science Day (28th February). A large number of students and general public visited the museum on these occasions. Guided tour of the museum was provided by scientists and research scholars of the Institute. The exhibits on evolution of Himalaya, Geological Clock, Drifting Continents, Glaciers, and models of the extinct mammals remained the center of attraction. Also in order to spread awareness to the public and the students regarding the Institute, Museum activities and regarding the personal protection in case of earthquakes, brochures, both in Hindi and English were distributed on gratis basis. This year to mark the Golden Jubilee celebration of the Institute, a special exhibition was arranged in the museum on the eve of the Foundation Day of the Institute. A pictorial section completely devoted to old memories of the Institute since its beginning in 1968 was displayed.

This year, Institute organized two mega outdoor exhibitions at (i) India International Science Festival held in Lucknow during Oct. 04-08, 2018 and (ii) Indian Science Congress held at Lovely Professional University, Jalandhar during Jan. 03-08, 2019. In both the events, activities and achievements of the Institute, along with posters and charts on earthquakes, drifting continents, evolution of Himalaya, glaciers, landslides etc. were displayed along with the various fossils, rocks, and mineral specimens from Himalaya. Both the exhibitions received a tremendous response from the students and general public at large.

TECHNICAL SERVICES

Analytical Services

The number of samples analyzed by various laboratories is as follows:

Laboratory / Instruments	Number of sample analysed		
	WIHG Users	Outside Users	Total
XRF lab	922	611	1533
ICP-MS lab	797	1009	1806
Stable isotope lab	963	686	1649
SEM lab	351	178	529
Luminescence Dating (TL/OSL) lab	124	39	163
Laser Particle Size Analyser (LPSA)	453	125	578
Dendrochronology Lab.	165 (Tree cores)	-	165
Micropaleontology Lab	150	60	210
Palynology Lab	54	-	54
Fission Track lab & mineral separation lab	188	10	198

Photography Section

During the reporting period, the photography section has clicked ~ 3600 images using SLR digital cameras for the various functions and activities organized within the Institute. This include Foundation Day, Founders Day, National Science Day, National technology Day, Republic Day, Independence Day, Various Seminars / workshop and meet, Cultural program, superannuation event of the staff of the Institute. No new cameras/ lenses/flash guns were procured during the reporting year. Majority of scientists already have cameras issued permanently to them for use in the field and laboratory and the remaining scientists and research scholars are provided cameras from the pool as and when they require it.

Drawing Section

The Drawing Section catered to the cartographic needs of the Scientists of the Institute including the sponsored projects. During 2018-19, the section has provided 22 geological maps / structural maps / geomorphological maps / seismicity diagrams for the scientists and research scholars of the Institute, besides the tracing of nine topographic sheets/ aerial photo maps and two geological columns have been prepared. The section has also provided name labels, thematic captions during different activities and functions of the Institute including writing work on the photo identity cards of the employees of the Institute.

Sample Preparation Laboratory

The sample preparation laboratory provided thin/ microprobe/polished sections to the requirements of the Institute Scientists and Research Scholars. During the year 2018-19, the laboratory provided 1247 thin and polished sections to various users for carrying out microscopic, fluid inclusion and EPMA studies. The laboratory also processed crushing/ grinding of 1371 rock samples for carrying out major, trace and REE analysis by ICPMS, XRF and XRD methods.

Computer Section

Computer Section caters to the computational requirements of the Scientists and other employees of the Institute. Besides catering the hardware & software need of the Institute, it also look into the interconnectivity of the computers and the internet related services. For this purpose, different servers like DNS, mail, web, ftp, database, etc. have been configured. In order to keep these servers secured, Linux operating system have been installed. Open source packages have been used, wherever possible, in the configuration of the servers. All these servers are regularly updated and are being maintained.

The section takes utmost care to maintain a virus and spyware free environment in all the computers by using centralized anti-virus and anti-spyware solution and the latest security solutions. The support is also being provided for different softwares being used in the Institute. The section utilizes the latest networking solutions to provide uninterrupted and high speed intranet and internet connectivity to the users, and takes care the maintenance, troubleshooting and upgradation of the facility. The Institute is connected with the high speed NKN (1 Gbps) link. This networking facility is not only limited to the offices, but to the WIHG residential colony and the Institute Guest House also.

This year, ArcGIS licenses was upgraded and also the stand alone licenses were converted to floating licenses for greater utilization. A centralized data storage facility for storing scientific data has also been provided to the users. The website of the Institute is hosted on the Institute server. The institute journals and other publications are also available through our website. This year the old mailing solution was replaced with the professional mailing solution. The new mailing system is UNICODE supported.

As per the DST guidelines, the manual procedure for applying of sample analysis through the Central Laboratories has been migrated to web based online portal http://waics.wihg.res.in and from this year all the applications from both internal and external users, for sample analysis are accepted using the portal only. Lab wise status of sample registration, analysis of sample is also available online through WAICS portal and through sms to respective user. The final analysis report is also downloadable from the dashboard of the user. Besides the section provide support for the Hindi typing.

CELEBRATIONS

4th International Yoga Day

4th International Yoga Day was celebrated in the Institute on June 21, 2018. On this occasion, more than 80 Scientist, employees and research students practiced for Yoga between 6:30 AM to 7:30 AM under the directive and guidance of a Yoga Instructors.

Foundation Day

Golden Jubilee Foundation Day was celebrated in the Institute during June 26-29, 2018. The first day of the celebration was declared as open day for general public, whereby Institute museum, exhibition Hall, Photo gallery and all the laboratories of the Institute remained open for the visitors. At the end of the day, Group Antakshari was played by the employees of the Institute. The second day was marked with the cultural program organized by the research scholars of the Institute and this was followed by the Ethnic & Traditional dress show by the staff and research scholars. On June 28, 2018. A popular lecture by Prof. D. Balasubramanian titled "You do not require a degree in Science to become a Scientist" was delivered. This was attended by most of the sister research and teaching organizations located in Dehradun.








Glimpses during the Group Antakshri being played by the staff and research scholars of the Institute on June 26, 2018

Glimpses of the Cultural program

Ethnic and Traditional Dress Show

The 50^{th} Foundation Day was celebrated on 29^{th} June 2018 with great enthusiasm and vigor. On the occasion, Sh Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand was the Chief Guest and Dr Shailesh Nayak, Director NIAS, Bengaluru was the Guest of Honour. The Foundation Day Lecture was delivered by Dr Shailesh Nayak. The event was also attended by sister organizations located in Dehradun as well the Ex - employees of the Institute. During the event (i) Compendium of the Institute highlighting the milestone of the Institute research contribution, (ii) Bibliography of the Research publications by the Scientists of the Institute, (iii) Book “Active tectonics of Kumaun and Garhwal Himalaya” authored by Jayangondaperumal, R., Thakur, V.C., Joe V., Rao, P.S., Gupta, A.K. and (iv) Monogram “Lithostratrigraphy, Biostrtigraphy and Palaeogeography of the eastern Karakoram, India” authored by K.P. Juyal were released.

The occasion was marked by the distribution of awards by the Guest of Honour to the best research paper published by the Institute scientists as well as to the best worker of the institute. Institute 'Best Paper Award - 2017' was given to the paper titled “Geometry of the Main Himalayan Thrust and Moho beneath Satluj valley, Northwest Himalaya: constraints from receiver function analysis” published in Journal Geophysical Research Solid Earth, Vol. 122(4) by Dr Devajit Hazarika, Monika Wadhawan, Ajay Paul, Naresh Kumar and K. Borah. The best worker award was given to Mrs. Manju Pant (AFAO) for her sincere and dedicated services to the Institute. Prof. R.C. Mishra Memorial Gold Medal was award to Dr Suman Lata Rawat for her contribution in the field of Palaeoclimatic studies using pollens in the Higher Himalayan terrain.

Shri Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand releasing the Bibliography of the Institute and Shri Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand, Dr Shailesh Nayak, Director NIAS, Bengaluru along with Dr (Mrs) Meera Tiwari, Dr V.C. Thakur and Dr Kishor Kumar releasing a book

Shri Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand addressing the gathering and Dr Shailesh Nayak, Director NIAS, Bengaluru delivering the Foundation Day Lecture

Awardees for the Prof. R.C. Mishra Memorial Medal, Institute Best Paper Award -2017 and the Best Worker Award

Independence Day

Institute celebrated Independence Day on August 15, 2018. On this occasion, Dr (Mrs) Meera Tiwari, Director In-Charge unfurled the National Flag. To mark the occasion, several sports and fun competitions were organized for the Staff and their family members and prizes were distributed to the winners.

Swachchata Pakhwara

Institute observed Swachchata Pakhwara during 15 Sept - 02 Oct. 2018. Under this program the voluntary cleaning of i) Institute campus, ii) part of the GMS road and adjacent areas iii) Wadia Colony iv) Laboratories and the Office rooms of the Institute were carried out. A team from institute also performed cleanliness drive in a schools located in the vicinity.

Cleaning Drive in the Campus, GMS Road and in a school

Founder's Day

The Birth Anniversary of Prof. D. N. Wadia, on the 23rd October is celebrated every year as 'Founder's Day'. In the Honor of Prof. D. N. Wadia, generally a lecture by some eminent scientist is organized. This year lecture was delivered by Dr. Anjan Ray, Director, Indian Institute of Petroleum (IIP) on *"Combating Climate Change with Domestic Carbon Resources in the Himalayas"*.

Vigilance Week

Like previous year, the Institute observed "Vigilance Week" during Oct. 29-Nov. 03, 2018 with the theme "*Eradicate corruption- Build a new India*". Towards this, the scientists and staff of the Institute took pledge on 29th October 2018.

Employees of the Institute taking pledge towards building corruption free India

Rashtriya Ekta Diwas (National Unity Day)

Rashtriya Ekta Diwas (National Unity Day) was observed on 31st October to commemorate the birth anniversary of Sardar Vallabhbhai Patel. Scientists and staff of the Institute took pledge for Nation building and to re-affirm the idea of a strong, united and resilient India.

Republic Day

Dr. Kalachand Sain, Director unfurled the National Flag on the Republic Day, January 26, 2019 and addressed the gathering. To mark the occasion, plantation was done in the Institute and various sports activities, craft exhibition, and competitions were organized for the employees and their children. A cultural event 'Udbhav' was performed mainly by the research scholars.

Republic Day Celebration in the Institute

Science Week

Science Week has been observed in the Institute during February 22-28, 2019 as a part of the 'National Science Day' celebration. Various activities were organized for school children and for the employees of the Institute. Various educational institutions of Dehradun were invited for participation in the Science Quiz and Hindi Essay Competitions. Besides these, Hindi and English slogan competition was also held in which scientists, staff and research scholars participated. To encourage the participation, the winners were awarded with the citation and token cash prizes.

Dr. Ashesh Siawal, GM (Geology), KDMIPE, ONGC was the chief Guest for the National Science Day i.e. February 28, 2019 and he delivered the 'National Science Day Lecture' on the "Mesozoic-Cenozoic Evolution of Indian Margin: Implications of Hydrocarbon Exploration". The lecture was attended by a large number of students of different schools, general visitors and by the Institute staff. The occasion was also marked by distribution of prizes by the Chief Guest to the winners of the Science Quiz and Hindi Essay competitions.

Students from different school visiting the Institute and participating in the competition

International Women Day

Institute celebrated 'International Women Day' on March 08, 2019. All the female employees and the research scholars gathered to share their respective experiences in life and celebrated the event with enthusiasm.

DISTINGUISHED VISITORS TO THE INSTITUTE

- Parliamentary Standing Committee on Science & Technology, Environment & Forest led by Shri Anand Sharma (INC).
- Sh Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand
- Ambassador of Norway to India HE Nils Ragnar Kamsvag along with Ms Marta Gjortz Second Secretary Norwegian Embassy
- Dr Jayant Narlikar, the famous Indian Astrophysicist and recipient of Padama Vibhushan
- Dr Shailesh Nayak, Director National Institute of Advanced Studies NIAS, Bengaluru
- Padmashri Dr. Harsh Gupta, Former Director, National Geophysical Research Institute (NGRI), Hyderabad
- Shri Ram Singh Meena, ADG, Uttarakhand Police
- Prof. Chandra Sekhar Nautiyal, Vice Chancellor, Doon University
- Dr D.K. Verma, Superintendent Archaeologist, Archaeological Survey of India (ASI), Dehradun
- Dr. Chris J. Spenser, School of Earth & Planetary Sciences, Curtin University, Australia
- Prof. Andrew Meigs, Oregon State University, Oregon, USA
- Dr. J. S. Mehta, Dy Director General, Geological Survey of India (GSI), New Delhi
- Prof Ram Sagar, Senior Scientist, Indian Institute of Astrophysics (IIA), Bangalore
- Sh Vijaya Dhingra, State teacher and coordinator of 'The Art of Living'
- Dr. Anjan Ray, Director, Indian Institute of Petroleum (IIP), Dehradun
- Dr. Ashesh Siawal, GM (Geology), KDMIPE, ONGC, Dehradun

STATUS OF IMPLEMENTATION OF HINDI

STATUS OF IMPLEMENTATION OF HINDI

As per the policy and guidelines for implementing Hindi as Rajbhasha, Institute is committed to guidelines and attempting in the direction of progressive use of Hindi in daily office work and in the research fields of the Institute. This year under the banner of Rajbhasha Implementation Committee of the Institute, one day workshop on *'Rajbhasha and Vigyan'* was organized on 22nd June 2018 in the Institute. The main objective of workshop is not only to promote the communication of scientific information and knowledge in Hindi but also to make it available to the reach of common man. The workshop was inaugurated by Prof. Chandra Sekhar Nautiyal, Vice Chancellor, Doon University. In his remark, he stressed upon the need of scientific articles in Hindi and encouraged WIHG scientists to initiate writing of geoscience articles in Hindi.

Prof. Chandra Sekhar Nautiyal, Vice Chancellor, Doon University, along with Dr Meera Tiwari and Dr Kishor Kumar lightening the lamp

After the inauguration, eminent scientists delivered the lectures on the diverse field. Dr D.K. Verma, Superintendent Archaeologist from Archaeological Survey of India, Dehradun conveyed about the quality of Hindi language and gave minor details of Archaeological works. Subsequently, Dr Ajay Paul, Senior Scientist of WIHG explained about the earthquake hazard, and its mitigation and preparedness for the cause of the society. He analysed the migration problem of Uttarakhand Hill areas and suggested some remedial measure too. Dr Gautam Rawat, Rajbhahsa Adhikari, then explained the technical aspect of Hindi typing and gave brief details about the contribution of CDAC India and other agencies in developing technical tools for Hindi language. Quality of water and remedial measures for water treatment were explained by Dr S.K. Bartarya. Dr Lekh Chand explained how the pollution problems can be avoided by adaptation of organic farming and natural ways of living. A small drama and a short kavvi samelan was also organised during the workshop.

In the closing ceremony, Shri Ram Singh Meena, ADG of Uttarakhand Police. the chief guest explained the role of police in natural hazards and appreciated the efforts of institute.

Shri Ram Singh Meena, ADG, Uttarakhand Police addressing the gathering

The workshop was well attended by the representatives from NARAKAS offices code, Institute employees, Research students,project staffs etc..

Hindi Pakhwara wascelebrated from 14 Sep to 28 Sept., 2018 through organization of various programs.It was inaugurated by Shri Kushal Kothiyal, State Editor, Dainik Jagran and an eminent Journalist. In his opening remark, he portrayed the evolution of Hindi since its birth and explained how Hindi is connected with common man and what role it plays in binding the society before and after independence. Dr. Mridul Joshi, Prof. from Hindi Department, Gurukul Kangri Vishwvidyalaya, presented the status of Hindi in the global scenario. Dr Mukund Joshi, Retd. Professor presented the development of Geological time series and its relevance in reference to India. There have been lectures from institute scientists too who delivered their scientific talk in Hindi. Beside the lecture series, debate competition and Essay Writing for school children, Geological field photo and its description competition and self-written poetry, essay writing for employees were organized.

There has been inspection of Rajbhasha implementation by the committee from Rajbhasha section of Department of Science and Technology on 24 - 25th January 2019.

MISCELLANEOUS ITEMS

1. Reservation/Concessions for SC/ST employees

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 employee's grievances

There is a Grievance redressal Committee consisting of five senior scientists/officer for redressal of employees' grievances. Six grievances of the employees of the Institute were received. Adequate action were taken to resolve these grievances.

4. Welfare measures

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

To inquire into the complaints of sexual harassment of women employees at work places in the Institute, a separate Committee has been constituted. The Committee consists of seven members. The Chairman and three other members of the Committee are female officers, which includes a female officer from the Department of Food and Civil supplies, Govt. of Uttarakhand. No complaint of sexual harassment of women employees at work places was received by the Committee during the year 2018-19.

6. Status of Vigilance Cases

There is one vigilance case pending during the year 2018-19.

7. Information on the RTI cases

Four applications for seeking information under the Right to Information Act, 2005 were carried forward from the previous year 2017-18.

The details of information on the RTI cases during the year 2018-19 are as under:

Details	Opening balance as on 01.04.2018	Received during the year 2018-2019	Number of cases transferred to other public authorities	Decisions where requests/ appeals were rejected	Decisions where requests/ appeals accepted
1	2	3	4	5	6
Requests for information	04	59	01	Nil	62
First appeals	Nil	02	Nil	01	01

*02 applications under the Right to Information Act, 2005 were carried forward to the next financial year 2019-20.

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	63	22	40	125
Total	63	67	38	40	208

9. Sanctioned and released budget grant for the year 2018-2019

Plan : ₹ 2366.09 Lakhs

Non-Plan : NIL

Total : ₹ 2366.09 Lakhs

STAFF OF THE INSTITUTE

Scientific Staff

1	Dr. Kalachand Sain	Director
2	Dr. Meera Tiwari	Scientist 'G'
3	Dr. Kishor Kumar	Scientist 'G' (Retired on 30.09.2018)
4	Dr. Rajesh Sharma	Scientist 'G'
5	Dr. G.Philip	Scientist 'G'
6	Dr. D.Rameshwar Rao	Scientist 'G' (Retired on 30.11.2018)
7	Dr. S.K.Bartarya	Scientist 'G' (Retired on 30.06.2018)
8	Dr. S.K.Parcha	Scientist 'G' (Retired on 30.04.2018)
9	Dr. H.K.Sachan	Scientist 'G'
10	Dr. Sushil Kumar	Scientist 'F'
11	Dr. D.P.Dobhal	Scientist 'F'
12	Dr. Vikram Gupta	Scientist 'F'
13	Dr. Suresh N.	Scientist 'E'
14	Dr. Pradeep Srivastava	Scientist 'E'
15	Dr. Ajay Paul	Scientist 'E'
16	Dr. S.S. Bhakuni	Scientist 'E'
17	Dr. R. Jayangondaperumal	Scientist 'E'
18	Dr. A.K.Singh	Scientist 'E'
19	Dr. Kapesa Lokho	Scientist 'E'
20	Dr. K.S. Luirei	Scientist 'E'
21	Dr. P.S. Negi	Scientist 'E'
22	Dr. A.K.L Asthana	Scientist 'E'
23	Dr. Gautam Rawat	Scientist 'D'
24	Dr R.K.Sehgal	Scientist 'D'
25	Dr. Jayendra Singh	Scientist 'D'
26	Dr. B.K. Mukherjee	Scientist 'D'
27	Dr. Santosh Kumar Rai	Scientist 'D'
28	Dr. Naresh Kumar	Scientist 'D'
29	Dr. Devajit Hazarika	Scientist 'D'
30	Dr. Dilip Kumar Yadav	Scientist 'D'
31	Dr. Kaushik Sen	Scientist 'D'
32	Dr. Satyajeet Singh Thakur	Scientist 'D'
33	Dr. Swapnamita Choudhuri	Scientist 'D'
34	Dr. Narendra Kumar Meena	Scientist 'D'
35	Dr. Param Kirti Rao Gautam	Scientist 'D'
36	Dr. Manish Mehta	Scientist 'D'
37	Dr. Aparna Shukla	Scientist 'D'
38	Dr. Rajesh S.	Scientist 'C'
39	Dr. Vikas	Scientist 'C'
40	Dr. Som Dutt	Scientist 'C'
41	Dr. Anil Kumar	Scientist 'C'
42	Sh. Saurabh Singhal	Scientist 'C'
43	Dr. Narendra Kumar	Scientist 'C'
44	Dr. Parveen Kumar	Scientist 'C'
45	Dr. Vinit Kumar	Scientist 'C'
46	Dr Sudipta Sarkar	Scientist 'B'
47	Dr. M. Prakasam	Scientist 'B'
48	Dr. Aditya Kharya	Scientist 'B'
49	Dr. Paramjeet Singh	Scientist 'B'
50	Dr. Suman Lata Rawat	Scientist 'B'
51	Dr. Chhavi Pant Pandey	Scientist 'B'
52	Dr. Aliba AO	Scientist 'B'
53	Dr. Sameer Kumar Tiwari	Scientist 'B'
54	Dr. Pinkey Bisht	Scientist 'B'
55	Dr. C. Perumalsamy	Scientist 'B'
56	Dr. Pratap Chandra Sethy	Scientist 'B'

Technical Staff

1	Shri Sanjeev Kumar Dabral	Sr. Technical Officer
2	Shri Chandra Shekhar	Sr. Technical Officer
3	Shri Samay Singh	Sr. Technical Officer
4	Shri Rakesh Kumar	Sr. Technical Officer
5	Shri H.C. Pandey	Sr. Technical Officer
6	Shri N.K. Juyal	Sr. Technical Officer
7	Shri T.K. Ahuja	Technical Officer
8	Shri C.B. Sharma	Assistant Engineer
9	Shri S.S. Bhandari	Librarian
10	Shri Rambir Kaushik	Asstt. Pub. & Doc. Officer
11	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
12	Shri Bharat Singh Rana	Librarian
13	Dr. Jitendra Bhatt	Jr. Technical Officer
14	Dr. Pankaj Chauhan	Jr. Technical Officer
15	Shri Lokeshwar Vashistha	Sr. Lab.Technician
16	Dr. S.K. Chabak	Sr. Lab.Technician
17	Shri R.M. Sharma	Sr. Lab.Technician
18	Shri C.P. Dabral	Sr. Lab.Technician
19	Ms. Sarita	Sr. Technical Assistant
20	Shri Rakesh Kumar	Sr. Technical Assistant
21	Shri Shiv Pd. Bahuguna	Sr. Lab. Assistant (Retired on 31.07.2018)
22	Shri Rajendra Prakash	Sr. Lab. Assistant
23	Shri Tirath Raj	Sr. Lab. Assistant (Retired on 31.07.2018)
24	Shri Nand Ram	Elect.cum-Pump.Optr.
25	Shri Balram Singh	Elect.cum-Pump.Optr.
26	Ms. Sakshi Maurya	Technical Assistant
27	Ms. Disha Vishnoi	Technical Assistant

28	Shri Abhimanyu Yadav	Technical Assistant - Lien Vancancy (Terminated on 17.09.2018)
29	Shri Prateek Negi	Artist cum Modeller
30	Shri Rahul Lodh	Lab Assistant
31	Shri Nain Das	Lab Assistant
32	Shri Tarun Jain	Draftsman
33	Shri Pankaj Semwal	Draftsman
34	Shri Santu Das	Section Cutter
35	Shri Puneet Kumar	Section Cutter
36	Shri Hari Singh Chauhan	Field-cum-Lab-Attendant
37	Shri Ravi Lal	Field-cum-Lab-Attendant
38	Shri Preetam Singh	Field-cum-Lab-Attendant
39	Mrs.Rama Pant	Field Attendant
40	Shri R.S.Negi	Field Attendant
41	Shri Ramesh Chandra	Field Attendant
42	Shri B.B.Panthri	Field Attendant
43	Shri M.S.Rawat	Field Attendant
44	Shri Sanjeev Kumar	Field-cum-Lab-Attendant
45	Shri Deepak Tiwari	Field-cum-Lab-Attendant
46	Shri Ajay Kumar Upadhaya	Field-cum-Lab-Attendant
47	Ms. Sangeeta Bora	Field-cum-Lab-Attendant
48	Sh. Deepak Kumar	Field-cum-Lab-Attendant
49	Ms. Anjali	Field-cum-Lab-Attendant

Administrative Staff

1	Shri Pankaj Kumar	Registrar
2	Ms. Deepti Datta	Finance & Accounts Officer (Reigned on 08.08.2018)
3	Shri A.S.Negi	Administrative Officer
4	Mrs. Manju Pant	Asstt. Fin. & Accounts Officer
5	Shri Manas Kumar Biswas	Store & Purchase Officer
6	Mrs. Shamlata Kaushik	Assistant (Hindi) (Retired on 31.05.2018)
7	Smt. Rajvinder Kaur Nagpal	Stenographer, Grade - II
8	Ms. Shalini Negi	Stenographer, Grade - II
9	Shri M.C.Sharma	Office Superintendent
10	Shri S.K.Chhettri	Accountant
11	Shri Rahul Sharma	Assistant
12	Shri S.K.Srivastava	Assistant
13	Shri R.C.Arya	Assistant
14	Mrs. Prabha Kharbanda	Assistant
15	Mrs. Kalpana Chandel	Assistant
16	Ms. Richa Kukreja	Stenographer, Grade - III
17	Mrs. Anita Chaudhary	Upper Division Clerk
18	Shri Shiv Singh Negi	Upper Division Clerk
19	Mrs. Neelam Chabak	Upper Division Clerk
20	Mrs. Seema Juyal	Upper Division Clerk
21	Mrs. Suman Nanda	Upper Division Clerk
22	Shri Kulwant Singh Manral	Upper Division Clerk
23	Shri Vijai Ram Bhatt	Upper Division Clerk
24	Shri Girish Chander Singh	Upper Division Clerk
25	Shri Rajeev Yadav	Lower Division Clerk
26	Shri Deepak Jakhmola	Lower Division Clerk
27	Shri Dinesh Kumar Singh	Lower Division Clerk
28	Ms. Rachna	Lower Division Clerk

Ancillary Staff

1	Shri Sohan Singh	Driver (Retired on 31.10.2018)
2	Shri Shyam Singh	Driver (Retired on 30.11.2018)
3	Mrs. Kamla Devi	Bearer
4	Mrs. Deveshawari Rawat	Bearer
5	Shri S.K. Gupta	Bearer
6	Mrs. Omwati	Bearer
7	Shri Jeevan Lal	Bearer
8	Shri Surendra Singh	Bearer
9	Shri Pritam	Bearer
10	Shri Ramesh Chand Rana	M.T.S.
11	Shri Pankaj Kumar	M.T.S.
12	Shri Ashish Rana	M.T.S.
13	Shri Harish Kumar Verma	M.T.S.
14	Shri Dinesh Parsad Saklani	Guest House Attendant cum Cook
15	Shri Sunil Kumar	Guest House Attendant cum Cook
16	Shri Rohlu Ram	Chowkidar
17	Shri H.S. Manral	Chowkidar
18	Shri G.D. Sharma	Chowkidar
19	Shri Satya Narayan	Mali
20	Shri Hari Kishan	Safaiwala

Contractual Staff

1	Shri Neeraj Bhatt	Lower Division Clerk
2	Shri Dhanveer Singh Shah	Lower Division Clerk
3	Smt. Megha Sharma	Lower Division Clerk
4	Shri Rezaw Uddin Chaudhary	Driver
5	Shri Rajesh Yadav	Driver
6	Shri Bhupendra Kumar	Driver
7	Shri Manmohan	Driver
8	Shri Vijay Singh	Driver
9	Shri Rudra Chettri	Bearer
10	Shri Laxman Singh Bhandari	Chowkidar
11	Shri Pradeep Kumar	Chowkidar
12	Shri Kalidas	Chowkidar
13	Shri Ummed Singh	Chowkidar

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

Governing Body
(till Nov 13, 2018)

Sl.	Name	Address	Status
1.	Prof. S.K. Tandon	Block-A, House No. 566-C, Sushant Lok, Phase-I, Gurgaon-122009	Chairman
2.	Representative of the Secretary, DST	Dept. of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi - 110016	Member
3.	Prof. M.P. Singh	124, Chandganj Extension (Opp. CN-7, Sector-B), Aliganj, Lucknow-226024 (U.P.)	Member
4.	Dr. U.C. Mohanty	School of Earth, Ocean and Climate Sciences, Indian Institute of Technology-Bhubaneswar, Bhubaneswar-751007	Member
5.	Prof. D.C. Srivastava	Head, Department of Earth Sciences, Indian Institute of Technology-Roorkee, Roorkee-247667	Member
6.	Dr. Rajesh K. Srivastava	Faculty of Science, Department of Geology, Banaras Hindu University (BHU), Varanasi-221005	Member
7.	Dr. D.S. Ramesh	Director, Indian Institute of Geomagnetism, Plot No. 5, Sector 18, New Panvel, Navi Mumbai-410218	Member
8.	Dr. Rajiv Nigam	Chief Scientist, CSIR-National Institute of Oceanography GOA-403 004	Member
9.	Shri J.B. Mohapatra	Joint Secretary and Financial Adviser, Department of Science and Technology Technology Bhawan, New Mehrauli Road, New Delhi-110 016	Member
10.	Dr (Mrs) Meera Tiwari	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary
11.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Non-Member Asstt. Secretary

(w.e.f. Nov 13, 2018)

Sl.	Name	Address	Status
1.	Prof. Ashok Sahni	Emeritus Professor, Lucknow University, 98, Mahatma Gandhi Marg, Lucknow -226001	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	Member
5.	Prof. Harilal B. Menon	Department of Marine Sciences, Goa University, Taleigoa, Plateau Goa-403206	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	Member
9.	Prof. Pramod K. Verma	Department of Applied Geology, Vikram University, University Road, Madhav Bhavan (Near Vikram Vatik), Ujjain-456010	Member
10.	Prof. S.K. Dubey	Former Director, Indian Institute of Technology - Khargapur Khargapur - 721302	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, Dehra Dun-248001	Member Secretary
13.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun-248001	Non-Member Asstt. Secretary

Research Advisory Committee
(till Feb 13, 2019)

Sl.	Name	Address	Status
1.	Prof. D.C. Srivastava	Head, Department of Earth Sciences, Indian Institute of Technology, Roorkee-247667	Chairman
2.	Dr. S. Sinha Roy	(Ex-Deputy D.G., GSI), Birla Institute of Scientific Research, Statue Circle, Jaipur-302001	Member
3.	Prof. Kusala Rajendran	Centre for Earth Sciences, Indian Institute of Science, Bangalore-560012	Member
4.	Prof. M. Jayananda	Geology Department, Centre for Advanced Studies, Delhi University, Delhi-110007	Member
5.	Dr. R.S. Dattatrayam	H.No. 6-3-1099/1/3, Flat No. 504, Aditya Classic Apartments, Nest to Katriya Hotel, Somajiguda, Hyderabad-500082	Member
6.	Dr. V.M. Tiwari	Scientist, National Geophysical Research Institute, Uppal Road, Hyderabad-500007	Member
7.	Dr. J.R. Kayal	73-B, Thakur Pukur Road, Kolkata-700063	Member
8.	Prof. M.K. Panigrahi	Department of Geology & Geophysics, Indian Institute of Technology-Kharagpur, Kharagpur-721302	Member
9.	Prof. S. Tripathy	Deputy Director & Head, School of Earth Ocean and Climate Sciences, Indian Institute of Technology-Bhubaneswar, A-2702, Toshali Bhavan, Satya Nagar, Bhubaneswar-751007	Member
10.	Prof. R.P. Tiwari	Dean, School of Engineering & Technology, Mizoram University, Aizawl-796009	Member
11.	Prof. Sunil K. Singh	Geosciences Division, Physical Research Laboratory, Navrangpura, Ahmedabad-380009	Member
12.	Dr. Snehmani	Joint Director, Snow and Avalanche Study Establishment, Him Parisar, Sector - 37A, Chandigarh-160036	Member
13.	Dr(Mrs) Meera Tiwari	Director. Wadia Institute of Himalayan Geology, Dehradun-248001	Member
14.	Dr. S.K. Parcha	Scientist `F', Wadia Institute of Himalayan Geology, Dehradun-248001	Member Secretary

(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
1.	Dr. Shailesh Nayak	Director, National Institute of Advanced Studies, Indian Institute of Science campus, Bengaluru- 560012	Chairman
2.	Professor Talat Ahmad	Vice Chancellor, University of Kashmir, Hazratbal, Srinagar Jammu & Kashimir- 190006	Member
3.	Professor D.C. Srivastava	Department of Earth Sciences, Indian Institute of Technology-Roorkee, Roorkee-247667	Member
4.	Professor 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.	Professor N.V. Chalapathi Rao	Department of Geology, Banaras Hindu University(BHU), Varanasi - 221005	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	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- 248 001	Member
11.	Professor Biswajit Mishra	Geology and Geophysics Indian Institute of Technology-Kharagpur Kharagpur, 721302	Member
12.	Professor Avinash Chandra Pandey	Director, Inter- University Accelerator Centre, Aruna Asaf Ali Marg,Near Vasant Kunj, New Delhi- 110 067	Member
13.	Professor Ajoy Bhowmik	Associate Professor, Department of Applied Geology Indian Institute of Technology (Indian School of Mines), Dhanbad- 826004	Member

Sl.	Name	Address	Status
14.	Dr. Vandana Prasad	Scientist, Birbal Sahni Institute of Paleoscience, 53, University Road Lucknow-226007	Member
15.	Dr.Prantik Mandal	Chief Scientist, Co-ordinator & Professor at AcSIR-NGRI, Theoretical & Computational Geophysics Group, CSIR-NGRI, Uppal Road, Hydearbad-500007	Member
16.	Professor Anil V. Kulkarni	Distinguished Visiting Scientists, Divecha Centre for Climate Change, Indian Institute of Science, Bengaluru- 560012	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, 33, General Mahadeo Singh Road, Dehradun-248001	Member Secretary

Finance Committee
(till Feb 13, 2019)

Sl.	Name	Address	Status
1.	Prof. M.P. Singh	124, Chandganj Extension, (Opp. CN-7, Sector-B), Aliganj, Lucknow-226024	Chairman
2.	Dr (Mrs) Meera Tiwari	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
3.	Shri J.B. Mohapatra	Additional Secretary & Financial Adviser, Dept. of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi - 110016	Member
4.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
5.	Ms. Deepti Dutta	Finance & Accounts Officer, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

(w.e.f. Feb. 13, 2019)

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- 121001	Member
3.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehra Dun-248001	Member
4.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehra Dun-248001	Member
5.	Mrs. Manju Pant	Assistant Finance & Accounts Officer, Wadia Institute of Himalayan Geology, Dehra Dun-248 001	Member Secretary

Building Committee
(till Feb. 13 2019)

Sl.	Name	Address	Status
1.	Dr (Mrs) Meera Tiwari	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Chairman
2.	Shri J.B. Mohapatra	Additional Secretary & Financial Adviser, Dept. of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi - 110016	Member
3.	Representative of ONGC	Tel Bhawan, Oil & Natural Gas Corpration, Dehradun-248001	Member
4.	Representative of Survey of India	Surveyor General's Office, Survey of India, Hathibarkala, Dehradun-248001	Member
5.	Dr. Rajesh Shrma	Scientist 'G', Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
6.	Shri Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
7.	Shri C.B. Sharma	Assistant Engineer, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
1.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehra Dun 248001	Chairman
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

STATEMENT OF ACCOUNTS

P.S. SETHI & CO.
CHARTERED ACCOUNTANTS
SRE Off.: *1/7416, Chander Nagar, Near Radha Krishna Mandir,* Saharanpur
D.Dun Off.: *10, Indraprasth Enclave, Shimla bypass Road, Majra* ***DEHRADUN***

Tel.No. 09837562985 *Email:rkguptasre@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, 2019 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

AUDITOR'S REPORT

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, 2019;
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.

We are thankful to the staff and the Management for the co-operation extended to us during the course of audit.

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
FCA, DISA (ICAI)

FRN: 04545C
M.NO: 402349

Date: 30th Sept, 2019
Place: Dehradun

P.S. SETHI & CO.
CHARTERED ACCOUNTANTS
SRE Off.: *1/7416, Chander Nagar, Near Radha Krishna Mandir,* Saharanpur
D.Dun Off.: *10,Indraprasth Enclave, Shimla bypass Road, Majra* *DEHRADUN*

Tel.No. 09837562985 *Email: rkguptasre@yahoo.com*

Annexure-1 to the Consolidated Financial Statement of Audit Report (F.Y. 2018-19)

The following observations were noticed during the course of audit for the Financial Year 2018-19. The same have been discussed with the management and comments/explanations of the management thereon have also been observed.

Sl. No.	Comments/Observations by Chartered Accountants
1.	The Institute is maintaining accounts on cash basis except interest accrued on investments, which is not conformity with the generally accepted accounting policy adopted in India and as per the accounting standard-1 "Disclosure of Accounting Policies" issued by the Institute of Chartered Accountants of India. The "Uniform Accounting Format" of financial statements of the central autonomous bodies as has been made compulsory by the Ministry of finance w. e. f. 01.04.2001 and adopted by the Institute also, recommends accrual method of accounting.
2.	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.
3.	The internal control regarding fixed assets needs to be strengthened. The following observation are made: a) The physical verification of fixed assets for the financial year2018-19has not been undertaken. While auditing the accounts in the store section it was observed following Assets Register were maintained by the store section:- **[Details]** A. 1. Assets-1 2. Assets-2 3. Assets-3 4. Assets-4 5. Assets-5 B. General Equipment C. Field Equipment D. Vehicle register E. Engineering Section F. Fixed Assets buildings. Physical verification of the above mentioned Assets have not been carried out by the verifying officer till date. Reason of not doing the needful may be specified. **Physical verification of library not conducted.** While auditing the accounts pertaining to the Library located inside WIHG it was observed that physical verification of the books/journals and magazines available in the library have not been physically verified till the date of completion of audit report. The reason for not complying with the rule laid down in GFR regarding physical verification of Assets may be specified.
4.	It has been noticed that Institute is not following the E-Tendering process as per Govt. of India procurement rules. It is recommended that the said procedure should be adopted.
5.	It was observed that Institute is maintaining its financial accounting in the software developed in FOXPRO Database with clipper compilation which is based on the huge codification process and not has the window base verification system. This software is obsolete in the present scenario comparing with the recent available Accounting software in use. To maintain the accounts of institute it is suggested that

AUDITOR'S REPORT

a software which is more user friendly to all the staff working in the account section and that to customized as per the need of the institute be developed. The management of the Institute needs to take urgent action.The institute has purchased "Tally Software" for maintaining records of the financial transactions/ledgers etc. The shifting of all records/ledgers to Tally Software is under process.

6. During the audit it was observed that the Mr. Uttam Singh has been suspended in November, 2013 but there is CPF balance of Rs. 34658/- outstanding in the books of institute.

7. It was observed that several projects are appearing in Financial Statements where no transactions has undertaken since long, the management is advised to take appropriate action for final settlement.

Non-maintenance of books of accounts in respect of 58 projects While auditing the balance sheet of the project it was observed that Balance Sheet for a total number of 135 projects was prepared up to the current financial year. However books of accounts for 58 projects were neither prepared nor maintained by the WIHG. The reason for not maintaining the books of accounts for the above projects may be specified.

8. During the course of audit it was observed that there is outstanding demand of Rs. 57466.02 in traces website the year wise and form wise break is as follows:

F.Y.	Form Type	TDS demand
Prior Years	26Q	1209.00
2016-17	26Q	12859.58
2017-18	26Q	20294.00
2018-19	26Q	23103.44

9. **Non Adjustment of Advances against the staff Debtors:**

Some advances against staff debtors are pending for recovery since long time, please clarify, if they are irrecoverable nature, initiative for write off is required.

10. **Excess Payment made to M/s Technische University Munchen:**

The payment made to above firm in GBP 1005.30 instead of EURO 1005.30 and that reason over/excess payment made to party due to currency exchange change rate.

11. **News Paper Exps. 10034/- paid in 2018-19 and booked in 2019-20:**

The News paper expensed paid thru cheque no. 8038 dated 29/03/2019, but this amount in not booked in news paper exps. in 2018-19 and stand in BRS of 2018-19.

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
FCA, DISA (ICAI)
FRN: 04545C
M.NO: 402349

P. S. SETHI & CO. Chartered

Date: 30th Sept, 2019
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31ST MARCH 2019)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	73,53,40,049	90,09,45,252
Reserves and Surplus	2		-
Earmaked/ Endowment Fund	3	17,86,224	16,94,704
Secured Loans & Borrowings	4		-
Unsecured Loans & Borrowings	5		-
Deferred Credit Liabilities	6		-
Current Liabilities & Provisions	7	1,95,81,291	77,97,706
TOTAL		**75,67,07,564**	**91,04,37,662**
ASSETS			
Fixed Assets	8	37,06,15,597	42,01,92,828
Investments from Earmaked/		-	-
Endowment Funds	9	47,115	47,115
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	38,60,44,852	49,01,97,719
TOTAL		75,67,07,564	91,04,37,662
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))

(MANJU PANT)	**(PANKAJ KUMAR)**	**(DR. KALACHAND SAIN)**
A F & A.O	**Registrar**	**Director**

Date : 30th September, 2019
Place : Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31ST MARCH 2019

(Amt in Rs...)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12		-
	Grants/ Subsidies	13	25,17,62,408	27,24,90,958
	Fees/Subscription	14	47,500	22,000
	Income from Investments	15	8,69,959	8,35,524
	Income from Royalty, Publication etc.	16	1,13,894	1,01,396
	Interest earned	17	2,55,56,417	2,89,13,765
	Other Income	18	84,56,509	42,94,625
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**28,68,06,687**	**30,66,58,269**
B	**EXPENDITURE**			
	Establishment Expenses	20	24,05,99,595	18,86,74,970
	Other Research & Administrative Expenses	21	6,55,99,486	7,58,61,070
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	82,20,852	80,18,401
	Depreciation Account	8	8,92,76,205	6,54,92,175
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	22,938	(59,025)
	Loss / (Profit) on sale of Assets	A-19	-	(6,360)
	TOTAL (B)		**40,37,19,076**	**33,79,21,231**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		(11,69,12,389)	(3,12,62,962)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	BALANCE BEING SURPLUS /(DEFICIT) CARRIED TO CORPUS FUND		**(11,69,12,389)**	**(3,12,62,962)**

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))

(MANJU PANT)	**(PANKAJ KUMAR)**	**(DR. KALACHAND SAIN)**
A F & A.O	Registrar	Director

Date : 30th September, 2019
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2019)

(Amt in Rs...)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	28,57,01,945	22,32,58,909
Grants - in - Aids	26	26,48,29,408	35,70,93,255
Grants - in - Aids/Other Receipts (Ear Marked)	27	2,39,42,213	4,30,68,133
Loan & Advances	28	18,70,68,496	18,60,02,345
Loan & Advances (Ear Marked)	31		-
Fees/Subscription	14	47,500	22,000
Income from Investments	15	8,69,959	8,35,524
Income from Royalty, Publication etc.	16	1,13,894	1,01,396
Interest earned	17	1,77,06,510	1,60,54,330
Other Income	18	84,56,509	42,94,375
Investment (L/C Margin Money)	34		3,97,02,823
		78,87,36,434	87,04,33,090
PAYMENTS			
Establishment Expenses	20	24,05,99,595	18,86,14,970
Other Administrative Expenses	21	6,55,99,486	7,58,64,070
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	80,39,565	80,18,401
Loans & Advances	29	18,77,63,212	17,47,88,411
Loans & Advances (Ear Marked)	32	-	-
Investment (L/C Margin Money)	35	-	2,49,55,000
Fixed Assets	36	3,96,98,974	6,94,31,641
Ear Marked Fund Expenses	33	2,32,85,376	4,30,61,653
Grant - in - Aid (Ear Marked) Refunded	30	-	-
Closing Balance	25	22,37,50,226	28,57,01,945
		78,87,36,434	87,04,33,090

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))

(MANJU PANT)
A F & A.O

(PANKAJ KUMAR)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 30th September, 2019
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,2019

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.

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.

(Manju Pant)	**(Pankaj Kumar)**	**(Dr. Kalachand Sain)**
A.F. & A.O	**Registrar**	**Director**

Date : 30th September, 2019
Place: Dehradun

P. S. SETHI & CO. Chartered Accountants

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2019

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)	57466.02
	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. 2018 -19 is as follows:

Remuneration to auditors		
i)	As Auditors	47,200/-
	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, 2019, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2019.

(Manju Pant)	**(Pankaj Kumar)**	**(Dr. Kalachand Sain)**
A.F. & A.O	**Registrar**	**Director**

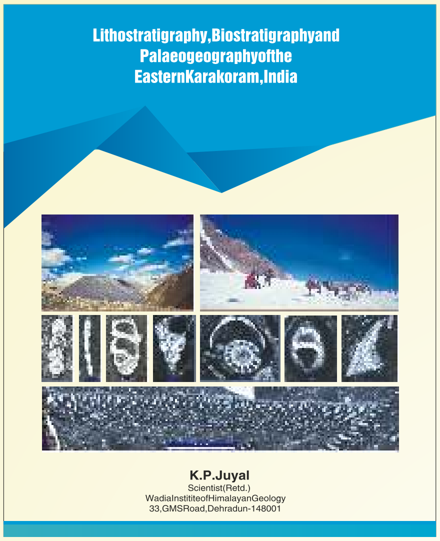
Date : 30th September, 2019
Place: Dehradun

P. S. SETHI & CO.
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

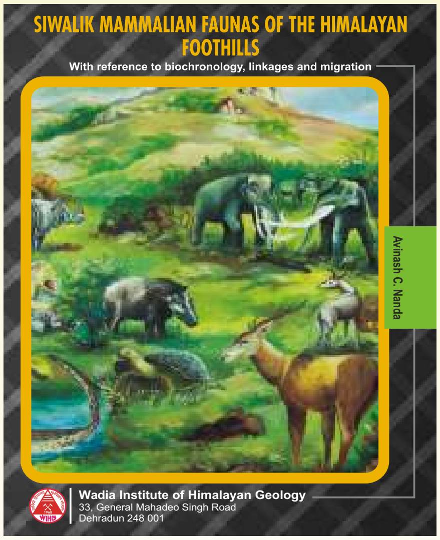
Latest Publications

2018



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

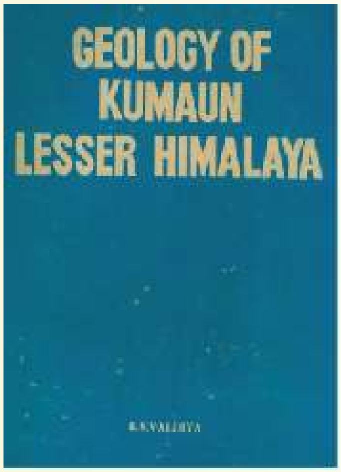
2015



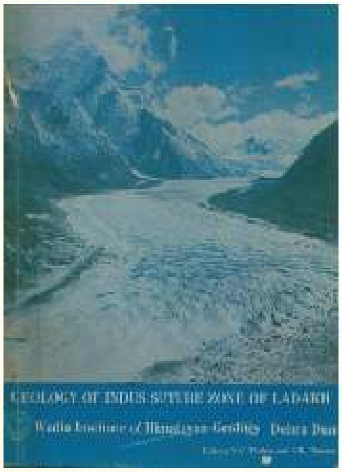
Rs.1200/- (India), US$ 100/- (Abroad)

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

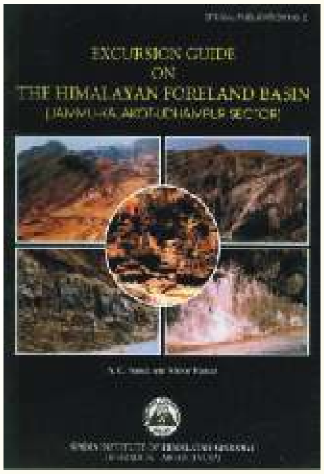
Previous Publications



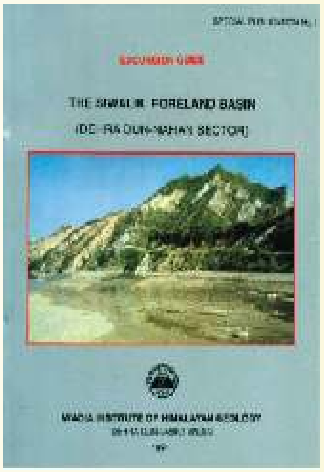
Rs.180/- (India), US$ 50/- (Abroad)



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

Asstt. Publication & Doc. Officer

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
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Institutional	500.00	50.00
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Volume 17 (1996)*

HIMALAYAN GEOLOGY

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Volume 18 (1997) to Volume 26 (2005)*
Volume 27 (2006) to Volume 30 (2009)
Volume 31 (2010) to Volume 32 (2011)*
Volume 33 (2012)
Volume 34 (2013) to Volume 36 (2016)*
Volume 37 (2015) to Volume 38 (2017)
Volume 39 (2018)

Revised Annual Subscription (w.e.f. 2018):	(in Rs)	(in US$)
Institutional	2000.00	150.00
Individual (incl. postage)	600.00	50.00
Individual (excl. postage)	500.00	

Volume 40(2019)

OTHER PUBLICATIONS

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

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

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