WIHG

Wadia Institute of Himalayan Geology

WIHG Celebrating
Golden Jubilee Year
(1968-2018)

ANNUAL REPORT
2017-2018

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ANNUAL REPORT
2017-18

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WIHG ORGANISATIONAL SET-UP

A GLANCE OF THE INSTITUTE ACTIVITIES

The Institute played a lead role in geological and geophysical investigations of the Himalayan region to understand earthquake activity, the glacial-monsoon linkage, the climate-tectonic linkage and insight study of the crust-mantle boundary across the India-Eurasia plate. The Institute carried out the research activities under five thrust area themes, which include: the geodynamic evolution of the Himalaya and adjoining mountains; Indian monsoon-tectonic interaction and exhumation of the Himalaya; earthquake precursor's studies and geo-hazard evaluation; biodiversity-environmental linkage; and Himalayan glaciers, their role in Indian monsoon variability and hydrological changes in the Indus-Ganga Basin.

Brief outline of the Institute achievements for the year

In order to understand the complex tectonic set up of Siang Valley of Arunachal Pradesh, preliminary field works have been carried out to install ten Broad Band Seismometers to know subsurface structures between Pashighat in the frontal Himalaya to the suture zone close to Tuting. Conversely, the investigations of seismic anisotropy in the crust beneath the eastern part of Ladakh-Karakoram zone has been carried out based on shear wave splitting analysis of *S*-wave of local earthquakes and *P* to *S* or *Ps* converted phases originated at the crust-mantle boundary. The study reveal complex nature of anisotropy with NW-SE and NE oriented Fast Polarization Directions in the upper ~22 km of the crust, and has been attributed to the combined effects of existing tectonic features as well as regional tectonic stresses. Moreover, the moment tensor inversion results based on the seismic moment tensors of 11 moderate earthquakes with Mw magnitude in the range of 4.0-5.0, reveals the presence of dominant thrust fault kinematics to be persisting along the Himalayan belt, and that a shallow low and high angle thrust faulting is the dominating mechanism in the Garhwal-Kumaun Himalaya. The results support the critical taper wedge theory, wherein the micro seismicity cluster is inferred as a result of intense activity within the Lesser Himalayan duplex system.

The Magnetotelluric investigations along Nahan-Leopargil profile revealed that lower crust is moderately conductive throughout the profile, while at the middle of upper crust a high conductive layer is present, which have a break in the region below the Himalayan Seismic Belt of NW Himalaya similar to that observed in structure of Garhwal Himalaya, where the MHT ramp is identified at the base on the break and conductance. While on the other hand, the Electrical Resistivity Tomography 2D profile survey was conducted along two profiles in Kala Amb region near trench site with an aim of delineating subsurface extensions of identified features in resistivity section. The profile showed a north dipping fault at 54 m distance from zero electrode position toward south, clearly distinguishing two separate zones of lithology. Besides, the liquefaction feature identified in the trench wall section seems to be uprooted from a depth greater than 36 m. Studies based on continuously operating reference station GPS data were also obtained across the Ganga Tear which suggest that there is 'NO' significant kinematic displacement across the NE-SW trending Ganga Tear. But, significant kinematic movement is observed along SE direction and sub-parallel to the Himalayan Frontal Thrust, which indicates that apart from the Arc perpendicular movement there is also an active movement along the Himalayan Frontal Arc. Attempts have also been made to select new sites for trench excavation surveys between river Kosi and Kali along HFT, to study Quaternary landforms and document signatures of active tectonics. Tectonic scarps have been identified at Bastia, Chorgallia, Damuwadhunga and Patapani for trench excavation surveys in future.

A study of mantle section of Nidar ophiolite in NW Himalaya, demonstrate preservation of octahedral type C-phases in the form of diamond and graphite in the peridotitic rock, sourced from base of the upper mantle. The study of the blueschist rocks from Shergol Ophiolitic Mélange record three types of fluid inclusions, in which Type-I (two-phase carbonic-aqueous), Type-IIa (two phase aqueous fluid) are hosted in garnet & quartz included in garnet, and they were likely to be entrapped at or near to peak P-T conditions (~19 kbar, 470°C, respectively), and produced through metamorphic devolatilization reactions occurring in the subducting slab. In the Sutlej River valley, the structural data of the Haimanta Group have been analyzed to understand the geometry and kinematics of the basal

part of the hanging wall of the SW verging South Tibetan Detachment, and the studies recognize a new normal fault dipping towards ENE near the base of the hanging wall. On the other hand, the *P-T* pseudosection modelling of the mineral assemblage of magmatic enclaves that are sporadically distributed in the Jaspa granite of Ordovician age in Himachal Pradesh show *P-T* stability field in the range of ~4.5-7.3 kbar and ~440-500°C, respectively.

The pollen and LOI records from the fluvial sedimentary sequence of Upshi, J&K are studied to reconstruct the paleoclimatic signatures over the last ~2535 yrs BP, and the studies suggest that the period between ~1220 to 940 yrs BP (760 to 1010 AD) corresponding to the Medieval Warm Period, while the region before and after this period in the last ~2535 yrs BP witnessed cold-dry conditions. The observations from the paleolake sediments of Chamoli Garhwal on the other hand show increased values of TOC, LOI and phosphorous between ~5930 and 1750 yr BP and between ~1010 and 500 yrs BP (940 to 1450 AD), which suggests higher productivity under favorable warm-wet climate conditions, a period corresponding to the global Medieval Warm Period. Furthermore, the low productivity of the organic content from ~500 to 320 years BP (1450 to 1630 AD) indicates the cold-dry conditions in the Garhwal region, a period corresponding well with the Little Ice Age. Studies have also been carried out on the oxygen isotope results of speleothem sample, collected from the Chakrata region, Uttarakhand which suggests for a consistent decline in the Indian summer monsoon during 217 to 183 Kyr BP. The study suggest that strong summer monsoon conditions prevailed in the region from 223 to 217 and 182 to 169 Kyr BP. The reconstruction of June-July precipitation for Dokriani region, Uttarakhand using $\delta^{18}O$ isotope tree-ring chronologies of one deciduous (*Aesculus indica*) and two conifer (*Abies pindrow, Picea smithiana*) species, also revealed continuous decreasing trend of precipitation in the last 273 years since AD 1743, and with driest period in the late 20th and early 21st century.

The study of acritarchs from Infrakrol Formation of Lesser Himalaya show that their mode of preservation and occurrence is comparable to the lower assemblage biozone of the Doushantuo Formation (age ranging from 635 to 550 Ma) in the Yangtze Gorges section of South China. It is interpreted that the Infrakrol Formation is coeval to the Lower Tianzhushania Assemblage Zone and can be bracketed within the same age range. The calcareous algae *Dasyporella silurica*, *Moniliporella multipora* and *Vermiporella fragilis* are reported for the first time from the Middle Ordovician Thango Formation of the Spiti Basin. The presence of these calcareous algae reflects significant biogeographical and biostratigraphical importance and indicates a shallow marine depositional environment for the Thango Formation for Spiti Basin. Eighteen new specimens of the sole apatemyid mammal known outside North America and Europe, the *Frugivastodon cristatus* were described from the Early Eocene Cambay Shale Formation of Vastan Lignite Mine, Gujarat, India. The new fossils show that the Indian apatemyid is unique and represents a new morphotype among this family. The paleobiogeographic analysis suggests that *Frugivastodon* dispersed from Europe into India during the early Ypresian. A detailed study of the faunas of the Himalayan foreland basin was also attempted, and it was noticed that the Siwalik age faunas are not only present in the Himalayan foreland basin; but these are 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.

On the basis of detailed mapping of glacial moraines of Pensilungpa glacier, five stages of glacial advance were identified, the older glacial stage-I has been dated to be ~33±6 ka, stage-II glaciation began with the onset of Last Glacial Maximum, stage-III represent the Younger Dryas cooling stage, whereas, the stage-IV and stage-V glaciation occurred during the early Holocene cooling event and late Holocene, respectively, and dated between 2 to 8 ka. The Institute had also mapped a total of ~3300 landslides in the state of Uttarakhand based on field studied, available datasets in literature and using the satellite imageries. The landslides cover surface area of ~68 km^2 and include landslides generated by natural processes as well as by human intervention on the slope.

The geochemical studies of groundwater samples collected from tubewells and hand pumps from Soan basin of Una district have been studied and they show that the ionic ratios of $(Ca+Mg)/HCO_3$, $(Ca+Mg)/(HCO_3+SO_4)$ and Na/Cl are mainly controlled by weathering of rocks particularly by dissolution/precipitation of calcrete and calcite present in rock veins and Ca-Na feldspar present in conglomerate deposits comprising gneiss, granite, slate and quartzite derived from the Higher and Lesser Himalaya during the formation of Siwalik rocks. Factor

analysis carried out also further suggested that rock weathering and anthropogenic processes associated with high nitrate and iron concentration as major factors affecting the water chemistry of the area. Further, in search of Natural Mineral Resources in Himalaya, the recent field and laboratory investigations in parts of Himachal Pradesh focusing on the Parbati and Garsa valleys showed sporadic mineralization that includes mainly chalcopyrite and pyrite in the Naraul area, while in the Uch area of Parbati valley arsenopyrite is also predominant along with the presence of galena, chalcopyrite and pyrite.

Academic Pursuits

The Institute under the on-going research programs pursued during the year, has published 84 research papers both in national and international journals, and around 60 papers are in press/accepted/communicated. More than 89% of the papers have been published in SCI journals with the annual impact factor of around 150, that is with an average impact factor per paper ~2. Three scientists visit abroad to attend workshops/ seminars. Some of the scientists are members of various national and international committees/boards. Scientists of the Institute have participated in National seminars as well as delivered lectures on various topic in various organizations/universities. During the year, 10 Ph.D. theses have been awarded and 3 submitted for the award of Ph.D. degree. Apart from the regular Ph.D. program, the Institute has initiated several programs for young researchers that include an extended summer and winter training/dissertation programs, and during the year more than 150 post-graduate and graduate engineering students from various Universities/IIT's/Institutions got benefited. Also, to popularize Earth Science amongst students, scientists of the Institute have actively participated in teaching in schools and colleges of Uttarakhand. The Institute has established high end analytical facilities to carry out cutting edge geoscientific research and unique field installations for earthquake precursory research as well as monitoring health of Himalayan glaciers. These analytical facilities act as a National Facility and provide services to various researchers working in Universities/IIT's/ Organizations and Industries. The Institute as an integrated interdisciplinary approach has established collaborations with reputed organizations working in the field of geosciences. To disseminate and share new emerging trends of research in geosciences, the Institute organized *2nd National Geo-Research Scholars Meet* in the Institute during May 17-20, 2017 exclusively for research scholars, young scientists and faculty members.

It is also a proud moment for the Institute that Dr. V.C. Thakur, ex-Director is conferred with 'Padma Shri' by Government of India. Dr. A.K. Mahajan (on lien) has been conferred with 'National Geoscience Award-2017' and Dr. Prakasam has been awarded 'Indian National Science Academy (INSA) Visiting Scientist Fellowship for the 2017-2018'.

The Institute scientists have brought out a book published by Springer on *'Active tectonics of Kumaun and Garhwal Himalaya'*, authored by Drs. R. Jayangondaperumal, V.C. Thakur, V. Joe, P.S. Rao and A.K Gupta. The Institute also published a monograph on *'Lithostratigraphy, Biostratigraphy and Paleogeography of the eastern Karakoram, India'* authored by Dr. K.P. Juyal. The Institute also regularly brings out the Himalayan Geology publications, and during this year volumes 38(2) and 39(1) were brought out along with 'Drishtikon' volume 6.

Golden Jubilee Year of the Institute (30th June, 2017 to 29th June, 2018)

This year happens to be the Golden Jubilee Year of the Institute, the Institute initiated and geared-up to celebrate various activities marking the 'Golden Jubilee Year' of the Institute. Action Plan of Golden Jubilee activity was drawn, and following activities have been planned and initiated:

- Organize National Seminar on *'Earth Sciences in Himalaya: Recent advances and future challenges'* including field workshop on May 16-18, 2018.
- Organize 'Lecture Series' by eminent geoscientists. The Lecture series was initiated by Prof. K.S. Valdiya and it was followed by Prof. Ashok Sahni, Prof. V.K. Gairola, Prof. Jai Krishna during the year ending March 2018.
- Organize bi-monthly lectures by retired Directors and Scientists of the Institute, especially for young scientists and research scholars of the Institute. As part of this program during the year, Drs. V.C. Thakur, N.S. Virdi, B.R. Arora, A.C. Nanda, A.K. Dubey and R. Islam delivered lectures.
- Bring out a bibliography of the papers published by Institute scientists, and make a CD of it, and to release the same on the 50th Foundation Day i.e., June 29, 2018, the culmination of the Golden Jubilee Year.
- Prepare Compendium Highlighting the Milestone

of the Institute research contribution.

- Bring out a volume 'Reminiscences of Golden Days', a compilation of personal views expressed by present and retired scientists about the Institute, for its release on 50th Foundation Day of the Institute.
- Collect and catalogue old or rare and historic photographs related to Memories of the Institute since its inception depicting various activities of the Institute, again planning its release on 50th Foundation Day of Institute.

Lectures Delivered by Eminent Personalities

- Padma Bhushan Prof. K.S. Valdiya delivered the first lecture marking the Golden Jubilee Year of the Institute on *'Calamity in Uttarakhand: Lessons Learnt',*
- Padma Shri Prof. V.P. Dimri delivered the Founder's Day Lecture on *'Carbon Dioxide Geosquestration to Protect Pahad: A Non-linear System'.*
- Dr. V. K. Saraswat, Member NITI Aayog delivered Foundation Day Lecture on *'Pursuit of Science for Humanity'.*
- Prof. D.C. Srivastava of IIT Roorkee delivered J.B. Auden Lecture on *'A Glimpse through some fault zones in Himalaya'*
- Prof. Durgesh Pant, Director, SERC, Uttarakhand had delivered the 'National Science Day Lecture'.
- The Institute observed 'International Fossil Day' on October 16, 2017 to create awareness about the fossils and life of the past, wherein Dr. R.J. Azmi delivered the 'Fossil Day Lecture' on *'Fossils: Importance and some Indian context'.*

Other Highlights

A book written by Padma Bhusan Prof. K.S. Valdiya on the life of Padma Vibhusan Sh. Sundar Lal Bahuguna, noted environmentalist and leader of Chipko movement was released by Sh. Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand at a function in the Institute on September 7, 2017 in the gracious presence of Sh Sundar Lal Bahuguna himself.

The Institute on October 26, 2017 organized half day workshop for the delegates of joint Indian Academy of Highway Engineers (IAHE) Noida and Japan International Cooperation Agency (JICA), Japan. The Institute under the *'Education and awareness program for earthquake preparedness and hazard mitigation in the Chakrata and other tribal regions of Uttarakhand*', delivered lectures about earthquake science, demonstrated earthquake science though instruments and distributed leaflets for earthquake preparation before, during & after an earthquake, and finally, earthquake mock drill were also performed. These activities have been educated in the Eklavya Adarsh Residential School located in Kalasi, Chakrata and in the Kendriya Vidyalaya, Rishikesh.

The Institute also observed the 3rd International Yoga Day on June 21, 2017, and as a part of the Government of India fortnight campaign, *'Swachhta Hi Seva'* was followed by the Institute from September 15, 2017 to October 02, 2017.

A meeting of the Research Advisory Committee of Wadia Institute of Himalayan Geology, Dehradun was held on June 7-8, 2017. Interviews for the promotion of the scientists due from (i) January-June, 2017, (ii) July-December, 2017 were conducted and results were declared, and (iii) initiated process for the period January-June 2018. Similarly, the back lock promotions of administrative staff through DPC were cleared.

Implementation of Hindi

Hindi pakhwara was celebrated in the Institute during September 14-28, 2017, during which various competitions like poetry, essay and debate were organized. In keeping with the annual program for the implementation of the official language policy of the Union of India, various steps were taken to promote use of Hindi in routine work as well as in scientific research. The scientists and staff of the Institute were time and again apprised with the various orders and constitutional provisions of official Language. General orders, circulars and notices were issued in Hindi as well as in English. Various incentive schemes for encouraging progressive use of Hindi were also implemented. The Annual Report of the Institute for the year 2015-16 was published in bilingual form (Hindi and English), along with volume 23 of the in-house Hindi magazine *'Ashmika'.*

Meera Tiwari
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)

Structure and tectonic analysis in Satluj River Valley

In the Sutlej River valley, the structural data of the basal rocks of the Haimanta Group have been analysed to understand the geometry and kinematics of the basal part of the hanging wall block of the SW verging South Tibetan Detachment (STD) that marks the tectonic boundary between the Higher Himalayan Crystallines (HHC) and Tethyan Sedimentary Sequence (TSS). A series of foliation-parallel thin shear zones, and high-angle normal faults dipping towards NE have been identified. The extensional tectonics led to the development of conjugate set of normal faults and associated folds across the STD. Hanging wall bed rotation across listric STD has oriented the earlier gentle-dipping bedding foliation and axial planes of earlier inclined folds to sub-horizontal. Near the base of the hanging wall block, a new normal fault dipping towards ENE is recognized. A ~20 m wide zone of occurrence of leucogranite, characterized by a network of intrusion of tourmaline-bearing leucogranites into the metapelites within the Haimanta rocks is observed. This zone is being interpreted as an extensional normal fault imbrication, which may be linked with the orogen-perpendicular seismically active N-S trending Kaurik-Chango normal fault. Tertiary tourmaline-bearing leucogranites indicate their intrusion during syn- to post-kinematic deformation related movement of rocks along the STD.

Structure and tectonic analysis was carried out across Jutogh Thrust in Sutlej River Valley. Erosion of Jutogh Thrust Sheet (JTS) exposed the Lesser Himalayan metasedimentaries, which form the Kulu-Larji-Rampur (KLR) window. As a result, the base of the JTS is exhumed and is demarcated by the Jutogh Thrust (JT), which has thrusted the Jeori Gneisses of the Jutogh Formation over the quartzite-metabasic sequence of the LHS. Brittle thrust faults have developed along the surface trace of the JT and also in the northern limb of the KLR window near the JT. The basal part of the hanging wall block of the JT is characterized high strain zone as evident by the occurrence of conspicuously developed mylonitic gneisses. In the left bank of the Sutlej River a new brittle fault (Brauni Gad fault) is recognized along a perennial Brauni Gad. The Brauni Gad fault does not cross the Sutlej River course, which implies that there already existed a NE-SW trending fracture zone or a NE-SW trending transverse fault along the present river course of the Sutlej. It is known that the foci of the present seismicity events are focused along the Main Himalayan Thrust (MHT) ramp that exists beneath the northern flank of the KLR window or beneath the surface trace of the JT. Therefore, it is interpreted that the inter-seismic deformation along blind thrust has been controlling the growth of the KLR window and the out-of-sequence thrusting along the JT.

Magnetotelluric investigation along Nahan-Leopargil profile

Magnetotelluric investigations along Nahan-Leopargil profile (Figs. 1 and 2) revealed that there is significant difference of resistivity variation between upper crust and lower crust along this profile. Lower part of the upper crust predominately reflects low resistive character, whereas the top of the upper crust is resistive. Lower crust is moderately conductive throughout the profile. At the middle of upper crust, a high conductive layer is present, which have a break in the region below the Himalayan Seismic Belt (HSB) of NW Himalaya. The break is similar as in geoelectrical structure of Garhwal Himalaya, where the MHT ramp is identified base on the break and conductance. However, unlike Garhwal Himalaya, the high conductive layer is not continuous in the MT section. Also, there are number of resistive isolated blocks placed within low resistive variation of upper crust. The MT sounding however, were not decomposed for regional response, but rotated response were modelled. The high conductive feature also appear relatively at shallower depth. While comparing sounding curves of this profile with sounding curves of Bijnaur-Mallari and Pilibhit-Malpa profile, the longitudinal inequalities in subsurface geo-electric structure is clearly observed at different periods. Nonlinear conjugate gradient algorithm was utilized for inverting the transfer functions rotated along the regional structure. It is 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

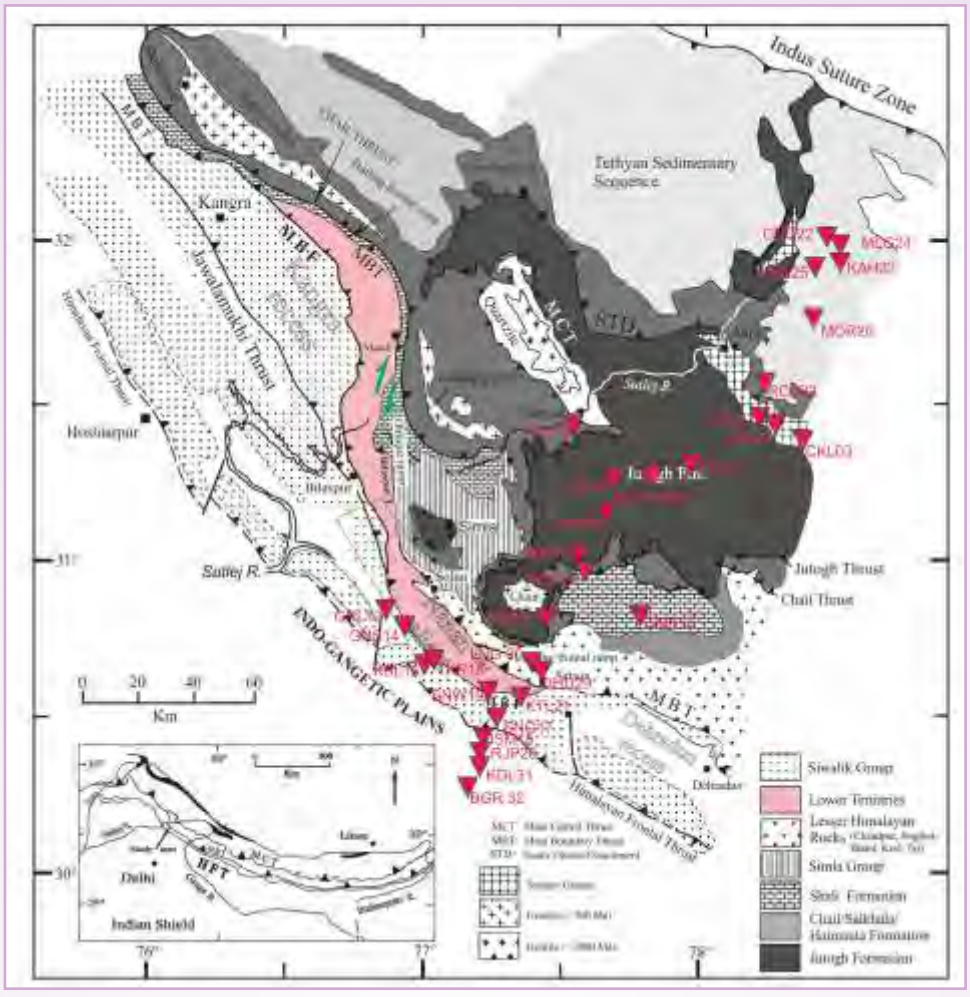

Fig. 1: Location map of MT sites along Sutlej River valley profile.

the region along the investigated profiles. Further, seismicity show that there are two seismogenic zones in the region, one is associated with the HSB and another is controlled by the transverse Kaurik-Chango Fault Zone in the Himachal Himalaya. The detection of continuous high conductive layer corresponding to the MHT zone may be masked due to presence of less resistive character of upper crust. To overcome this, we have initiated LMT investigations along the Sutlej River valley profile and this year we collected 6 LMT sites in frontal Himalaya.

Crustal structure and Moho Geometry in the frontal Himalaya

Investigation of crustal and Moho geometry beneath different parts of the Indian continent are obtained using surface wave tomography. In one of the studies, the characteristics of dispersion curves of Rayleigh and Love waves of 2005 Kashmir earthquake and its

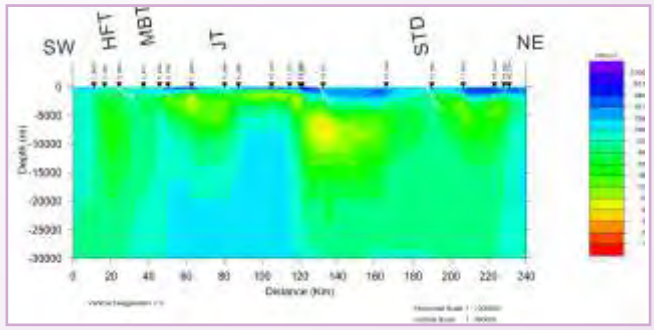

Fig. 2: An initial geo-electrical model along Nahan-Leopargil profile using selected sites.

aftershocks are utilized to investigate the sub-surface structural variations within the northern margin of the Indian continent (Indo-Gangetic Plains and the Salt Range) and the frontal part of the NW Himalaya. Surface waves of these earthquakes recorded in the Broad Band Seismometers (BBS) for earthquake events

of magnitude greater than 4.5 and focal depth less than 50 km are used at Ajmer, Delhi and Shimla stations. The observed group velocities along different paths mainly divided into three transects from earthquake source to station locations are in the range of 2.17 km/s to 3.94 km/s for the surface wave period variations from 4 s to 55 s. This data set is sufficient to investigate the crustal and uppermost mantle structures along frontal Himalaya and adjoining southern part. Paths covering northern margin of the Indian continent to the south of Himalayan wedge has very low group velocities for periods less than 10 s that indicate the presence of thick sediments. Similar results are reported earlier for this part of the Indian continent.

The observed results show that there is a high difference between Rayleigh and Love wave fundamental group velocities for the paths crossing Himalayan wedge. It is the result of the effect of anisotropy in the northern part of Indian continent due to ongoing collision of India and Eurasia tectonic plates. Average dispersion curve is obtained for the particular transect using a weighted value close to the mean and then the dispersion curves were inverted non-linearly to obtain shear wave velocity structure and variation of anisotropy with depth for the crust and uppermost mantle. Nearly 6 km thick sediments divided into two layers (unconsolidated and consolidated) are seen in the Indo-Gangetic Plain (IGP) deposited above underthrusting Indian plate. The Conrad and Moho depths increase from south (beneath Ajmer) to north (beneath Shimla), the station lying in the Himalayan wedge (Fig. 3). The average Moho and Conrad depths along these paths from earthquake source to Ajmer station is 42.5 km and 8.5 km, to Delhi station is 44 km and 19.5 km, to Shimla station is at 46 km and 26.5 km, respectively. Anisotropy effect in the western Himalaya is most pronounced in the lower crustal material of the under-thrusted Indian plate. It is quite large in the uppermost mantle below the frontal Himalayan region. We infer that anisotropy in the lower crust and uppermost mantle could be due to development of preferably oriented folds, faults and fractures and possible reorientation of crystals as a consequence of ongoing deformation caused by the continent-continent collision. Similarly, the sub-surface structure is also obtained for the others part of the Indian continent, which includes Himalaya, Karakoram Fault, Tibet, Bay of Bengal and IGP.

Establishment of a broadband seismological stations along Chandigarh-Ambala ridge

Six digital broadband seismic observatories are installed in 2017 (Fig. 4). Five are located to the south of the Himalayan Frontal Thrust along Chandigarh-Ambala (CHD-AMB) subsurface ridge beneath the Indo-Gangetic Plains, and one observatory is near north of the Main Boundary Thrust. These installed seismic stations are transverse to the trend of major Himalayan thrusts and are useful to extend research work to across the frontal part of the Himalaya. The installed six Broadband Seismic Stations (BBS) is aimed to reveal sub-surface features beneath Chandigarh-Ambala ridge. These BBS were installed at Sataun in Himachal Pradesh, Adibadri, Kaithal and Zind (in Haryana), Jakhal and Samana (in Punjab) in the month of December 2017, after the completion of field survey for site selection and construction of Pit & Hut at all these six places. Two and half month record of seismic data from each observatory is collected in the month of February 2018. The collected data are under the processes of extraction of seismic events and their locations. After preliminary location, more earthquake

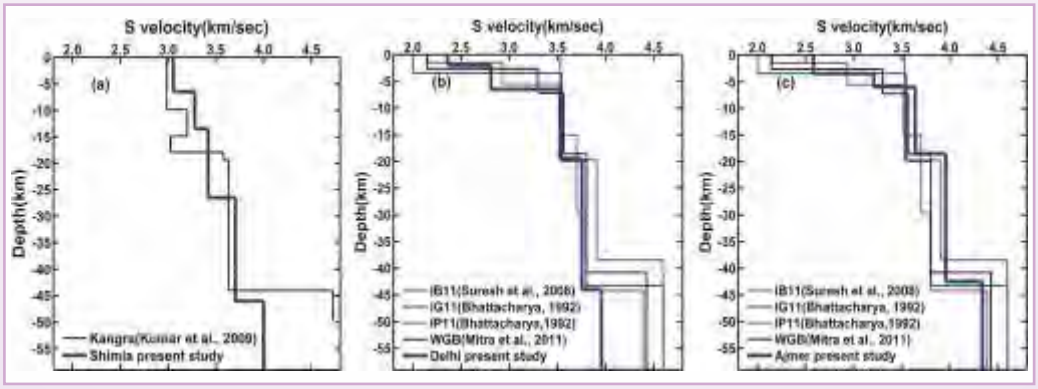

Fig. 3 : Shear wave velocity structure (Thick blue line) obtained from present data using joint inversion and its comparison with previously available results for (a) Shimla (b) Delhi and (c) Ajmer paths, respectively (Kumar et al. 2017).

data from the existing seismic stations of WIHG network, such as Ambala, Jagadhari and Khanna seismic stations of the same region will be added and final hypocentral parameters will be determined. This new addition of seismic data will reduce the uncertainty in the event location process, which in turn will give better Fault Plane Solution (FPS) results. The FPSs with minimum error will help in delineating the transverse tectonic present in this region. These digital data will also be used in other components of this project such as seismic tomography, receiver function studies, etc. The data is also useful to have seismic station control from the south for locating the seismic events of the Himalayan Seismic Belt located south of the MCT. This enhances the azimuthal coverage of the seismic stations of the WIHG seismic network.

The characteristics of transverse fault/lineaments other than CHD-AMB ridges will also be determined with well constrained FPS of moderate-size earthquakes. Data set of many FPSs of this particular region will also be used to evaluate the state of the stress pattern through the Stress Tensor Inversion (STI). We analyzed the stress pattern of different stress regimes of the northwest Himalaya. These results will be integrated with seismological and geological investigations to obtain seismotectonic models for the region.

Crustal anisotropy beneath the eastern Ladakh-Karakoram zone

Investigation of seismic anisotropy in the crust beneath

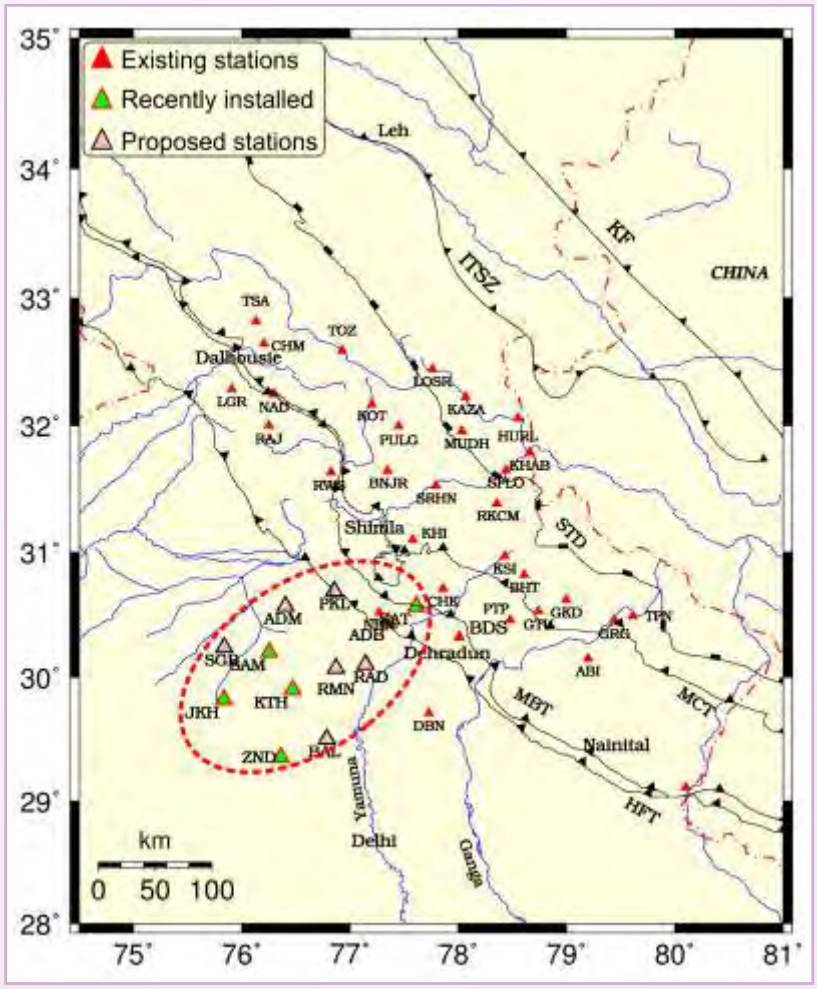

Fig. 4 : Station location map of Wadia Institute of Himalayan Geology (WIHG), with major tectonic thrusts, the triangles are the existing seismic stations of WIHG-Network. The dotted ellipse show the locations of recently installed seismic stations along the Chandigarh-Ambala Ridge (CHD-AMB) region. The green colour triangle = New Seismic stations, Red Triangles = existing seismic stations, pink triangles = planned to be installed long the CHD-AMB Ridge region.

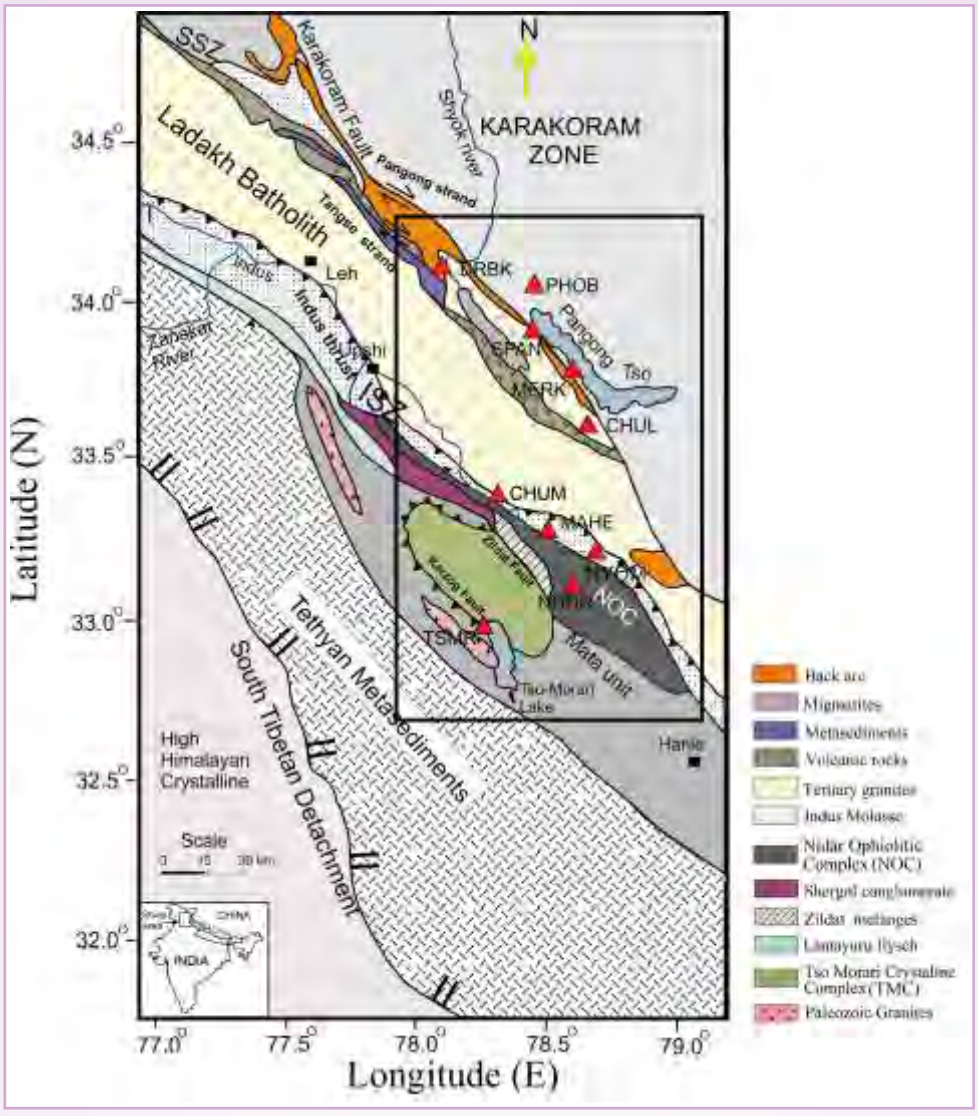

Fig. 5 : Simplified geological map showing parts of the Tethyan Himalaya, Indus Suture Zone (ISZ) and Karakoram zone (modified after Maheo et al. 2004; Epard and Steck, 2006). The Shyok Suture Zone is indicated as SSZ. The seismological stations are shown by red triangles. The study area is marked by a black rectangular boundary. An inset map of India and adjoining regions is shown at the bottom left corner with a rectangular box indicating the study area.

the eastern part of Ladakh-Karakoram zone (Fig. 5) has been carried out based on shear wave splitting analysis of *S*-wave of local earthquakes and *P* to *S* or *Ps* converted phases originated at the crust-mantle boundary. Most of the local earthquakes are confined within the depth range of 6-22 km in the study region. Therefore, the splitting analysis of S-wave of local micro earthquakes provides important information of seismic anisotropy originate due to deformation in the seismically active upper part of the crust. Waveform data of total 28 local earthquakes with magnitude range 1.6-4.1 (ML) and depth range 6-22 km have been selected out of 170 local earthquakes. For investigation of average anisotropy of the entire crust, splitting analysis of Moho converted *Ps* phase is an essential tool, as selected local earthquakes are mostly shallow focus earthquakes and cannot be used for investigation of lower crustal anisotropy. The source of the *Ps* phase is also well defined, which originates at the crust-mantle boundary and reaches the recording station travelling almost vertically through the crust, beneath the recording site bearing the anisotropic information of the

entire crust. The *Ps* phase is clearly observable in Receiver Functions of teleseismic earthquakes. The Receiver Functions were computed with the help of Iterative Deconvolution method of Ligorria and Ammon (1999). Total 84 *Ps* phases from receiver functions of 50 teleseismic earthquakes have been selected for splitting study based on the clear record of *Ps* phases on the radial RFs as well as significant energy in the corresponding tangential component indicating the presence of anisotropy

Splitting analyses of both the S-wave and *Ps* phases were carried out based on cross correlation method. The study reveal complex nature of anisotropy with NW-SE and NE oriented Fast Polarization Directions (FPD) in the upper ~22 km of the crust with maximum delay time δt ~0.3 s. The observed anisotropy in the upper crust is attributed to the combined effects of existing tectonic features as well as regional tectonic stresses. The *Ps* splitting analysis shows more consistent FPDs oriented parallel or sub parallel to the Karakoram Fault (KF) and other NW-SE trending tectonic features existing in the region with larger delay time δt: 0.75 s. This suggests that the dominant source of anisotropy in the trans-Himalayan crust is confined within the middle and lower crustal depths. The predominant NW-SE trending FPDs consistently observed in the upper crust as well as in the middle and lower crust near the KF zone support the fact that the KF is a crustal-scale fault which extends at least up to the lower crust. Dextral shearing of the KF creates shear fabric and preferential alignment of mineral grains along the strike of the fault, resulting in the observed FPDs. A similar observation in the Indus Suture Zone (ISZ) also suggests crustal scale deformation owing to the India-Asia collision.

Geodetic study across Nahan salient

The geodetic work is the new component added recently to the project objectives to study the surface deformation and surface strain partitioning across various structures from the Nahan salient to the north including STD and the Kaurik-Chango Fault. It has been observed that the distributed seismicity (shown in Fig. 6 for magnitudes more than 3) along this section is off from the overall trend of the Himalayan Seismic Belt (HSB); but has an influence of surface and sub-surface structures in the form of enhanced topography and the folded ramp structure. The lack of instrumental GNSS data along this sector lead to various assumptions on

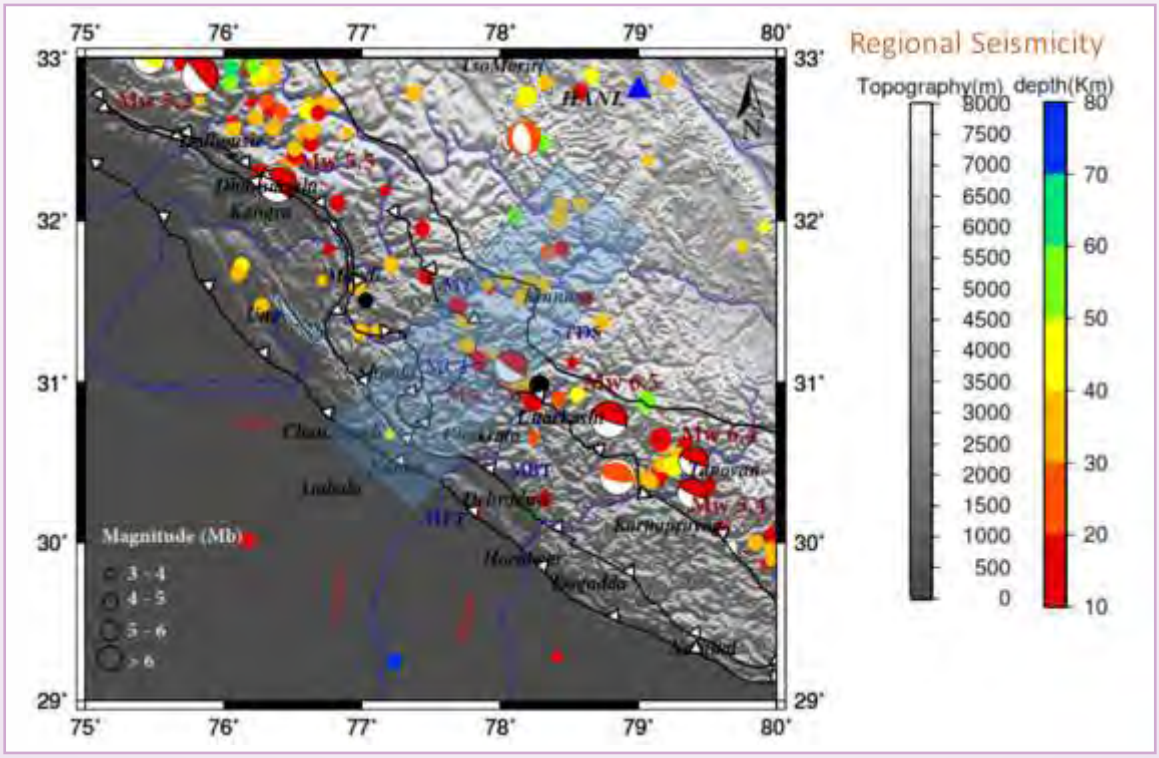

Fig. 6 : Seismicity and depth distribution of earthquakes along the Himalayan Seismic Belt (HSB) around the Nahan corridor (shown in rectangle). Data source: (2000-2017) USGS and FPS from the CMT catalogue for events from 1964-1999.

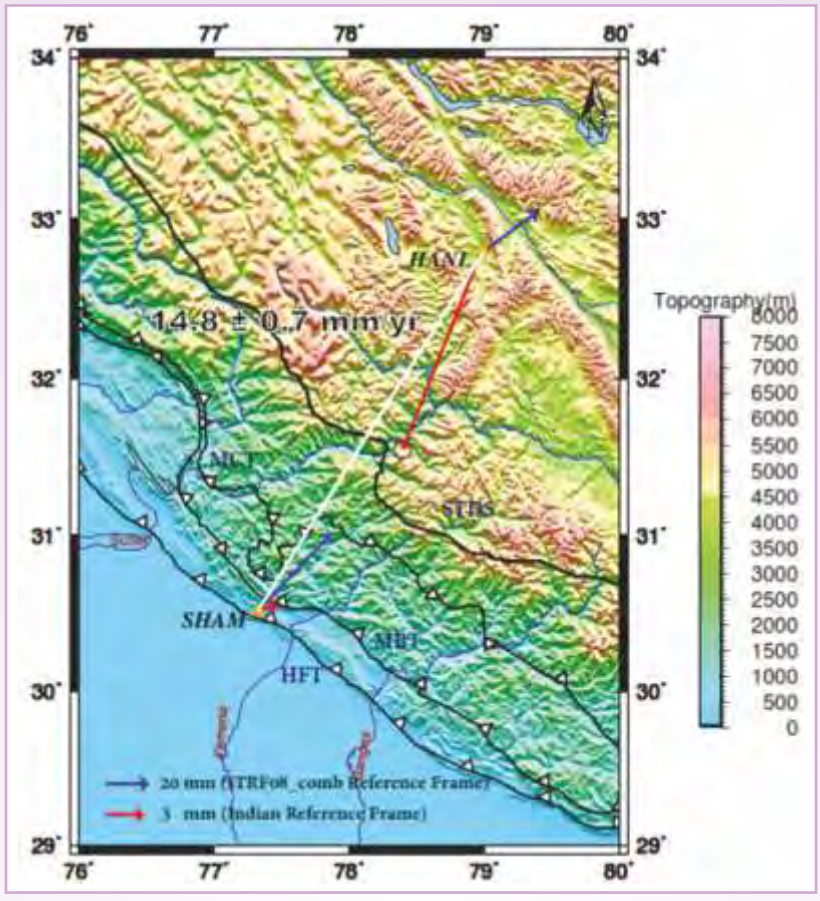

Fig. 7 : Surface velocity vectors at Sub (WIHG_Nahan) and Tethyan (Han Leh) Himalayan stations. Hanle velocities are from Jade et al., 2017, Nature Sci. Reports.

how the surface movement is taking place and the level of internal shortening across these structures; although, attempts are there to describe it as the involvement of thrust tectonics with along the arc or across the arc crustal movement along the geometry of the detachment surface. Based upon the data obtained from 2012 to 2016 of Sub-Himalayan station Nahan operated by WIHG, it has been observed that the surface shortening rate between the Sub and the Tethyan Himalaya (Hanle) across the Nahan traverse is 14.8±0.7 mm/yr and the same is shown in figure 7. However, it is yet to be known how this overall shortening is getting accommodated in the interleaving structures from the Tethyan Himalaya to the Sub-Himalaya across a traverse from the Nahan salient. Considering this fact, more equipment would be installed, however, based on the inputs received the first set of four equipment which is under procurement would be deployed, accordingly; one at south of the HFT and the other two at the footwall and hanging wall sides of the MCT. The remaining one unit would be deployed at the south of Vaikrita Thrust.

GPS Data from Nahan station, which has been processed using GAMIT/GLOBK software, shows the rate of uplift of around 2 mm/yr with influence of periodic components. The surface deformational rates would be quantified and would be integrated with inputs on the structure of the sub-surface geometry of the MHT from receiver function analysis. This would help to quantify the present day strain partitioning and the crustal convergence rate across the study area.

TAT 1.2

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

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

Preliminary petrography were carried out on migmatite samples collected from Leopargil. These migmatites are located in Sutlej valley at the junction of Spiti and Sutlej River in Himachal Pradesh. Migmatite is comprised of

melanosome and leucosome. The melanosome is metamorphosed upto garnet grade. It has plagioclase, amphibole, garnet, biotite, and quartz. The leucosome is comprised of quartz, feldspar, amphibole and chlorite. Mineral chemistry and Fluid inclusion study is under progress. We have separated zircons from melanosome and leucosome for geochronology.

Mono phase and bi-phase fluid inclusion were noticed during the petrography. Mono phase inclusions are primary in nature. Whereas bi-phase inclusions are primary as well as secondary in nature. The trail of pseudo-secondary bi-phase inclusion also noticed. Three generation of trail of secondary bi-phase inclusions are present in the study area. The re-equilibration inclusion reveal tectonic activity in the study area.

The blueschist rocks from Shergol Ophiolitic Mélange record metamorphic peak conditions at ~19 kbar, 470°C. Several types of fluid inclusions are trapped in quartz and garnet, most of them being two-phase at room temperature. Based on the microtextures and fluid compositions, three types of fluid inclusions are recognized: Type-I are primary two-phase carbonic-aqueous fluid inclusions (V_{CO2} - L_{H2O}); Type-II are two phase aqueous fluid inclusions (L_{H2O} - V_{H2O}), either primary (Type-IIa) or secondary (Type-IIb); Type-III are re-equilibrated fluid inclusions. In the Type-I primary carbonic-aqueous inclusions, H_2O is strongly predominant with respect to CO_2; the homogenization temperature of CO_2 range from -7 to -2°C. The clathrate melting temperature in such inclusions varies in between +7.1 and +8.6°C. Type-II two-phase aqueous fluid inclusions show a wide range of salinity, from 7.8-14 wt. % $NaCl_{eq}$ (Type-IIa) to 1.65-6.37 wt.% $NaCl_{eq}$ (Type-IIb) with accuracy ± 0.4 wt.% $NaCl_{eq}$. Type-I and Type-IIa primary fluid inclusions are hosted in peak minerals (garnet, and quartz included in garnet), therefore they were likely entrapped at or near to peak P-T conditions. The dominantly aqueous fluid of both Type-I and Type-IIa inclusions was most likely produced through metamorphic devolatization reactions occurring in the subducting slab. Despite their primary nature, the isochores of Type-I and Type-IIa inclusions do not intersect the peak metamorphic conditions of the blueschist mineral assemblage, suggesting that these inclusions stretched or re-equilibrated during nearly isothermal decompression from 19 kbar to 3 kbar or less at T=290°C. This conclusion is further supported by their large variability in shapes and sizes which range from irregular inclusions ('C'/arc shaped, hook shape and satellite type). This decompression stage was followed by nearly isobaric cooling, testified by the occurrence of dendritic networks of decrepitated and 'imploded' fluid inclusions.

TAT 1.3

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

(Barun K. Mukherjee, Koushik Sen and Santosh K. Rai)

Chemical behavior of subduction zone rocks

The growth rate of continental crust critically depend upon the rate at which silicic crustal component is recycled into the mantle at the subduction zone and then revert back to the crust retaining chemical and mineralogical imprints of the mantle. This recycling phenomenon is often marked in the paleo-subduction zone in the form of ophiolitic sequence comprising of oceanic and mantle sections, fragment of subducted continental lithosphere, ophiolitic melange with the recycled oceanic crust and hydrous fluids and volcanic melt. At the subduction zone, the recycling of crustal material results in crust-mantle interaction, thereby creating mantle chemical heterogeneity. To estimate the recycling of crustal material and the pattern of crust mantle interaction at the plate subduction, a combination of studies has been planned using various proxies comprising mineralogy, petrology and isotope geochemistry. A study of mantle section of Nidar ophiolite in NW Himalaya, demonstrate preservation of octahedral type C-phases in the form of diamond and graphite in the peridotite rock, sourced from base of the upper mantle. These C-phases may be acted upon by the chemical behavior of the mantle, thereby also causing chemical heterogeneity. It is unclear how the crustal material is transferred from subducted lithosphere and got mixed into the mantle source of arc magmas, to understand this we use the resilient mineral zircon studies in the metasedimentary and meta-granite of ISZ. Study demonstrates that, zircons are subdivided into several domains based on their texture, minerals inclusions, and elemental distributions. The line scan using EDX analysis on zircon, display enriched U and Th concentration at the core of the grain, whereas their concentration shows changes at the outer-metamictic part of the grains. This geochemical signature can be recognized as outer metamorphic? overgrowth on the magmatic core of the grain. The initial results from zircon of continental gneisses have manifested, successive growth pattern of continental crust in variable P-T condition.

>70 Ma old acid volcanics and their role on India-Eurasia collision

The northward drift and indentation of the Indian continental block beneath Eurasia resulted in the complete consumption of the Tethyan Ocean that gave rise to the Himalayan Orogenic belt and the Tibetan Plateau, and at the same time also governed the shape of the Eurasian continental margin and triggered escape tectonics in SE Asia. However, the timing of this collision as well as accretionary processes between these two continental blocks and the intermediate Kohistan-Ladakh Arc (KLA) has remained a matter of controversy. One school of thought suggests accretion of KLA with the Eurasian plate took place at ~65 Ma followed by collision of India and Asia at ~55 Ma (Rehman et al., 2011 and references therein). On the other hand, there are numerous evidences of U-Pb and Hf isotopic data from the KLA that indicates collision of India with KLA at ~55 Ma and final India-Asia collision as late as ~40 Ma (Sen et al., 2018; Ji et al., 2009; Bouilhol et al., 2013). The timing and process of this continental accretion process is important to know for better understanding of (i) change in global ocean chemistry following consumption of Tethys, (ii) mantle heterogeneity related to opening of Indian Ocean spreading centre, and (iii) atmospheric changes in terms of CO_2 concentration etc. Sen & Collins (2013) reported presence of Paleozoic (~450 Ma) zircons within ~72 Ma old acid volcanics in eastern Ladakh. This would indicate accretion of KLA with Indian plate (of Paleozoic age) at around 70 Ma and revise our existing understanding of Indo-Eurasian collisional history.

Lithium-the key tracer to identify crustal recycling

The igneous and metamorphic rocks from the subduction zones serve as suitable objects for studying the recycling of crustal materials which finds important role in the collision setting. Towards this, we propose to use Lithium isotopes to trace fluid migration and its interactions with Earth's crust. At the subduction setup, variety of the Earth material have penetrated into the deep interior can expect to lead to variability in mantle Li isotopic composition which can be explored through the exhumed rocks in the Himalaya. Terrestrial lithium isotopic variation is dominated by the strong fractionation that occurs between minerals, particularly silicates, and water. This results in a wide range of the reported compositions for rocks (δ^7Li= –20‰ to +20‰) and fluids (δ^7Li= –5‰ to +45‰). Therefore, if we consider the presently exhumed rocks in the Himalaya which is now exposed to the surface as a mixture of crustal and mantle material, their apportionment is possible by using a simple mixing model. Therefore, δ^7Li is expected to provide information on the degree of crustal recycling to the mantle material.

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)

Metamorphic evolution of the Haimanta Group of rocks, Tethys Himalaya, Himachal Pradesh

The Jaspa pluton of ~500 Ma is exposed in the Keylong-Darcha route along the Bhaga River, which is a tributary of the Chandra-Bhaga River in the Lahaul area of Himachal Pradesh, India. It is outcropped as a sheet-like kilometer scale plutonic body characterized by its coarse- to medium-grained porphyritic texture. The granite has intruded the Proterozoic rocks of Tethys Himalaya belonging to the Batal formation of Haimanta group during the Ordovician period. Pognente et al. (1990) geologically studied the rock exposed in the northwest of Darcha and termed them as the orthogneiss of Kade unit, and reported an age of ~549±79 Ma.

The Jaspa granite encloses genetically related magmatic enclaves ranging in size from a few centimeters to tens of centimeters sporadically distributed in it, and readily differentiated from the host granite pluton by its melanocratic appeal and relatively high amount of biotite content. The boundary between magmatic enclaves and the host granite is, however, defused. The Jaspa pluton also encloses the rare pelitic xenoliths of Tethyan Himalayan Sequence rocks. Pelitic xenoliths (i.e., metasedimentary rocks) show bedding, and it has a sharp contact with the host granite pluton. The pelitic xenoliths the dimension of which range between a few centimeters to tens of centimeters belong to the Batal Formation of Haimanta group. The magmatic enclaves and the pelitic xenoliths in the Jaspa granite possess the mineral assemblage that includes: bt-ms-pl-qz-tur±grt±kfs±chl±ep±spn±ilm±ap. Anhedral to euhedral shaped garnets were observed in two samples; one each from magmatic enclave and pelitic xenolith. Among these, a relatively larger garnets are commonly anhedral in shape, whereas small garnets are commonly euhedral. The garnets are mostly inclusion-free, and if present, they are randomly oriented quartz with minor opaques. The chemical composition of the garnet shows that it is rich in spessartine and grossular content. Garnet of pelitic xenolith (sample X-4) is

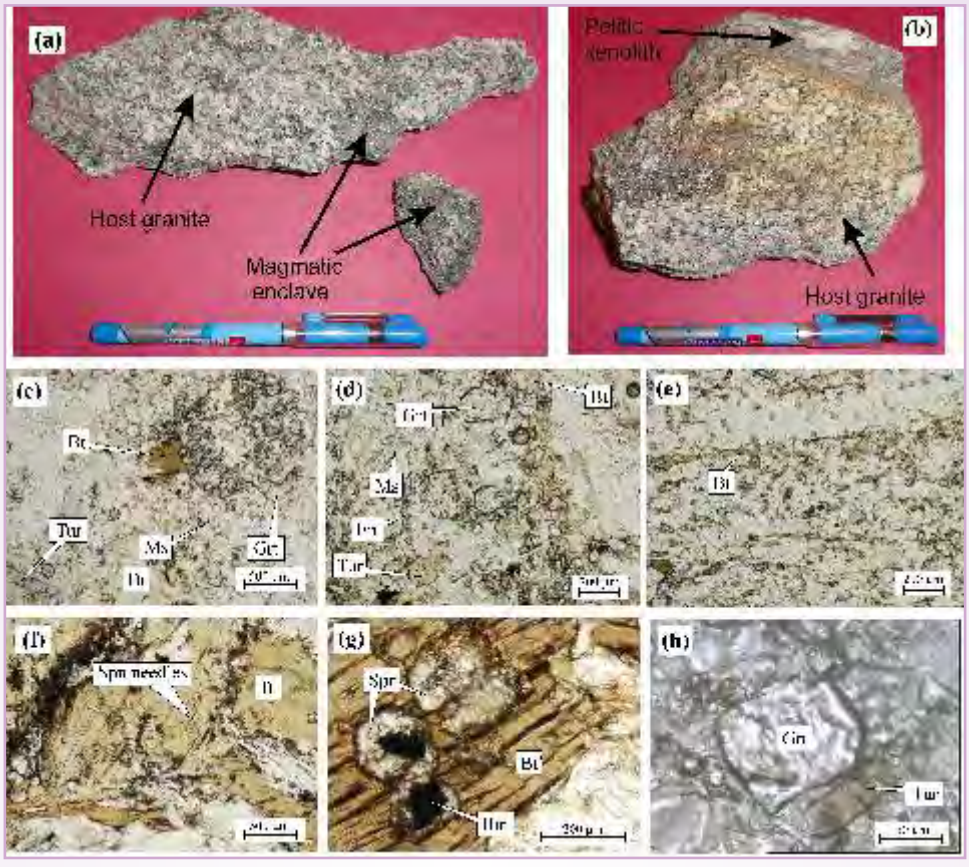

Fig. 8 : Photographs of hand specimens and photomicrographs of selected samples from the study area. (a) Magmatic enclave associated with the host Jaspa granite (sample X-2 and H-2); (b) sample showing both the host Jaspa granite and pelitic xenolith (sample X-4 and H-4). Note, pelitic xenolith in the top of the sample has primary bedding feature with quartz-rich bands. A sharp contact is distinct between host granite and pelitic xenolith (sample X-4 and H-4); (c) Photomicrograph of magmatic enclave sample X-2 showing mineral assemblage: ms-bt-grt-pl-qz-tur. Please note, a large altered biotite in the centre (under plane polarised light); (d) photomicrograph of pelitic xenolith sample X-4 showing mineral assemblage: ms-bt-grt-pl-qz-ep-tur. In the central part, high relief prismatic grains are epidote (under plane polarised light); (e) biotite flakes aligned parallel to the bedding plane. Light coloured minerals are mostly quartz (sample X-4); (f) high relief needle-shaped grains as inclusion in biotite are sphene (titanite) (sample H-1); (g) sphene coronae around ilmenite within biotite (sample X-5); (h) coexisting garnet and tourmaline (sample X-4).

chemically homogenous, and the garnet of magmatic enclave (sample X-2) is chemically zoned, in which the spessartine and grossular contents increase from core to rim, whereas almandine and pyrope contents decrease. The salient features of the petrographic observations are shown in figure 8.

To understand the metamorphic conditions of the rocks, the core and the rim compositions of the garnet-bearing samples, X-2 (magmatic enclave) and X-4 (pelitic xenolith) were considered for P-T estimations using geothermobarometers. The garnet-biotite pair of sample X-2 yielded metamorphic temperatures in the range of 409-531°C, whereas for sample X-4 it is 376-451°C. Garnet core composition for both samples (i.e. X-2 and X-4) yielded higher metamorphic temperature as compared to rim composition. The pressure estimates show that the rocks have attained the metamorphic pressures in a range of 5.7 to 8.6 kbar. The *P-T* pseudosection (Fig. 9) constructed for bulk rock composition (XRF data) of one of a selected mafic magmatic enclave samples (X-2) suggest that the assemblage: grt-bt-ms-ep-pl-spn-qz-kfs of this sample is stable in a *P-T* stability field range of ~4.5-7.3 kbar and ~440-500°C. The *P-T* pseudosection modelling shows that the assemblage was developed from the chl-

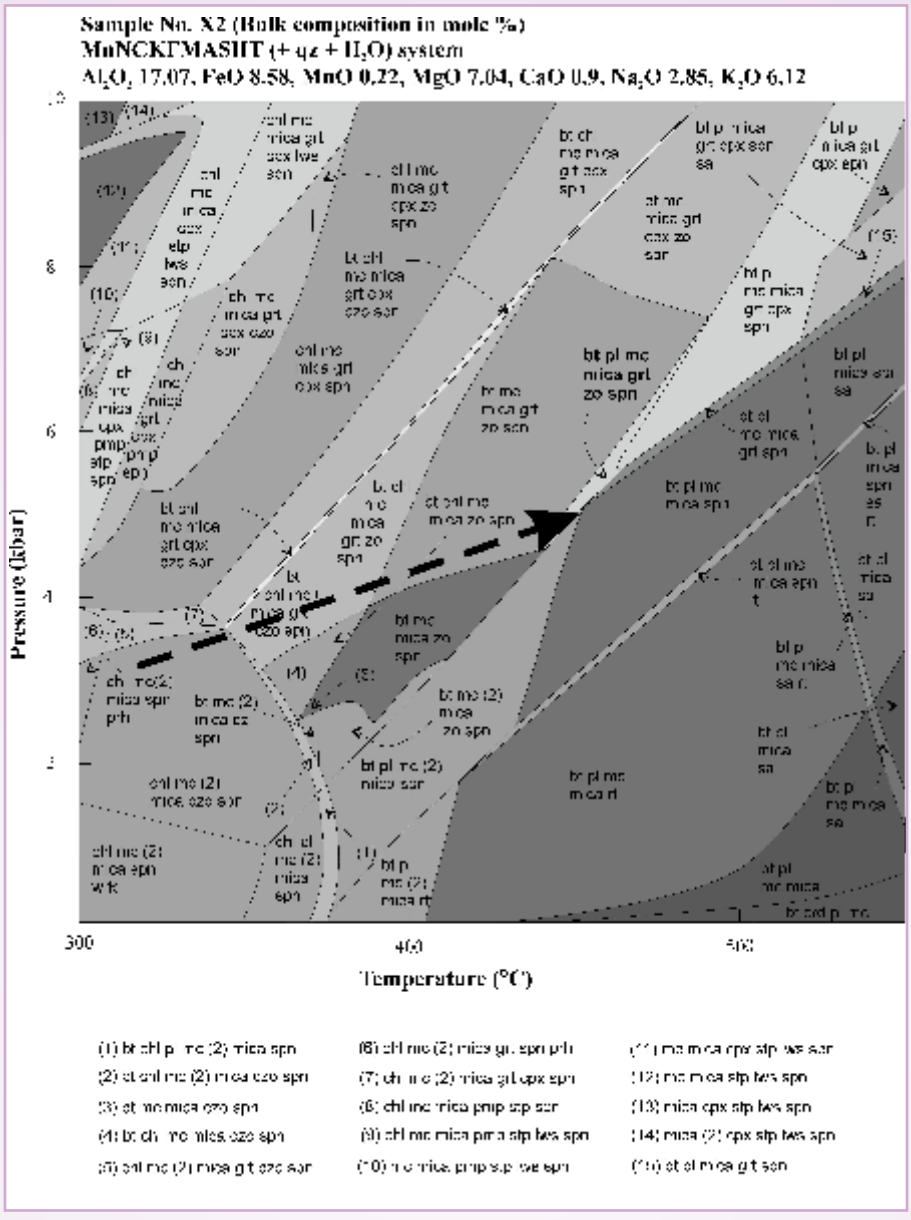

Fig. 9 : A *P-T* pseudosection in the MnNCKFMASH system (+quartz + H_2O) at $aH_2O = 1$ considering fixed bulk rock composition for sample X-2. The stability field of mineral assemblage is shown in bold letters. An arrow has drawn considering the metamorphic field gradient of 30°/km indicating that the assemblage of sample X-2: grt-bt-ms-ep-pl-sph-qtz-kfs has formed from the chl-mic-spn-ep bearing low *P-T* assemblages.

kfs-spn-ep bearing low *P-T* assemblages with increasing metamorphic grade, with a Barrovian trend of metamorphic field gradient of 25-35°C/km. Garnet and epidote appear in the rock at ~3.5 kbar and ~350°C, while chlorite gets exhausted with increasing *P* and *T,* and disappears from the rock at ~4.0 kbar and ~390°C along the predetermined metamorphic field gradient. The P-T results considering the core and rim compositions of garnet suggest that the terrain underwent burial with cooling metamorphic history after reaching the peak P-T conditions of metamorphism. Presence of intrusive Miocene leucogranite within the Jaspa granite in the study area suggests that such burial and cooling metamorphism is due to cooling of the terrain with the burial of Tethys Himalayan rocks after the leucogranite emplacement.

Yttrium zoning in garnet of Main Central Thrust Zone of Alaknanda valley

The garnets of the Main Central Thrust Zone of Alaknanda valley, NW Himalaya shows concentric zoning of yttrium content. Yttrium content gradually decreases from core to rim. Garnets were developed at garnet grade metamorphism from chlorite-biotite bearing low-grade metamorphic assemblages. Breakdown of Y bearing phases are the principal sources of yttrium during growth of garnet. The decrease of the modal amount of yttrium bearing source mineral during garnet growth gave rise to zoning of yttrium content in garnet. The yttrium zoning took place during prograde metamorphism at *P-T* range of 550-582°C and 6.3-7.5 kbar.

Mineralization studies in Himachal Pradesh

Ten days field work and laboratory investigations were carried out on mineralization in parts of Himachal Pradesh focusing on the Parbati and Garsa valleys. The studied area consists of slate, phyllite, metabasic, quartzite, limestone belonging to, two main lithostratigraphic units namely Largi Group and the Banjar Group. The Banjar Group is a volcano-sedimentary sequence and is also intruded by Bandal Granite. Towards eastern and northeastern part, Central Crystallines are present thrusted over the Banjar Group. In the Naraul area sporadic mineralization includes mainly chalcopyrite and pyrite while in the Uch area of Parbati valley arsenopyrite is also predominant. Mineralization overall shows syngenetic and epigenetic characters: syngenetic disseminated sulphides are observed in volcanosedimentary sequence whereas at the thrust contacts the mineralized veins are seen at least at two locations Uch and Sainj. The mineralogical assemblage of Uch area, as also identified through petrography and Raman spectroscopy work, scorodite is noticed with arsenopyrite, galena, chalcopyrite and pyrite. Scorodite is a hydrated iron arsenate mineral with the chemical formula $FeAsO_4 \cdot 2H_2O$. It is found in hydrothermal deposits and as a secondary mineral. In Naraul and Sainj area malachite encrustations are present and the ore assemblage consists of chalcopyrite, covellite and bornite together with pyrite.

Fluid inclusions study of mineralized quartz vein from Uch mineral occurrence shows four types of fluid inclusions: (i) Multiphase saline aqueous inclusions, (ii) monophase carbonic inclusions, (iii) aqueous-carbonic inclusions and (iv) aqueous-biphase inclusions. High saline aqueous inclusions are uncommon and restricted. A large solid daughter crystal is present in these liquid>gas fluid inclusions. Carbonic dark monophase inclusions are found coexisting with aqeous-carbonic inclusions. They occur in groups and in trails, which at times cut across the grain boudaries presenting secondary nature of the fluid in inclusions. Aqueous-carbonic inclusions are filled with an aqueous and a carbonic fluid. The liquid-liquid meniscus at room temperature is not uncommon indicating low density of the carbonic fluid. The proportion of carbonic and aqueous phase is widely varying from 60:40 to 20:80. They are most common in the studied samples. Many inclusions are also present in the trails which terminate within the grain boundary. They also occur in scattered random distribution. Aqueous monophase inclusions are light colored and upto 10 micron in size with regular and oval to subhedral shapes. This type of inclusions are found associated in assemblages of different biphase inclusions. The micro Raman spectroscopy of immiscible fluid confirm the presence of CO_2, however, no evidence of methane and/or N_2 was recorded. Presence of water is also confirmed through Raman data.

Barite mineralization in quartzite from Sirmour of Himachal was also studied to check the presence of sulphides, if any, in the assemblage. No such visible ore could be found in association with barite. Raman spectroscopy of barite characteristically shows a dominated Raman band at 988 cm^{-1}. Other bands such as at 462 cm^{-1} also recorded. Unusually, an additional band for calcite was also recorded, which has been interpreted because of the mixing of the fluid during syngenetic precipitation.

TAT 1.5

Exhumation History of Higher Himalayan Crystallines of Zanskar, NW India

(Vikas Adlakha)

The project aims to constrain the shallow crustal exhumation history of the HHC of Zanskar Himalaya and to test how erosion and tectonics interplay to control the exhumation behaviour of the regional Gianbul Dome in the HHC of Zanskar. First phase of field work in the HHC of Zanskar has been carried out, geological and structural data map has been prepared for the HHC of Zanskar that covers regions across the Gianbul dome. The structural data suggests that the easternmost HHC of Zanskar represents a dome structure bounded by Chenab Normal Fault (CNF) zone in the SW and Zanskar Shear Zone (ZSZ)/STD in the NE. 24 samples (Fig. 10) have been processed for Fission Track Thermochronology (of which 16 samples are from distal

transect across the Gianbul dome, 5 samples from vertical transect along the CNF zone, and 3 samples from vertical transect along ZSZ/STD). Mineral separation of all the samples has been done. All samples have yielded apatite and zircon. Out of the above samples, 5 apatite samples and 5 zircon samples for Fission Track dating from vertical transect along the CNF zone have been sent for thermal neutron irradiation to FRM II reactor, Germany. Further Fission Track Analysis work is under progress.

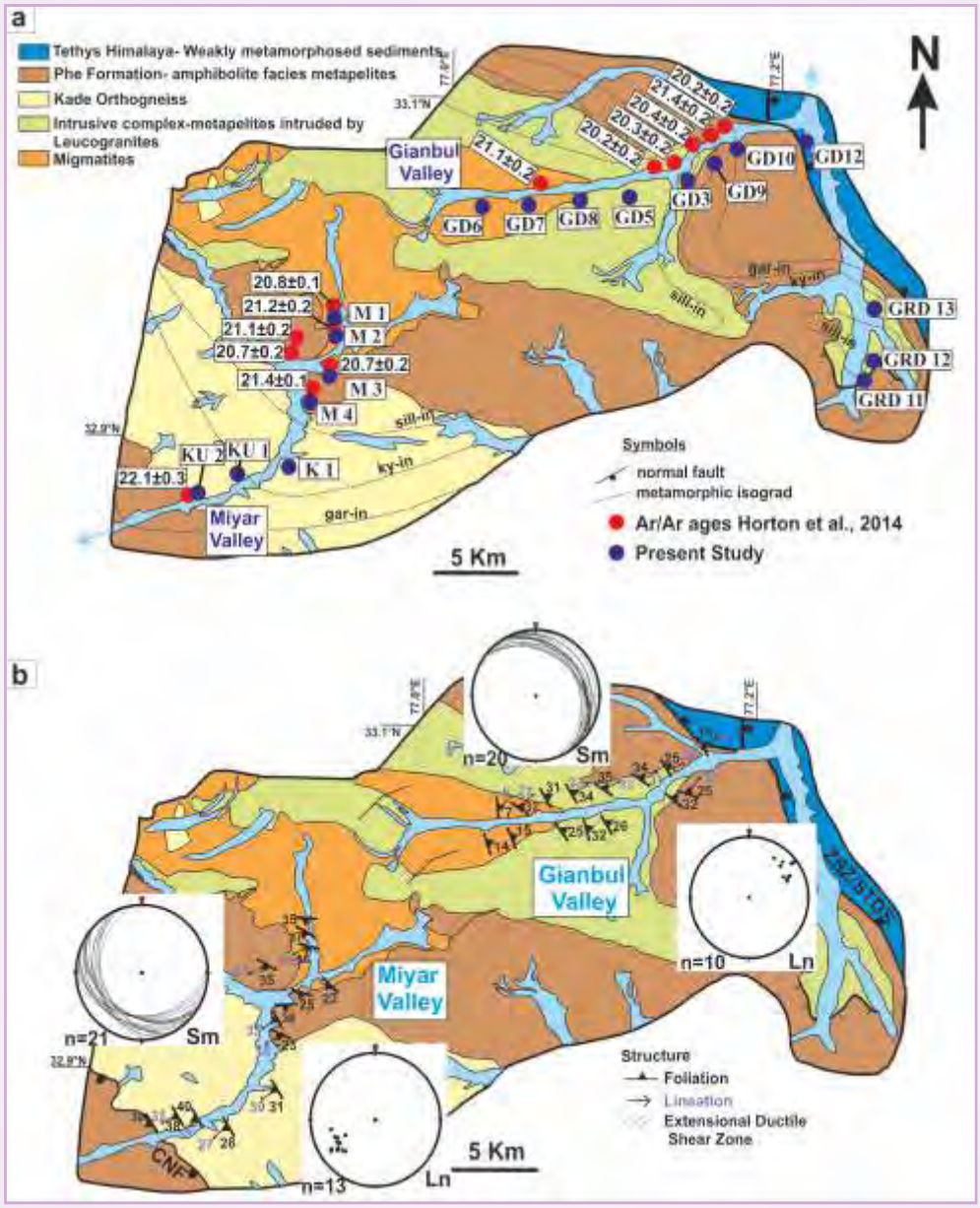

Fig. 10: (a) Sample locations for Fission Track Thermochronology in Gianbul dome region along with (b) structural data.

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, M. Prakasam, Saurabh Singhal and Pinkey Bisht)

Lake and peat records

Upshi, Jammu and Kashmir : The pollen and LOI records from the fluvial sedimentary sequence of Upshi, J&K are studied to reconstruct the paleoclimatic signatures over the last ~2535 yrs BP. The preliminary results obtained from pollen and LOI proxy indicate significant changes in vegetation and precipitation during the late Holocene period (~2535 to 90 yrs BP). The period from ~2535 to 1770 yrs BP is characterized by the dominance of non-arboreal taxa and fern suggesting the strengthened monsoonal activities in the region. Between ~1720 and 1370 yrs BP, increased percentages of *Cheno/Am* and Poaceae and decreased percentages of Artemisia, Caryophyllaceae, Compositae, Ranunculaceae and Aquatic pollen taxa suggest prevalence of cold-dry conditions. The period from ~1220 to 940 yrs BP (760 to 1010 AD), corresponding to the Medieval Warm Period, shows increase in LOI percentages and meadow taxa that suggests higher vegetation growth under favorable climatic conditions. Subsequently, from ~430 to 90 yrs BP increased percentages of *Cheno/Am* and other non-arboreal taxa reveals cold-dry condition in the region, corresponding to the globally recorded Little Ice Age period. The environmental magnetism and elemental concentrations data from the same profile are also in accordance with the pollen and LOI results.

Dendrochronology

Reconstructed June-July precipitation extending back to AD 1743 for Dokriani region, Uttarakhand using together $\delta^{18}O$ isotope tree-ring chronologies of one deciduous (*Aesculus indica*) and two conifer (*Abies pindrow, Picea smithiana*) species. Reconstructed June-July precipitation series (AD 1743-2015) revealed continuous decreasing trend since AD 1743 with driest period in the late 20th and early 21st century in the last 273 years (Fig. 11a). Such decreasing trend was also observed in monsoon precipitation data of different regions of India. Tree-ring isotope proxies from neighbouring regions also indicated decreasing trend in monsoon rainfall as revealed in the present study. Consistency in proxy and monsoon records from different regions underscore the utility of the reconstructed June-July precipitation in understanding the south Asian monsoon variability in long-term perspective. Besides, ring-width chronologies of *Betula*

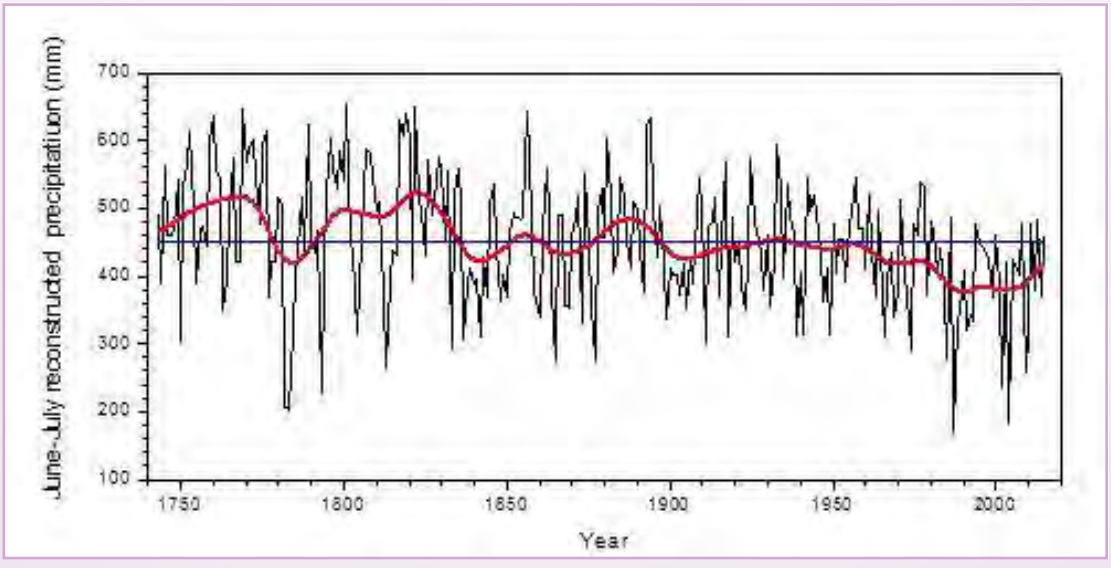

Fig. 11a: June-July precipitation reconstruction (1743-2015) for Dokriani region, Uttarakhand, red bold line is 30 years smoothing spline. Horizontal line is mean of entire reconstructed series (1743-2015).

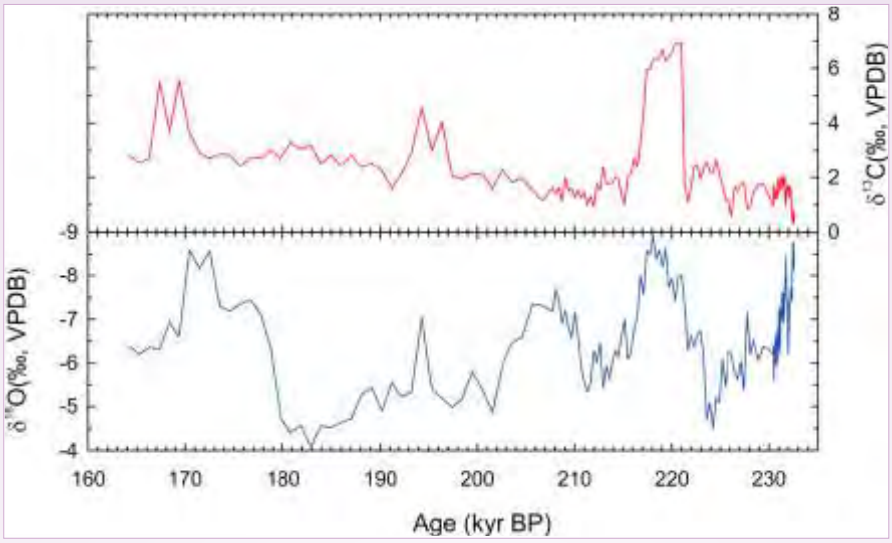

Fig. 11b: Proxy ($\delta^{18}O$ and $\delta^{13}C$) records of ISM variability between 233 to 164 kyr BP from Bhiar Dhar cave, NW Himalaya.

utilis for Bhojbasa (AD 1611-2016) and Chirbasa (AD 1583-2016) were developed for Gangotri region.

Field work was also carried out for 15 days along with Dr. R.R. Yadav (CSIR-Emeritus Scientist, WIHG) and Ms. Tanupriya Rastogi (Institute JRF) in the Dokriani glacier region in October, 2017 and collected increment cores from trees (*Abies spectabilis, Betula utilis*) growing on valley slopes and shrubs (*Juniperus indica*, *Salix.,* and *Rhododendron campanulatum*) growing on lateral moraines in the vicinity of the glacier snout. Soil samples were also collected from these moraines to understand the maturity of soil for the vegetation establishment. Mounted *Abies spectabilis* tree cores for further studies. Polishing of *Abies spectabilis* tree cores was done until the cellular details became discernible. Ring-width measurement of 90 tree cores has been completed. Successfully dated annual growth rings of 30 cores of *Abies spectabilis* to the level of calendar year of their formation.

Speleothem

A total of 172 subsamples were extracted from a speleothem sample, collected from the Chakrata region, Uttarakhand. The subsamples were extracted at every 0.5 mm interval and analyzed for oxygen isotopes using stable isotope ratio mass spectrometer attached with the gas bench facility. The results suggest consistent decline in the Indian summer monsoon during 217 to 183 Kyr BP (Fig. 11b). Strong summer monsoon conditions prevailed in the region from 223 to 217 and 182 to 169 Kyr BP.

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)

Denudation of the continental rocks serves a major pathway for the cycling of elements in oceans, atmosphere and surface sediments. Chemical denudation of silicate rocks has significant control as it draws CO_2 from the atmosphere and hence influences the climate on longer time scales under greenhouse conditions. In this context, the uplift of the Himalaya contributes to CO_2 mediated silicate weathering in the river basins covering Indus-Ganga-Brahmaputra (I-G-B) River systems, and thus has bearing on the long term changes in the global climate. However, the alternative mechanism of silicate weathering is also possible if it is mediated through H_2SO_4, which consumes no CO_2 from the atmosphere. Therefore, in such case there will no net climatic effect in terms of cooling on longer time scale. This may be understood as follows.

Silicate weathering (1):

$$CaSiO_3 + \downarrow 2CO_2 + 3H_2O \rightarrow Ca^{+2} + 2HCO_3^- + H_4SiO_4$$

Carbonate weathering (2):

$$CaCO_3 + \downarrow CO_2 + H_2O \rightarrow Ca^{+2} + 2HCO_3^-$$

Carbonate (in oceans) (3):

$$Ca^{+2} + 2HCO_3^- \rightarrow CaCO_3 + \uparrow CO_2 + H_2O$$

Net (1 & 3) effect (~1 My time scale):
$CaSiO_3 + \downarrow CO_2 \rightarrow CaCO_3 + SiO_2 \rightarrow CO_2$ mediated Silicate weathering is a sink of CO_2 → Cooling effect

Other possibility: Sulphuric acid mediated (Black Shales & Pyrites) Silicate weathering:

$$4FeS_2 + 15O_2 + 8H_2O \rightarrow 2Fe_2O_3 + 8H_2SO_4;$$

$$H_2SO_4 + 9H_2O + 2NaAlSi_3O_8 \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2SO_4^{2-} + 4H_4SiO_4 \rightarrow \text{No } CO_2 \text{ is consumed}$$

The work focuses on the nature of the weathering in the Indus River system and is based on the major ions and stable isotopes δ^3C_{DIC}) in dissolved phase. The available data shows that the alkalinity in these rivers has an affinity with silicate weathering mediated with CO_2 or H_2SO_4. Co-variation of $[HCO_3+SO_4]$ with [Ca+Mg] suggests that the alkalinity in these rivers may be originated with silicate weathering mediated either by H_2SO_4 or dissolution of halites. Further, it shows that the silicate weathering could be one of the plausible mechanism to produce the alkalinity in these rivers. This observation is consistent with the fact that lithologies present in the Indus valley contain silicate minerals including quartz, plagioclase, alkali feldspar, biotite and muscovite which can produce silica and alkalinity together in solution after their dissolution. This study makes a case for the possibility of silicate weathering mediated by the H_2SO_4 which does not consume atmospheric CO_2. Therefore, we propose to devise a proxy for the apportionment of H_2SO_4 contribution from the total consumption of CO_2 via silicate weathering in the Indus drainage basin. In order to address the silicate weathering, we want to use isotopic composition Lithium (Li) which is mainly sourced from silicate rocks. We plan to conduct laboratory based weathering experiments of various lithologies under controlled temperature with different strengths of H_2SO_4 and Carbonic acid to detect the measurable variations in Li isotopes (δ^7Li). This is planned as follows. For a given silicate rock (at fixed temperature)

$$H_2SO_4+9H_2O+2Na(Li)AlSi_3O_8 \rightarrow Al_2Si_2O_5(OH)_4+2Na(Li)^+ +2SO_4^{2-}+4H_4SiO_4;\ \delta^7Li=x\ ‰ \ldots.(A)$$

$$Ca(Li)SiO_3+2CO_2+3H_2O \rightarrow Ca^{+2}(Li^+)+2HCO_3^-+H_4SiO_4;\ \delta^7Li=y\ ‰ \ldots.(B)$$

In a case where x & y yield distinct values → would form the basis for apportionment. Towards this, we have set up the required ion exchange column chromatography procedures for Li.

In addition to this, we have also carried out work on the analytical studies related to the geomorphic aspects of rivers including the Ramganga basin of Garhwal Himalaya. The studies have shown a variety of landforms, the bulk being represented by the massive fluvial terrace, piedmont fans, flood plains and intra-basinal depressions filled with Quaternary deposits. Interplay of Quaternary tectonic is clearly visible in the area. Ramganga a spring and rain-fed river originating from Dudhatoli Dhar near Gairsain and drains through the inner Lesser Himalayan litho-tectonic zone and traverses transversely through the Himalayan foreland before finally joining to river Ganga near Kannauj. The Upper catchment of this river is subjected to neotectonic forces of Himalaya that decreases significantly in its foreland counterpart. The whole catchment however receives water from a single climatic system i.e. SW summer monsoon. These significant differences in hydrological and tectonic conditions in the two zones of this river i.e. Himalaya and foreland make it an ideal laboratory to understand, the time resolved, process based source-sink relationship within these zones.

TAT 2.3

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

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

To achieve the goals of the project following work has been done:

Renuka Lake Core Sediment Samples

Top 2 m core : The top 126 cm sediment core from Renuka Lake is analyzed for multi-proxy analysis. The objective is to record high resolution climatic changes in the Lake. The 2 m core is dated by radionuclide ^{137}Cs and ^{210}Pb dating techniques. The higher sedimentation rate in this lake (0.69 cm/year) helped in finding out recent climatic changes in the lake and its tele-connection. The study of diatoms from top 2 m cores show major significant changes in last few decades. The diatoms record from the lake also show good correlation with other parameters which control the diatoms population.

Complete 8 m core : The complete 8 m core sediments from Renuka Lake were analyzed for Total Organic Carbon (TOC) and grain size. The environmental magnetic analysis on 8 m core of the lake has been completed. Clay mineralogical analysis of complete 8 m core by X-Ray Diffractometer is also completed. The clay mineralogical result shows the presence of Illite, Chlorite and Kaolinite in different proportion. Quantification of the XRD data is completed. The ^{14}C AMS age dating of 9 Lake Core samples were carried

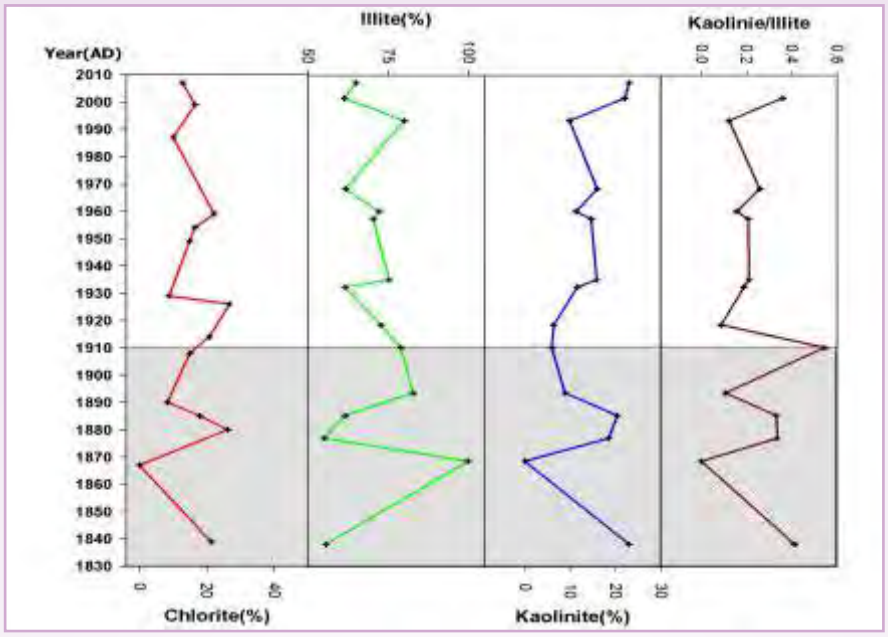

Fig. 12: Clay mineralogical Record from Renuka Lake during 1830-2010 AD.

out. The clay mineralogical record and geochemical records from the lake have been represented in figure 12 and figure 13, respectively.

Rewalsar Lake Core Sediment Samples

Rewalsar Lake is a Lesser Himalayan lake important for its location on the pathway of south-west monsoon. The Rewalsar Lake cores have been analyzed for reconstructing past climate from the mid-altitude region of the Himalaya.

- TOC analysis of 12 m of the lake core samples (Core-3 to Core-14 below the Lake Floor) was performed in the Institute. The TOC results show gradual increase with broad fluctuations down the sediment column.
- Sediment grain-size analysis of 9 m of the lake core samples (Core-6 to Core-14 below the Lake Floor) were performed using Laser Particle Size Analyzer (LPSA) in the Institute. The result shows dominating silt percent followed by clay and sand. The silt percent records decreasing trend down the column, while the clay shows reverse trend.

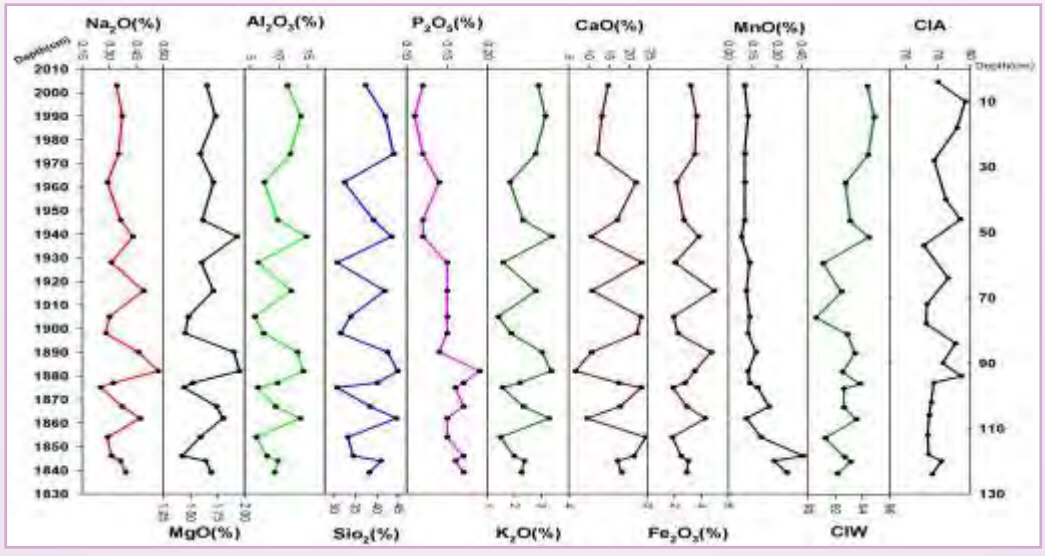

Fig. 13: Geochemical Record from Renuka Lake during 1830-2010 AD.

- Geochemical analyses were performed on 2 m of the lake core samples (Core-6 to Core-7 below the Lake Floor) using ICP-MS in the Institute.
- Magnetic mineralogical analyses for all the magnetic parameters were performed on 14 m of the lake core samples (Core-1 to Core-14 below the Lake Floor). The result will help interpreting Lake paleo-environmental studies.
- The AMS ^{14}C age dating of 5 lake core samples were also carried out.

Renuka and Rewalsar Lake Water Samples

The water samples from the Rewalsar and Renuka Lakes were collected for the study of trophic status of these lakes and the analyses are under process. The water samples were also collected from Dal Lake of Kashmir and Dal Lake of Mcleodganj (Dharamshala, HP) followed by analyses and interpretation. The Rewalsar and Renuka Lakes sediment samples were extracted and prepared for the analyses of phosphorus fractions.

TAT 2.4
Black Carbon monitoring in north-west Himalaya

(P.S. Negi and Chhavi Pandey)

PSN carried out field with a view to monitor BC aerosols and biomass burning (BB) in high Himalayan region, especially in snowbound and glaciated area. Monitoring stations were established at Chirbasa (3600 m asl) and Bhojbasa (3800 m asl) in Gangotri Glacier Valley (Fig. 14). Observation site is established to record long term seasonal behavior with annual variation in BC aerosols, however, the data of 12 months spanning between January-December, 2016 recorded at Chirbasa station is adequate enough to show the seasonal variability (Fig. 15). The detail monthly variation depicted in the figure 15 shows that maximum BC concentration was 1899 ng/m^3 biomass burning with 1180 ng/m^3 black carbon during the month of May and minimum concentration of 168 ng/m^3 biomass burning and 123 ng/m^3 black carbon was recorded in the month of August.

Field investigation reveals that both natural as well as anthropogenic factors contribute BC aerosols in the Gangotri Valley. The tourist season which commence from April-June, shows remarkable increase in BC aerosols concentration due to anthropogenic activities that increases immensely to cater the transport, food, shelter and other associated everyday need of tourists, pilgrims and other visitors in the area. Although,

Fig.14: BC measurement site at Bhojbasa.

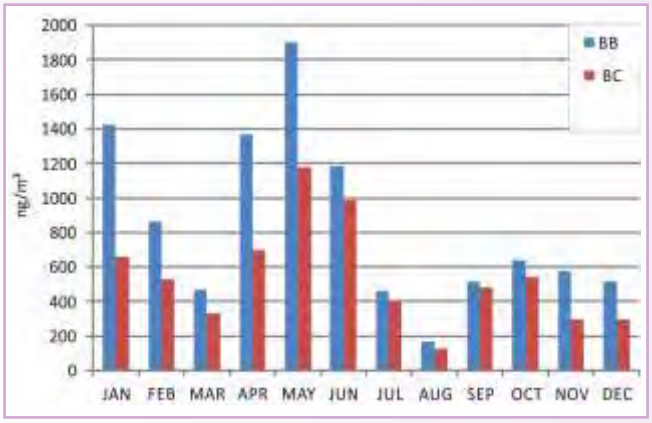

Fig. 15: Monthly variation of BC concentration.

visitors of the Gangotri temple that are confined to the entrance point of the valley but have a direct bearing on BC aerosols emission to the surrounding area. It is reported that wind blow from down valley to uphill can easily transport BC to the monitoring station from Gangotri temple vicinity. Moreover, summer tourist season is also a season for local forest fires that has been active contributor of biomass burning component of BC aerosols. The second highest BC aerosols concentration reported during September and October which are also autumn tourist months and contribute significant aerosols to the surrounding atmosphere. The lowest BC concentration was recorded during the month of August followed by the December and it is observed that due to the absence of tourist activities and forest fire incidences during these months, the BC concentration in the atmosphere remains at lowest level. Moreover, natural phenomenon such as rain wash of the pollutants-aerosols from atmosphere during rainy season before August and snow precipitation during winter season, especially in the month of December also considered

one of the important reason for low BC concentration during these months.

The foremost local sources of organic BC aerosols observed during field study are forest fires, domestic and commercial fuelwood burning and seasonal burning of unused agricultural and forest biomass. Hence, biomass burning (BB) is reported higher in comparison to BC throughout the year. The forest fires and unused agriculture burning contribute significantly to BB during summer season, especially in May to June months, while sources for elemental black carbon include exhaust from automobiles and electricity generators that use fossil fuel viz., petrol, diesel and Liquefied Petroleum Gas (LPG). Excessive use of kerosene and LPG stove during tourist season also considered to be a significant source of BC pollution. Besides these local sources, considerable amount of black carbon travels along with wind currents from Asian cities and other part of World and accumulates over the Himalayan region due to low pressure gradient. The annual BC average at Chirbasa is 0.691 μ gm/ m^3 which is far below in comparison to nearest stations viz Nainital with 1.40 μ gm/m^3 and Kullu with 4.60 μ gm/ m^3 in northwestern Himalayan region. However, the reported BC concentration in ambient air at observation site is far below from the respirable pollutants limit i.e., 60 μ gm/m^3 set by the Indian National Ambient Air Quality Standard and World Health Organization i.e., 25 μ gm/m^3.

Further, a report on 'Debris flow and lake formation near to Gaumukh during July 2017' was prepared after field investigation and the same is submitted to Government of Uttarakhand.

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)

Arabian Sea core sediments using grain size characterization, environmental magnetic parameters, elemental ratios and clay mineralogy have been used to understand the Indian monsoon variability and sediment source. Grain size analysis of ~9 m core samples has been done. Analysis for bulk magnetic susceptibility of 109 samples, grain size of 130 samples and for clay mineralogy of 92 samples has been done. A total number of 63 samples for ICPMS are prepared for rare earth and trace element geochemistry.

Off-shore age-depth model based on foraminifera, nanofossils and magnetic stratigraphy suggest an average sedimentation rate of 7 cm/kyr from the late early Pleistocene to the Present. The oxygen isotope stratigraphy of the sediment core provided sedimentation rates, which varies from 2.67-10.79 cm/kyr at top 11.9 m (data shared by Dr Rajeev Saraswat, NIO, Goa).

Variation in mean grain size along with sand, silt and clay percent from top 9 m is plotted. Excursion in sand and silt with the mean grain size at various depth is noticed, whereas the clay size shows anti-correlation. The increase in sand percentage can be linked with (i) high energy turbidity current in the upper fan area leads to the erosion of coarser sediments, and (ii) the enhanced sediment flux from the feeder channels (Indus and Narmada River).

The bulk magnetic susceptibility and frequency dependent magnetic susceptibility are controlled by the fine silt fraction suggesting superparamagnetic minerals. The magnetic susceptibility and χARM suggested clay sized magnetic minerals (Fig 16A). A sudden shift in the magnetic parameter beyond ~168 kyr might suggest change in sediment source (Fig 16B).

The grain size characterization, magnetic parameters along with geochemistry are used here to trace the terrigenous and biogenic sediment input in the proximal part of the Indus Fan. The increase in the Y, Ti and Nd suggest increase in terrigenous input (Table 1) in the Arabian Sea. Ba/Ti indicated the biogenic input which is further well correlated with the poor Cd concentration (Fig 17; used as a proxy of anoxic conditions). Cd shows poor correlation with the Y, Ti and Nd elemental concentrations, indicates low terrigenous sediment input and discharge conditions in the feeder channels (Indus and Narmada River) during ~88-101, ~118-131 and ~148-156 kyr.

Table 1: Pearson correlation matrix indicating the good correlation between the terrigenous sediment flux proxies.

	Ba/Ti	Y	Ti	Cd	Nd
Ba/Ti	1.00				
Y	0.53	1.00			
Ti	0.37	0.82	1.00		
Cd	*-0.14*	*0.08*	*0.08*	1.00	
Nd	0.36	0.74	0.87	*0.14*	1.00

Variations in total reflectance (L*) reveal changes in the relative contributions of terrigenous and biogenic components. The low L* values (darker in color) of

sediment laminae indicate organic-carbon rich and/or dark colored minerals in the sediment. This also shows good correlation of terrigenous sediments input seen via Y and Nd concentrations.

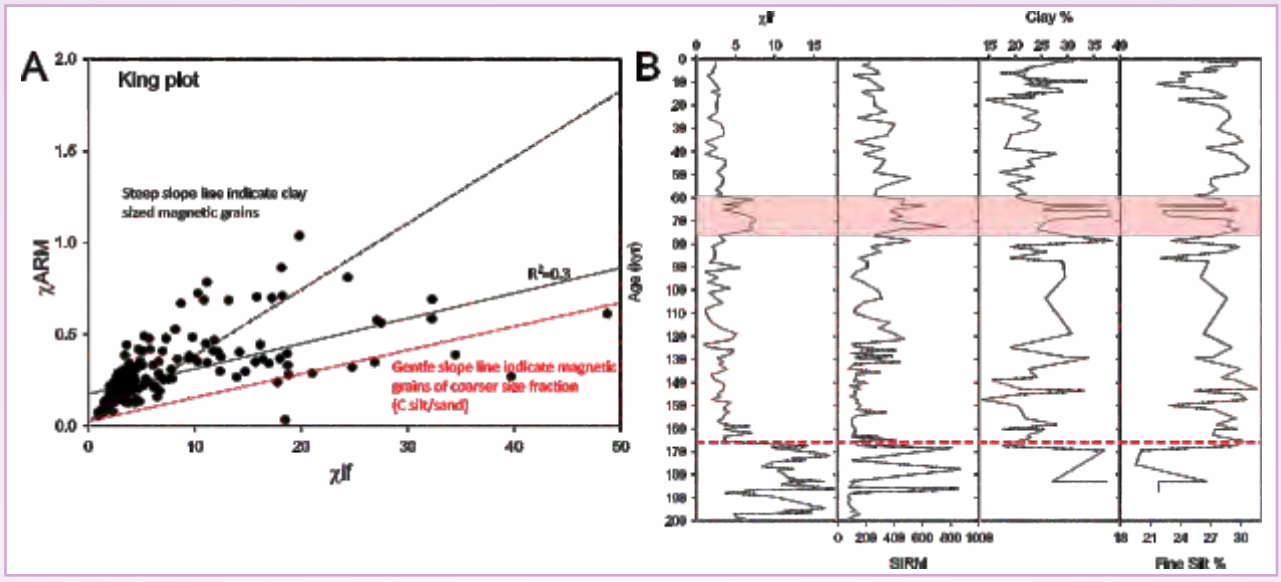

Fig. 16: (A) King plot is a bivariate plot between χARM and χlf suggest higher magnetic properties are because of smaller magnetic grains. (B) The variation in magnetic susceptibility χlf, SIRM and grain size suggest enhancement in χlf with increase in clay fraction.

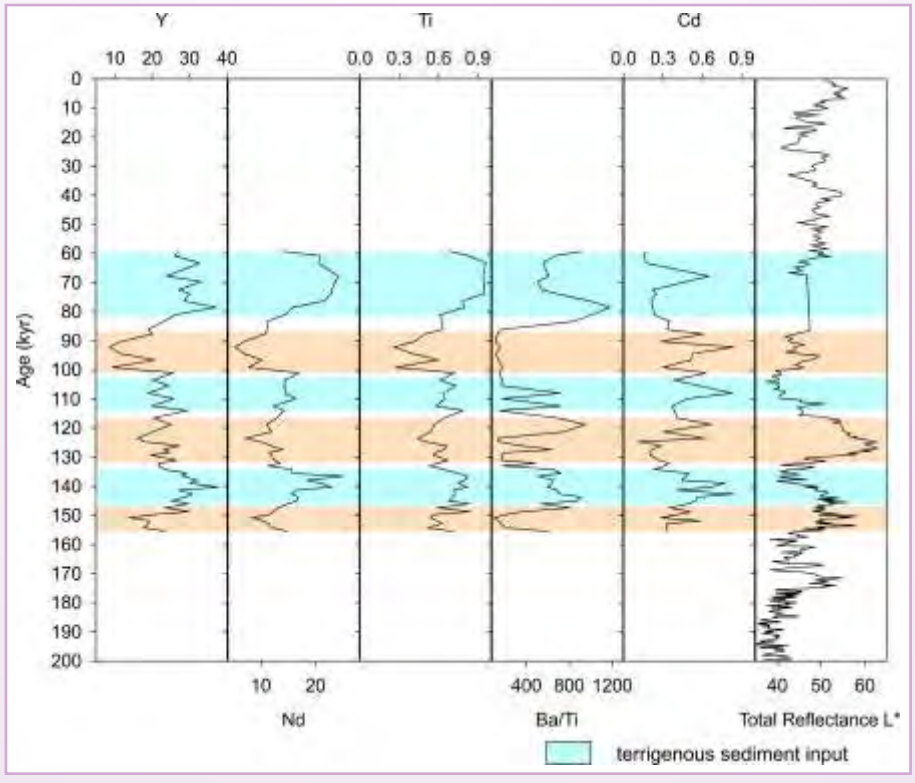

Fig. 17: Elemental concentration (Y, Nd and Ti) used as a terrigenous sedimentary flux. Ba/Ti is used to understand paleo-productivity, whereas the Cd represents the oxic-anoxic conditions. Total reflectance (L*) suggests relative contributions of terrigenous and biogenic components.

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, Narendra Kumar, Chhavi P. Pandey and Parveen Kumar)

The Himalaya, world's tallest mountain range, 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 address seismotectonics and the evolution of stress pattern of the region in better way, WIHG is operating a regional seismic network in the NW Himalaya and adjoining regions (Fig. 18). Accurate assessment of the earthquake hazard is critical step for earthquake risk mitigation.

Microseismicity, tectonics and seismic potential in the Western Himalayan segment

The tectonics and seismic potential of the western Himalayan segment (30-33°N; 76-80°E) of the NW Himalayan region have been determined in this study. 423 earthquakes were located in the NW Himalaya between 2004 and 2013 using more than 4495 P and 4453 S differential travel times to determine the moment tensors for 8 (Mw $\geq$ 4.0) of these earthquakes using their broadband regional waveforms. The geometry of the

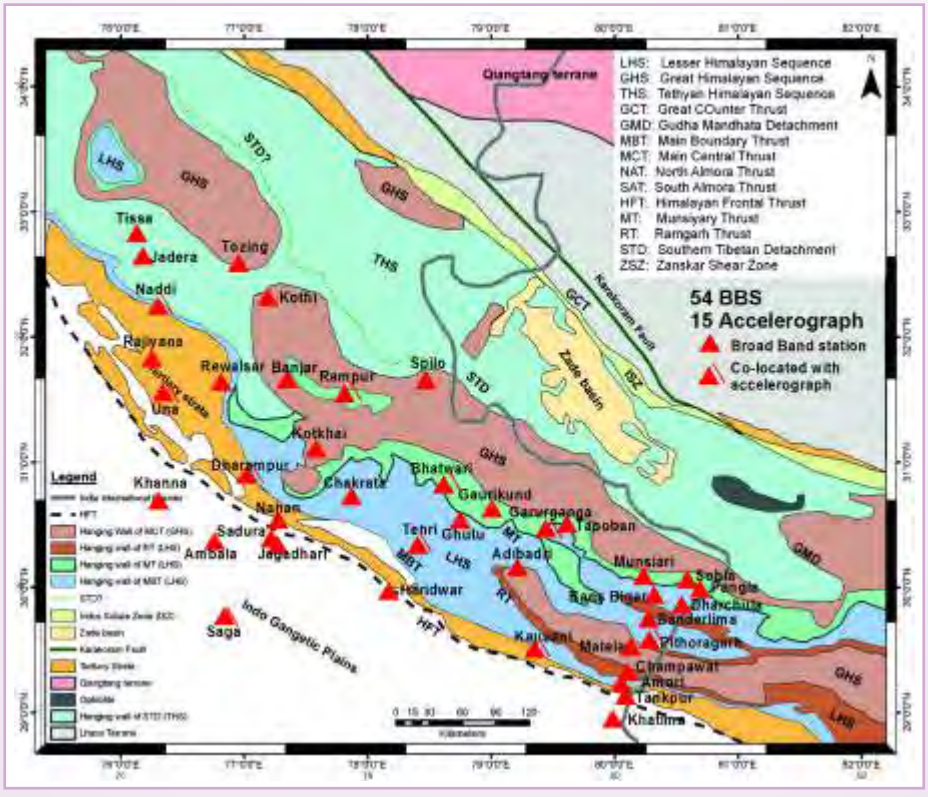

Fig. 18: WIHG regional Seismic Network, Stations operating in the Ladakh and Jammu & Kashmir regions are not shown in this map.

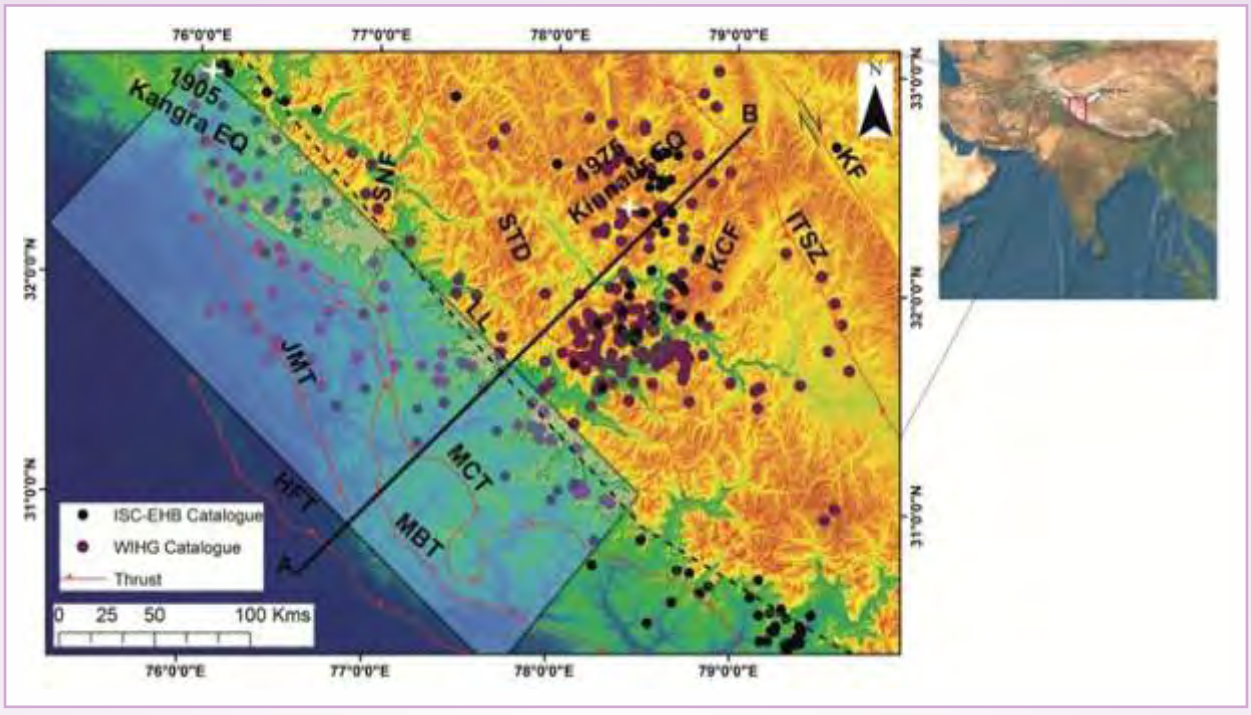

Fig. 19: General Seismotectonic Map of the NW Himalaya showing the epicentre of 1905 Kangra earthquake and 1975 Kinnaur earthquake. Major tectonic breaks ITSZ: Indus-Tsangpo Suture Zone; MCT: Main Central Thrust; MBT: Main Boundary Thrust; HFT: Himalayan Frontal Thrust; JMT: Jawalamukhi Thrust; KCF: Kaurik-Chango Fault; SNF: Sundarnager Fault along with the topography as well as the focal mechanism solutions of some major earthquakes that occurred in the region in the past (Modified after GSI, 2000). The map also shows the relocated earthquake epicentres. LL: The dotted line is designated as locking line (Bollinger et al., 2004). The shadow rectangle signifies the western Himalaya seismic gap between the epicentre of 1905 Kangra earthquake (Mw=7.8) and 1975 Kinnaur earthquake (Mw=6.8). The NE-SW transect AB is also shown in the figure. The right hand upper panel shows the India map with the solid red rectangle highlighting the study area shown below.

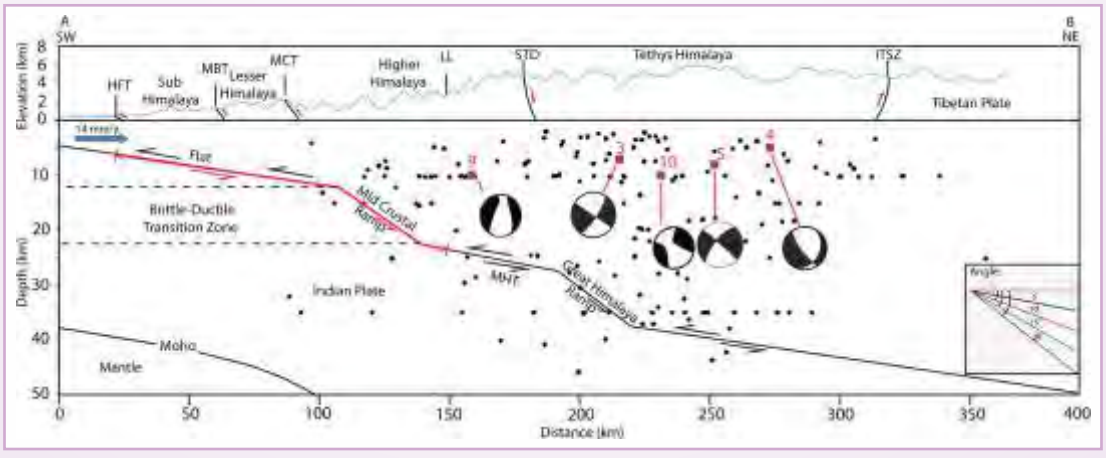

Fig. 20: It shows the generalised cross section AB taken across the major tectonic breaks starting from the Himalayan Frontal Thrust (HFT) in the south to Indo-Tsangpo Suture Zone (ITSZ) in the north. This cross section greatly characterize the status of the Main Himalayan Thrust (MHT) and its sub-surface geometry in the NW Himalaya. The maximum depth of the investigation below the cross section is 50 km. The cross section clearly postulates the locking zone and also the motion velocity of 14 mm/y for the Indian plate in the north direction. The section also shows the two ramps of the MHT plane below the Main Central Thrust (MCT) and the South Tibetan Detachment (STD). The depth range for these ramps is mentioned in the text. (Modified after Powers et al., 1998; Gao et al., 2016; Caldwell et al., 2013; Hazarika et al., 2017).

Main Himalayan Thrust (MHT) plane which varies along the strike of the Himalaya in flat and ramp segments with a dip ranging between ~2.5 to ~4° to ~19° below the Himalayan Frontal Thrust (HFT) in the south and to the South Tibetan Detachment (STD) in the north has also been deduced. Two crustal ramps were reported in this study with a depth variance below the Main Central Thrust (MCT) and to the South Tibetan Detachment (STD) between 12 to 22 km and 28 to 40 km depths, respectively. The estimated earthquake potential prevailing in the western Himalayan seismic gap lying between the epicentral zone of the 1905 Kangra earthquake and the 1975 Kinnaur earthquake reveals that the total amount of energy released since the last great event is only a fraction (3-5%) of the accommodated energy i.e. 1.1E+28 dyne-cm/yr (Figs. 19 & 20). This suggests that if an earthquake hits this NW Himalayan segment in the future, its magnitude might be around Mw $\geq$ 8.0.

Evidence of multifaceted SKS/SKKS splitting directions in the Sikkim Himalaya

Investigations have been carried out on the anisotropy strength and fast-axis orientation using an SKS/SKKS splitting technique of seismic phases at Sikkim Himalaya, which is a seismically active zone situated in the central portion of the Great Himalayan Arc in the Indian region. The region lies between two major plate boundary faults, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT) at its north and south, respectively, along with a few regional lineaments. Eight broadband seismic stations were used to acquire two years of tele-seismic earthquake data, from which 66 good quality anisotropic measurements were derived. In general, the splitting results from both the SKS and SKKS phases show a complex pattern of fast-axis orientation along the northern periphery of the MCT (Fig. 21). However, at the central part of the Sikkim between the MBT and the MCT, both results are consistent with the upper mantle deformation of the Indian Plate. We also observed that the anisotropic strength varies between 0.6 to 3 s and is skewed towards higher anisotropy with orthogonal polarization, which indicate the presence of a two-layer anisotropy. Modelling of 66 anisotropic measurements indicate that the bottom-layer fast-axis orientations are towards N18^{0}E with higher anisotropic strength of ¶t=1.3 s, which elucidates the pristine nature of the upper mantle deformation as a result of asthenospheric flow. But, the tectonic deformation of the upper mantle within the lithosphere is prominently observed in the top layer, where the fast axis orientations are towards N48^{0}E with lower anisotropic strength of ¶ t=0.6 s.

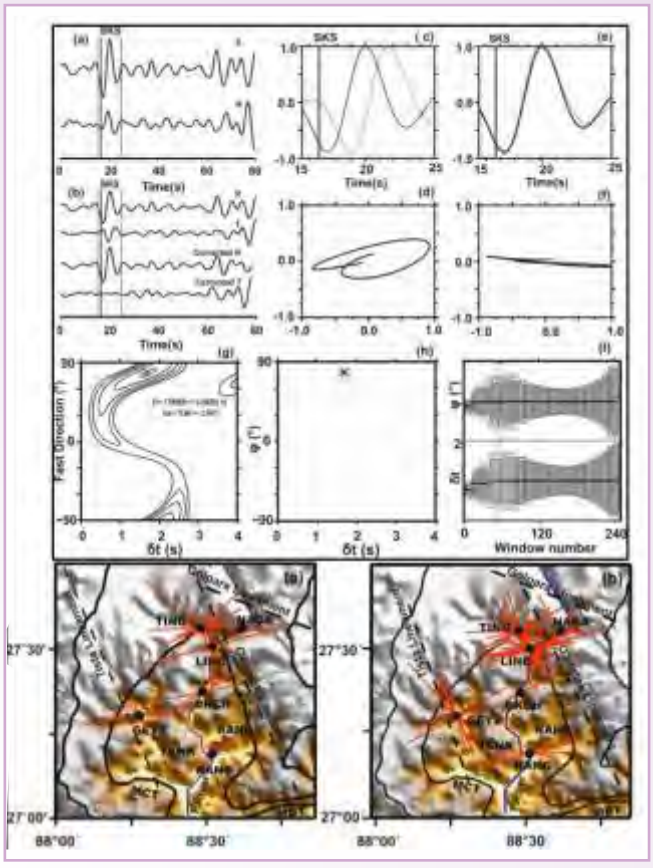

Fig. 21: Diagnostic plots of a splitting measurement. (a) Original Q and T components with SKS wave pick (b) Radial and transverse components, uncorrected (top) and corrected (bottom) for splitting. c) Uncorrected fast (solid) and slow (dash) waveforms. (d) Elliptical particle motion of the waveform. (e) Plots of corrected fast and slow wave (f) Plot of corrected particle motion. (g)The error surface, which is contoured according to the confidence regions, shows the outline of the 95% confidence region. (h) Plot of cluster analysis and solutions from each window. The best solution is indicated by a cross sign. (i) Plot of the results from all windows on which a shear-wave splitting analysis was performed. Below the orientation and length of red bars indicate the fast polarization azimuths (f) and delay time (δt) in the Sikkim Himalaya respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Estimation of source parameters of 25th April 2015 Nepal earthquake

The destructive M_w=7.8 earthquake happened in Nepal Himalaya, 80 km NW of Kathmandu city on 25th April

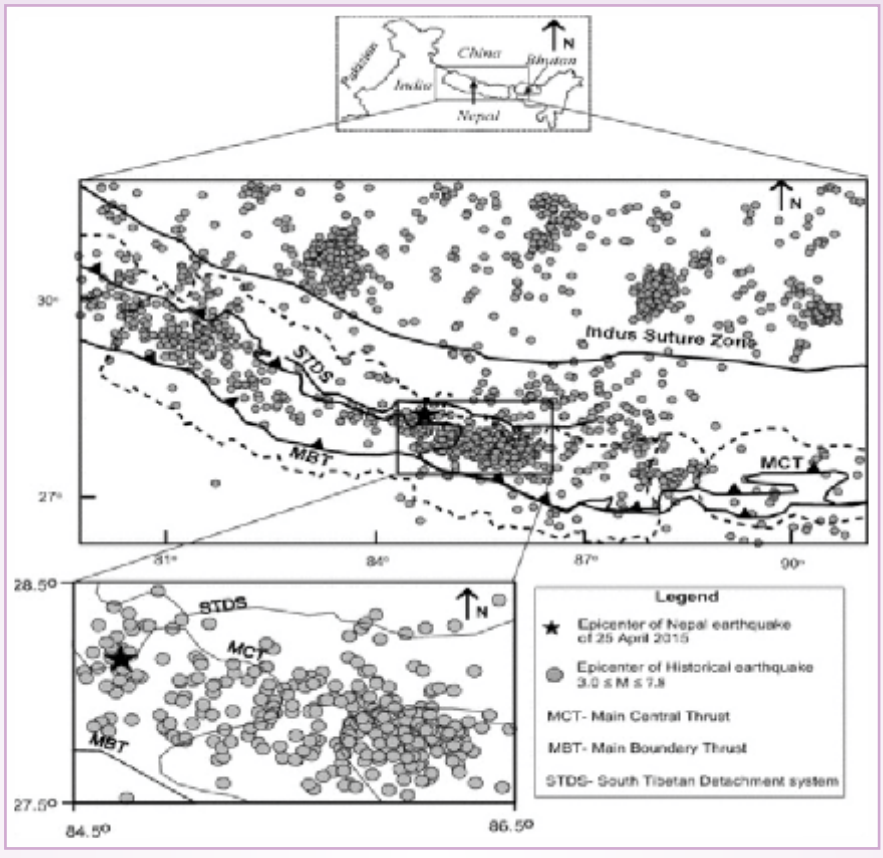

Fig. 22: Seismicity plot of Nepal Himalaya region illustrating seismicity around the Kathmandu. Grey circle shows the location of historical earthquakes occurred during 1971–2015 from USGS catalog.

2015. A number of aftershocks in which one of them is M_w=7.3 which occurred on 12th May 2015 are observed around the Kathmandu city of Nepal. The strong motion data of Nepal earthquake and its eight aftershocks having magnitude range between 5.3 and 7.3 recorded at Kathmandu station is used to determine site effects and attenuation factor. Kathmandu city, capital of Nepal, is situated in a valley which consists of sediments of more than 300 m depth. Hence, strong motion data recorded at Kathmandu station is strongly affected by site effect and anelastic attenuation. S-phase spectra recorded at Kathmandu station are corrected for site effect and anelastic attenuation to compute the source parameters of the events. The site effects and anelastic attenuation are estimated from inversion of strong motion data by using the inversion technique suggested by Joshi (Bull Seismol Soc Am 96:2165-2180, 2006). The shear wave quality factor ($Q_\beta(f)$) is computed at Kathmandu station by using the inversion scheme as $Q_\beta(f)=68f^{0.58}$. The site effects and attenuation factor obtained by inversion technique are used to correct the spectrum for site effect and anelastic attenuation. The corrected source spectrum is compared with theoretical spectrum (Brune in J Geophys Res 78:4997-5009, 1970) to estimate various source parameters. Both horizontal component (North-South and East-West) are utilized to estimate the source parameters of 25th April 2015, M_w=7.8 Nepal earthquake and its aftershocks. The best-fit theoretical spectrum provides final values of source parameters, i.e., stress drop, seismic moment, and source radius as 48.7 bars, 5.96×10^{27} dyne cm and 37.75 km, respectively, for the 25th April 2015, M_w=7.8 earthquake and 1.40×10^{27} dyne cm, 44.7 bars, and 23.90 km, respectively, for the 12th May 2015, M_w=7.3 earthquake (Fig. 22).

Estimation of the local 1-D velocity structure

The resulting 1-D crustal structure based on 2837 P-wave arrivals and 2680 S-wave arrivals from 251 well located earthquakes yields a 4-layer velocity model down to the depths of 20 km. A fifth homogeneous layer extends down to 46 km. Following which a multistep moment tensor inversion algorithm is used to infer seismic moment tensors of 11 moderate earthquakes

with Mw magnitude in the range of 4.0-5.0, through the modeling of full waveforms and amplitude spectra at regional distances. To further support the moment tensor, the solutions were modelled. The moment tensor inversion result reveals the presence of dominant thrust fault kinematics, persisting along the Himalayan belt. Shallow low and high angle thrust faulting is the dominating mechanism in the Garhwal-Kumaun Himalaya. The results thus support the critical taper wedge theory, where we infer the micro seismicity cluster as a result of intense activity within the Lesser Himalayan Duplex (LHD) system.

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)

Seismotectonically the northeastern region of India is one of the very active region. This region has experienced two great earthquakes one is 1897 Shillong earthquake (Ms 8.7), and the other one is 1950 Assam earthquake (M 8.7) (Nandy, 2001; Kayal, 2008). The 1950 earthquake and several of its aftershocks have occurred at the eastern extremity of Arunachal Pradesh. Several researchers have worked in the field of seismology in this part of Himalaya, such as Kayal et al. (2006), Baruah et al. (1997, 2013). We have gone through the past seismicity of this region, using seismic events downloaded from International Seismological Centre (ISC). A number of studies have been made on seismicity and seismotectonics in the northeastern part of India, particularly in the Shillong-Mikir Plateau (Angelier and Baruah, 2009; Kayal et al., 2006; Baruah et al., 2013; Bora et al., 2013). However, seismotectonic of this region is still need to be studied. We propose to deploy 10 numbers of seismic stations to study the seismotectonic and subsurface structure using broadband seismological data beneath Siang Valley of Arunachal Pradesh. The first station will be installed at Pashighat in the frontal Himalaya and last will be at the suture zone, close to Tuting. The other tentative seismic stations will be placed along two sections, one along Rottung, Boleng, Geku, and the other along Palling Yingkong, Mariyang, Silli and Mebo as shown in figure 23. Despite the complex tectonic set up of this region, we have designed to put our stations touching upon the sections of Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and Tidding-Tuting Suture Zone (TTSZ). The ITSZ is

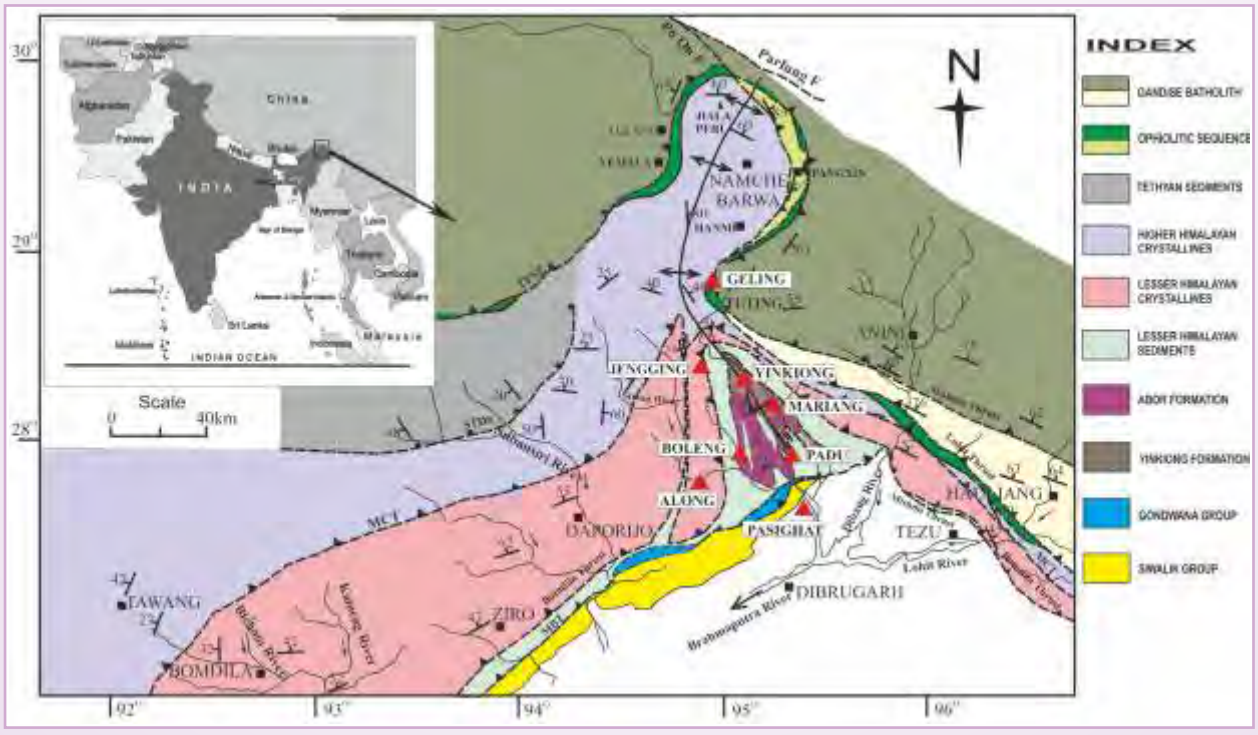

Fig. 23: Figure showing the tentative locations of seismic stations (red-triangles) which will be installed in an around Siang valley of Arunachal Pradesh.

considered as an eastern extension of the Indus-Tsangpo Yarlung Suture Zone (ITYSZ). Following the installation the recorded digital data will be processed to calculate hypocentral and other earthquake parameters which will be useful for further research.

As per the proposal, information related to the area have been gathered from previous published/ unpublished literatures, and the procurement process for purchasing of 08 numbers of Broadband Seismograph (BBS) is under process. In the meantime, we will do the site selection and pit & hut construction work at all the proposed sites.

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 Himalayan Frontal Thrust along Himalayan arc has produced numerous large-magnitude earthquakes throughout the last two centuries that are constrained through instrumental and historical records. Earthquake geological studies have established comparable constraint for pre-instrumental ruptures of the fault. Incomplete historical records and inferred rupture locations lead to uncertainties surrounding the timing and nature of earlier events, which can be addressed through paleoseismic investigation. The need for additional paleoseismological data is particularly critical along segments of the HFT that lack a large-scale 20th century rupture, such as the Central Seismic Gap (CSG) which lies between the areas affected by the 1905 CE Kangra (Himachal Pradesh, India) and 1934 CE Nepal-Bihar earthquakes (Fig. 24). Establishing the timing of past earthquakes along the CSG is critical in assessing regional seismic hazards for areas proximal to the HFT that have both large populations and inadequate infrastructures. Furthermore, it is of particular interest due to an apparent long-term quiescence that suggests the potential for impending large-scale rupture. Our object is to compile recent paleoseismological findings from seven published trench sites into a coherent OxCal age model for large-magnitude ruptures along the CSG (Fig. 25). Our results indicate that the western half of the

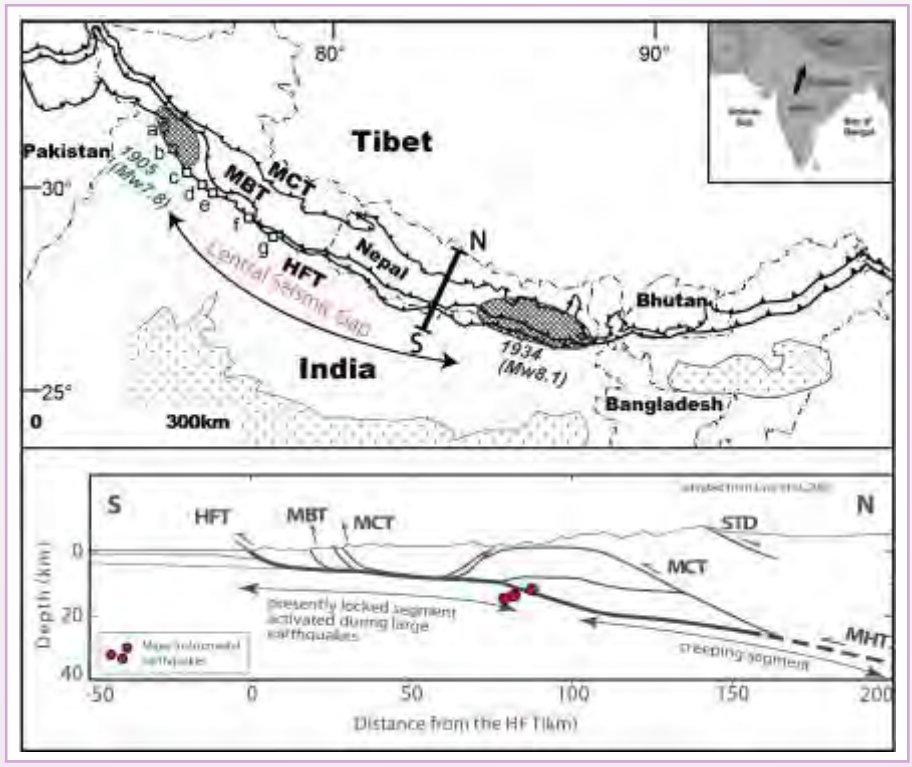

Fig. 24: Map showing Central Seismic Gap along with trench investigation across the HFT. Hollow Square previously trenched sites a) Hajipur, b) Bhatpur, c) Chandigarh, d) Kala Amb, e) Rampur Ganda, f) Lal Dhang, g) Ramnagar (Kumar et al. 2006; Malik et al. 2010; Kumahara & Jayangondaperumal, 2013) discussed in the text, and White Square shows location of trenched site in this study.

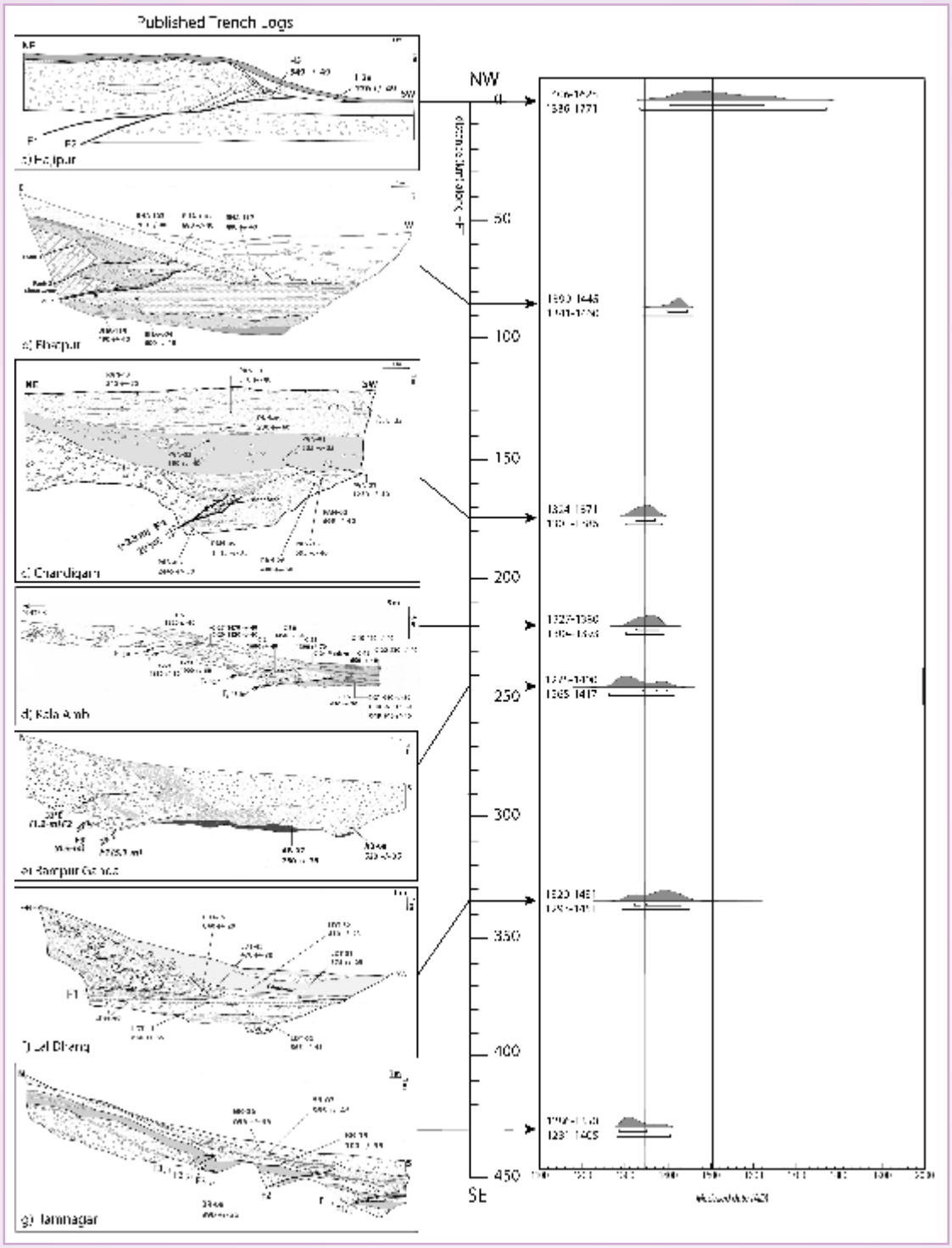

Fig. 25: Evidence of paleoearthquakes at seven trench sites along the HFT (Kumar et al., 2001, 2006; Malik et al., 2010; Kumahara and Jayangondaperumal, 2013) have been reinvestigated using Bayesian Statistics. NOTE: One- and two-sigma confidence intervals are given for rupture dates at each site, alongside probability distribution functions developed from radiocarbon age results using the OxCal software program (Bronk Ramsey, 2009a). Vertical lines indicating dates of putative earthquakes in 1255 CE, 1344 CE, 1505 CE and 1555 CE are superimposed. Radiocarbon sample collection locations are shown on each trench log and trench sites are labeled alphabetically, corresponding to labeled locations in Fig. 24.

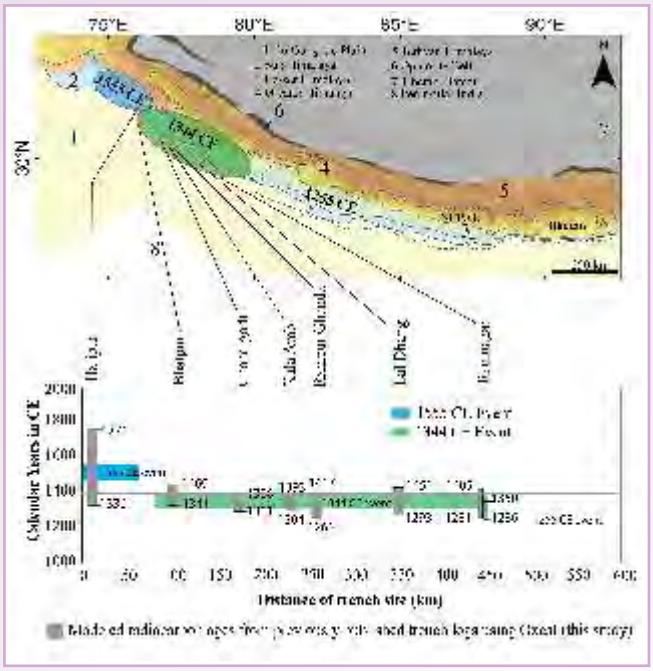

Fig. 26: (top) map showing areas affected by penultimate large-scale (~8 Mw) earthquakes, as inferred from trench investigation across the Himalayan Frontal Thrust (HFT). Modeled two-sigma confidence intervals for seismic events at each of the modeled sites are shown as grey bars on graph (bottom). Results indicate that the western section of the CSG likely ruptured in an event corresponding to historical accounts of an earthquake in 1344 CE.

CSG likely ruptured in the event corresponding to historical accounts of an earthquake in 1344 CE (Fig. 26).

TAT 3.4
Neotectonics between North Almora Thrust (NAT) and Himalayan Frontal Thrust (HFT) of Kumaun Himalaya: Implication to morphotectonic evolution

(K.S. Luirei and S.S. Bhakuni)

From the geomorphology evolved in the immediate hanging wall block of the HFT in Ramnagar area uplift along the HFT is evident. Across the HFT there is sudden increase in height in the immediate hanging wall block further north there is gradual decrease in height in the form of depression/flat/dun further north there is again gain in height. This observation is mainly based on topographic maps, DEM and Google earth image and field evidences. Cross sections (Swath profiles) have been drawn across the HFT and the Sarpduli-Dhikala Thrust, and the obtained cross section profiles show depression between these two thrusts (Fig. 27). In the Himalaya such depressions or intermontane basins are known as the Duns, which resulted from subsequent deformation in the sub-Himalayan zone which is accommodated by a southward-propagating fold-thrust system that led to the growth of longitudinal, front-parallel intermontane valleys or synclinal valleys (Nakata, 1972; Singh et al. 2001; Thakur et al. 2007, Goswami & Pant 2007). The intermontane basin of the middle belt of the Siwalik of Malani area has been referred to intermontane flat plains or newer duns (Valdiya, 1993) in this study it has been named as Malani basin. Longitudinally the Malani basin measures about 60 km in length and width of about 6 km trending almost E-W from Ramnagar in the east to east of Saneh in the west. Tectonically and topographically it is bounded in the north by Siwalik ridge constituting the footwall block of the Sarpduli-Dhikala Thrust and in the south by low Siwalik Hills evolved as a result of uplift along the HFT. All the streams cut across the basin and the HFT which suggests that the streams predates the present topography, except Chuka Nala which is diverted towards the SW due to rising of the mountain front and confluence with Ramganga River before exiting into the Gangetic plain. Sawaldeh Sot shows deflection towards the mid-section of the depression but eventually it cut across the frontal ridge. The frontal part of the Siwalik hills are drained by incised meandering streams suggesting that the once major terrain have been uplifted due to migration of the deformation towards the edge of the range as a result of uplift along the HFT. In the western section of the Malani basin which is not included in the present study, the main stream is Sona Nadi and this stream flows axially in the Malani basin. In the Ramnagar area along the Kosi River a broad syncline is observed in the country rock of Upper Siwalik in the hangingwall block of the HFT. In Laldhang and Dhela there are gentle anticlines in the immediate hangingwall block of the HFT, these folds have form in response to thrusting along the HFT. Near Himmatpur stream cutting across the HFT has exposed tilted post-Siwalik sediments in the bottom of the hanging wall block of the HFT by 7° towards N and uplifted by about 10 m. Post Siwalik sediments overlying the Siwalik bedrocks are exposed 10 to 20 m above the present river bed in the HFT. Drainages are sensitive to tectonic activity and realigned as per the tectonic setting, a number of structural controls on drainage pattern is observed in the present study area from major river such as Kosi River to small tributary streams. Bhandarpani Sot and Udal Nadi very small tributaries of Kosi River flow almost in straight line. Bhandarpani Sot flows along the Sarpduli-Dhikala Thrust in almost SE-NW trend in a wide valley. Sarpduli-Dhikala Thrust a thrust fault where Lower

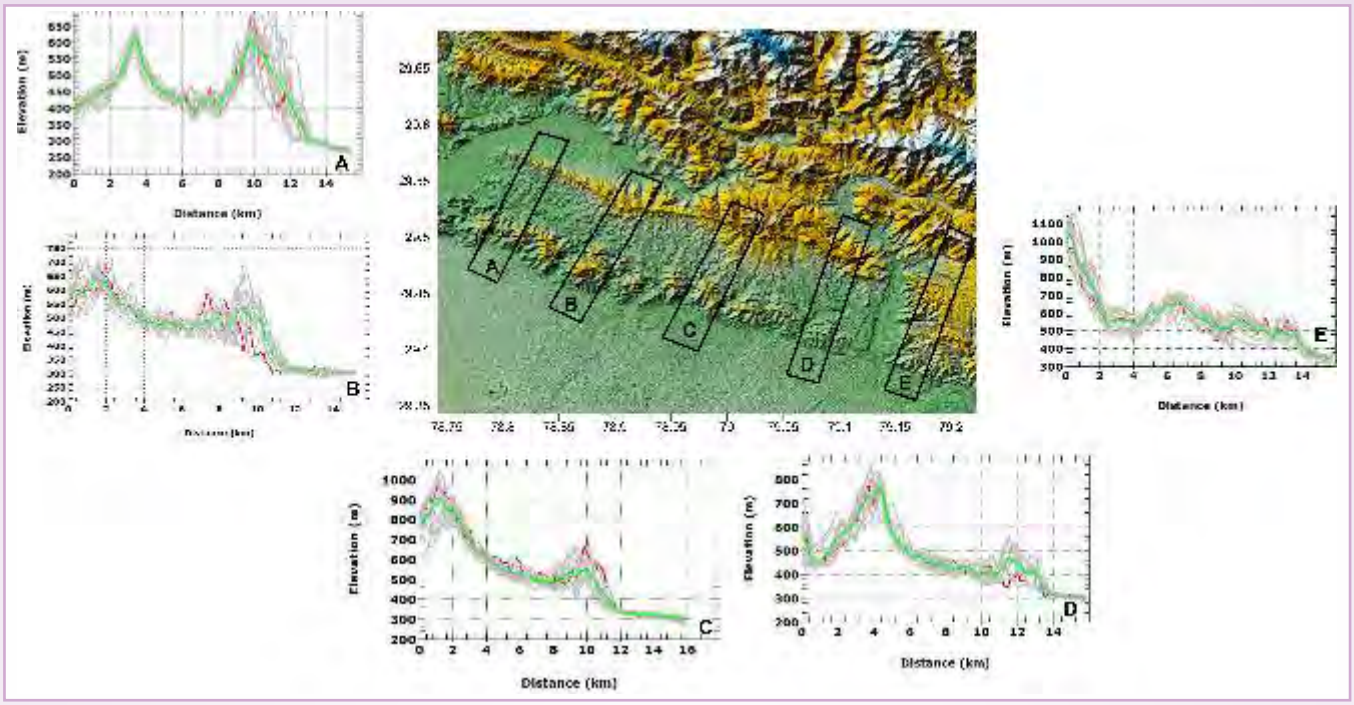

Fig. 27: Swath profiles showing the evolution of the Malani Dun as a result of uplift along the Himalayan Frontal Thrust between Kalagarh and Ramnagar, Kumaun sub-Himalaya.

Siwalik rocks are thrust over the Upper Siwalik behaves locally as normal fault in this section. The wideness of the valley may be due to localized extensional tectonics. Udal Nadi a tributary of Bhandarpani Sot also have almost straight channel for about 5 km. The linearity of this stream course may be related with the same tectonic processes responsible for Bhandarpani Sot. In the field normal fault related fabric conjugate to the Sarpduli-Dhikala Thrust are observed near Udal Nadi along Ramnagar-Amgari road section. In the northwest extension Dhangari Sot a tributary of Kosi River and Sanguri Nala a tributary of adjoining Ramganga River have linear pattern along this fault in almost NW-SE trend. Ghilmoriya Sot takes 90° at the fault zone from NNE flowing it becomes NW flowing. Chahal Sot and Kali Gad tributaries of Khichari Gad have the same trend and are related with the tectonic escarpment marked by Nakata (1972). Between MBT and HFT Kosi River shows its adjustment as it crosses the MBT, S-DT and the HFT where narrowing down of the valley is observed either in the hanging wall or the footwall blocks. In the MBT and Sarpduli-Dhikala Thrust zones Kosi River narrows down in the footwall block, while in the HFT it narrows down in the immediate hanging wall block of the HFT. Baurar Gadhera a tributary of Kosi River also shows tectonic control by the MBT where in the footwall of the MBT abrupt narrowing down of the valley is observed. East of Ramnagar the narrowing down of the river valley have provided suitable site for construction of small dam. Streams such as Sawaldeh Sot, Dehela, Sot, Phika Sot, Jamnagwan Sot and Dhara Sot west of Ramnagar and Khichari Nadi east of Ramnagar have incised meandering valleys in the hanging wall block of the HFT while further upstream they have wide valleys. These streams are older than the present topography as they cut across the rising hills in the mountain front as a result of uplift along the HFT. The incised meandering channel suggests prior to uplift the streams were flowing in relatively mature terrain. Sawaldeh Sot shows linearity in the upstream section in the depression zone.

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)

3.5a Quaternary landforms between river Kosi and Kali along HFT

(G. Philip and N. Suresh)

Fluvial terraces and alluvial fans are important geomorphic features that can provide records of

sediment accretion and incision history and are the most common landforms used to infer climate change and tectonic impacts on landscapes. Field work was carried out between river Kosi and Kali, along HFT to study Quaternary landforms and document signatures of active tectonics. Tectonic scarps have been identified at Bastia, Chorgallia, Damuwadhunga and Patapani for trench excavation surveys. An attempt has been made to select new sites for trench excavation surveys to estimate the recent tectonic activity.

Kota Dun

Topographic maps, GoogleEarth images and field work have helped to delineate several geomorphic and tectonic features in Kota Dun. The Kota Dun extends in NW-SE direction for about 21 km between rivers Kosi in the west and Baur in the east. The average width of the Dun is about 5 km. The Dun is bordered by Siwalik mountain and comprises of Lower Siwalik Subgroup in the north along Dhikala Thrust. The southern boundary of the Dun is demarcated by Upper Siwalik Subgroup. In the Kota Dun, four alluvial fans were identified, of these only Kotabagh and Dechauri fans have been observed in detail. These fans are originated from Siwalik mountains in the north. The Dechauri Fan, situated in the eastern part of the Dun, was deposited by Baur River, presently flowing along the eastern margin of the fan. The Kotabagh Fan was deposited by Dabka River, presently flowing along the western margin of the fan. Both the fans were entrenched by respective streams and vertical scarps and successive terraces were formed on the eastern margin of the Dechauri Fan and on the western margin of Kotabagh Fan. The Baur River has shifted towards east whereas the Dabka River has shifted to the west and abandoned paleo-channels were preserved along the fan margins. The incision of the fans has resulted in the formation of different levels of terraces. Five levels of terraces were observed in the Dechauri Fan whereas two levels were identified in the Kotabagh Fan. The sedimentary fill forming the fans comprises dominantly of gravels followed by sand and mud. The clasts are subrounded to rounded, pebble to boulder sized, clast to matrix supported and occurs as sheet to channelized deposit. The fans comprises quartzite, sandstone, carbonate and phyllite clasts derived from the hinterland. To constrain the ages of deposition, OSL samples were collected from the exposed sections of the Kotabag Fan and from the top of the Dechauri Fan and the analysis is under progress.

The Kotabag and Dechauri fans are displaced by tectonic activity. 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. Displaced fan sequences are observed in the hanging wall of the thrust. At the proximal part of the Kotabagh Fan, about 40 m vertical offset has been identified. At the proximal part of Dechauri Fan, the topmost fan terrace also shows a 40 m offset.

It has been observed that the frontal hills along HFT, separating the Duns from Indo-Ganga Plain, rise abruptly and at places such as 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 west and also show knee-bend deflection in the downstream. The work is under progress.

3.5b Electrical resistivity studies across HFT at Kala Amb

(Gautam Rawat, G. Philp and N. Suresh)

Non-invasive geophysical techniques were employed across the HFT at Singhauli near Kala Amb in the northwestern Frontal Himalaya to understand shallow subsurface geological structures and their nature in relation to active tectonics. Electrical Resistivity Tomography (ERT) 2D profile survey was conducted along two profiles in Kala Amb region near trench site with aim of delineating subsurface extensions of identified features in resistivity section, and also to test the efficiency of this method for applicability in recognition and geometrical characterisation of active faults across morphotectonic scarps or fault traces in a region of late Quaternary tectonic activity. The survey carried out covered a total 188 m length of profile, with 48 electrodes spaced at 4 m apart. Schulmberger and Wenner configuration is utilised for recording electrical potential and induced potential. Apparent resistivity is calculated using the observed potentials. The 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 model perturbation vectors also. The final inversion is achieved in 5 iterations with absolute error 2.2 of convergence. 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 54 m distance from zero electrode position toward south clearly distinguishes two separate

zone of lithology. Beside this the liquefaction feature identified in the trench wall section appear to be uprooted from a depth greater than 36 m.

3.5c Geodetic studies

(S. Rajesh and. P.K.R. Gautam)

One of the objectives of the project is to understand the short term tectonic deformation happening across and parallel to the Himalayan Arc between Kali and Beas rivers. The tectonic deformation cause uplift, extension, shortening or subsidence in the Sub and Lesser Himalayan regions. We attempted to monitor the short term surface deformation in the Sub and Lesser Himalayan region by analyzing the existing permanent stations GPS data in the study region. In Indian reference frame, all sites show predominantly southward and arc normal velocity which increases towards north. Preliminary results suggest that in the Lesser-Himalaya within Garhwal-Kumaun region, the resultant horizontal movement is towards SW with an average movement less than 10 mm. In general, within the Lesser Himalaya the maximum horizontal displacement is observed in the Kumaun region at stations situated in Pithoragarh and Munsyari sites. The magnitude of these resultant horizontal movement reduces to less than 5 mm towards west of Dehradun region although the SW trend has been maintained. However, stations in the Sub-Himalayan region especially close to the HFT the resultant horizontal movement is roughly towards SE. This was observed at stations close to Biharigarh and Nahan where the movement is less than 3 mm. Thus, based on the existing data set it could primarily be inferred that there is a 90^{o} offset in the sense of movement of the Sub-Himalayan block in the Garhwal region with respect to the northern Lesser Himalayan region. Since MBT is the major plate boundary structure that separates both these blocks, it should experience and should be capable to accommodate substantial lateral movement apart from the North-south compression. In fact, surface deformational structures are observed at north and south of the MBT at many localities in the Garhwal and Kumaun region. Apart from this, variable surface movement has been observed from ~36 to 48 mm/year longitudinally towards east at a few permanent GPS sites in GHUT, WIHG, BDRI and MUNS in the Garhwal Kumaun Himalayan region in the global ITRF08 reference frame.

Base line change of various GPS stations in the Himalayan region have also been investigated and observed that stations like BIHA, SHAM, WIH2 situated in the Sub-Himalayan region show extension with respect to station in the Ganga basin at Lucknow; for e.g., stations BIHA and SHAM show an extensional rate of around 4.26 and 5.32 mm/yr, respectively. This also corroborates with the earlier observation of SE displacement of Sub-Himalayan block. Interestingly, we also observed that these Sub-Himalayan stations in the Dehradun region show E-W shortening or along the Arc shortening with respect to stations located further west in the Himachal Himalaya at NADI and KOTI. The base line shortening between BIHA and KOTI station is maximum around -8.4 mm/yr. Thus, there exist opposite sense of accommodation at the west and east of Dehradun re-entrant, where elongation is a possible mechanism towards east but shortening is the counter mechanism that occurs towards west from Dehradun. However, this observations needs to be analyzed further by acquiring more data in the study region. Accordingly, around 30 campaign points are selected in the Garhwal-Kumaun region, and field observations would be carried out at these locations.

TAT 3.6

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

(Vikram Gupta, D.P. Dobhal and Ajay Paul)

Landslides and related mass movement activities have been studied in the selected transacts of Uttarakhand and Himachal Pradesh, and an inventory of active and possible slope failures has been prepared using various datasets like previous literature, remote sensing products including satellite images on the google earth platform, previous year's field data as well as from the updated field data in selected areas along the major river valleys. A total of ~3303 landslides have been mapped in the state of Uttarakhand. These landslides cover surface area of ~68 km^{2}. These include landslides generated by natural processes as well as by human intervention on the slope. Many of these landslides have been found to be concentrated along or within a range of 50 m from the drainage. Their distribution is observed to exponentially decrease away from the drainage. The same is true for the road-cut or the cut slopes. The decoupling of natural and human-induced landslides is underway.

Further, in order to understand the spatial distribution of landslides 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 for the Sutlej river and the Yamuna river valleys. The computation for these indices for other major river valleys is being carried out. 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, while on the other hand 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.

Beside this, the potential landslide damming of the Sutlej river by the Urni landslides, located in the Higher Himalaya in the Kinnaur district of Himachal Pradesh has also been evaluated. Some of the conclusions drawn from the study of landslides in the Sutlej valley are:-

- Based on the common causative factors and spatial proximity, 55 landslides are found to be in six clusters. The clusters in the orographic interior (Tethyan Sequence) reflect the dominance of aridity and weaker litho units, whereas in orographic front, higher rainfall and tectonic activity prevail.
- Total area and volume of 55 landslides are 1.05×10^7 m^2 and 4.4×10^7 m^3, respectively. The Tethyan Sequence and Kinner Kailash Granite (KKG) in the orographic interior constitute 67% and 46% of the total landslide area and volume, whereas Lesser Himalayan Crystalline (LHC) and LHS in the orographic front comprise 14% and 12% of the total landslide area and volume. This contrast in orographic interior and front is found to exist mainly because of rockmass difference as orographic interior is dominated by weak lithology (slate/phyllite/schist), whereas orographic front in the study area mainly consists of hard gneisses. The HHC, however, consists of 19% and 42% of the total landslide area and volume, respectively. This dominance in landslide volume is associated with the higher uplift and higher rainfall in this orographic barrier region.
- Landslides length, width, area, and volume followed a decreasing trend in downstream direction (NE to SW) along the Sutlej valley from the Tethyan Sequence (TS) to Lesser Himalayan Sequence (LHS). However, abrupt increase in the dimension (length, width, area, and volume) is observed at the hanging wall side of the Munsiari Thrust (MT) and Main Central Thrust (MCT) and footwall side of the Sangla Detachment (SD). This distinct change near these regional faults pertains to spatially varying lithotectonic and climatic conditions. The rockmass in the footwall side of SD is highly sheared because of fault reactivation, whereas hanging wall side of MCT and MT receive high uplift and high rainfall.
- The dimensional distribution of landslides attained a power law between landslide area (A) and volume (V) with a scaling relationship of $V = 0.180\times A^{1.208}$. This relationship is noted to vary based on landslide type and provided a scaling exponent (γ) of 1.48 for debris slides; 0.93 for rockfall; and 0.98 for rock avalanche. The rockfall and rock avalanche are scale variant and their dimensions are more sensitive to lithology, climate and tectonic conditions, whereas debris slides follow least control of these factors on their dimensions.

Since the region of Uttaranchal and Himachal Himalaya lies in the Central Seismic Gap between the two great earthquakes of 1934 (Bihar-Nepal) and 1905 (Kangra), the area has been studied to understand the present day seismicity in the region. It has been noted that area witnessed two moderate earthquakes in 1991 (M6.5, Uttarkashi) and 1999 (M6.6, Chamoli), one large earthquake in 2015 (M7.8, Nepal) and fifteen earthquakes of magnitude between 4 and 6 in last ten years. The delineation of the active faults and Peak Ground Acceleration (PGA) contour map have also been drawn. The PGA contour map shows two clusters of maximum ground shaking in the region.

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 palaeoenvironment and correlation of evolutionary trend with global bioevents.

(Meera Tiwari)

The base of the Ediacaran Period in the Krol belt is represented by pink carbonates, known as cap carbonate globally, overlying the diamictite of the Blaini Formation. The diamictite bearing Blaini Formation overlies the metamorphosed deposits of the Shimla Group. The lower diamictite of the Blaini Formation is regarded as a deposit of the middle Cryogenian and the upper part of the Blaini Formation as late Cryogenian/Marinoan glaciation, which includes diamictite and pink carbonate. Moreover, isotopic age of the upper part of diamictite of the Blaini Formation (678±10 Ma) suggests its possible correlation to the Nantuo Formation (643±7 Ma) of China, Nuccaleena Formation of South Australia (~635 Ma), and the Ghaub Formation of Namibia (~636 Ma).

The potential independent evidence of acanthomorphic acritarchs is now-a-days has been employed as a proxy for biostratigraphic correlation and paleogeographic reconstructions. The lower and middle Ediacaran acritarch assemblages play a significant role in the study of biological and environmental evolution. Well-preserved large Acanthomorphic Acritarchs from the Infrakrol Formation and Krol A suggests their potential as one of the best known Ediacaran assemblage. The assemblage consists of *Tianzhushania spinosa*, *T. polysiphonia*, *Papillomembrana compta*, *Schizofusa* sp., *Paratetraphycus giganteus*, *Gloeodiniopsis lamellosa*, *Sphaerophycus medium*, and some very peculiar but unnamed forms also noticed. The assemblage is dominated by *Tianzhushania spinosa* which is used to define the acanthomorph biozones for regional and global biostratigraphic correlation of the lower-middle Ediacaran succession. The spatial abundance of this form is evident in the Infrakrol Formation. In the Yangtze Gorges region of south China, two acanthomorphic acritarch assemblage zones have been established, namely, lower *Tianzhushania* spinosa and upper *Hocosphaeridium anozos–Hocosphaeridium scaberfacium–Tanarium conoideum* assemblage. These are the most diverse and best studied acanthomorph assemblages of the Doushantuo Formation of South China. The lower assemblage zone is dominated by Tianzhushania spinosa which does not extend to the upper assemblage zone. In Australia five assemblage zones are established. The *T. spinosa* biozone is not identified in Australia so far. The occurrence of *Tianzhushania spinosa* in the Infrakrol Formation of India, confirms its coevality to the lower *Tianzhushania spinosa* biozone in the Doushantuo Formation of South China, whereas its correlation with the Australian counterpart is not directly feasible. Among them, the acritarch Tianzhushania spinosa has a characteristic large (350-750 lm in diameter) multi-lamellate non-sculptured vesicle with processes that penetrate the wall layer to support an external membrane. *Tianzhushania* is interpreted variously as planktic copepod eggs, animal resting eggs and embryos thus indicating its pelagic nature. A non-metazoan holozoan relation has also been proposed. Similarly, the genus *Papillomembrana compta* is characterized by its large vesicle with numerous bulbous processes. It is regarded variously as reproductive structure of a thallophyte and/or microphytoplankton, and is considered to have originated in the Cryogenian Interglacial epoch with FAD older than 635±18 Ma.

The Raman analysis of some selected forms of *Tianzhushania* and other LAA reflects the presence of aromatic organic compounds which confirms the biogenicity of the recovered forms, whereas the presence of phosphate is also noted in some forms. This phosphate may have either formed in the shallow sea environment where progressively shallow upwelling cells must have brought the deeper phosphorous enriched oceanic waters or may have been brought by fluvial transport. It is also possible that organic phosphorus released to pore waters due to decomposition/breakdown of organic matter within the microbes formed the phosphate.

The mode of preservation and occurrence of Infrakrol acritarchs is comparable to the lower assemblage biozone of the Doushantuo Formation in the Yangtze Gorges section of South China. It is interpreted that the Infrakrol Formation is coeval to the Lower Tianzhushania Assemblage Zone and can be bracketed within the same age range. Zircon U-Pb samples from the interbedded ash beds within Doushantuo Formation have yielded ages of 635.2±0.6 Ma for the Member I, 632.5±0.5 Ma for the Member II, and 551.1±0.7 Ma for the Member IV (Condon et al., 2005) which are

consistent with the youngest zircon age of 643±7 Ma given by Hofmann et al. (2011) for tillites of the Blaini Group.

TAT 4.2

Bio-event stratigraphy of the Lower Paleozoic succession of Himalaya in context with global event stratigraphy

(S.K. Parcha)

Significance of trace fossils in the Cambrian sequences of Himalaya

The work on ichnofossils has helped to elucidate the temporal paleoenvironment and infer the paleoecological distribution of ichnofossil assemblage based on modern analogue of ocean slope and shelf zone, which existed in the Tethyan region of the Spiti basin during Lower Cambrian. The Ichnofossils indicates that the Kunzum La Formation was deposited in the deep to shallow shelf setting. The diverse assemblage of trace fossils reported from different part of early Cambrian succession in Spiti Basin is useful to explain the temporal paleoenvironment and paleoecological conditions. These studies further suggest that there existed a low energy depositional environment at this level of sedimentation. The distribution of trace fossils in the studied section reflects low to moderate energy level. The availability of nutrients have strongly increased their distribution as well as abundance in the Chandratal section.

Precambrian-Cambrian boundary was marked on the basis of ichnofossils in the Zanskar Himalaya. Contributions were made in understanding developmental processes among trilobite species using biometric approaches. All this work is in the rugged terrains of the Himalayan region that remained less explored. In absence of body fossils demarcation of Precambrian/Cambrian boundary can be marked in the Spiti as well as in the Zanskar Basin, on the basis of ichnofossils, *Treptichnus pedum*. Ichnofossil and trilobite assemblages in the Kunzum La Formation of Parahio Valley can be correlated locally, regionally and globally. Ichnofossils identified from Spiti and Zanskar section, provides evidences regarding the developmental patterns during the early phase of life on earth. A high behavioural diversity ranging from suspension to deposit feeders dominates the ichnocenosis. The ichnofauna represents resting as well as grazing traces along with trails mostly preserved in intercalated shales, siltstones and sandstone beds. The ichnofacies association indicates anaerobic to dysaerobic trends of the Ichnofauna from *Cruziana*, *Skolithos* and partially by *Nerites* ichnofacies Ichnofossil assemblage from the Spiti suggests that the benthic paleocommunity was dominated by annelids or similar worm like animals; which were predominantly living within the sediments while the trilobite were trailing on the sea floor. Availability of nutrients strongly influenced their distribution as well as abundance. The ichnofossils studied from the Zanskar are important in deciphering the age of the pre trilobite bearing horizons. The increase in the ichnofaunal diversity along the Phe-Karsha transition zone reveals abundance of oxygen and organic matter.

Ontogeny of fossil trilobite Pagetia: implication in Middle Cambrian Stratigraphy of Spiti Himalaya

The Middle Cambrian is the thickest and most extensively fossilliferous succession in the Spiti Basin. The morphometric analysis of species from the Cambrian successions of the Himalayan regions capitulates insight into the developmental constraints, and life-history strategies of early trilobite clades. Correlation of Middle Cambrian succession of Tethys Himalaya based on Agnostid trilobites - Agnostid trilobites identified from the Zanskar section indicates that these forms are useful for the correlation of the Middle Cambrian successions and some of the species which are key marker species in demarcating the late middle Cambrian and early part of upper Cambrian were also recognized, which make them more important elements for the correlation of the Middle Cambrian succession of this region with other well-known sections of the world. In addition to agnostids various other trilobites were also identified, the detailed study of them is going on and more field work needs to be carried out in other sections in order to get well preserved specimens

The Cambrian-Ordovician unconformity is of regional extent, and the biostratigraphic database indicates that the minimum hiatus is associated with the unconformity in Spiti ~15 m.y. Two extinction events have been marked in the Cambrian successions of the Tethyan Himalayan regions. These results demonstrate that there were some regional differences about the diversification of biological activities in the earliest Cambrian.

Calcareous algae from the Ordovician succession (Thango Formation) of the Spiti Basin

The calcareous algae *Dasyporella silurica*, *Moniliporella multipora* and *Vermiporella fragilis* are reported for the first time from the Middle Ordovician (Dapingian to

Darriwilian) Thango Formation of the Spiti Basin of northern India (Pin Valley, Tethys Himalaya). The species *Moniliporella multipora* is reported for the first time from the entire Spiti Basin. This algal assemblage is broadly comparable to that of the directly overlying Pin Formation in the Spiti Basin, as well as that reported from the Ordovician succession of the Tarim Basin and from Kazakhstan. The presence of these calcareous algae reflects significant bio geographical and biostratigraphical importance and indicates a shallow marine depositional environment for the Thango Formation for Spiti Basin.

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

(Kishor Kumar)

The study of Eocene vertebrates from the Himalayan and Peninsular sections and their palaeogeographic implications was continued. A new gymnodont fish *Avitoplectus molaris* gen. et sp. nov., was described from the lower Eocene Cambay Shale Formation. It has fused dentaries without a beak and a remarkable series of teeth that are unique among all known fossil and living Tetraodontiformes (Figs. 28 to 30). The teeth are molariform, with raised spokes radiating inward from the emarginated peripheral edge of the crown. Although many of the 110 tooth loci in the fossil have lost their teeth, in life the teeth would have grown to fit tightly together to form a broad and continuous crushing surface. Preliminary comparisons with extant taxa of gymnodonts with fused dentaries (e.g., *Diodon, Chilomycterus*, and *Mola*) show similarities in jaw structure, but further study of the dentition is needed to better understand the evolutionary position of the new fossil.

Several new fossil specimens from the Cambay Shale Formation at Tadkeshwar lignite mine in Gujarat document the presence of two previously unknown early Eocene primate species from India. A new species of *Asiadapis* is named based on a jaw fragment preserving premolars similar in morphology to those of *A. cambayensis,* but substantially larger (Fig. 31). Also described is an exceptionally preserved edentulous dentary (designated cf. *Asiadapis*, unnamed new species) that is slightly larger and much more robust than previously known Cambay Shale primates (Fig. 32). Its anatomy most closely resembles that of Eocene adapoids, and the dental formula is the same as in *A. cambayensis*. A femur and calcaneus are tentatively allocated to the same taxon (Fig. 33). Although the dentition is unknown, exquisite preservation of the dentary enables an assessment of masticatory musculature, function, and gape adaptations, as well as comparison with an equally well preserved dentary of the asiadapid *Marcgodinotius indicus* also from Tadkeshwar. The new *M. indicus* specimen shows

Fig. 28: Macrophotographs of the jaw of †Avitoplectus molaris (WIF/A 2340). A. Anterior labial view. B. Ventral view showing complete fusion of left and right dentaries and the prominent mandibular foramina. C. Dorsal view showing general arrangement of molariform teeth to form the crushing surfaces.

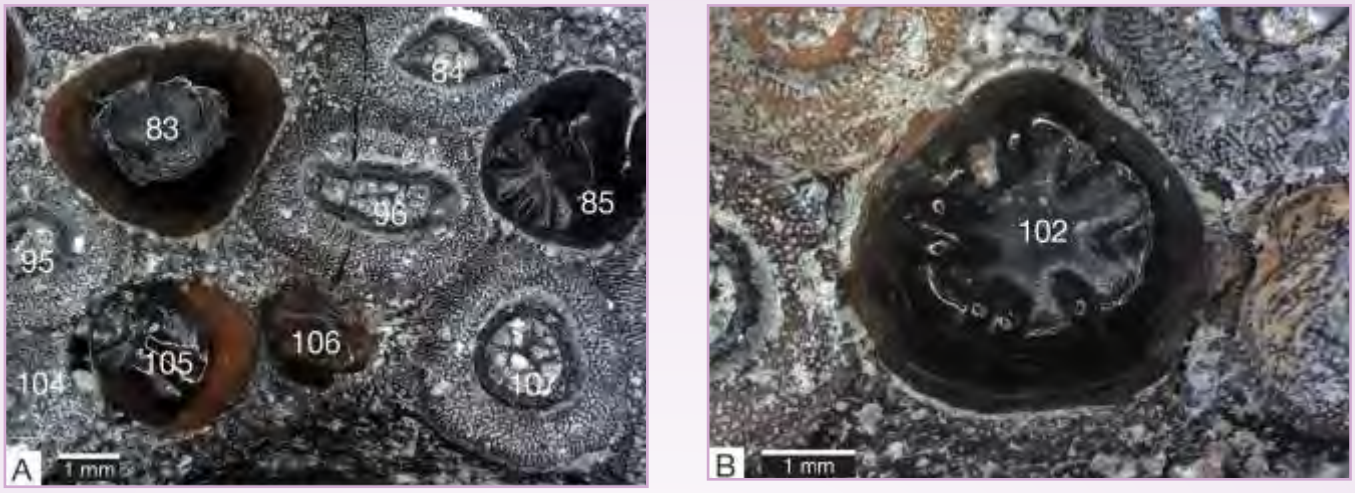

Fig. 29: Details of tooth diversity, wear, and replacement in Avitoplectus molaris (WIF/A 2340). A. Group of functional and incoming teeth near the posteromedial surface of the jaw. Loci 83 and 85 are functional teeth. Loci 105 and 106 are incoming teeth. Other loci indicated (84, 95, 96, 104, 107) are present as pedicels only. B. An unworn functional tooth with 8 "spokes."

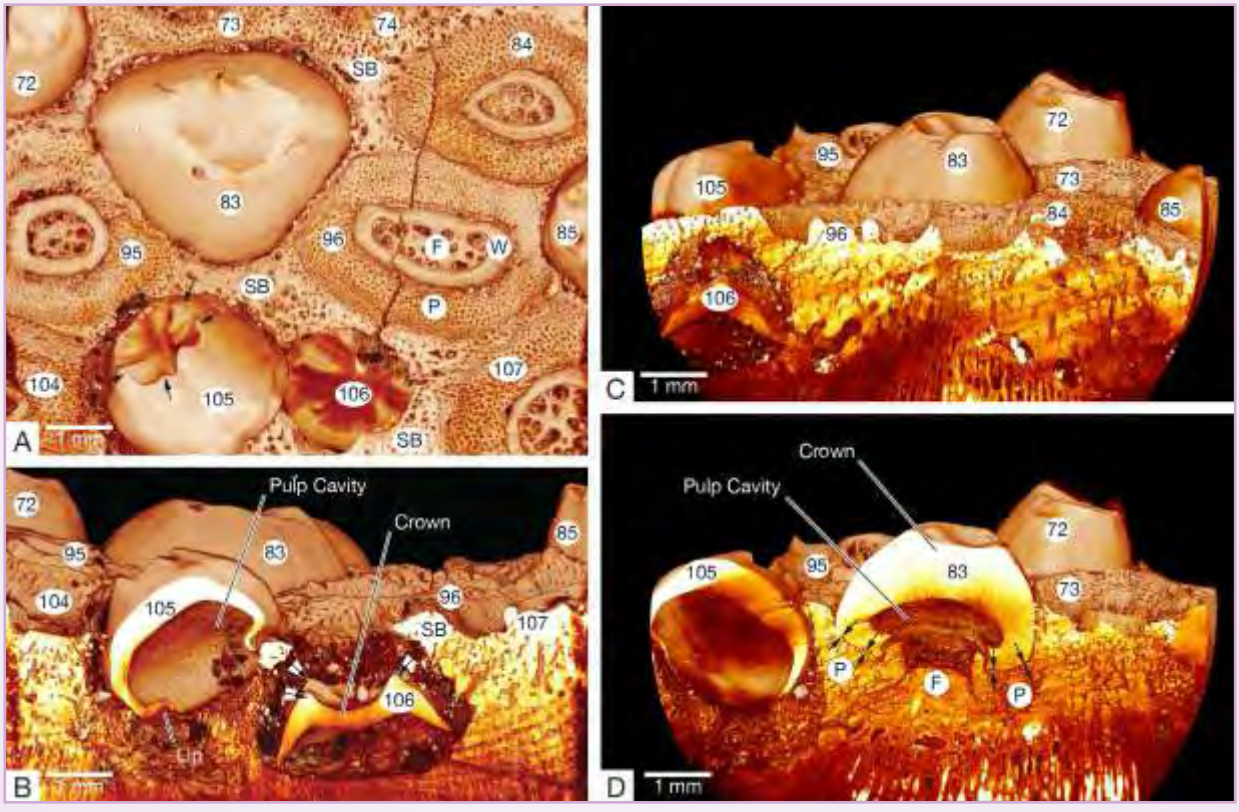

Fig. 30: Micro-CT reconstructions of jaw of Avitoplectus molaris (WIF/A 2340). to show aspects of tooth replacement. The same portion of the jaw is shown in different orientations in parts A–D; loci are numbered for identification. A. Toothed surface of the jaw showing details of the pedicel attachments where teeth have been lost. Arrows indicate spokes of incoming tooth 105. B. Digital dissection of the dentary from the lingual side to show tooth replacement. Arrows indicate spokes of incoming tooth 106. C. Digital dissection of the dentary cut at a 90° angle to the plane shown in Fig. 6B. D. Same view as part C, cut further medially through the dentary to show tooth attachment. Black arrows indicate attachment of tooth 83, a functional tooth, to its pedicel base. P =pedicel, SB = spongy bone, F = floor of pulp cavity.

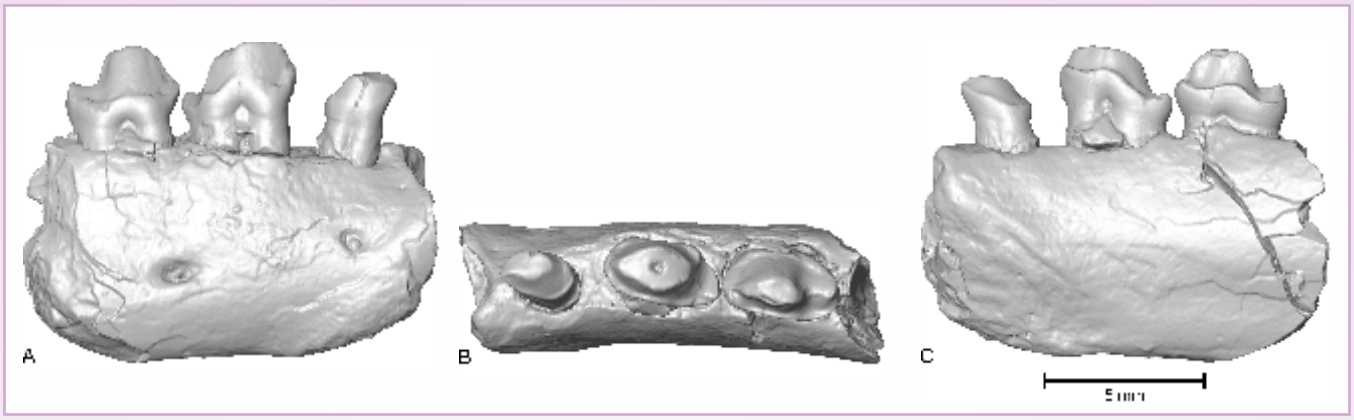

Fig. 31: Asiadapis tapiensis, sp. nov., holotype, GU/RSR/ TAD 9239, right dentary with P2-4 in buccal (A), occlusal (B), and lingual (C) views.

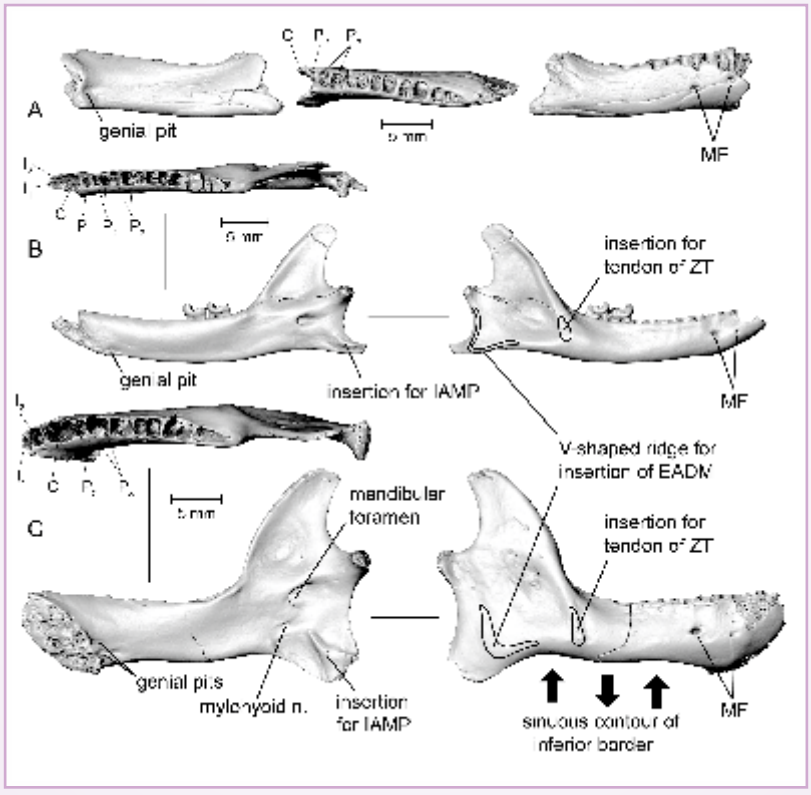

Fig. 32: Comparison of dentaries of cf. *Asiadapis* sp. nov. and *Marcgodinotius indicus* from Tadkeshwar mine. A, cf. *Asiadapis* sp. nov., GU/RSR/TAD 9004. Left to right, lingual, superior (occlusal), and buccal views. B, *M. indicus*, WIF/A 2334, in superior (above), lingual (left), and buccal views. C, cf. *Asiadapis* sp. nov., GU/RSR/TAD 9014, in superior (above), lingual (left), and buccal views. EADM, external aponeurosis of deep masseter muscle; IAMP, internal aponeurosis of medial pterygoid muscle; MF, mental foramina; n., nerve; ZT, zygomatic temporalis muscle.

significant gape adaptations but was probably capable of only weak bite force, whereas cf. *Asiadapis* probably used relatively smaller gapes but could generate relatively greater bite forces.

A new herbivorous mammal from the early Eocene Cambay Shale Formation, Tadkeshwar Lignite Mine, Gujarat is approximately the size of a small phenacodontid (e.g., *Ectocion parvus*). It is represented by two mandibular fragments, the more complete of which documents nearly the entire symphysis and mandibular body plus P_3-M_3. It has incipiently

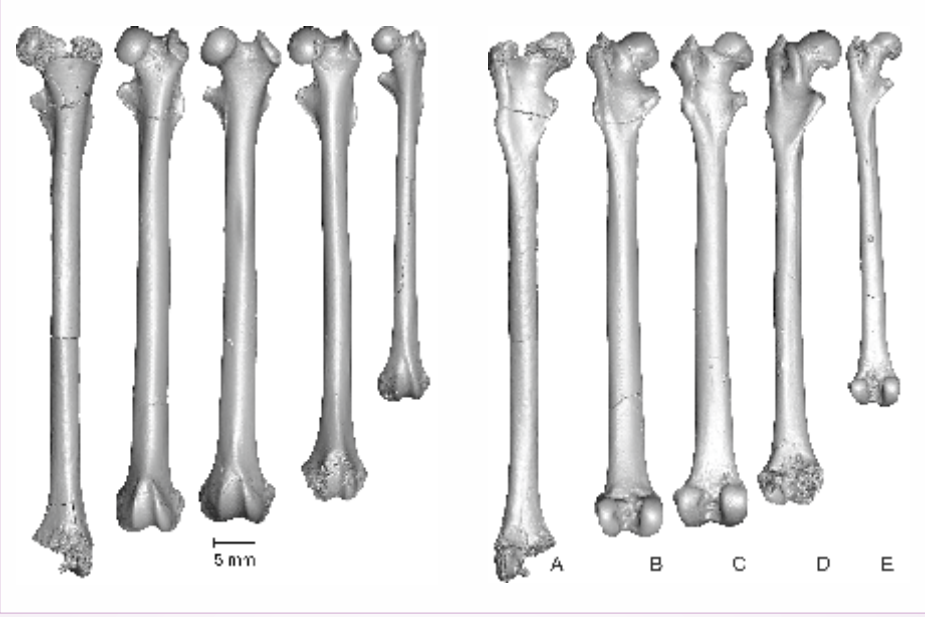

Fig. 33: Anterior (left) and posterior views (right) of left femur of cf. *Asiadapis* sp. nov. (A, GU/RSR/TAD 9012) from Tadkeshwar mine compared with femora from Vastan mine, all to the same scale: B, *Vastanomys major*, GU/RSR/VAS 1684; C, *Vastanomys major*, GU/RSR/VAS 793 (right femur, reversed); D, *Asiadapis cambayensis*, GU/RSR/VAS 756; E, *Marcgodinotius indicus*, GU/RSR/VAS 1685 (right femur, reversed).

selenolophodont molars with strong exodaenodonty, absent paraconids, weak but distinct entolophids, and prominent ectostylids. Molar size increases distally, but M_3 does not develop a prominent third lobe. Premolars are simple, with prominent protoconids and short talonids but little development of other trigonid cusps. The mandibular symphysis is strongly fused, and there is an enlarged anterior alveolus, but probably not the most anterior tooth. The combination of features present in the new taxon does not closely match that of any known mammal, but there are some similarities to a diversity of ungulates from Africa, Asia, Europe, and North America. Preserved morphology is insufficient to confidently assess the affinities of the new taxon, but a link to Quettacyonidae, also endemic to the Indian subcontinent, is morphologically and biogeographically plausible. If this scenario is correct, it suggests that the new taxon could be a survivor of the endemic mammalian fauna of Indian prior to its initial faunal contact with Asia.

Eighteen new specimens of the sole apatemyid mammal known outside North America and Europe: *Frugivastodon cristatus* were described from the Early Eocene Cambay Shale Formation of Vastan Lignite Mine, Gujarat, India. This mammal was previously represented only by one isolated lower molar, which hindered the establishment of its relationships among Apatemyidae. The new fossils show that the Indian apatemyid is unique and represents a new morphotype among this family. It is notably characterized by mesiodistally elongated lower molars with reduced m3, a small hypocone on the upper molars, and a transversely wider M1 than in other apatemyids. The new data supports the inclusion of the enigmatic Bridgerian *Aethomylos* within Apatemyidae. The Indian *Frugivastodon* and the North American *Aethomylos* might represent a distinct clade of Apatemyidae that originated around the Paleocene-Eocene boundary. The paleobiogeographic analysis suggests that *Frugivastodon* dispersed from Europe into India during the early Ypresian. We also review the dispersal events that characterized the history of Apatemyidae.

Recent field work in the Paleocene-Eocene sections of western India, yielded a few important additional vertebrate fossils. Matrix of bulk samples macerated in the field itself is being sorted under the microscope for recovery of microvertebrates.

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)

NE India has the largest sedimentary basin in India, and is considered to be as a natural museum where different

rock sequences from Archean(?)-Proterozoic to Pleistocene sediments are found. It has 70% of sedimentary rock succession in India, and thus form the best platform to carry out research on Tertiary fauna and flora to elucidate the past geological processes. In the reporting year, the studies on Tertiary fauna and flora from the NE India was continued in order to understand the biostratigraphy and the paleoenvironment.

Middle Miocene calcareous nannofossils from the Upper Bhuban Formation

Calcareous nannofossils have been used for refining the biostratigraphy and paleoenvironment of the Upper Bhuban Formation (UBF) of a part of Mizoram. A calcareous nannofossil assemblage comprising of eleven species and eight genera have been recognized (Fig. 34). Though the nannofossil yield is poor with a

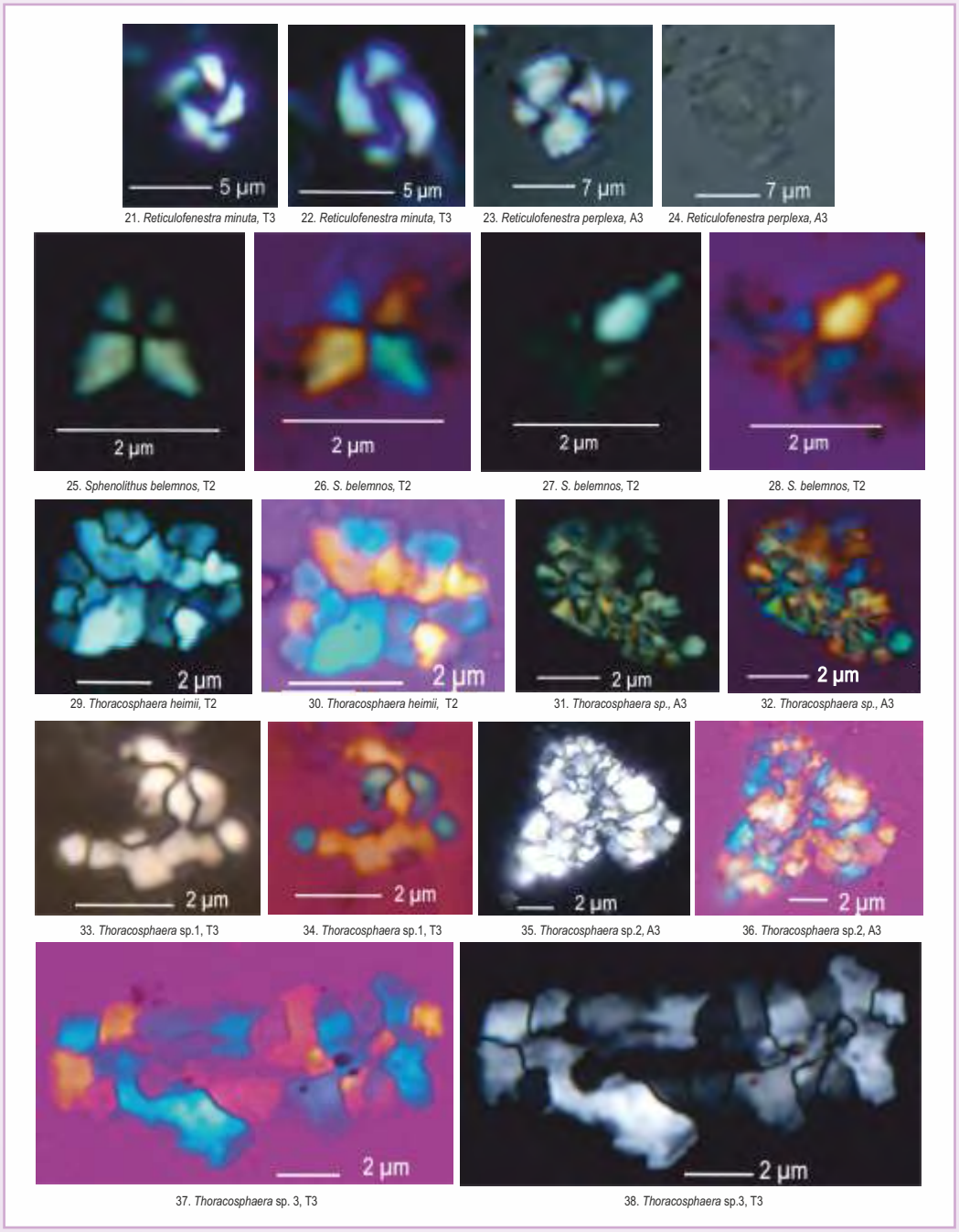

Fig. 34 : Middle Miocene calcareous nannofossils from the Upper Bhuban Formation of Mizoram, Indo-Burma Range.

moderate to low preservation, their study is significant for determination of the age, and paleoenvironment. By integrating the calcareous nannofossil and known foraminiferal assemblage data, we could further constrain the studied succession to Calcareous Nannofossil Zone CNM7 after Backman et al. (2012), which is equivalent to early part of the middle Miocene. The relatively good abundance of Helicosphaera, presence of Discoasters and the published foraminiferal data indicate hemipelagic depositional setting for the UBF in Mizoram.

Ichnology of the Laisong Formation (late Eocene-early Oligocene) of the Naga Hills

The late Eocene-early Oligocene Laisong Formation, basal Barail Group from the Naga Hills, Indo-Burma Range has yielded low diversity of trace fossils, i.e. *Chondrites, Gyrolithes, Ophiomorpha, Palaeophycus, Planolites,* and *Thalassinoides.* Three chnofabrics namely *Ophiomorpha-Palaeophycus, Thalassinoides* and *Chondrites-Planolites* have been identified. The *Ophiomorpha-Palaeophycus* ichnofabric grades upsection into *Chondrites-Planolites* ichnofabric in a fine- to medium-grained sandstone unit through a succession of alternating thinly bedded sandstone and mudstone containing *Thalassinoides* ichnofabric. The ichnofabric distribution is controlled primarily by the change in depositional energy levels from low to high. A low diversity of trace fossils and lack of graphoglyptids traces in the Laisong Formation of Naga hills supports proximal part of the hyperpycnal-deltaic lobes of delta-fed marine coarse-grained turbidite system.

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 significantly rich collection of the mega-vertebrates during the previous field works was made from the Lower Siwalik sediments of Udhampur region and the Middle Siwalik sediments of Kangra Valley. There are more than 125 specimens in the collection. The collection is in the form of well-preserved dentitions, maxillas and mandibles. The identification and photography of the specimens were carried out. Most of the specimens are identifiable up to the specific level, and the systematic palaeontology of the individual specimen was described. The specimen collection from the Lower Siwaliks of Udhampur is comparatively richer, and in all 46 mammalian species are identified representing varied families including, Rhinocerotidae, Suidae, Anthracotheriidae, Tragulidae, Giraffidae and Bovidae. A new fossil locality was discovered near Dunera, Punjab, and the preliminary studies suggest that it represents Middle Siwalik, in contrary to earlier reports of its Lower Siwalik representation.

In addition to this a large quantity of sedimentary material (mudstone and pseudoconglomerate) was macerated for micro-vertebrate potential. A few important microfossils were recovered from the Lower Siwaliks of Udhampur and the Upper Siwaliks of Patiali Rao section near Chandigarh, and the specimens are under study.

A detailed 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 belong to the Himalayan foreland basin in the past.

The palaeontological studies of the fossil material from the ravines in the Ganga Plain were carried out. The study shows that, (i) the stratigraphy of the ravined region evolved from >100 until at least 14 ka, (ii) owing to the fact that large mammals were part of the ecosystem until at least 50 ka, it can be suggested that the presence of ravine development in the region is younger than 50 ka. The chronology indicates that the surface aggraded until is ~14 ka and therefore the modern ravine formation in the region can be placed at $\leq$ 14 ka.

Studies were also carried on the few mammalian fossils evidently of Late Pleistocene age recovered from the Musanagar area situated on the bank of river Yamuna collected by Dr. Pradeep Srivastava and his team, show the presence of two mammalian groups. The fossil specimens are in the form of moderately preserved, isolated upper and lower dentitions. The two mammalian groups present in the collection are perissodactyl and artiodactyl. The former is represented by an extinct species of *Equus* (horse) and the later belongs to bovids. The mammalian faunal assemblage

recovered from the site, to some extent, can throw light on the prevailing habitat of the animals during that period. In the present collection, *Equus*, ?*Bos* and ?*Bubalus* are identified. Further, Ghosh et al. (2016) described an extinct elephant *Elephas* cf. *namadicus* from a late Pleistocene locality of MGP. This locality is adjacent to Musanagar site. The collective faunal findings at Musanagar suggest that, the region was occupied with swampy grasslands separated by shrub lands and bushes. Away from the river system humid forests may have also present.

In collaboration with the Panjab University, the analytical studies pertaining to Carbon ($\delta^{13}C$) and Oxygen ($\delta^{18}O$) values of pedogenic nodules from Ghaggar River section and a 6 m thick swamp deposit (Nadah section) were done in order to reconstruct the palaeoclimate and palaeovegetation. $\delta^{13}C$ and $\delta^{18}O$ values from gastropod shells were also studied from the palaeoswamp. $\delta^{13}C$ values of Ghaggar river section suggest the dominance of C4 vegetation from ~2.7 to ~0.6 Ma. However, there were times when C3/C4 mixed vegetation in the form of wooded grasslands existed. Around 0.6 Ma pure C_3 plants existed on the landscape.

Digitization of the mammalian faunal collection from Ramnagar, J&K was initiated. The relation of the Siwalik faunas with the pre-Siwalik faunas was worked out. Dispersal pattern of the mammalian faunas across the width of Himalaya was utilised to know the timing of uplift of Himalaya.

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)

Field work was conducted in Doda and Suru River basins during which time 24 stakes were installed over the surface of Pensilungpa glacier for measuring the accumulation, ablation and debris thickness of the glacier and to calculate the mass balance (Fig. 35a). Moreover, 10 and 3 stakes were installed over the Parkachik and Durung Drung glaciers, respectively with the aim of ascertaining differential ablation of clean and debris-covered ice. Each stake has been fixed to a depth of 6-10 m by a steam drill, before which the surface temperature was measured using an infrared thermometer, and once the ice was exposed the debris thickness was measured (Fig. 35b). In addition, 10 more moraine sediment samples for Optically Stimulated Luminescence (OSL) dating were collected to reconstruct the paleo-extent of the glaciers and understand the paleo-climatic conditions of the region (Fig. 35c). Furthermore, 2 discharge sites were established near the Parkachik at 3600 m asl and Pensilungpa glaciers snout, and one meteorological sites (AWS) will be installed near the benchmark glaciers. Also, 2 discharge sites were constructed near the Parkachik (at 3600 m asl) and Pensilungpa glaciers snout (Fig. 35d). The discharge site on the Pensilungpa glacier is ~2.5 km downstream from its snout (4600 m asl). The Parkachik glacier discharge site (8 m in length and 16.6 m wide) is at a distance of ~235 m downstream from the left portion of the snout. Besides, hydrochemistry of meltwater from Pensilungpa, Parkachik and Durung Drung glaciers is under taken to understand sources of ions in glaciers of Ladakh region of western Himalaya.

The measurements made on the ablation-stake network suggest that the net balance of the Pensilungpa glacier was negative in 2016-2017. The net balance of the glacier was ~(-)1.59 x10^6 m^3 we in 2016-2017 with specific balance 0.093 m we. During the measurement period 2016-17 the net ablation of the glacier was ~(-) 3.73 x10^6 m^3 we, while the net accumulation of the glacier was ~(+)2.14 x10^6 m^3 we. However, the ablation and accumulation gradients of the glacier were ~(-) 0.107/100 m and ~(+)0.11/100 m, respectively. The results also suggest that during same period, the Equilibrium Line Altitude of the glacier is situated at the height of the 5195 m asl. Finally, from the comparison of results of the Chhota Shigri glacier (-0.54 m we), Dokriani glacier (-0.32 m we) and Chorabari glacier (-0.73 m we) it was found that, the mass balance of the Pensilungpa glacier (-0.093 m we) is more than 5 time lower than the central Himalayan glaciers. Besides, in order to understand the dynamics of these glaciers, changes in surface ice velocities were estimated using cross-correlation technique on optical image pairs. Results show that, the Pensilungpa and Durung Drung glaciers slowed down by 18.75 and 20.30% during 1993-94 and 1999-2000, respectively, while between 1999-2000 and 2016-17 the Pensilungpa and Durung Drung exhibit a reduction in velocity by 33.79 and 30.56%, respectively. The average velocities of these glaciers in 2016-17 were 7.65 m a^{-1} (Pensilungpa) and 57.49 m a^{-1} (Durung Drung). Variations in meteorological parameters, mass fluctuations and debris cover extents seem to be the major driving forces behind the dynamics of these glaciers. Also, results from geodetic techniques suggest an average surface lowering of 11.71±0.14 m (rate: 0.69 m a^{-1}) for Pensilungpa and 5.47±0.14 m (rate: 0.32 m a^{-1}) for Durung Drung glacier for past 17 years (2000-2017). Thus, noticeable slowdown of these glaciers together with significant increase in supraglacial debris cover suggests a persistent mass loss scenario, and indicates towards the negative health of the glaciers.

On the Parkachik glacier site we collected 15 day discharge data during this field season. The measurements were made for four time intervals (9 am, 11 am, 2 pm and 5 pm), with an hourly reading after every two days and a fortnightly reading on 25-26 September, 2017 (Fig. 35e). 15 day melt-water discharge measurement revealed its strong relationship with snout disintegration pattern, evidenced twice during the said time period. Volume of water discharged from the glacier was estimated to be 7.91x0^6 m^3 for the measurement duration while the average daily melt-water discharge was 6.1 m^3/sec. Also, mean daily discharge estimated for the 15 days interval showed good positive correction (r = 0.78) with temperature

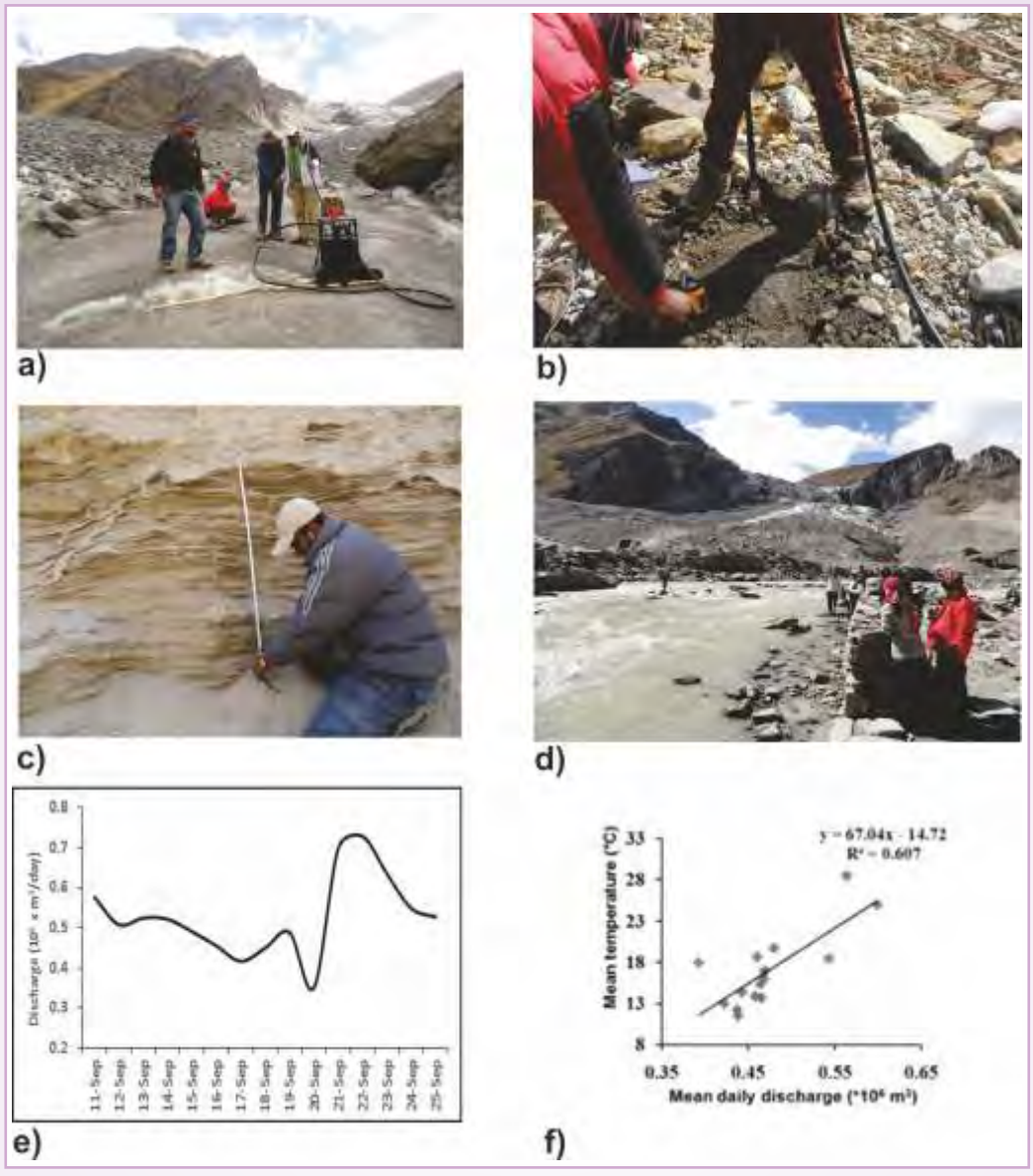

Fig. 35: Field photograph and graphs showing the field activity and results of 2016-17. (a) Stakes networking over the glacier surface, (b) temperature measurements (ice and debris), (c) OSL sample sites, (d) discharge site, (e) result of 15 days discharge at Parkachik glacier, and (f) relationship between daily discharges and mean daily temperature.

indicating the direct dependency of the former on land surface temperature conditions of the region (Fig. 35f).

On the basis of detailed mapping of glacial moraines five stages of glacial advance in the basin between Marine isotope stage 3/4 (MIS-3/4) and MIS-1 were identified. The study suggest that for the older glacial stage I, glaciation occurred during the cool and wet MIS 3/4 dated ~33±6ka. The stage II glaciation began with the onset of LGM (MIS-2). Stage III represent the Younger Dryas (YD) cooling stage, whereas, the stage IV and V glaciation occurred during the early Holocene cooling event and late Holocene (MIS-1) dated between 2 to 8 ka.

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

The intermountain Soan basin in Una district of H.P, India is located in a typical sedimentary rock sequence comprising sandstone, clay and boulder rocks in Outer

Himalaya. Hydrogeologically, the basin is divisible into hill region and synclinal valley fill in central part of the basin. Groundwater plays an important role in social and economic development of the area by meeting more than 90% demand for irrigation and drinking purposes. The groundwater samples collected from tubewells and hand pumps are analyzed for major ions, trace metals and stable isotopes ($\delta^{18}O$ and δD). Geochemically the dominant hydrochemical facies in the Una Basin are Ca-HCO_3; Ca-Mg-HCO_3 and Na-Cl type at few locations. A relatively lower ionic concentration in the valley fills indicates dilution and low residence time of water to interact with the aquifer mass due to high porosity and permeability. The ionic ratios of 0.9, 0.8 and 3.8 to 5.7 respectively for (Ca+Mg) : HCO_3, (Ca+Mg) : (HCO_3+SO_4) and Na : Cl, suggests that ionic composition of groundwater is mainly controlled by weathering of rocks, particularly by dissolution/ precipitation of calcrete and calcite present in rock veins and Ca-Na feldspar present in conglomerate deposits comprising gneiss, granite, slate and quartzite derived from the Higher and Lesser Himalaya during the formation of Siwalik rocks. Although, Na, K, NO_3 and SO_4 are introduced in the groundwater through agricultural practices, Na has also been introduced through ion exchange processes that have occurred during water-rock interaction, as indicated by negative CAI values. Factor analysis further suggests three major factors affecting the water chemistry of the area. The first two factors are associated with rock weathering while third is anthropogenic processes associated with high nitrate and iron concentration. Fe and Mn concentrations exceeding WHO and BIS standards are also present at few locations in the study area. The recharge of groundwater in the Outer Himalaya is entirely through Indian Southwest Monsoon and depleted ratios of $\delta^{18}O/\delta D$ in valley region indicate infiltration from irrigation in recharging the groundwater and fractionation of isotopes of precipitation due to evaporation before infiltration. High d-excess values and inverse relation with $\delta^{18}O$ are indicative of secondary evaporation of precipitation during recharge of groundwater.

SPONSORED PROJECTS

MoES Sponsored Project

Title: Multi-Parametric Geophysical Observatory for Earthquake Precursory research at Ghuttu, Garhwal Himalaya

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

Multi-Parametric Geophysical Observatory (MPGO), a state-of-the-art experiment of continuous measurement of different geophysical and meteorological parameters are being carried out at Ghuttu, Garhwal Himalaya for the last more than 10 years. The observatory located at a remote site away from culture noise is established through Ministry of Earth Science (MoES) sponsored project under the National programme of earthquake precursory research. Multiple geophysical parameters ranging from inert gas (radon), geomagnetic, electromagnetic, gravity, crustal deformation, seismic along with meteorological and hydrology domain are incorporated at this single site for earthquake precursory research. The detail information of the work carried out during 2017-2018 is given below

Strong motions recorded at MPGO

Digital accelerograph, for strong motion recording is one of the component of MPGO, Ghuttu. This data includes only strong events of local and regional distances which are very useful to analyse pre-, co- and post-seismic changes. The Peak Ground Acceleration (PGA) plot of vertical component, along with magnitude and epicentre distance is shown in figure 36. In this data set, Mw 5.3 (Ml 5.6) Rudraprayag event of February 6, 2017 is the strong nearby earthquake. The vertical component PGA value varies between 0.2 to 29.2 mg. This data is used to search for the anomalous changes

Assessment of different components of borehole and atmospheric data set

Continuous data of different parameters recorded in two different boreholes of 10 and 68 m depth at two nearby locations (Kopardhar and Dhopardhar) at MPGO Ghuttu is plotted in figure 37 as temporal variation observed during 2017. Earthquakes occurred at local distances are plotted in figure 37(a) with the origin time of the occurrence of earthquakes. The size of red star denotes magnitude events which varies between 3.0 and 5.6. The impact of these events at this site is measured with seismic index parameter. This is the quantification

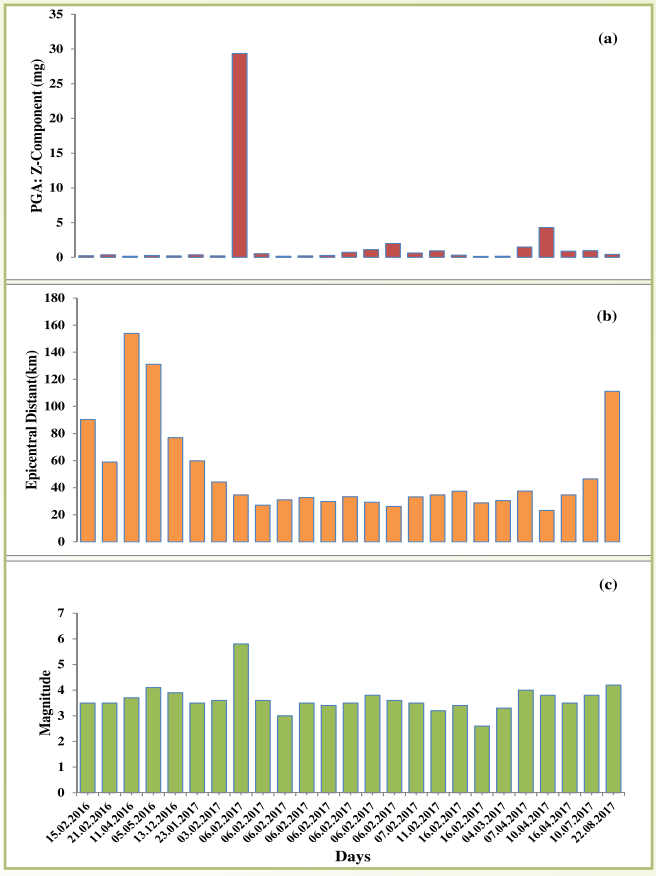

Fig. 36: Earthquake data recorded by strong motion at MPGO, Ghuttu. (a) Peak Ground Acceleration (PGA) of vertical component (b) Epicentre distance (c) magnitude and date of occurrence.

of earthquake impact in the epicentre zone which is measured by the magnitude and epicentre distance where magnitude increases its value and epicentre distance is inversely related. Therefore, close and stronger event has more impact for which expectation of anomalous changes during earthquake preparation period and its occurrence should be more. Temporal variation of radon emanation in soil and water is shown in figure 37(b) and figure 37(c), respectively. The level of the water table, rainfall precipitation, subsurface temperature measured at different depths within the borehole, atmospheric temperature and atmospheric pressure variations are also plotted simultaneously. Unfortunately, the radon probe of underground water was not working for most of the period. Whole data set indicates a very small amount of anomaly in the soil radon because the changes during monsoon period are

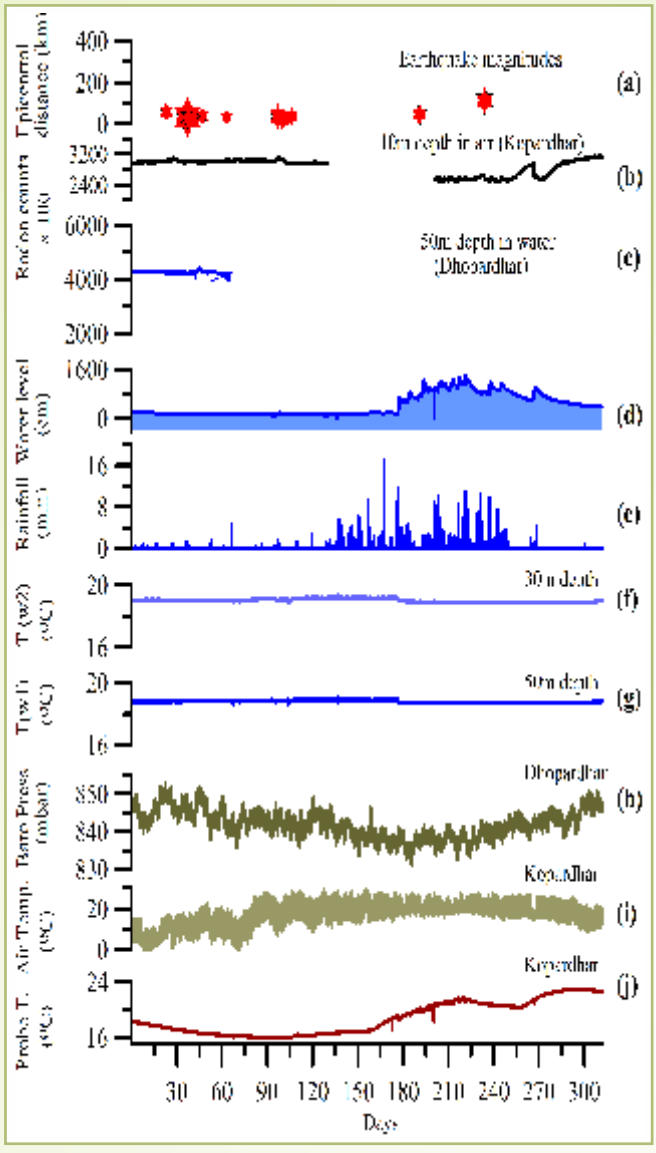

Fig. 37: Temporal variation of borehole data of MPGO Ghuttu of 2017. (a) earthquake magnitude and epicentre distance (b) soil radon at 10 m depth (c) water radon observed at 50 m depth (d) water level changes (e) rainfall (f) temperature at 30 m depth (g) temperature at 50 m depth (h) atmospheric pressure (i) atmospheric temperature (j) temperature at 10 m depth.

high and therefore other anomalies are suppressed. During monsoon period, July to August a high precipitation of rainfall adds water within uppermost crust charging the ground water table. Therefore, high fluctuation and an increase of water level is observed during this period. The sub-surface temperature at 10, 30 and 50 m depths remains almost constant with some fluctuations during the monsoon period. Atmospheric temperature and atmospheric pressure have very high daily fluctuations interlinked with each other and influenced by solar radiations. These two parameters also show annual variation suggesting seasonal changes.

High variations of these parameters recommend to assess and remove the background regional effect at a particular site for extracting anomalous changes associated with seismic activity. Figure 38 plots data of only 65 days of January and February months of 2017 to recognise changes with respect to Mw 5.3 located at ~40 km distance. This is the strongest event of this region occurred during 2017 which has 29.37 mg PGA value at vertical component at this site. Before the occurrence of this earthquake, a trend of high soil radon is noticed for about 10 days with first gradual increase reaching to highest value about 7 days before earthquake origin time. The amplitude of anomaly is not high but it can be treated as anomalous changes. Further analysis of this data after removing the effect of atmospheric pressure enhances the amplitude of this anomaly. Comparison of this data set with the data series of other years indicates that this anomaly is very low. Nepal earthquake of 2015 has high amplitude and of longer duration anomalous changes in both radon and water radon.

Magnetic data observations

Ultra Low Frequency (ULF) geomagnetic data is analyzed corresponding to the above mentioned Rudraprayag earthquake. Considering earthquake process as a self-organized critical (SOC) system based on flicker noise characteristics, fractal dimension for each day is estimated and plotted in figure 39. In this study hourly data is used from 19:00-20:00 hrs (UT) corresponding to local midnight (00:30-01:30 hrs) for each day. The selection of midnight data is to have minimum influence of ionospheric origin signals and cultural disturbances. Frequency band 0.03-0.1 Hz is selected because seismo-EM signals dominant in this frequency band and spectrum follows power law. A broad fractal dimension variability between 0.5 and 1.3 was observed in X component of ULF band variations. This variability is reduced and limited to 1.3 to 1.5 just before and after 10 days of Rudraprayag earthquake.

Diurnal gravity and pressure variation

Earthquake precursory research is the phenomenon work of identification of anomalous changes in the seismic and geophysical time series prior to the occurrence of strong seismic event. The time series are analyzed with different techniques to remove the background noise from the influencing factors of local,

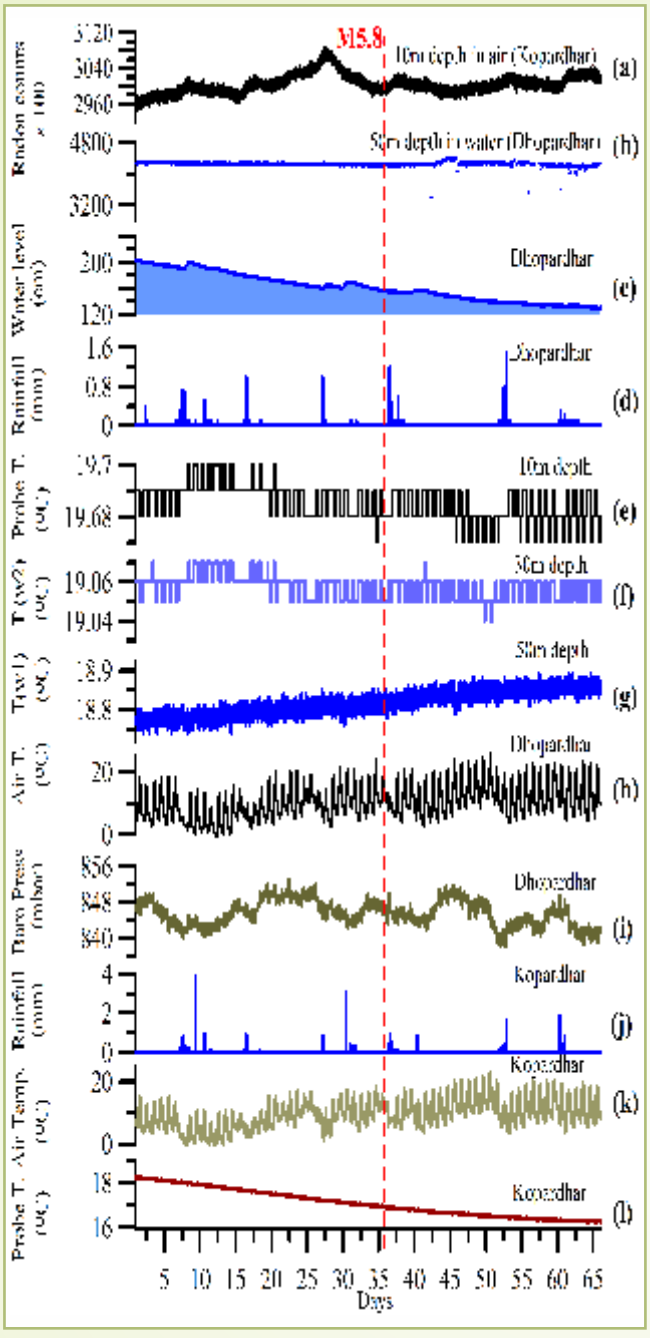

Fig. 38: Records of borehole data of MPGO, Ghuttu for the period of January-February, 2017 (a) soil radon at 10 m depth (b) water radon at 50 m depth (c) water level changes (d) rainfall (e) temperature 10 m depth (f) temperature 30 m depth (g) temperature 50 m depth (h) atmospheric temperature Dhopardhar (i) atmospheric pressure Dhopardhar (j) rainfall Kopardhar (k) atmospheric temperature Kopardhar (l) temperature 10 m depth Kopardhar.

regional and global fields so that to enhance the strength of anomalous signal. We studied the gravity and

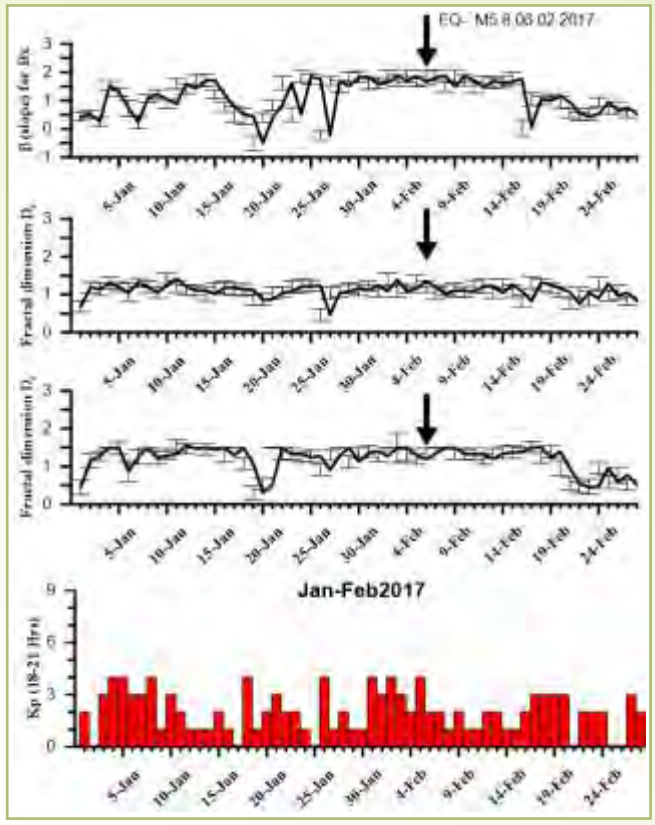

Fig. 39: Variability of fractal dimension from 01 January 2017 to 28 February 2017 corresponding to the Rudraprayag earthquake (M5.8) of 06 February 2017 (Upper three panels). The variation of Kp index (lower panel). The day of occurrence of the earthquake is shown by downward vertical arrow.

atmospheric pressure data recorded simultaneously at MPGO, Ghuttu to remove the inter-dependent effects from these two time series. The gravity data is continuously recorded at the Kopardhar station of MPGO, Ghuttu using high precision Superconducting Gravimeter (SG). Temporal gravity variations is extracted at 1 sample per second (SPS) with a variation to sub-micro gal. The atmospheric pressure is recorded at two sites, Kopardhar and Dhopardhar (at a separation of ~1 km) with continuous sampling of 1SPS and 15 minutes respectively. Four years data (2007-2013) suggest strong diurnal and semi-diurnal patterns in both time series (Fig. 40). Solid earth tides data is extracted from gravity measurement for further analysis of both time series. It is found that the mean monthly air pressure is lowest during the summer (June-July) and highest during winter (October-January) with an annual variation of ~10 hpa. The diurnal variation is ~2 hpa with two minima and two maxima. Atmospheric pressure is monitored routinely as a part of the

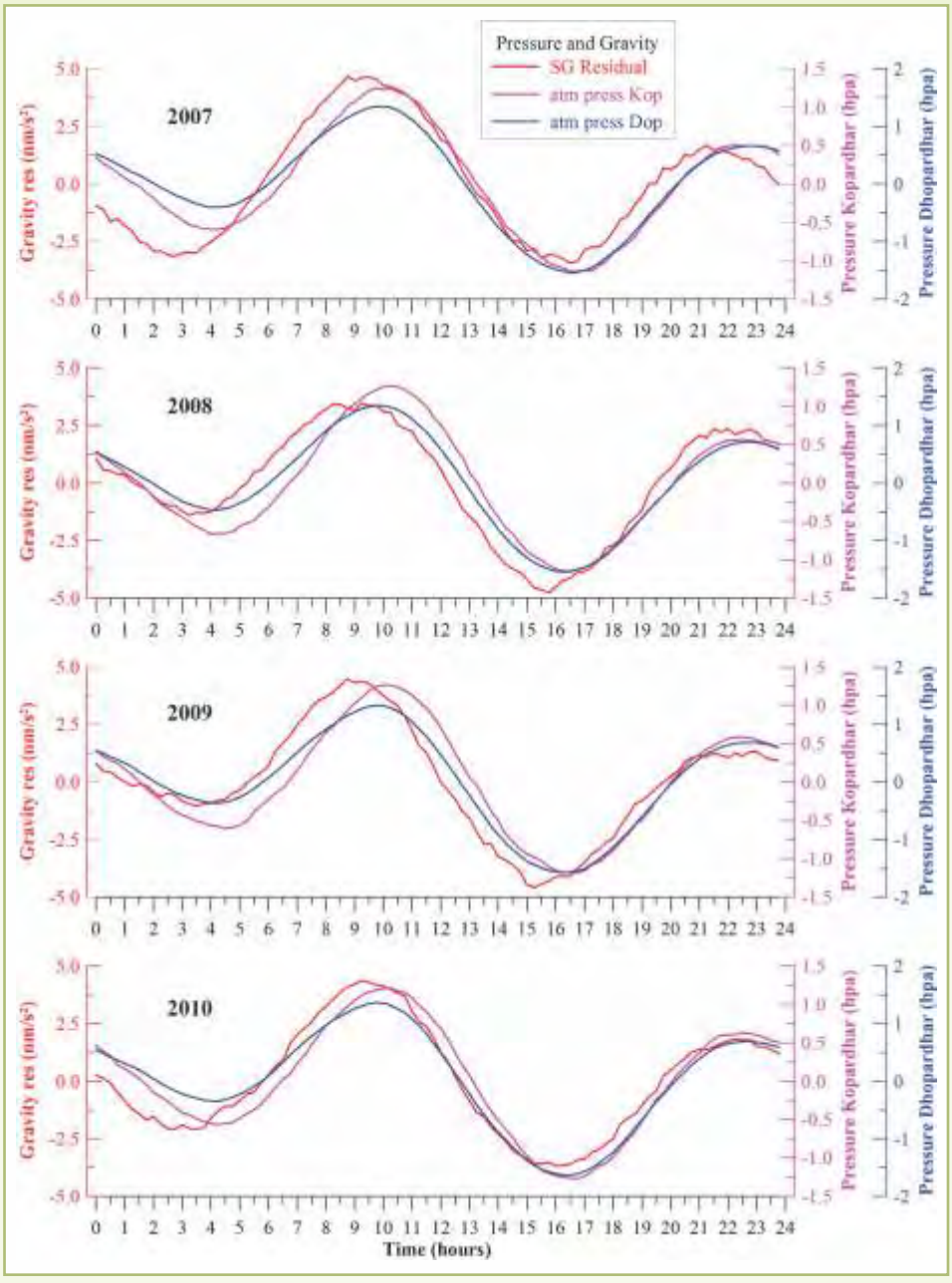

Fig. 40: Residual air pressure obtained after subtraction of average values from continuous. Atmospheric pressure (hpa) were recorded at 15-min interval at two sites (Kopardhar and Dhopardhar); gravity values (nms-2) were recorded at Kopardhar only.

meteorological and geo-hydrological observations. A clear diurnal and near sinusoidal behaviour is seen in these data sets (Fig. 40). Trends in three time series of both the sites suggest strong diurnal and semi-diurnal changes. The power spectrum is used to describe the harmonic component of pressure time series which is obtained through Fast Fourier Transform (FFT) technique. The obtained spectrum plot of whole seven year data set has two distinguished peaks at one and two cycles per day. Atmospheric tides are generated with the combination of gravitational tidal forces, the diurnal temperature cycle and the resonance of the atmosphere.

This study shows strong atmospheric pressure fluctuations in rhythm with the solid earth tides and atmospheric tides in the Garhwal Himalaya. The pressure variation is 2.7-2.8 hpa/day which is slightly

less than that of previous reported values for the tropics. However, it is much higher than that of Polar Regions. Periodic annual changes are observed in the order of ~10 hpa with lower values in summer in the Polar, and higher values in winter with abrupt variations during the monsoon. Parallel observation of continuous temporal records of gravity obtained by using Superconducting Gravimeter supports the influence of tidal forces on atmospheric mass along with semi-diurnal, diurnal and annual trends.

Continuous GPS measurement of crustal deformation

The analysis of Continuous Operating Reference Station (CORS) measurements of crustal deformation in Garhwal Kumaun Himalaya (Fig. 41) confirm strain accumulation on the Main Himalayan Thrust (MHT) under the Outer and Lesser Himalaya with a slip deficit rate of 18 mm/year over a width of ~100 km. For the precise analysis, we remove the seasonal variations from each site using the global models of atmospheric and hydrological loads. During the study, we assumed that the rate of long term convergence is generally equal to the slip deficit rate as only less than 10% of this rate contributes to permanent deformation (Avouac, 2003) and the rest of the deformation is considered as recoverable. The small and moderate earthquakes in the Himalayan seismic belt do not contribute much towards the convergence. Another assumption is that slip rates across the plate boundaries are stationary over the periods of hundred to thousand years. In the Garhwal-Kumaun region, the last great earthquake probably occurred in 1505. Rajendran et al. (2015) suggested that the 1505 earthquake did not affect this region and they suggested that the last earthquake in this region was probably in thirteenth century. This is also supported by Jayangondaperumal et al. (2017) who suggested an earthquake in 1344 CE. If the current rate of strain accumulation applies over past 700 or even 500 years, then sufficient slip deficit has accumulated in the region to be released in a great earthquake.

The study provide evidence for active deformation and strain accumulation for future great and major earthquake in the Garhwal-Kumaun Himalaya. The seismicity based on low and moderate magnitude earthquakes is along a narrow belt around the surface trace of MCT which shows that the locking line coincides with the Himalayan earthquake belt and the topographic front with topography contour of 3.5 km. Other than the evidence of strain accumulation, the GPS measurements also show seasonal variations. These temporal changes are largely caused by the atmospheric

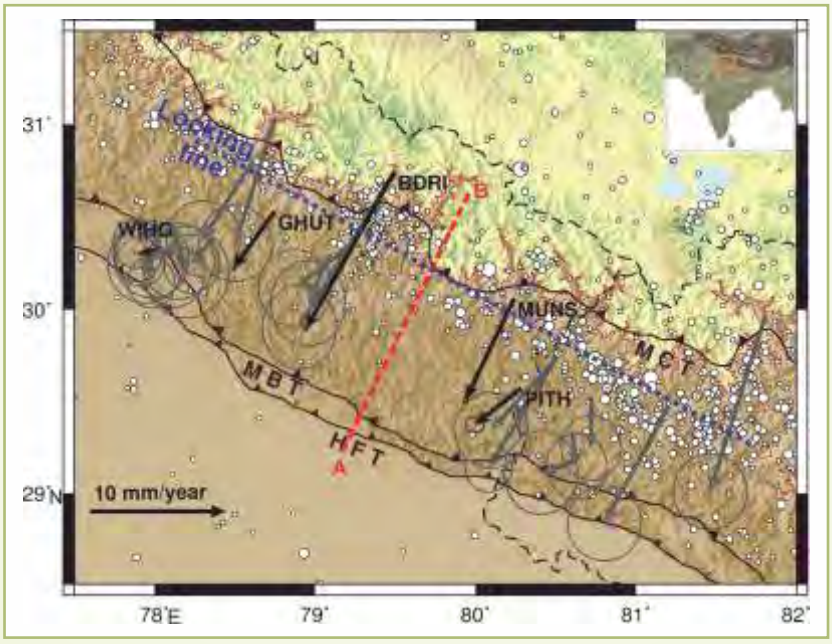

Fig. 41: Site velocities in Indian reference frame of present data (black arrows) and velocity from campaign mode studies (grey arrows from Banerjee and Bürgmann, 2002). All the measurements are projected along profile AB across the major boundaries (HFT, MBT, MCT). White circles are the earthquake epicentres from ISC catalogue during the period 1970-2015 and blue dotted line shows the location of locking line, estimated from this study.

and hydrological variations in addition may be influenced by other factors which need to be explored with observations of longer period.

Crustal structure beneath MPGO Ghuttu based on Receiver Function Modeling

The teleseismic data recorded by a newly established broadband seismological station of MPGO, Ghuttu, have been analyzed using Receiver Function (RF) method for investigating structure of crust. The new broadband seismograph station was established in 2015 and the teleseismic data recorded during the period 2015-2016 have been used for this study. The seismograph station recorded earthquake data with a sampling rate 100 samples per second in continuous mode. The seismograph station consists of Trillium-240 sensor, Taurus data logger. The data are time stamped and synchronized by Global Positioning System (GPS) receiver attached to the data logger. About 100 teleseismic waveform data have been selected based on the criteria: (i) magnitude Mb $\geq$5.5, (ii) epicentral distance 30-90° and higher signal to noise ratio (visual inspection). The information of these earthquakes are obtained from the PDE catalog of US Geological survey (http://neic.usgs.gov). *P*-wave receiver functions computed from earthquakes arriving from different back azimuths show strong variation in the intra-crustal structure. In order to study the azimuthally varying structure, the RFs are classified into four groups based on (i) back azimuth (BAZ) and (ii) ray piercing points computed at Moho depth (named as NE, SE, NW, and SW group). Prior to RF modeling, the H-*k* stacking method of Zhu & Kanamori (2000) has been applied to selected RFs from different groups with clear converted phases and crustal multiple. The H-*k* stacking results show an average crustal thickness of 48$\pm$1.5 km with *Vp*/*Vs* ratio 1.76$\pm$0.01. The RFs from each BAZ group are separately modeled to investigate azimuthal variation. The time domain linearized inversion scheme of Ammon *et al.* (1990) is used for modeling the radial RFs to obtain shear wave velocity model. A strong azimuthal variation of the intra-crustal structure is evident from the inverted models. The inverted models shows an Intra-Crustal Low Velocity Layer (IC-LVL) at depth range ~15-26 km, which is much prominent for NE group with ~17 % reduction in shear wave velocity at the IC-LVL. The waves corresponding to this group arrives from NE BAZ and pierce the Main Central Thrust (MCT) zone. This ray piercing zone at mid crustal depth is characterized by presence of fluid/partial melt as reported by magnetotelluric (MT) studies (Israil et al., 2008; Rawat et al., 2014) causing significant reduction in shear wave velocity. A step jump in the S-wave velocity (*Vs*) is observed at the bottom of this low velocity zone (at ~26 km) and is marked as the Main Himalayan Thrust (MHT). The intra-crustal positive phase prior to the Moho *Ps* phase is observed on the RFs from all BAZ. Based on previous study (Caldwell *et al.* 2013), this phase can be considered as converted phase originated at the MHT. In contrast to NE group, depth of the MHT is comparatively shallower for SE, NW and SW group. This is in conformity with north dipping ramp structure on the MHT reported by previous studies (Caldwell et al. 2009; Rawat et al. 2009). The depth of Moho inferred from inverted models are in conformity with H-*k* stacking result.

MoES Sponsored project

Present day subsurface configuration and Geodynamics of the Kumaun Himalaya: An Integrated Geophysical and Geological Investigation

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

Crustal structure & Seismicity study

During this reporting period the broadband seismological profile consisting of 10 stations along the Kali river Valley, Kumaun Himalaya has been extended by adding three more stations established at Chandani (CHDN), Lohaghat (LGHT) and Damora (DMRA). These additional stations help in reducing the station spacing to obtain high resolution data for imaging crustal structure. The seismological stations are shown in figure 42.

Crustal thickness and Poisson's ratios were estimated at 13 broadband seismic stations established along the Kali river valley, Kumaun (Central) Himalaya using the dataset recorded during May 2016 - November 2017. The seismological profile stretches from Indo-Gangetic plain (IGP) in the south to Higher Himalaya in the north, passing through the Sub- and Lesser-Himalaya. Earthquake data recorded during November 2016 - December 2017 were retrieved from field stations. The teleseismic earthquake data with magnitude $\geq$5.5 and epicentral distance range 30-90° have been extracted from continuous mode data for crustal structure based on Receiver Function (RF) analysis. The hypocentral information of the earthquakes are acquired from catalog of United States Geological Survey (www.neic.usgs.gov). The distribution of epicenters of the recorded earthquakes are shown in figure 42 (inset). The receiver function (RF) method has been adopted to study the structure and

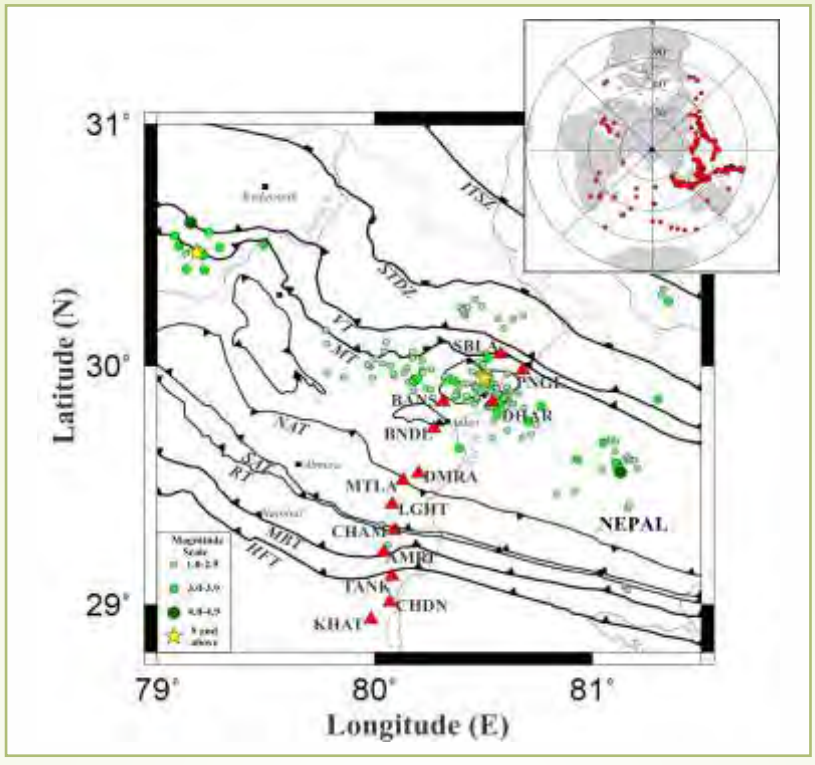

Fig. 42: Map showing major tectonic features of the northwest Himalaya. The broadband seismological stations along the Kali river valley is shown by red triangles. The filled circles with different colour and size show epicentres of local earthquakes with different magnitudes recorded during the period May 2016 - June 2017. The azimuthal distribution of teleseismic earthquakes recorded during the period May 2016-November 2017 used for receiver function analysis is shown in the inset.

composition of the crust beneath the profile. Time domain iterative deconvolution method of Ligorria and Ammon (1999; *Bull. seism. Soc. Am.,* 89, 1395–1400) has been adopted for RF computation. The representative RFs at each station are shown in figure 43. The H-*k* stacking method (Zhu and Kanamori, 2000) has been adopted to analyze the RFs for obtaining average crustal thickness and Poisson's ratio of the crust beneath each station. The study reveals that the crustal thickness beneath the IGP is ~38 km which gradually increases upto ~43 km at the northern most station located in the Higher Himalaya. The Poison's ratio (h) varies within the range 0.23-0.28. Low values of h are recorded in the Sub-Himalaya and inner Lesser Himalaya, which supports more of felsic composition in the region, as compared to exceptionally high h value in the Dharchula region (~0.28) of the outer Lesser Himalaya. The H-*k* stacking results are depicted in figure 44. Such high Poisson's ratio cannot be explained by presence of any solid or dry crustal rocks. The extremely high Poisson's ratio value is interpreted as due to possible presence of mid-crustal fluid/partial melts beneath the region. Also, analysis of about 200 local earthquakes during 2016-17 show a large number of micro-to-moderate magnitude earthquakes forming a cluster at shallow to mid-crustal depths beneath the region (Fig. 42). Presence of fluids influences the rheological property, thus modulating the mechanical and shear strength of crustal rocks producing cluster of observed seismicity beneath the Dharchula region.

Sub-surface structure investigation through seismic tomography

Ambient noise tomography is an important tool to image the shallow crustal structure of the Earth. Using one year of ambient noise data from the 10 broad band seismic stations along the Kali River we extracted the dispersion curves of Rayleigh and Love wave between a pair of seismic stations. These seismic stations are installed along the Kali River starting from Indo-Gangetic (IGP) and up to South Tibetan Detachment (STD). The southernmost station, Khatima is located ~30 km south of the Himalayan Frontal Thrust (HFT) and the northernmost station Sobla is close to the STD. About 140 interstation Rayleigh and Love wave empirical Green's functions with sufficient signal-to-noise ratio

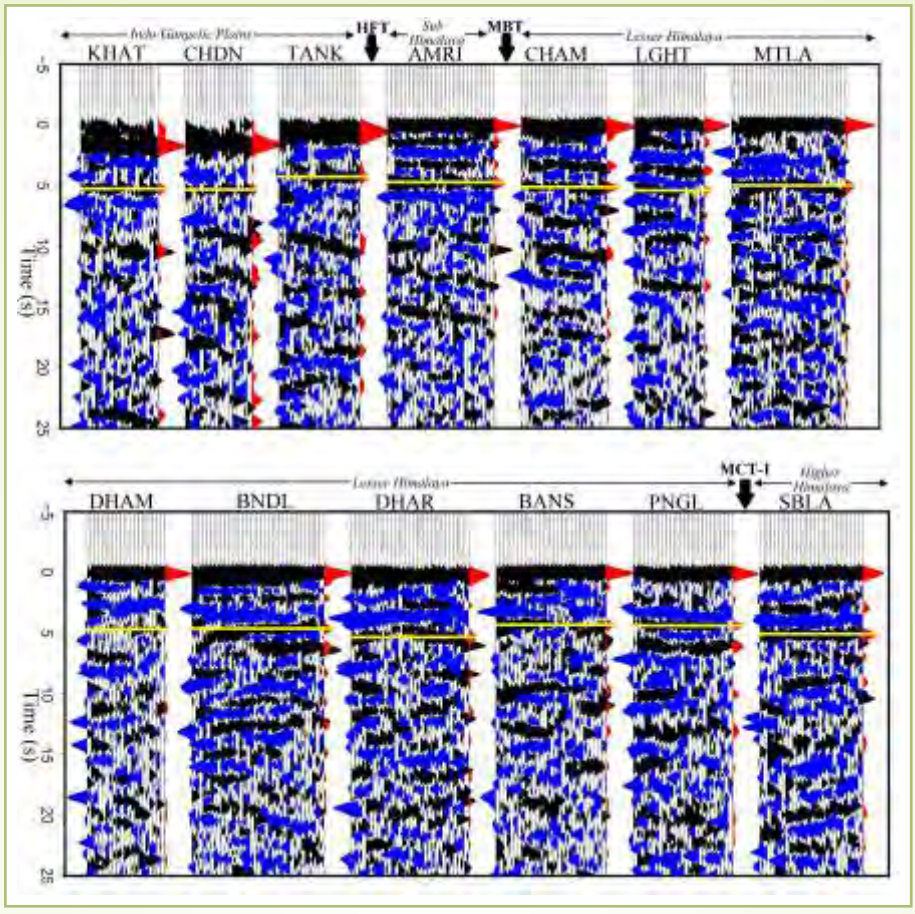

Fig. 43: Time section plot of Receiver Functions of 13 stations arranged from south to north. The stacked RFs are shown as red waveform while the *Ps* phase is marked with yellow line.

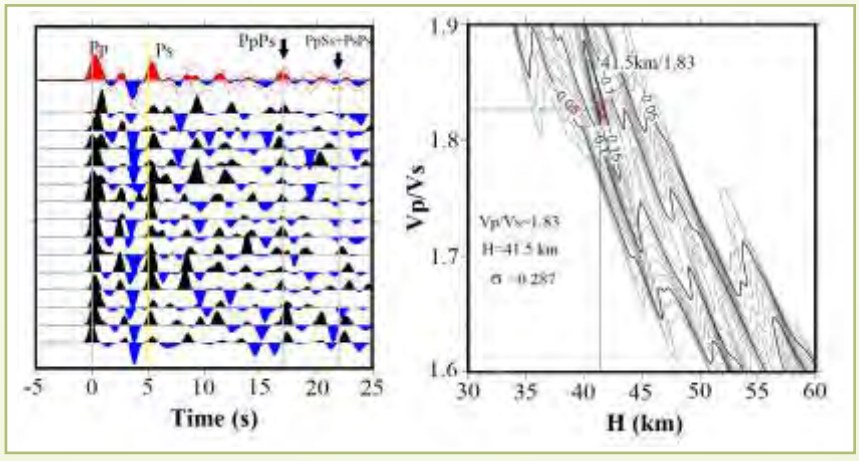

Fig. 44: Example of H-k stacking analysis at DHAR station for selected RF data. The RFs used for HK stacking analysis is shown in on the left panel with their stack RF at the top along with ±1 SD bound computed during stacking. The Moho converted phases is marked by yellow line and its multiples are marked by grey lines at ~17-22 s. The results of stacking analysis are shown on the right panel. The best estimated and values are indicated by the center of the red error ellipse. The average crustal thickness (H) and Poisson's ratio (ϸ) is obtained as H=42 km, and 0.287 respectively.

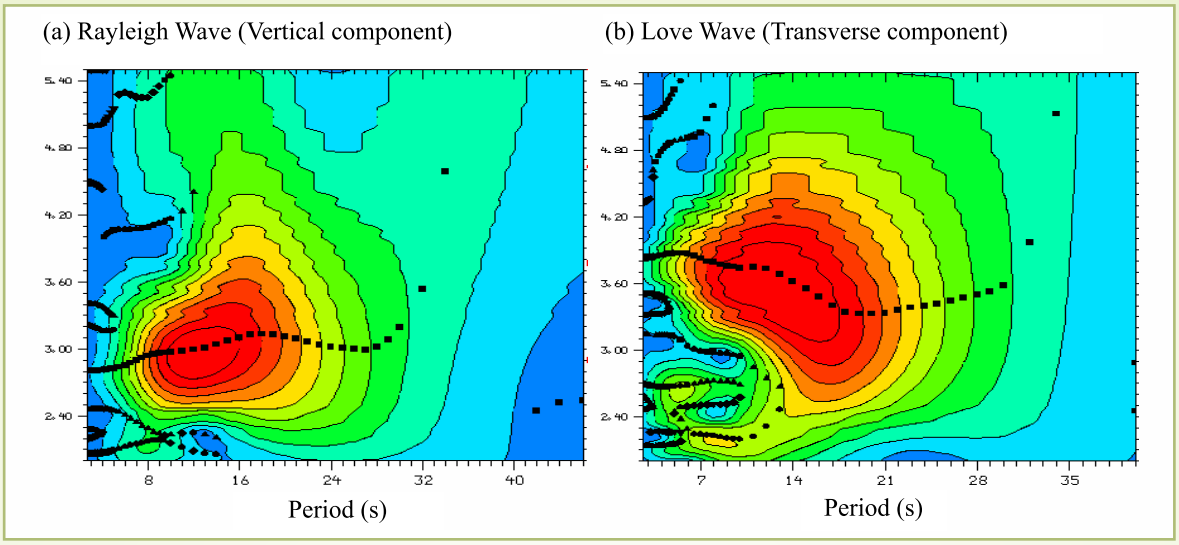

Fig. 45: The frequency-time image constructed from the dispersion curve between Tanakpur and Sobla station using ambient noise data. The red indicates high amplitude and the blue indicates low amplitude. The black dots represent the observed group velocities. (a) the dispersion curve of Rayleigh wave obtained from the vertical component (b) the dispersion curve of Love wave through the Transverse component.

are obtained and used for fundamental group velocity dispersion curves. The obtained dispersion curves are for the period range of 3-25 s using frequency-time analysis technique. The dispersion of Rayleigh wave obtained for the station pair of Tanakpur and Sobla is given in figure 45. The doted black line throughout the measured period range is the dispersion curve of the fundamental Rayleigh wave.

After extracting the continuous raw data, the preprocessing involves deconvolving instrument response, removing the mean and trend, band-pass filtering in the period range 2-100 s, temporal normalization and spectral whitening. We used the multiple-filter technique (MFT) to estimate the group velocity dispersion curve in the period range 3-25 s for each stacked Rayleigh and Love wave green function. The dispersion curves of the IGP has a low velocity (~2.2 km/s) for the smaller period (3-6 s) compared to the other station pairs. It indicates the presence of sediment deposits in the upper most crust as observed previously by Kumar et al. (2018) to other parts of the IGP. As shown in figure 42, the group velocity for this period range for the other pair of stations of the Himalayan region has comparatively high velocity. However, for higher periods (~20 s) for these ray paths the velocity is less, which is the part of the low velocity of the dispersion curve. It may be interpreted with low shear wave velocity in the deeper section of the upper crust. Similar observations are there for the other pair of stations, and therefore, it is a good data set for the sub-surface crustal structure investigation. These are the preliminary results and the additional data of 2-3 years will strengthen the observations.

Magnetotelluric Component

Thickness of sediments in foreland basin is an important parameter for assessing earthquake hazard in foreland basin and south of it. For this, the impedance tensor of sites in foreland basin including sites in Indo-Gangetic plain are analyzed. The morphology of apparent resistivity curves indicate one dimensional nature of regional geoelectrical structure and therefore 1-D modelling applied to get the depth of different layers. Occam inversion is used for the purpose. Within top 1 km two layers of difference in resistivity are delineated. The thickness of first layer is of approximately 400 m and second layer thickness is approximately 550 m. There is moderate difference in resistivity. The top is interpreted as a younger alluvium, whereas the second is interpreted as lower Siwalik.

Geological Analysis

Detailed geochemical and geochronological studies of the Munsiari Formation and the Chhiplakot Crystallines granitic gneisses were carried out to understand their pre-Himalayan tectonic setting, as well as their stratigraphic position within the Himalaya. Bulk rock geochemistry of the basement crystalline rocks show calc-alkaline and shoshonitic compositions for the

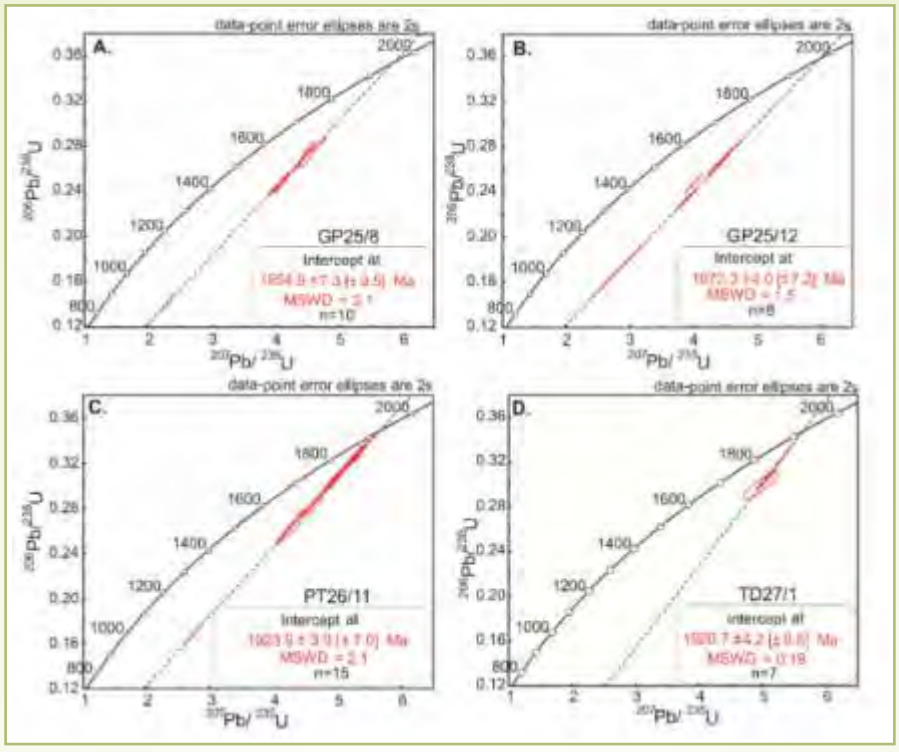

Fig. 46: U-Pb concordia plot for (A-B) Munsiari augen gneiss sample GP25/8 (A) and sample GP25/12 (B), and (C-D) Chiplakot Crystalline Belt sample PT26/11 (C) and sample TD27/1 (D). MSWD is the mean square of weighted deviates.

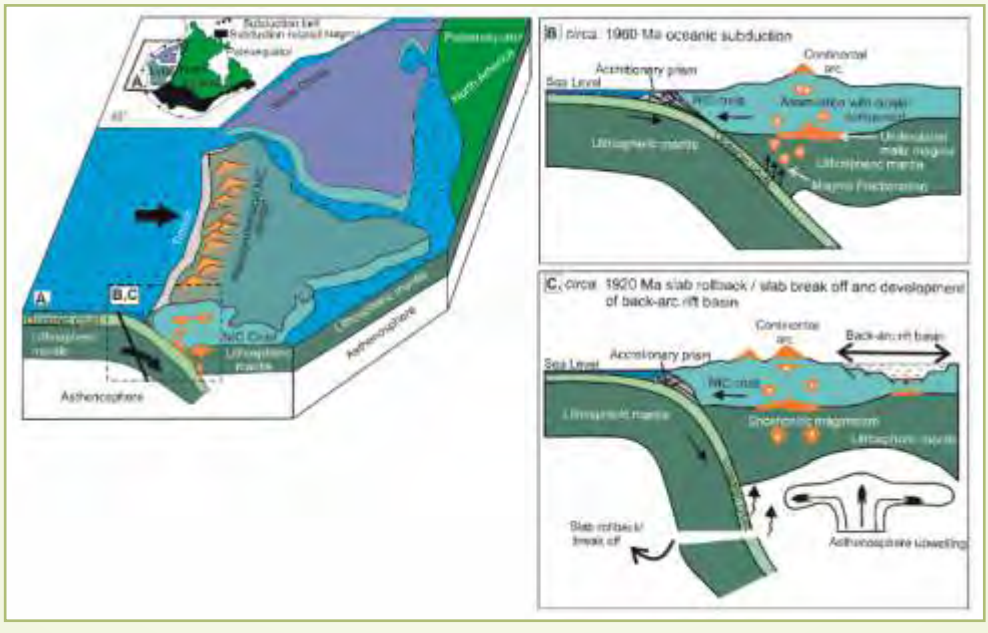

Fig. 47: Cartoon showing different stages of Paleoproterozoic tectonic evolution of northern margin (present-day inner Lesser Himalaya) of north Indian continental crust (NIC; not to scale). (A) Configuration of Indian continent during the Paleoproterozoic and arc magmatism along its northern margin. Figure 1C, prepared after Hou et al. (2008), is shown in the inset. Box marked in the figure shows cross section of the subduction setting that is blown up and shown in two stages in B and C. (B) Oceanic subduction along the north Indian continental crust margin resulting in highly fractionated and assimilated calc-alkaline magmatism. (C) Slab roll-back/break-off, resulting in shoshonitic magmatism and development of back-arc rift basin.

Munsiari and the Chhiplakot Crystallines, respectively. Depletion in Nb, Sr, P and Ti points out towards a magmatic arc origin for both the units. U-Pb chronology of zircon of these samples provide ages varying from ~1950 to 1970 Ma for the Munsiari augen gneiss, and ~1920 Ma for the Chhiplakot Crystallines (Fig. 46). Based on these results, we have concluded that these two crystallines are of Lesser Himalayan origin have formed due to active subduction along the north Indian continental margin during the Paleoproterozoic that resulted in the formation of the supercontinent named Columbia (Fig. 47).

MoES Sponsored Project

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

(Ajay Paul)

The seismicity studies of Garhwal-Kumaun-Himachal (GKH) region (Fig. 48) have been reviewed in the light of Nepal earthquake. The region lies between west of Nepal Earthquake (Mw7.8) and the 1905 Kangra earthquake. The stress drop of 25th April 2015, Mw7.8 earthquake from our data is nearly 234 bars. From the

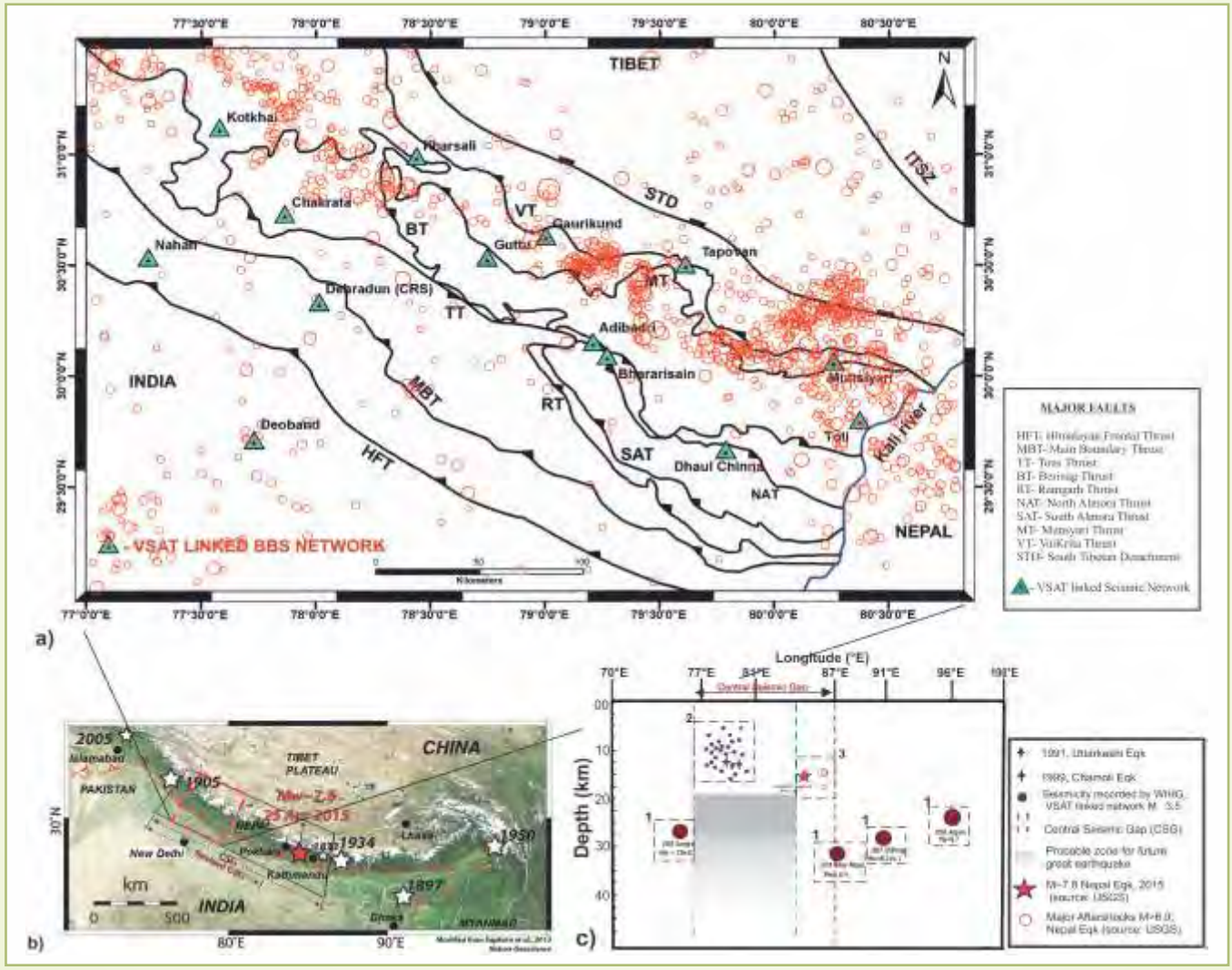

Fig. 48: (a) Epicentral location map of local earthquakes (2007-2015) drawn on the tectonic map of the Garhwal-Kumaun region (map modified after Valdiya, 1980). (b) Epicentral location of four great earthquakes along the Himalayan arc and the location of Seismic Gap for great earthquake. The red dotted block shows the study area. (c) Focal depths of four great earthquake, recent 2015 Mw7.8 Nepal earthquake and events M≥3.5 in the study area since July, 2007. This hatchet box indicates stress drop values corresponding to M~8 Microseismic events here have stress drop values less than 10 bars. Recent Nepal earthquakes have stress drop ~240 bars and the aftershocks M>6.0 have stress drop ~100 bars.

source parameters analysis of the 1184 local events it has been found that 836 events have stress drop values less than one bar. 242 events have stress drop values between 1 and 10 bars. Only 106 events have stress drop greater than 10 bars. The highest value is 69 bars for an earthquake of magnitude 4.9 of 22nd July 2007. The energy accumulation budget when compared with strain energy release indicates that there is a stress drop deficit in this region (GKH). The seismicity events are shallow focused with low stress drop indicating brittleness and vulnerability to high strain accumulation of the upper crust. It has been observed that location of hypocentres of majority of the events, which are concentrated along the Main Himalayan Thrust (MHT), lie within 10-20 km depth. Generally, it is believed that the lower crust is ductile in nature, hence it cannot hold the energy for a large earthquake, but the past great earthquakes have focal depth ≥15 km in the lower crust. Except 1950 Assam earthquake, none of the other great earthquakes are instrumentally recorded, hence authors understand that, their focal depths are not well constrained. Therefore, the upper part of lower crust (shaded grey in figure), can be suggested as the probable zone for the location of great earthquake in future.

Rampur Earthquake Swarm in Himachal Pradesh and its seismo-tectonic implications

On 28th August 2016, a swarm activity of 58 earthquake events occurred near to the Rampur region (henceforth termed as Rampur swarm) of Shimla district in Himachal Pradesh. Two medium intensity earthquakes measuring magnitude of 4.6M and 4.3M on Richter scale had jolted the region. However, there were no reports of casualties and damage to properties. This region along the Sutlej valley is seismically active but comparatively quiet as compared to the further northern part. This swarm occurred in Rampur region of the Kullu-Rampur Tectonic window (KRT window) and is characterized by existence of several tectonically active faults/thrusts. The objective of study is to determine the source parameters and mechanism of these events to understand the possible seismo-tectonic implications in the region. In order to determine the spectral parameters for SH wave, Brune's source model has been employed to evaluate source parameters. This is significant to understand the dynamic rupture process and the scaling relations of the earthquakes and to characterize the events source. To determine the focal mechanism of the events, two different MT inversion techniques were used viz., ISOLA focimt. The ISOLA method has been utilized to perform the full waveform inversion for the earthquakes of M≥3.5 which has better signal-to-noise ratios (SNR) with minimum four station records. For the smaller events with 2.6<M<3.2 magnitudes, the focimt method with at least eight station records have been used. Instrument corrections were also performed for these events during the raw data preparation.

Spectral analysis shows low stress drop values (from 0.05 to 28.9 bars), suggesting that the upper crust has low strength to withstand accumulated strain energy in this region. The Moment Tensor (MT) solutions of 12 earthquakes ($\geq 2.7M_L$) obtained by waveform inversion yield the shallow centroid depths between 5 and 10 km. All these events are of dominantly thrust fault mechanism having an average dip angle of ~30°, which is comparable to the surface trend of the BT i.e. ~35° in the region. The P-axes and the maximum horizontal compressive stresses are NE-SW oriented; the relative direction of the Indian Plate. The seismic cross sectional study along the Sutlej valley illustrates that this swarm activity would be the result of reactivation of BT or along the duplexes/splays to the Main Himalayan Thrust. During the inter-seismic period, the trapped fluids in a high conducting layer may migrate upward through the overlying brittle crust in response to the continuous accumulation of stress in the region. A decrease in the shear wave velocity (Vs) has been observed at the depth of 9 to 20 km, hence the role of the fluids cannot be ruled out which decreases the frictional strength and it alters the prevailing stress conditions of the surroundings.

DST-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, Ladakh: An Integrated Magnetotelluric, Seismological and Structural Approach

(Gautam Rawat, Devajit Hazarika and Koushik Sen)

Magnetotelluric transfer function estimated at eight sites were analyzed for dimensionality indicators. Conventional skew parameter and Bahr's phase sensitive skew are calculated for each site. Figure 49 displays the Bahr's phase sensitive skew for the profile. From the figure it is observed that for most of the period, this parameter is below 0.3, a threshold limit beyond which MT responses are considered 3D. MT sites at the north and south extreme of profile is having higher phase sensitive skew, indicating the complex interaction of MT signals with boundary thrust zones and subduction system at profile ends.

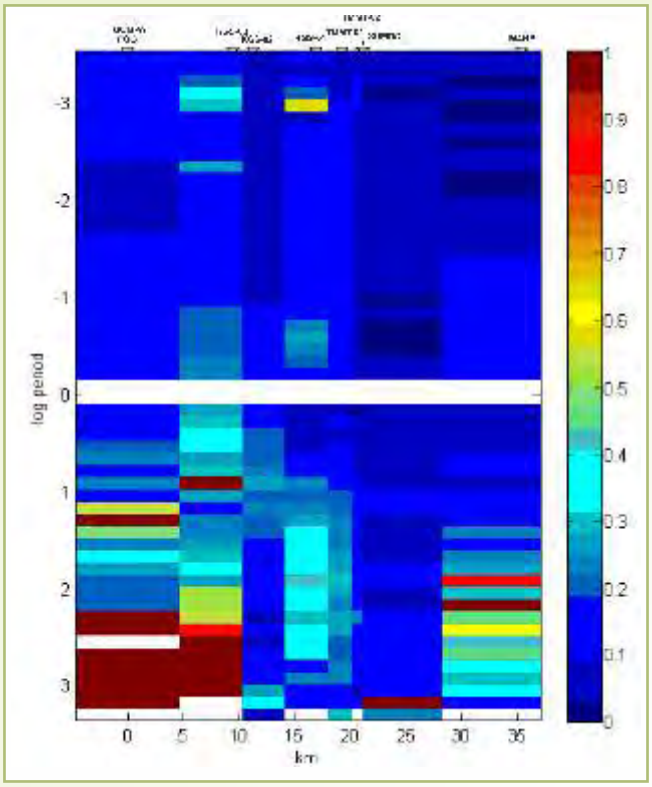

Fig. 49: Bahr's Phase Sensitive Skew for MT sites along Tso Morari

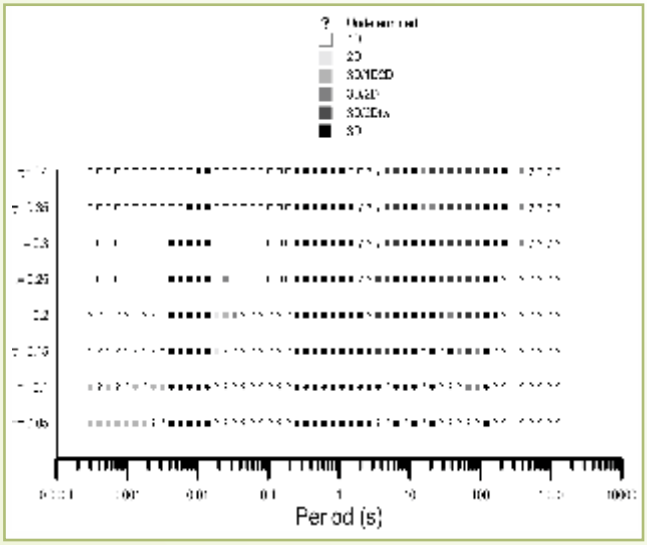

Fig. 50: Dimensionality distribution over different period band, like underdetermined, 1D, 2D, 3D/1D2D, 3D/2D and 3D/2Dtw.

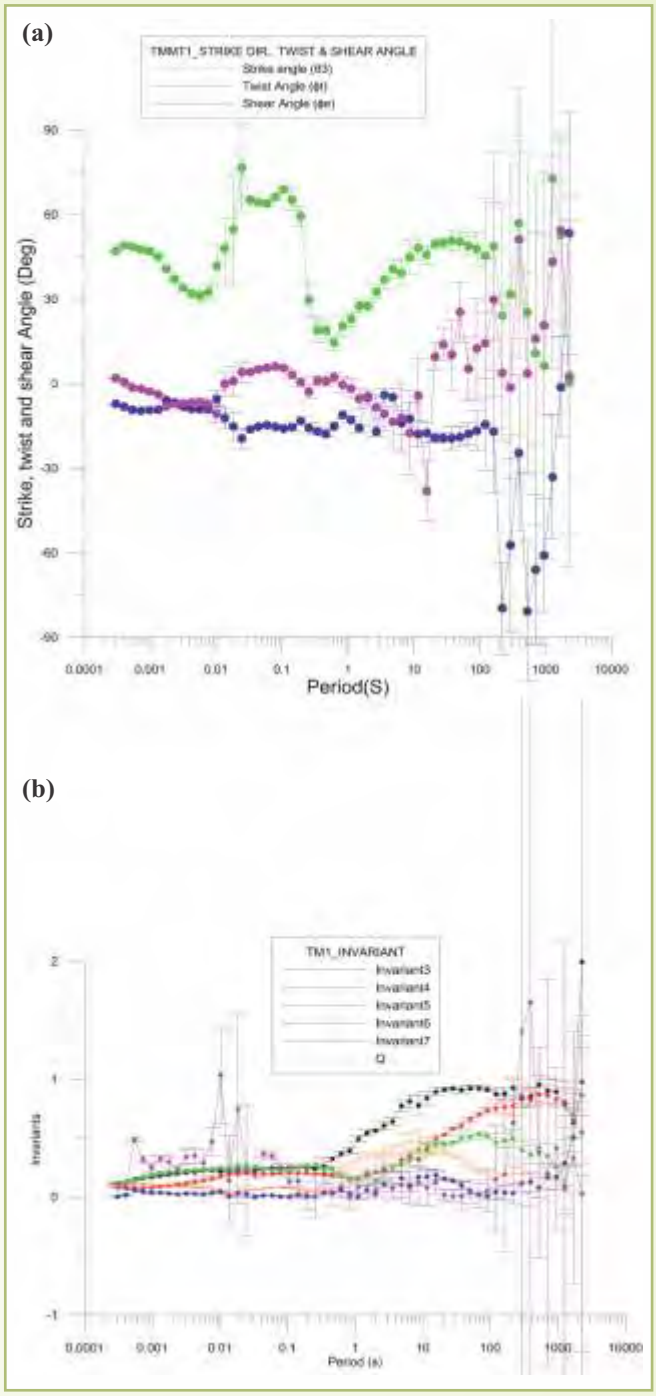

Fig. 51: (a) Strike Angle, Twist angle and shear angle shows the pattern of dimensionality. (b) WAL Rotational Invariants have shown their own kind of dimensionality of structure.

Further we have attempted WALDIM dimensionality analysis based on WAL rotation invariant. Figure 50 summarizes the outcome of this analysis for Gompa site. This figure clearly shows the effect of threshold parameter tau for classification of dimensionality parameter. If we couple it with Bahr's phase sensitive skew variation of Gompa 1 site, we find that for Tso-Morari region tau = 0.25 is consistent with it. Therefore

to our further analysis, we have used tau = 0.25 as a threshold limit.

From figure 51(a), the WALDIM analysis suggest variation of strike with period, and approximately two strikes angles are visible for the Gompa site. The strike angle for 100 Hz to 1 sec is different from strike below 1 sec and above 100 Hz. The two different strike angles indicate orientation of two different tectonic fabrics in the region. However, we are still in the process for understanding this relation.

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. Jayangondaperumal and Pradeep Srivastava)

The pattern of strain accumulation and its release during earthquakes along the eastern Himalayan syntaxis is unclear due to its structural complexity and lack of primary surface signatures associated with large-to-great earthquakes. This led to a consensus that these earthquakes occurred on blind faults. Toward understanding this issue, paleoseismic trenching was conducted across a ~3.1 m high fault scarp preserved along the mountain front at Pasighat (95.33°E, 28.07°N). Multi-proxy radiometric dating employed to the stratigraphic units and detrital charcoals obtained from the trench exposures provide chronological constraint on the discovered paleo-earthquake surface rupture clearly suggesting that the 15th August, 1950 Tibet-Assam earthquake (*Mw* ~ 8.6) did break the eastern Himalayan front producing a co-seismic slip of 5.5±0.7 m. This study corroborates the first instance in using post-bomb radiogenic isotopes to help identify an earthquake rupture.

MoES Sponsored Project

Neo–active tectonics of Surin Mastgarh anticline and associated structures around Ravi River exit area in the Panjab Sub-Himalaya: Implication for seismotectonics of the Kashmir seismic gap region

(R. Jayangondaperumal, V.C. Thakur and N. Suresh)

We mapped geomorphic surfaces across the Surin Mastgarh Anticline (SMA) in three river valleys of Ravi, Uji and Chenab, and quantified the growing rate of SMA. The estimated shortening rate for SMA is comparable with the long-term deformation rate inferred based on retro-deformation method and it accords with the geodetic rate.

DST-SERB Sponsored Project

Facies Mapping of Gangotri Glacier Using AWIFS Data: A Super Resolution Approach

(Aparna Shukla and M.K. Arora (PEC University of Technology, Chandigarh)).

Glacier surfaces can be classified into a range of facies or zones, which can be used as proxies for annual mass balance, and also play a significant role in understanding the glacier dynamics. The main focus of the proposed study is twofold: (i) to investigate the utility of a super-resolution approach to develop large scale glacier facies maps of Gangotri glacier using moderate resolution AWiFS by applying at different scale factors (Fig. 52), and (ii) to apply the developed technique over an extended area including tributary glaciers of Gangotri and to facilitate monitoring of the frontal changes. Based on their surface reflectance, various glacier facies were identified in the study area and then classified at sub-pixel level using multi-temporal AWiFS data (2005-2016) in combination with ancillary data. The sub-pixel classification outputs were then used in the developed super resolution mapping algorithm (tested on synthetic data initially) to produce glacier facies maps at large scale and results were validated against the Sentinel-2A MSI data. Zoom factor (is an important parameter in SRM that determines the degree of sharpening achieved, and its impact on the classification accuracy was also assessed using synthetic and July 2016 datasets. The 10 m super resolved maps were then used to derive boundaries of Gangotri and attached tributary glaciers for the estimation of glacier retreat. The spatio-temporal distribution of these glacier facies was also assessed which further helped in determining the firn line altitude.

Results showed that the improved Pixel Swapping Algorithm (PSA) is quite effective in spatially locating the features mapped at sub-pixel level. For eight-class problem, overall accuracy (OA) and Kappa coefficient (K^) obtained from the sub-pixel classification of July 2016 and September 2016 ablation datasets were found to be 63.48% & 62.81% and 0.50 & 0.45, respectively. The same for three-class problem (October 2006 post-ablation dataset) the values raised to 77.87% and 0.64, respectively. Despite the decadal gap, sub-pixel classification accuracy got improved by 14% in this case. Likewise, SRM of July 2016 and September 2016 datasets for eight-class problem gave overall accuracies (OAs) and K^ of 89% & 87% and 0.80 & 0.77, respectively. While for three-class problem (October 2006 dataset) OA and K^ improved to 91% and 0.85,

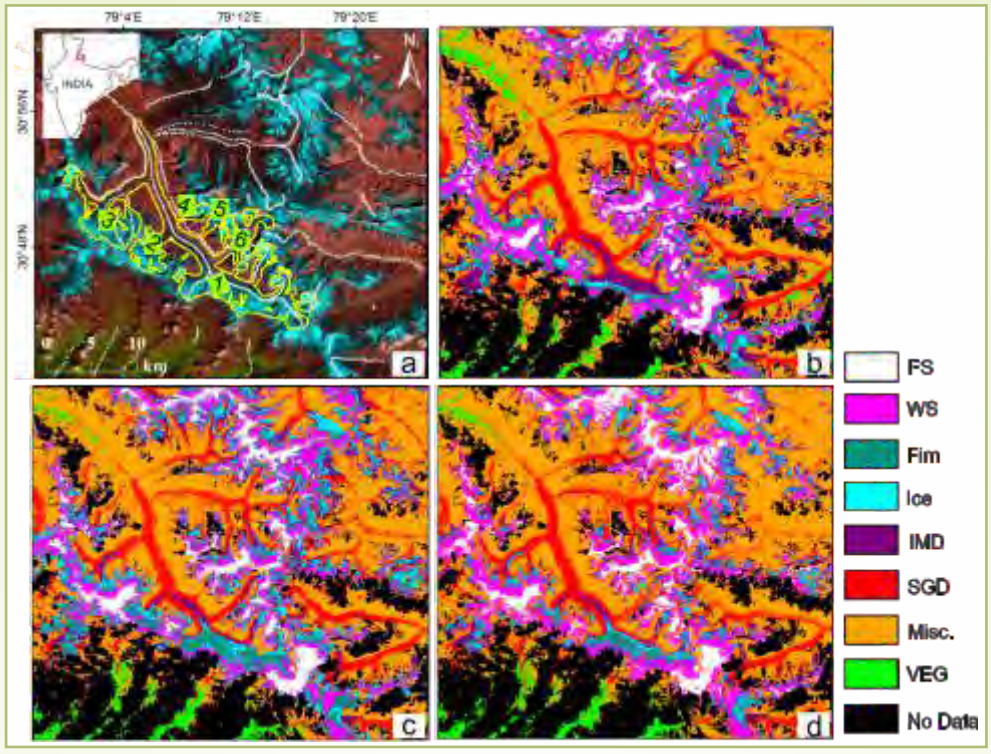

Fig. 52: Super resolution mapping of Gangotri and surrounding glaciers. (a) MSI image in false color composite showing the study area. (*1= Gangotri glacier, 2=Ghanohim glacier, 3= Kirti Bamak glacier, 4= Glacier X, 5= Glacier Y and 6= Swachhand glacier)*; (b) and (c) 10 m super resolved maps derived from July 2016 and September 2016 datasets; and (d) 10 m reference hard classified map obtained from MSI data.

respectively. Hence, reducing the input number of classes significantly increases the sub-pixel classification and SRM accuracy. Table 2 compares the areal estimates of glacier facies derived from 10 m super resolved maps (Z_f= 6) of input July 2016 and September 2016 data and the reference hard classified map (Fig. 52).

While assessing the impact of on the classification accuracy, it was observed that small zoom factors give better super resolved maps from synthetic data and increasing the zoom factor leads to distortion in class shape and jagged boundaries. Whereas, in case of AWiFS data which generates the super resolved map at a spatial resolution comparable to the original reference data produces the best SRM results. For example, in this case reference map is generated at 10 m spatial resolution and the input fraction images at 60 m spatial

Table 2: Area of mapped glacier facies estimated from super resolution mapping (during July 2016 and September 2016) input images and hard classification (at 10 m spatial resolution) of reference data. *RF= Reference Fractional; HC=Hard Classified; FS=Fresh-snow; WS=Wet-snow; IMD=Ice-mixed debris; SGD=Supraglacial debris; Misc.= Miscellaneous; VEG= Vegetation.*

Super resolved area (km^2)	FS	WS	Firn	Ice	IMD	SGD	Misc.	VEG
AWiFS July 2016	55.02	191.932	92.638	48.699	94.347	166.533	630.414	42.363
AWiFS September 2016	90.102	174.332	95.187	89.763	69.577	172.727	588.06	42.20
MSI September 2016	91.911	208.928	53.583	58.517	63.511	173.953	640.518	33.559

resolution. Aof 6 was therefore found to be optimal in our case, giving the highest OA of 89% for July 2016 dataset.

The spatio-temporal variability of glacier facies present on the surface of Gangotri and its attached tributary glaciers revealed that during the years 2005-2016 there has been progression in the area of FS, WS and IMD by 36%, 15% and 64%, respectively. While the firn and ice facies have declined in area by 47% and around 54%, respectively. SGD cover has also shown 8% increase in its area. During this time period, IMD, ice and firn have changed the most, and the AAR has decreased from 0.48 to 0.46. The firn line of main trunk of Gangotri glacier has shifted to higher elevation by ~154±23 m. A similar upward shifting of firn line altitude was observed for its tributary glaciers like Ghanohim glacier, Kirti Bamak glacier and Glacier X and has moved by ~72±16 m, 107±23 m and ~6±1 m, respectively. Whereas, the firn line has migrated to lower elevations for Swacchand glacier and Glacier Y by 31±1m and 224±62 m. Further, Gangotri glacier showed an average retreat of 364.244±375 m (33.11307 m/y) during the period 2005-2016. The differential rate of retreat has also been seen at different portions of the snout. Left lateral shows the maximum retreat rate of 62.962 m/y, followed by right lateral (retreat rate=33.650 m/y) and minimum retreat rate is observed at the central part (17.920 m/y). For shorter time periods, maximum retreat was found during 2005-2006 (~101±82 m) while it was minimum during 2010-2011 (19±37 m).

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, S.K. Bartarya and Vikram Gupta)

This National Mission project on Sustaining Himalayan Eco-system mainly pertains to establishing database and information system about geological resources (Quaternary deposits, 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 the work towards compilation of geological data from primary and secondary sources have been undertake for the Uttarakhand Himalaya. Himachal Pradesh Council for Science and Technology, Shimla has been contacted to chosen as one of the Task Force Partner to work towards data collection in the Himachal Himalaya. The search for two more task force partners is underway to work in the Jammu & Kashmir and in the northeastern Himalaya.

In general, there is an immediate and sensitive response of spring flow and recharge of aquifers to rainfall events in the Himalayan terrain. It has been observed that due to continuously changing climatic conditions, rainfall is gradually decreasing in the Kumaun Himalaya. During 1991-2010, the number of rainy days has declined from 60 to 50, and annual average rainfall has decreased from 135 cm to 112 cm with few exceptions in between. This decreasing rainfall has drastically impacted the groundwater storage level in the region. The groundwater storage level in the Kumaun Himalaya is ~12% as against the recommended norm of minimum 31%.

In the south and west districts of Sikkim, the relation between the discharge of springs and rainfall pattern has also been noted. In this region, spring discharge follows an annual, periodic rhythm that is strongly dependent on the amount of rainfall. The drought prone areas receive little rain during the pre- and post-monsoon season and thus show dependence on rainfall for the recharge of aquifers. The results indicate that in the scenario of climate change, changing precipitation pattern can adversely influence the discharge of springs in the rain shadow region of the Himalaya. However, in the Kashmir region, spring discharge shows an inverse relation with precipitation. During 1995-2005, a decrease of ~40-70% in the discharge of springs has been noted, and this was positively correlated with the melting of glaciers. In Kashmir, most of the recharge areas are in uplands and melting of snow and glaciers supports the groundwater system.

The recent updated inventory of glaciers in the Indian Himalaya documents large number of smaller glaciers (<1 km^2) with their subsistence above 4500 m asl. These small glaciers (<1 km^2) accounts 66% of the total number, covering 12% of the total glacierized area with only 4% of the total ice volume in the region. However, the larger glaciers (>5 km^2) are 7% in number with 60% of glacierized area and 77% of total ice volume. Further, smaller glaciers lies above the 4500 m asl maintained the microclimate of the high altitude region. Whereas, the larger glacier flow downward to the valley up to 3800 m asl and sustain the cold climate in the valley. Continuous mass loss and recessional rate

of larger glacier concurrently increasing the number of glaciers due to fragmentation of the tributary glaciers.

The collation of spatial distribution of all the landslides have also been carried out for input to the GIS environment. An emphasis was also given on the compilation of data related to cloudbursts that have been occurring in the Himalayan region. It has also been noted that during recent past their frequency has increased many fold, thus posing threat to habitat of the region. There is a pronounced effect of climate change on the distribution and the frequency of landslides in the IHR. Of late, it has been noted that there is a pronounced shift in the climatic factors in the form of (i) increased extreme climatic/rainfall events in the Himalayan region, (ii) more area falling under the influence of rainfall, which were dry otherwise, and (iii) the increased frequency of cloudbursts. All these factors have contributed towards increased occurrences of landslides in the Himalayan region. Further, it has been noted throughout the Himalaya that after 2009 the intensity of rainfall particularly during monsoon has increased manifold. Also the century witnessed numerous extreme climatic events that has been recorded.

Database on the mines and mining activities for the state of Uttarakhand, Himachal and Jammu & Kashmir have been prepared. In general, these activities are concentrated along some particular known mineralization zones, and cause damage to the environment and many slope instability problems. Further work towards data compilation in the GIS environment is continuing.

DST Sponsored Project

Geotechnical characterisation of the soil/rocks with special reference to active landslides in Mandakini valley, Garhwal Himalaya

(Vikram Gupta)

The said project has been completed in March 2018. One of the motivation for the formulation of this project was that during June 2013 Kedarnath extreme climatic event, more than 3,000 active landslides have been generated in the state of Uttarakhand, and of all the valleys in the Uttarakhand, Mandakini valley was the worst affected. Though geological set up of the area was well known, there was no record of geotechnical characterisation of soil and rocks in the area. During the course of the project, it was decided to work in the Yamuna valley, therefore during the reporting period, work has been concentrated in the Yamuna valley. Landslides in the valley are common features and the inventory of active landslides in the upper Yamuna valley, particularly between Yamunotri Temple and Damta village has been carried out. A total of 76 landslides in the area were mapped and these landslides have been classified either as naturally occurring or anthropogenic, and also according to the processes involved i.e. rockfall and debris slide.

Detailed study on rock mass characterizations of rocks, between six km bridle path between Yamunotri Temple and Janki Chatti, located to the north of Main Central Thrust, has also been carried out. The path consists of rocks of the Higher Himalayan Crystallines mainly comprising quartzite, marble, augen gneiss and garnet bearing mica schist. It has been reported that numerous mass movement activities, mainly rockfall occur in the area and pose serious threat to the lives of people visiting the shrine every year. Therefore, geomechanical characterization of the slopes for the assessment of rockfall hazards through various rockmass classifications has been attempted. Different geomechanical characterization of slopes has been carried out at 24 locations using RMR, SMR, CSMR, GSI classification and kinematic analysis of discontinuities. It has been noted that kinematic analysis of discontinuities gives a conservative estimate of hazard in comparison to different classification of rock mass. It has been established that two locations falls under the category of very high hazards, ten under high hazard and twelve under moderate hazards (Fig. 53). These have been correlated with the conditions of rockmass. It has further been noted that different rock mass classification are in agreement with one another.

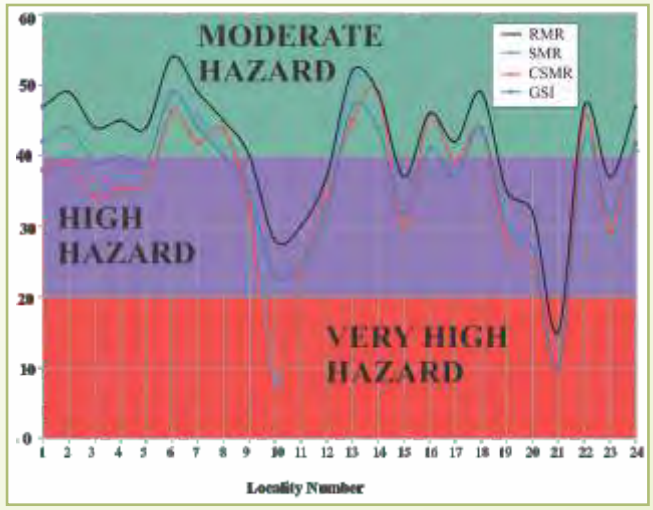

Fig. 53: Different rock mass classifications applied at 24 locations on the bridle path between Janki Chatti and the Yamunotri.

Fig. 54: Panoramic view of the Wariya Landslide with village Wariya seen on the crown portion of the landslide.

Besides, the Wariya landslide, located at latitude 30°55¹42.3ºN and longitude 78°23¹39.7ºE at an elevation of ~2130 m above msl has been studied in detailed for its geological, geomorphological and geotechnical characteristics. It is situated on the left flank of the Yamuna river and is ~45 km away from Barkot on the Barkot-Yamunotri road (NH-123). Village Wariya is located on the crown portion of the landslide (Fig. 54). The landslide is endangering about 99 household with about 436 people.

The landslide can be classified as Debris slide. It is retrogressive in nature. Dimensionally, the slide is ~235 m in width and ~75 m in height. The total area of the slide is about 36,368 m^2. The crown of the slide is at an elevation of 2090 m and located at about 20-30 m topographically below the Wariya village. The entire land above the landslide (the crown portion of the landslide) has been used for agriculture and settlement. The agricultural land and some houses close to the crown show signs of subsidence in the form of tilting of houses towards downslope as well as cracks in walls of the houses. In order to assess the conditions of slope in the present climatic scenario, finite element modelling (FEM) analysis of the slope has been carried out using Phase ^{2}. The results indicate that there is development of stress and strain in the lower portion of slope, topographically below the Wariya village (Fig. 55).

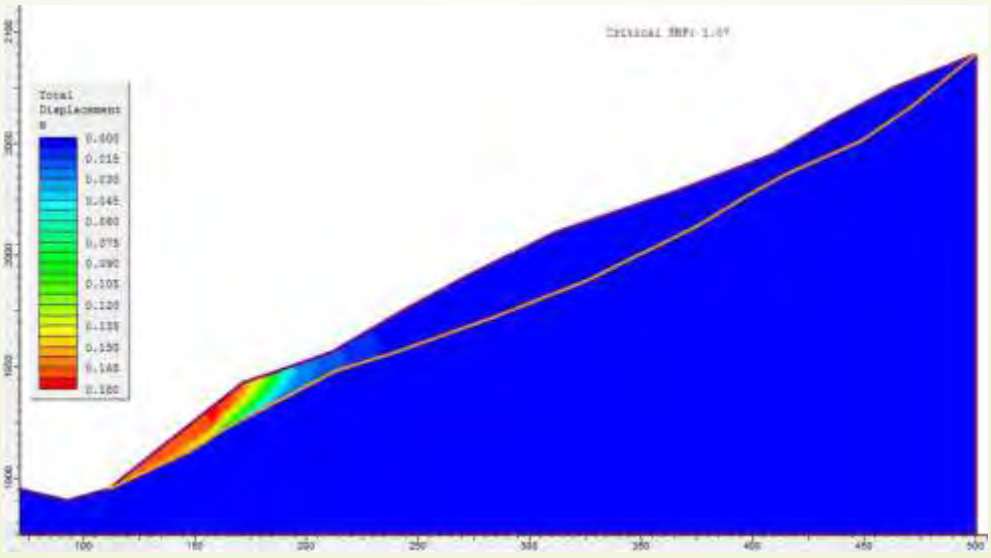

Fig. 55: FEM analysis of the Wariya landslide.

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 Drs. Reginald Hermanns, John Dehls and Ivanna Penna from Geological Survey of Norway; Dr. Rajinder Bhasin from the Norwegian Geotechnical Institute; Dr. A. Sengupta from IIT Kharagpur, Kharagpur; and Dr. Vikram Gupta from WIHG, Dehradun. The objectives of the project was to classifying natural slopes that may lead to landslides, with possible road & river blockage along two transects in Sikkim, based on hazard and risk analyses. The study area extends along two main transport corridors connecting Gangtok with Nathula (Tsomego Lake) and Gangtok to Lachen (North Sikkim Highway).

Reconnaissance survey of the area has been carried out during the reporting period. Data related to geological, geomorphological and location of the occurrences of landslides have been collected from various sources. PLEIADAS 1A/1B Tri-stereo satellite data having 50 cm resolution have also been procured. Three landslides, Yumthang Landslide, Dzongu Landslide in the tribal area, and 7th Mile Landslide on Gangtok Changu Road have been selected for detailed study. Out of these three landslides, debris from Yumthang and Dzongu slides has partly blocked the river to form artificial lakes. This landslide has been mapped with Terrestrial Laser Scanner (TLS) and Phantom 4 Pro Quadcopter.

The Yumthang rock avalanche has developed on slopes of southeast facing and northeast facing structures (Fig. 56). It is characterized by triangular facets, and the failed rock mass has propagated in two branches. The travel angle is ~32 degrees. The rock avalanche deposits have a fingered morphology in plain view. Three overlying lobate deposits on the northern part suggest three separated events. Google Earth imagery captured between November 14, 2015 and December 27, 2015 indicates that all failures occurred within one and half months. The deposits bracket an older rock avalanche of unknown age that was covered by native forest. Fallen and aligned trees on the old rock avalanche deposits and the opposite slope of the valley extend for about 300 m, and highlight the energy of the air blast. However, there is an asymmetric distribution of this air blast, probably caused by effects of local relief.

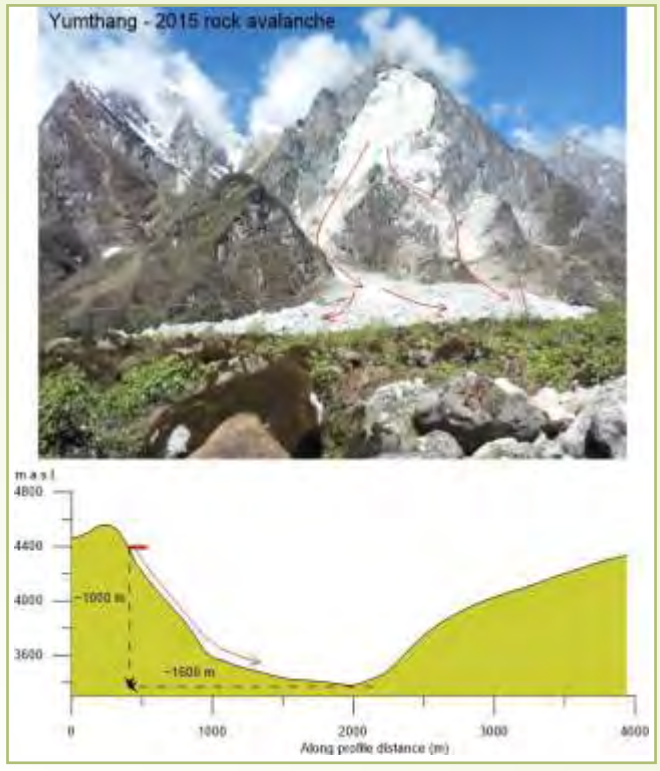

Fig. 56: View to the headscarp and deposits of the 2015 rock avalanche in Yumthang valley. Cross section profile shows the asymmetric profile of the valley, and the height and run-out of the 2015 rock avalanche. See the propagation controlled by triangular facets.

DST INSPIRE Faculty Project

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

(Aliba AO)

A geological field work was carried out in the Nagaland Ophiolite Complex (NOC), NE India to study the geological field relationships and petrology of the different units of the ophiolite sequence along selected traverse (Fig. 57). Special emphasis was given to identify high-pressure (HP) rock types, given the importance of these rocks in the overall metamorphic reconstruction of a subduction-zone setting complex. Blueschist facies rocks were observed from a few locations near Wui, Kenjong and Chipur village. Garnet is absent in all the studied rock samples. In the east of Wui and Kenjong village the rocks are very-fine grained and foliated (Fig. 58a). The main mineral assemblage in these fine-grained rocks are epidote+Na-Ca amphibole+glaucophane+muscovite+rutile±quartz. The main foliation in the rock is defined by epidote+amphibole. The more coarse-grained variety

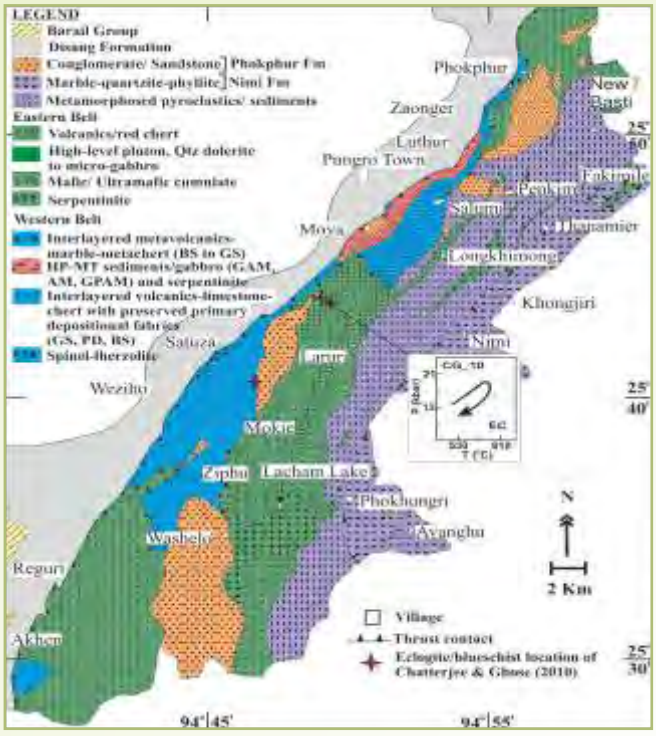

Fig. 57: Geological map of the Nagaland Ophiolite Complex, NE India (after Anon et al., 1986).

the rock is more massive and devoid of any prominent foliation. The mineral assemblages are Na-Ca amphibole+glaucophane+epidote+rutile+clinopyroxene. Near Chipur village, the HP rocks are distinguished by their protolith as metasediments and metavolcanics, respectively. The metasediments show gneissic banding with quartz-rich later interbanded with epidote+ amphibole-rich band (Fig. 58b). The other minerals associated with the metasediment is epidote and muscovite. The metavolcanics are more coarse-grained and shows some degree of deformation without any prominent foliation (Fig. 58c-d). The mineral assemblages are Na-Ca amphibole+glaucophane+ epidote+quartz+rutile±muscovite±stilpnomelane. In both these rock types, Na-Ca amphibole is rimmed by glaucophane (Fig. 58c-d). These type of textures are also reported from the amphibolites in the central portion of the NOC, and these rocks are inferred to have recorded a counter-clockwise P-T path of evolution (e.g. Bhowmik & AO, 2016).

Apart from the study of HP rocks, mantle peridotites were also studied in some detail which forms a major component of the NOC. The ultramafic rocks show well-preserved magmatic minerals with less-degree of alteration. These rocks range in composition from dunite, pyroxenite, lherzolite to spinel-lherzolite. Exsolution lamellae of clinopyroxene within megacrystic orthopyroxene and granular exsolution of clinopyroxene within megacrystic orthopyroxene is

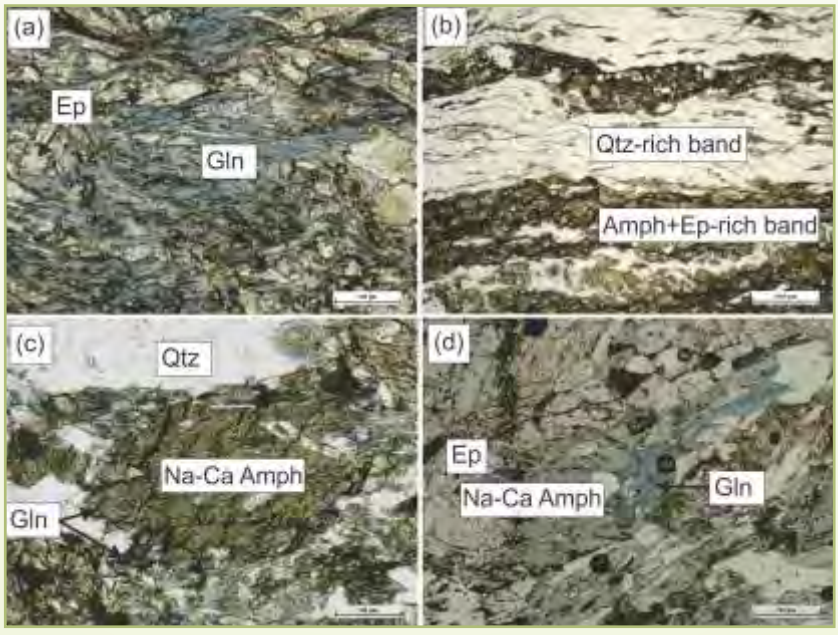

Fig. 58: Microphotographs of the Nagaland blueschist facies rocks in PPL. (a) A fine-grained, foliated epidote-blueschist facies rock. (b) Gneissic banding in the metasediments showing quartz-rich band alternating with amphibole + epidote-rich band. (c-d) Glaucophane rim around Na-Ca amphibole in more coarse-grained metavolcanic rocks.

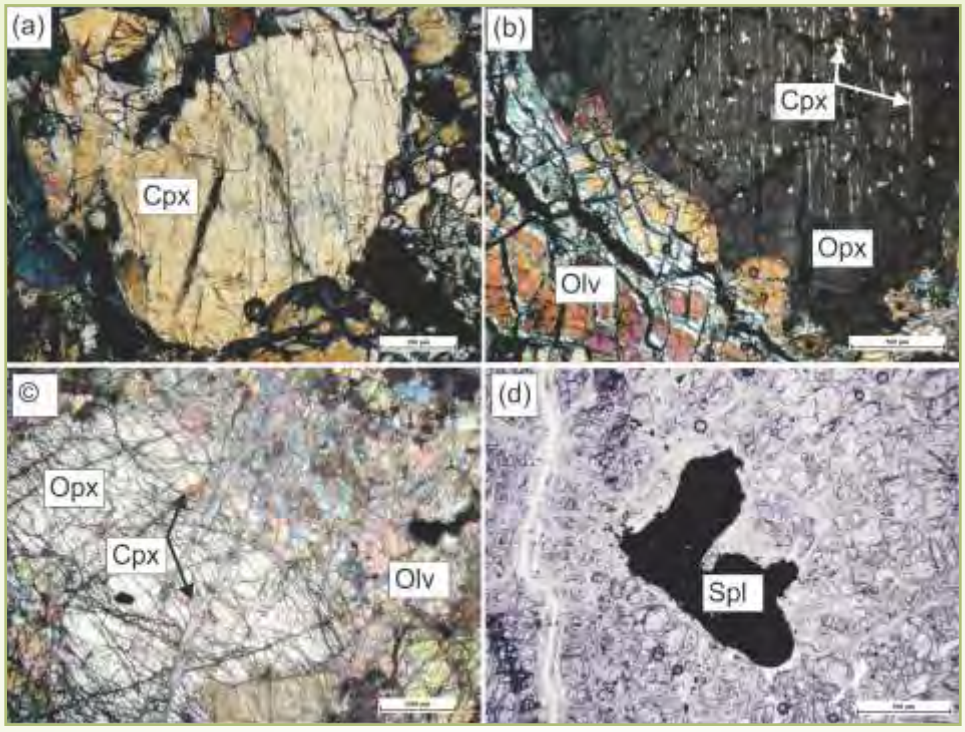

Fig. 59: Microphotographs of the Nagaland ultramafic rocks under XPL (a-c) and PPL (d). (a) A megacrystic clinopyroxene with embayed grain boundary. (b) Thin exsolution lamellae of clinopyroxene within orthopyroxene megacryst. (c) Granular-exsolution lamellae of clinopyroxene within orthopyroxene. (d) A coarse spinel grain with embayed grain boundary.

commonly observed in both lherzolite types (Fig. 59a-c). Fresh looking spinel grains with less degree of alteration is also commonly observed in all the ultramafic rock types (Fig. 59d). The dunites are the most-altered of all the ultramafic rock types and forms a complex network of cross-cutting serpentine veins.

DST-SERB Sponsored Project

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

(Vikas)

The project aims to document the tectonic evolution and exhumation history of the SE Karakoram terrane, Ladakh, India. The study area lies in eastern Karakoram, NW India, composed of different lithotectonic units namely: The Karakoram Shear Zone (KSZ), Karakoram Batholith (KB) and Karakoram Metamorphic complex (KMC). These rock units represent the margin of south Asian Plate and lie to the north of the Shyok Suture Zone (SSZ).

The granitoids from the metamorphic complex exposed along the Shyok Valley in Karakoram region, India have been subjected to geochemical and zircon U-Pb geochronological investigations to constrain the geodynamic and tectono-magmatic evolution of the Karakoram terrane through time. Outcrop-scale observations reveal the presence of pre- and syn-kinematic leucogranite bodies intruded within the granite and granite gneisses. Whole-rock geochemistry and mineral chemistry suggest subduction related calc-alkaline source for most of the host granitoids and crustal source for the leucogranites. The obtained geochronological ages from the granitoids mainly vary from ~160-14 Ma, and having specific geochemical and structural characteristics reveal that : (i) the initiation of subduction of the Tethyan oceanic lithosphere beneath the southern Asian plate margin is atleast ~160 Ma ago, and (ii) continuous deformation along ~1000 km long lithospheric scale dextral KF during ~27-14 Ma. Presence of deformed leucogranite dikes characterizing the signatures of dextral shear sense in a wide metamorphic complex suggests that the Karakoram Fault (KF) zone is a ~30-40 km broad dextral strike-slip shear zone existing in the Trans-Himalaya of Ladakh.

Thirty six samples (74 slides) for zircon and 37 samples (51 slides) for apatite have been irradiated at FRM II nuclear reactor, Germany from the transects of

(i) Changla-Darbuk-Shyok section, across the KF zone, (ii) Tangtse-Muglib section across the KF zone, and (iii) Shyok-Murgo section, along the KB. Fission Track counting is in progress for the generation of Fission Track Data from Karakoram. Zeta factor calibration has been done as per recommendations of International Union of Geological Sciences (IUGS) Sub commission on Geochronology following the procedures of Hurford (1990). In the prescribed method, zeta factor is determined for a given glass dosimeter (IRMM 540R) using a set of age standards (Fish Canyon Tuff and Durango Apatite). IRMM 540R glass for apatite have been used which have uranium content of ~15 mg/kg respectively. Brandon's programs of ZFACTOR v. 1.2 and ZETAMEAN v. 1.0 were used for zeta factor determinations. Mean Zeta values obtained for IRMM 540R glass comes out to be 258.05±7.62.

DST-SERB Sponsored Project

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

(Suman Lata Rawat)

Eleven days field work during 25th September to 05th October, 2017 has been carried out in Chamoli Garhwal region and collected surface samples to understand the modern vegetation and its relationship to the past vegetation and climate. Two trench profiles of 90 cm & 165 cm long were also sampled at 1 cm interval for Quaternary climate studies.

ISRO-IIRS Sponsored Project

Geodynamics and seismicity investigations in the northwest Himalaya

(G. Philip, Ajay Paul, S. Rajesh, N. Suresh, D.K.Yadav, Naresh Kumar, Devajit Hazarika, P. K. R. Gautam and P.K.Champati ray and Suresh Kannaujiya from IIRS, Dehradun)

Monitoring of current seismicity in the gap areas to understand the strain partitioning and earthquake fault segmentation studies

Compiled a homogenous seismic catalogue (1963-2015) using the data of WIHG, India Metereological Department (IMD), International Seismological Centre (ISC), National Earthquake Information Centre (NEIC) and the published research work. The data before 2005 is mainly taken from the catalogue compiled by Lyubushin et al. (2010) which also has historical seismic records starting from 1552. The recent seismic catalogue for the period of 1963-2015 contains 5410 events with lowest magnitude 2.2 and completeness for M4.5 starting from 1970. The epicenter locations of these events are plotted in figure 60 which indicates that the distribution is not homogenous for the study region. In general, there are zones of high and low seismicity but regions close to Hindukush-Pamir and the region close to Main Central Thrust (MCT) show high seismicity. Also, the distribution of sources in the depth section is uniform and the focal depth varies from mean sea level to over 300 km. Therefore, the catalogue contains shallow focused (0-70 km depth), intermediate focused (71-300 km) and deeper events to some extent. The seismic events in the Himalayan region are mainly shallow focused, and clustered close to the surface.

The data assisted us to lower the magnitude threshold to 2.4±0.2 for the catalogue completion upto 2015. It is evident that the seismicity is highly concentrated within Outer and the Higher Himalayan Crystalline region around the surface trace of MCT similar to central and eastern Himalayan regions. Deep seated sources are mainly located in the Pamir and Hindukush region where it is supposed that the part of the under-thrusting Indian tectonic plate is broken, submerged and still moving down.

Majority of hypocenters are concentrated within upper crust mainly around and above Main Himalayan Thrust (MHT) indicating the detachment zone highly stressed due to under-thrusting of Indian plate beneath the overriding wedge. The majority of the fault plane solutions of the Himalayan region are having thrust mechanisms indicating thrust dominant tectonic activity along the MHT and other major tectonic faults such as Himalayan Frontal Thrust (HFT), Main Boundary Fault (MBT) and MCT. The frequency-magnitude distribution of earthquake events indicates that comparatively, moderate magnitude earthquakes are dominant in this part of the Himalaya. However, the regions are capable of generating devastating earthquakes such as 1905 Kangra earthquake (Mw 7.8) and large magnitude Mw 7.6 recent 2005 earthquake of Kashmir region. Therefore, it is necessary to delineate the hazardous zones that are vulnerable to the occurrence of the future high magnitude earthquakes in order to reduce the casualties and damages.

Deformation monitoring, strain modelling and earthquake precursor studies using TEC with reference to significant earthquakes in Himalaya and surrounding region.

i) Co-seismic ionospheric GPS-TEC variations related with Himalayan and non-Himalayan earthquakes.

To understand the Co-seismic ionospheric disturbances

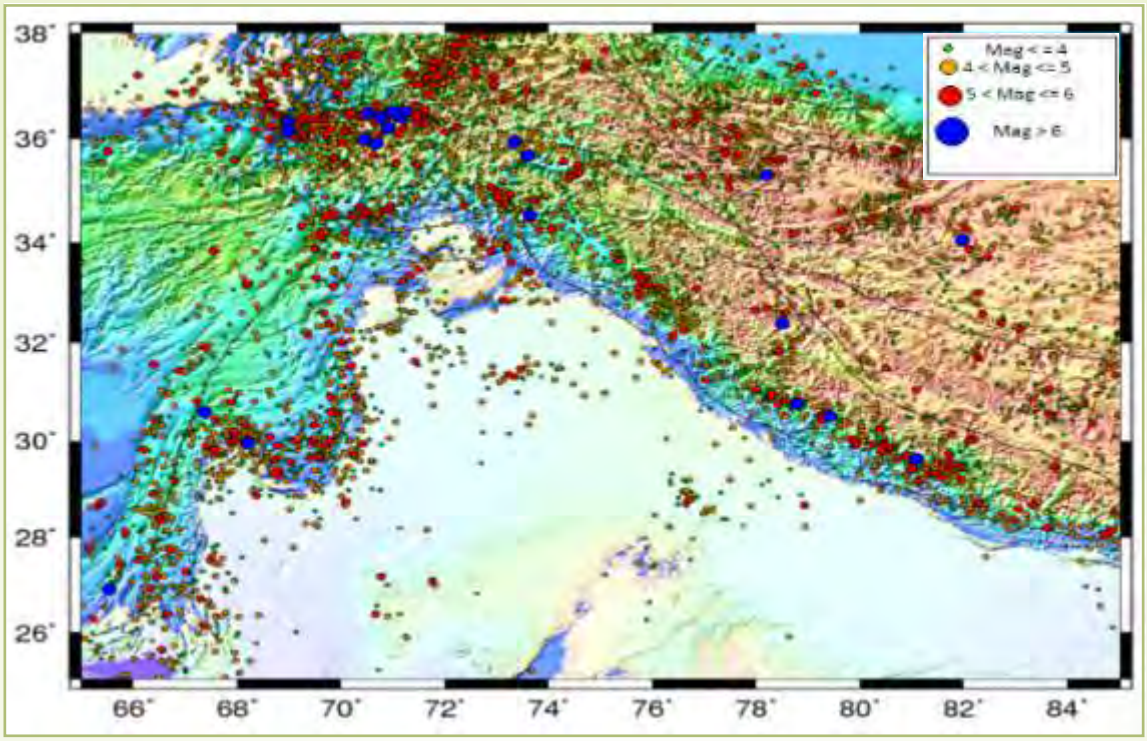

Fig. 60 : Earthquake epicenter distribution of M>2.2 occurred in the NW Himalaya region during 1965-2015.

(CIDs) due to different source characteristic earthquakes through GPS-derived vertical total electron content (VTEC), we investigated VTEC changes related with moderate, strong, major and great earthquakes occurred at different tectonic settings in both Himalaya and the non-Himalayan regions in an around the Indian tectonic Plate. The VTEC and its anomalies are computed using GPS data obtained from the WIHG local network of GPS stations in Himalaya with the IGS stations surrounding the epicentre region. Our results show that irrespective of the source characteristics, significant CIDs are observed during major and great earthquakes, namely; (i) the Mw 7.8, 25th April 2015 Gorkha earthquake, (ii) the Mw 7.6, 8th October 2005 Kashmir earthquake, and (iii) the Mw 8.6, 28th March 2005 Nias–Simeulue earthquake. We considered nine significant events that occurred during the period from 1999 to 2016 having magnitude range from 6.7 to 9.0. The Fault Plane Solution (FPS) as shown in figure 61 shows that in general the region is a thrust fault dominated system at the plate boundaries. We inferred that the CIDs originated because of earthquakes in Himalaya have relatively larger VTEC magnitudes (>15 TECU) that propagates faster in reaching and registering in the ionospheric layers compared with the non-Himalayan earthquakes.

ii) Near and Far field Co-seismic offsets related with Gorkha-Nepal earthquake

Followed by the 7.8 Magnitude Gorkha (Nepal) earthquake on 25th April 2015, the positional anomalies of CGPS stations of WIHG, IGS and from Nepal network have been analysed. The objective is to investigate the near (<100 km from the epicentre) and far field static and kinematic co-seismic offsets in the GPS measurements. The near field stations like KKN4 and CHLM shows predominant static offsets of 1.8 and 1.4 m, respectively in their resultant components. These near stations also show subsidence of half a meter to around a meter. However, far stations (>600 km) at Munsyari (MUNS) and Dehradun (LES2) do not show any significant co-seismic static offsets; but observed in their three component kinematic offsets with respect to the station, IISC at Bengaluru.

It is also observed that the Near Field (<100 km and in Red color) static offsets are mainly due to the rupture in Main Himalayan Thrust while the kinematic offsets are due to surface Rayleigh wave propagation. Appreciable static offsets in the far field are not observed, especially at more than 500 km away from the epicenter. However, the observed far field kinematic offsets are mainly due to surface shaking as a result of site effects due to Surface

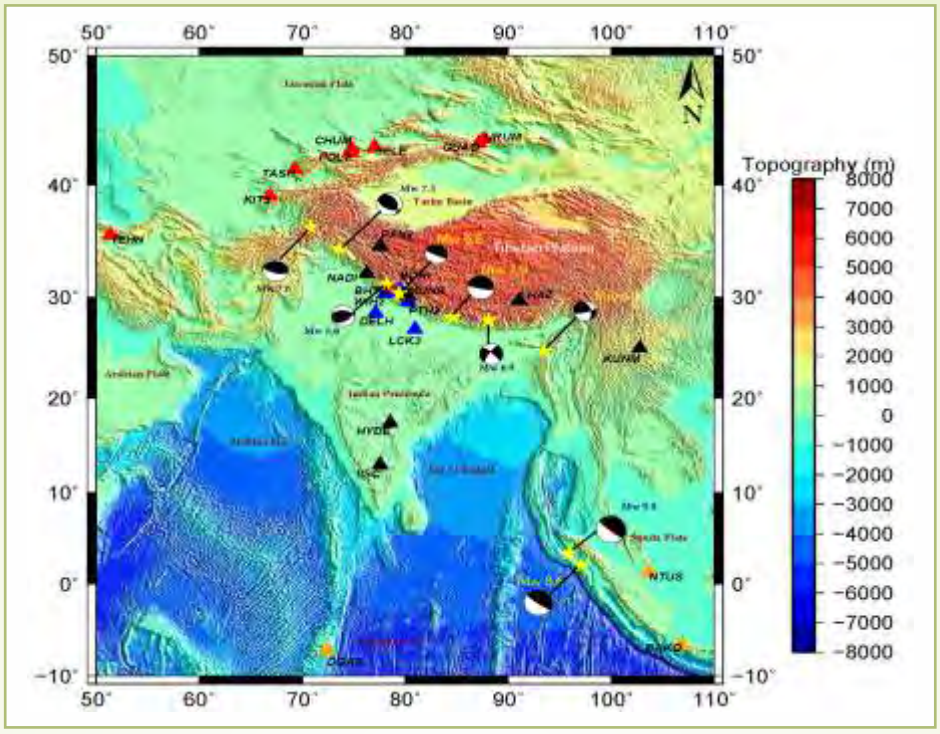

Fig. 61: Regional Topography and Bathymetry of the study area (Source: GEBCO); Yellow stars represent the epicentres of nine major earthquakes considered in this study. GPS station locations as colour filled triangles: - Blue for Nepal earthquake; Red for Kashmir earthquake; Orange for Sumatra earthquake and Black for common stations for all the three events. Fault Plane Solutions are from the CMT solution catalogue.

Rayleigh Wave propagation. The <1 Hz site effects at the GPS station due to Rayleigh wave propagation is an important, but yet to be explored area as for as the sub-Hertz site amplification studies are concerned.

Active fault mapping using high resolution Earth Observation data and geophysical investigation in selected sectors around MCT and HFT

During the reporting year, field based geological investigation carried out to understand the active tectonics in the NW Doon valley. Number of faults have been identified in the Quaternary sediments of Doon Valley. The Trans-Yamuna Active Fault (TYAF) delineated in the northwestern Doon Valley in the Sub-Himalaya has been investigated with reference to paleoseismicity. The study mainly focused on the Sirmuri Tal Fault (STF), an east-west trending active fault in the sub Himalaya. The STF delineated to the west of the Giri River is clearly observable both on satellite imagery and topographic map. The displacement of Quaternary sediments is observed with prominent offsetting of fluvial terraces at Sirmuri Tal. The relatively linear south-side-up fault trace with variable fault dips suggests that this normal fault system has a component of strike-slip as well. The STF cuts Lower Siwalik rocks, which are poorly exposed due to thick vegetation cover. The STF extends eastward through Quaternary fluvial terraces on the west side of the Giri River near Sirmuri Tal village. The apparent scarp height of the STF in the terrace area is about 40 m, significantly higher than other scarp heights along the fault. The paleoseismic investigation of the STF at the Giri River terrace did expose the fault, and suggests the displacement of late Holocene terrace deposits. The 30 x 8 x 5 m trench, which is perpendicular to STF has been excavated to understand the recent tectonic activity. The depressions created in the northern side of the fault scrap have been subsequently filled up by fluvial sediments. The trench excavation survey across the STF has also revealed earthquake induced deformation features which are believed to be attributed to recent large magnitude earthquakes occurred along the TYAF system. TheTYAF recognized in the Sub-Himalaya to north of the Himalayan Frontal Thrust demonstrates that, the recent strain release is not only concentrated in the Frontal Himalaya but also distributed over a broader area further to its north in the Sub-Himalaya.

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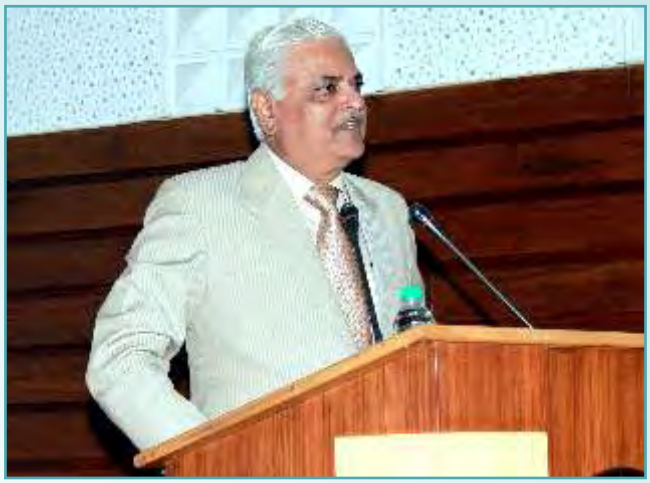
3. Gupta, Vikram 2017: along with other members drawn from various organizations submitted a Comprehensive Technical report on the "Carrying capacity of the Kasauli townhip, Himachal Pradesh" to Hon'ble National Green Tribunal.

4. Gupta, Vikram 2017: along with other members drawn from various organizations submitted a Comprehensive Technical report on the "Carrying capacity of the Shimla townhip, Himachal Pradesh" to Hon'ble National Green Tribunal.

SEMINAR/SYMPOSIA/WORKSHOP ORGANISED

2nd National Geo-Research Scholars Meet (May 17-20, 2017)

Institute organized 2nd National Geo-Research Scholars Meet to encourage research scholars and young researchers working in the field of geology across the country to present their scientific contribution and research idea on an open platform and also provide an opportunity to interact with the renowned geoscientists of the country. The event started with an inaugural function, wherein Director welcomed the Chief Guest, the retired justice Anil R. Dave of Supreme Court of India, and the Guest of Honour, retired justice S. N. Srivastava of Allahabad High Court. The introduction and background note of National Geo-Research Scholars meet was given by Dr. S.K. Tiwari. It was followed by address of Guest of Honour, and the Inaugural address by the Chief Guest. The inaugural session ended with vote of thanks by Mr. Akshay Verma.



Chief Guest Hon'ble Anil R. Dave, Retired Judge of Supreme Court of India delivering the Inaugural Address

The inaugural keynote lecture was delivered by Prof. Anil K. Gupta, Director, WIHG on the *'Changes in the Indian summer monsoon: human migrations, agricultural practices and societal collapses in India during the Holocene'*. Several other keynote lectures on various topics related to themes of the event were

Students presenting their work, and also actively interacting during the deliberations of the 2nd National Geo-Scholar Meet

Cultural events during the 2nd National Geo-Research Scholars Meet

delivered by distinguished renowned professors/ scientists of the country namely, Dr. Rajiv Nigam (NIO, Goa), Prof. R.D. Deshpande (PRL, Ahmadabad), Prof. S.N. Tripathi (IIT, Kanpur), Prof. Sunil K. Singh (Director, NIO, Goa), Prof. Malay Mukul (IIT, Bombay), Dr. V.M. Tiwari (Director, NGRI, Hyderabad), Prof. Rajeev Patnaik (Panjab University, Chandigarh), Dr. O.P. Mishra (MoES, New Delhi), Dr. Vineet Gahalaut (MoES, New Delhi), Dr. Ajay Manglik (NGRI, Hyderabad), and Prof. M.K. Panigrahi (IIT, Kharagpur).

The four days long event included field trip and paper presentation under five major themes, which include: (i) Societal impact of Earth Sciences, (ii) Geodynamics and Earth processes, (iii) Economic Geosciences, (iv) Geophysical techniques and their application, and (v) History of Indian Geosciences since the Vedic time. A total of 73 oral presentation and 143 poster presentation were made during the meet. The event was attended by 216 research scholars from 58 different organizations, including research institutes, Universities, IITs, IISERs. The event also included one day field excursion to show the signature of the Himalayan Frontal Thrust (HFT) and Main Boundary Thrust (MBT). During the event the young researchers were also showcased and demonstrated with the available analytical facilities of the Institute. Also, to encourage researchers' awards were given for the best Oral and Poster Presentations. A cultural event was organized for the participants in the evening.

AWARDS AND HONOURS

- Dr V.C. Thakur was conferred with 'Padma Shri', one of the highest civilian award of the country, for his distinguished service to the Nation in the field of Geology. The award, constituted by the 'Ministry of Home Affairs' was given by the Hon'ble President of India Sh Ram Nath Kovind.

Hon'ble President of India Sh Ram Nath Kovind giving away the prestigious Padma Shri Award to Dr. V.C. Thakur, ex-Director, WIHG

- Dr A.K. Mahajan (on lien) has been conferred with 'National Geoscience Award-2017' in the field of Geophysics/Applied Geophysics. The award was conferred by the Ministry of Mines, Government of India.
- Dr. Prakasam has been awarded 'Indian National Science Academy (INSA) Visiting Scientist Fellowship-2017-2018' to learn Stable and Clumped Isotope techniques under the mentorship of Prof. Prosenjit Ghosh, Centre for Earth Sciences, Indian Institute of Science, Bangalore.
- Institute's 'Best Paper Award-2016' was jointly given for two papers (i) 'Stable isotopes ($\delta^{13}C_{DIC}$, δD, $\delta^{18}O$) *and geochemical characteristics of geothermal springs of Ladakh and Himachal (India): Evidence for CO_2 discharge in northwest Himalaya'* authored by S.K. Tiwari, S.K. Rai, S.K. Bartarya, A.K. Gupta, M. Negi and published in 'Geothermics', and (ii) *'Paleoseismic evidence of a giant medieval earthquake in the eastern Himalaya'* authored by R.L. Mishra, I. Singh, A. Pandey, P.S. Rao, H.K. Sahoo, R. Jayangondaperumal and published in 'Geophysical Research Letters'.

VISITS ABROAD

- Dr. Suman Lata Rawat visited Zaragoza, Spain to attend the 5th Open Science Meeting (OSM) of the Past Global Changes (PAGES) during May 9-13, 2017.
- Dr. Kishor Kumar visited Royal Belgian Institute of Natural Sciences, Brussels, Belgium to interact with Dr. Thierry Smith on Early Eocene vertebrate fauna from Western India and their relationship with European Fauna, during June 4-12, 2017.
- Dr. S.K Bartarya visited ICIMOD Kathmandu, Nepal to present a paper on 'Hydro*geological Framework, Characteristics and Classification of Himalayan Springs*' in the '*Workshop on vanishing springs in the Himalaya: Synthesizing current state of knowledge*', during March 13-15, 2018.

Ph.D. THESES

Name of the Student	Supervisor	Title of the Thesis	IIT's/University	Awarded / Submitted
M. Prakasam	Prof. A.K. Gupta Prof. S. Ray	Neogene paleoclimatic and paleo-oceanographic changes: multiproxy records from ODP Hole 722B, Owen Ridge, Northwestern Arabian Sea	IIT Kharagpur, Kharagpur	Awarded
R.L. Mishra	Dr. R. Jayangondaperumal	Paleoseismic investigations along the Himalayan Frontal Thrust (HFT) between the mesoseismal zones of the 1934 Bihar-Nepal and 1950 Tibet-Assam earthquake, North Eastern Himalaya	Utkal University, Odisha,	Awarded
Manisha Sanguri	Dr. D.R. Rao Prof. A.K. Sharma	Metamorphic evolution of Munsiari formation and Vaikrita Group of Central Crystallines, Kumaun Himalaya, India	Kumaun University, Kumaun	Awarded
Amit Kumar	Prof. S. Mukhopadhyay Dr. Naresh Kumar Dr. S.C. Gupta	Subsurface velocity structure of NW-NE India and Bay of Bengal using surface wave	IIT Roorkee, Roorkee	Awarded
Monika Wadhawan	Dr Devajit Hazarika Dr. Vikram Gupta Prof. M. Agarwal	Shear wave velocity and crustal structure along Satluj valley, Northwest Himalaya	University of Petroleum and Energy Studies, Dehradun	Awarded
Sanjay Singh Negi	Dr. Ajay Paul Dr. Kamal	Understanding the Crustal Structure of Garhwal - Kumaun Himalaya	IIT Roorkee	Awarded
Anil Kumar	Dr. Pradeep Srivastava Dr. K.S. Mishra	Late Quaternary landscape evolution along the Indus River: responses to the climate and tectonics of Ladakh Himalaya.	University of Petroleum and Energy Studies, Dehradun	Awarded
Watinaro Imsong	Dr. S.C. Vaideswaran Dr. Sarat Phukan	Geomorphological appraisal of neo- tectonic activities in the Shillong Plateau, Northeast India	Guwahati University, Guwahati	Awarded
P. Saravannan	Prof. MK Panigrahi Prof. A.K. Gupta	Centennial to Millennial scale Paleocene-graphic changes in the eastern Arabian Sea during the Late Quaternary	IIT Kharagpur, Kharagpur	Awarded
A. Velu	Prof. A.K. Gupta Prof. MK Panigrahi	Neogene record of Indian monsoon variability from the Oman Margin and Owen Ridge, Northwestern Arabian Sea	IIT Kharagpur, Kharagpur	Awarded
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	Submitted
Akshay Verma	Prof. A.K. Gupta Dr. Suneet Naithani	Climatic Significance of Isotopic and Geochemical Signatures in Snow and Ice from Glaciers of Garhwal Himalaya, India	Doon University, Dehradun	Submitted

Tanuj Shukla	D.P. Dobhal H.C. Nainwal	Late Quaternary Glacial and Climate Records from Dokriani and Chorabari Glaciers of Uttarakhand Himalaya Using Optically Stimulated Luminescence and Stable isotope Techniques	HNB Garhwal University, Srinagar	Submitted

PARTICIPATION IN SEMINAR / SYMPOSIA / MEETINGS

Workshop related to *'Field trip for 36th International Geological Congress-2020'* held at Ministry of Earth Sciences (MoES), New Delhi on April 18-19, 2017
Participant: D.P. Dobhal

3rd International Conference on the *'Status and Future of the World's Large Rivers'* held at India Habitat Centre, New Delhi during April 18-21, 2017
Participant: Rajeev Ahluwalia

'Bhartiya Vigyan Samalen' held at Fergusson College, Pune during May 11-14, 2017
Participant: P.S. Negi

National Conference on *'Polar Sciences-2017'* held at NCAOR, Goa on May 16-17, 2017
Participant: Aparna Shukla

'ConTech 2017'- a group discussion on Raman spectroscopy held at Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore on May 27, 2017.
Participant: Rajesh Sharma

National Workshop on *'Indian Siwalik: Recent Advances and Future Research'* held at Geological Survey of India, Lucknow on June 21-22, 2017
Participant: R.K. Sehgal

Workshop on *'Connecting Science with Practices and Policy for Resilience towards Climate Change Risks in the Indian Himalayan Region'* held at Doon University, Dehradun on June 27, 2017
Participant: D.P. Dobhal

'Landslides' Project Expert Committee Meeting held at Manipur University, Imphal on July 13, 2107
Participant: Vikram Gupta

Workshop on *'Strengthening Resilience to Climate Change Related Disaster Risk'* held at Madhuban Hotel, Dehradun on July 21, 2017
Participant: D.P. Dobhal

2nd Post-Expedition Meeting held at NCAOR, Goa during July 25-27, 2017
Participant: Anil Kumar

First Stakeholder consultation meeting of working group on *'Himalayan Springs'* held at DST, New Delhi on August 8, 2017
Participant: Rajesh Sharma

Workshop on *'Quality infrastructure for surface water monitoring of the River Ganga'* held in New Delhi on August 17, 2017
Participant: S.K. Rai

'XXVI Indian Colloquium on Micropaleontology and Stratigraphy' held at University of Madras, Chennai during August 17-19, 2017
Participant: Kapesa Lokho

Meeting of Working Group-5 constituted by NITI Aayog held in New Delhi on August, 18, 2107
Participant: Rajesh Sharma

Workshop on *'Utilization of Saraswati Palaeochannel Maps for Ground Water Exploration'* organized by Regional Remote Sensing Centre (West), NRSC/ISRO, Jodhpur, Rajasthan on August 29-30, 2017
Participant: S.K. Rai

Workshop on *'Slope stabilization: Challenges, Techniques, and Solutions'* held in Secretariat, Government of Uttarakhand, Dehradun on September 11, 2018
Participant: Vikram Gupta

Meeting of the *'National Mission for Sustaining Himalayan Ecosystem Project'* with the Task Force Partners at WIHG Dehradun on September 21, 2017
Participants: Rajesh Sharma, S.K. Bartarya, D.P. Dobhal and Vikram Gupta

3rd Expert Committee Meeting (EC)-CCP of DST *'National Mission for Sustaining Himalayan Ecosystem Project'* at IIT Delhi on October 4, 2017
Participants: Rajesh Sharma and Vikram Gupta

38th Asian Conference of Remote Sensing-2017 on *'Space Applications Touching Human Lives'* held in New Delhi during October 23-27, 2017
Participant: Aparna Shukla

Workshop on *'Landslides for Engineers of Indian Academy of Highway Engineering-Japan International Cooperation Agency'* held at WIHG, Dehradun on October 26-27, 2017
Participant: Vikram Gupta

Tasks Force Meeting of NMSHE Project held at Wild Life Institute, Dehradun on October 29, 2017
Participants: Rajesh Sharma, S.K. Bartarya, D.P. Dobhal and Vikram Gupta

'Brain storming session on Cryosphere studies in the Himalaya' held at National Institute of Hydrology, Roorkee on October 31, 2017
Participant: D.P. Dobhal

Workshop of *'EX-AQUA 2017 - Palaeohydrological extreme events: evidences and archives'* held at IIT Kanpur, Outreach Centre, Noida during November 1-3, 2017
Participant: M. Prakasam

Workshop on *'Landslide Risk Mitigation'* held at Dr RS Tolia Uttarakhand Academy of Administration, Nainital during November 14-18, 2017
Participant: A.K.L. Asthana

Workshop on *'Geochronology'* held at IUAC, New Delhi on November 16-17, 2017
Participant: Suman Lata Rawat

'2nd Himachal Pradesh Science Congress' held at Shimla on November 20-21, 2017
Participant: Narendra Kumar

National workshop on *'Disaster Resilient Infrastructure in the Himalaya: Opportunity and Challenges'* held at Hotel Solitaire, Dehradun on November 21-22, 2017
Participants: Sushil Kumar, D.P. Dobhal, Vikram Gupta, Pradeep Srivastava, R. Jayangondaperumal, Perumal, B.K. Mukherjee and D.K. Yadav

International Seminar on *'The Himalayan Challenge: Towards Inter-disciplinary Dialogues for Sustainability and Development'* held at Doon University, Dehradun between 29th November and 1st December, 2017
Participant: D.P. Dobhal

'54th Annual Convention of Indian Geophysical Union' held at CSIR-NGRI, Hyderabad during December 3-7, 2017
Participants: Naresh Kumar, S. Rajesh, P.K.R. Gautam and V.S. Gokul

Fourth Indian Landslides Congress at IIT Bombay during December 8-9, 2017
Participant: P.S. Negi

Training on *'Multidisciplinary perspective on Science, Technology and Society'* held at National Institute of Advance Studies, Bangalore during December 8-23, 2017
Participant: Gautam Rawat

International Groundwater Conference organized by National Institute of Hydrology, Roorkee and Central Ground Water Board at New Delhi, during December 11-13, 2017
Participant: S.K. Bartarya

'34th Convention of Indian Association of Sedimentologists' held at Sant Gadge Baba Amravati University, Amravati, during December 19-21, 2017
Participant: Anil Kumar

Meeting on *'Zonal Plan of Bhagirathi Eco-sensitive zone'* held under the direction of Hon'ble National Green Tribunal at Secretariat, Government of Uttarakhand, Dehradun on January 9, 2018
Participant: D.P. Dobhal

'5th Meeting of the Technical Advisory Committee for Landslide Mitigation and Management' held in New Delhi on January 22, 2018
Participant: Vikram Gupta

Workshop on *'Rocscience software tools: 2 D and 3 D slope stability analysis'* held in New Delhi on January 29-30, 2018
Participant: Vikram Gupta

'Landslides' Project Expert Committee Meeting held at IIT Bombay, Mumbai on February 2, 2018
Participant: Vikram Gupta

INQUA-HaBCom Training Workshop on *'Methods and Challenges for Quantitative Palynology and Paleoecology in South Asia'* held at French Institute of Pondicherry, Pondicherry between 29th January and 4th February, 2018.
Participant: Suman Lata Rawat

State Directorate of Geology and Mining Programming Board Meeting at DGM Office Dehradun on February 06, 2018
Participant: Rajesh Sharma

4th PAMC Meeting on progress of *'Multi-Parametric Geophysical Observatory for Earthquake Precursory Research at Ghuttu, Garhwal Himalaya'* held at BHU, Varanasi on February 9, 2018
Participant: Naresh Kumar

National Seminar on *'Earth's interior'* held in Graphic Era (Deemed University), Dehradun on February 15-16, 2018
Participant: Sushil Kumar

Central Geological Programming Board Meeting of Geological Survey of India held in New Delhi on February 16, 2018
Participant: Rajesh Sharma

International Conference on *'State of the Cryosphere in the Himalaya: with a focus on Sikkim and Eastern Himalayas - gaps, challenges and opportunities'* held in Gangtok, Sikkim on February 19-20, 2018
Participant: Rakesh Bhambri

National Conference on *'Climate Change and Natural Resources; Impact and Sustainable Development in Indian Perspective'* held at University of Lucknow, Lucknow on February 20-21, 2018
Participant: Aparna Shukla

Meeting on *'Natioanl Mission for Sustaining the Himalayan Ecosystem (NMSHE)'* held at National Institute of Hydrology, Roorkee on Febuary 26, 2018
Participant: Rajeev Ahluwalia

NIAS-DST Training Programme on 'Science Policy and General Management' held at NIAS, Bangalore between 26th February and 9th March, 2018.
Participant: G. Philip

National Conference on *'Technological Empowerment of Women'* at Vigyan Bhavan, New Delhi on March 8-9, 2018
Participants: Kapesa Lokho and Suman Lata Rawat

First meet of the *'Core Group on River Chemistry Monitoring'* held at IISc, Bengaluru on March 9-10, 2018
Participant: Santosh K. Rai

Workshop on *'Application of Remote Sensing & GIS for tourism Development in Uttarakhand'* held at WIHG, Dehradun on March 13-14, 2018
Participants: D.P. Dobhal, P.S. Negi and A.K.L. Asthana

India-Japan Workshop on *'Disaster Risk Reduction'* held at Vigyan Bhawan, New Delhi on March 19-20, 2018
Participant: Sushil Kumar

Refresher Course in *'Landslide studies and Earthquake Geology'* held at GSI, Dehradun during March 19-25, 2018
Participants: A.K.L. Asthana and A. Luirei

LECTURES DELIVERED BY INSTITUTE SCIENTISTS

Name	Venue	Date	Topic
Pradeep Srivastava	DBS College, Dehradun	08.04.2017	Extreme flood events in Himalaya and Holocene climatic record
Santosh K. Rai	Bharatiya Vigyan Sammelan, Pune	11-14.05.2017	Geothermal spring sites from the Indian Himalaya and their importance in passing out the ancient, culture and traditional knowledge to the next generation
R.K. Sehgal	GSI, Lucknow	22.06.2017	On the status of the red bed successions exposed at the base of the Siwalik Group of NW India and palaeo-biogeographic significance of the Siwalik faunas
Pradeep Srivastava	Ladakh International Centre, Leh	06.09.2017	Geological records of Floods and Debris Flows in Ladakh Himalaya
S. Rajesh	IIRS, Dehradun	12.10.2017	Geodynamics and seismicity investigations in the NW Himalaya- GNSS component
Naresh Kumar	IIRS, Dehradun	12.10.2017	Monitoring of current seismicity in the gap areas to understand the strain partitioning and earthquake fault segmentation studies
Aparna Shukla	HNBGU, Srinagar	12-17.10.2017	Lecture series on 'Fundamentals of Remote Sensing and GIS' for PG students at the Department of RS & GIS
Rajesh Sharma	AMU, Aligarh	26.10.2017	Applications of Raman spectroscopy in Gemology
Aparna Shukla	DU, Delhi	26.10.2017	Geospatial techniques for multi-parameteric assessment of the Himalayan Cryosphere
Vikram Gupta	WIHG, Dehradun	26.10.2017	Various aspects of landslides in the Himalayan terrain to the Senior engineers of Indian Academy of Highway Engineering - Japan International Cooperation Agency
Aliba AO	WIHG, Dehradun	03.11.2017	Recurring metamorphic cycles in subduction zone setting: records from the Nagaland Ophiolite Complex, NE India
R. Jayangonda perumal	Uttarakhand State Disaster Management Authority, Dehradun	21.11.2017	Primary surface rupture of 1344 AD Great Earthquake along Garhwal and Kumaun Himalayan front
S.K. Bartarya	Kumaun University, Nainital	14.12.2017	Hydrogeological Frame work of Uttarakhand
S. Rajesh	IGNFA, Dehradun	26-27.12.2017	Lecture series on 'Geological structures and their topographic expressions'
Vikram Gupta	IGNFA, Dehradun	27.12.2017	Rock-types constituting the Himalaya
Vikram Gupta	IGNFA, Dehradun	29.12.2017	Denudational processes in the Himalaya
Vikram Gupta	Indian Association of Highway Engineering, Noida	05.01.2018	Landslide Hazards in the Himalaya
S. Rajesh	IGNFA, Dehradun	10-11.01.2018	Lecture series on 'Geological structures and their topographic expressions'
Vikram Gupta	Indian association of Highway engineering, Noida	15.01.2018	An overview of landslides in the Himalayan terrain

Pradeep Srivastava	HNBGU, Srinagar	28.01. 2018	Continental drift, plate tectonics and buildup of Himalaya
R.K. Sehgal	Anthropological Survey of India, Dehradun	31.01.2018	Recent advancements in the palaeontologic and stratigraphic studies of the Siwalik group of Northwestern Himalaya
Devajit Hazarika	Indian Institute of Public Administration, New Delhi	01.02.2018	Himalayan earthquakes and understanding of subsurface structure
Suman Lata Rawat	French Institute of Pondicherry, Pondicherry	04.02.2018	Late Quaternary climate records: A multi proxy Approach from Lahaul Himalaya
D.P. Dobhal	ICFRE, FRI, Dehradun	21.02.2018	Climate Change Impact on Glaciers
Pradeep Srivastava	Univ. of Dibrugarh, Dibrugarh	26.02.2018	Large floods in Himalaya
Rajesh Sharma	IBM Regional Office, Dehradun	01.03.2018	Mines and the Environment
Rajesh Sharma	Jammu University, Jammu.	15.03.2018	A viewpoint on Himalayan Mineralization
S.K. Bartarya	UPES, Dehradun	29.03.2018	Himalayan Springs and Environmental Constrains

MEMBERSHIPS

Name of Scientist	Membership details
Dr. Naresh Kumar	· Member, Indian Geophysical Union · Member, American Geophysical Union
Dr. Devajit Hazarika	· Member, Indian Geophysical Union · Member, American Geophysical Union
Dr. R. Jayangondaperumal	· Life Membership of Geological Society of India, Bangalore
Dr. D.P. Dobhal	· Member, Program Advisory Committee (PAC), Earth and Atmospheric Sciences, Science & Engineering Research Board (SERB), constituted by DST, New Delhi · National Coordinator for the Board Theme "Glacier mass Balance - approaches and problem" 39th International Geological Congrass-2020 · Member, Program Monitoring Committee (PMC), Himalayan Cryospheric Observations and Modelling (HiCOM), under the Polar Science and Cryosphere Research (PACER) program, National Centre for Antarctic & Ocean Research, Goa
Dr. Vikram Gupta	· Member Committee of Expert to advise Amarnath Shrine Board as directed by Hon'ble NGT
Dr. Sushil Kumar	· Member, American Geophysical Union
Dr. S.K. Bartarya	· Member, Technical Working Group of National Institute of Hydrology, Roorkee · Core Member of Himalayan Society for landslide and Environment, Nepal · Member, Society for Earth Scientist, India · Member, Indian National Committee for International Hydrological Program (IHP) of UNESCO, NIH Roorkee · Member Sectional Committee (WRD 3) of Bureau of Indian Standards (BIS), New Delhi on Ground Water and Related Investigations
Dr. Santosh K. Rai	· Member, State Ganga Rejuvenation, Protection and Management Committee, Uttarakhand · Member, Technical Committee of Haryana Sarasvati Heritage Development Board, Haryana

POPULAR LECTURES DELIVERED IN THE INSTITUTE

J B Auden Lecture

Prof. Deepak Srivastava of IIT Roorkee, Roorkee delivered the J B Auden Memorial Lecture titled, *'A Glimpse through some fault zones in Himalaya'* on June 9, 2017.

Prof. Sankar Chatterjee of University of Texas, USA delivered a lecture titled, *'The Longest Voyage of India, from Gondwana, its Collision and the rise of the Himalaya'* on July 21, 2017.

Golden Jubilee Year – 'Lecture Series'

The Institute is celebrating the Golden Jubilee Year, which started from June 30, 2017 and culminate on June 29, 2018 the Foundation Day of Institute. As part of the Golden Jubilee Celebration, the Institute initiated *'Golden Jubilee Year Lecture Series'* by eminent scientists of the India, and also by retired Directors and Scientists of the Institute especially for the sake of young scientists and research scholars of the Institute. The following lectures were delivered during the reporting period of the Annual Report:

- Padma Bhushan Prof. K.S. Valdiya delivered the first lecture titled, *'Calamity in Uttarakhand: Lessons learnt'* on September 7, 2017.
- Prof. Ashok Sahni delivered the lecture titled, *'Dynamics and Evolution of South and South East Asian Palaeogene Biota: Science, Speculation and Storytelling'* on January 23, 2018.
- Dr V.C. Thakur delivered the lecture titled, *'Geodynamics of the Himalaya'* on November 13, 2017.
- Prof B.R. Arora delivered the lecture titled, *'My Journey into the Himalaya: marriage of Geology & Geophysics'* on December 11, 2017.
- Prof. V.K. Gairola delivered the lecture titled, *'Dynamic recrystallization and microstructures developed during shearing experiments and their comparison with the sheared rocks from the*

Prof. K.S. Valdiya (Top Left), Prof. Ashok Sahni (Top Right), Dr. V.C. Thakur (Bottom Left) and Prof. B.R. Arora (Bottom Right) delivering the Lectures as a part of Golden Jubilee Year celebration of the Institute

Himalaya' on November 20, 2017.

- Dr A.K. Dubey delivered the lecture titled, *'Development of fold'* on November 28, 2017.
- Dr N.S. Virdi delivered the lecture titled, *'Active faults and neo-tectonic activity: Case study from NW Himalaya'* on February 2, 2018.
- Dr. A.C. Nanda delivered the lecture titled, *'Siwalik Group of India: recent: development and problem'* on February 27, 2018.
- Dr R. Islam delivered the lecture titled, *'Granite Magmatism in the Himalaya through space and time geochemistry and geodynamic evolution'* on March 3, 2018.
- Prof. Jai Krishna delivered the lecture titled, *'Geodynamic Evolution of Himalaya through Sequence Surfaces with Focus on the Vendian-Ordovician Record'* on March 26, 2018.

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section during the year brought out (i) Himalayan Geology volumes 38(2) and 39(1); (ii) Annual Report of the Institute for the year 2016-17 in Hindi and English; (iii) Hindi magazine 'Ashmika' volume 23; (iv) Newsletter 'Drishtikon' volume 6; (v) Compendium of activities of WIHG: Inception of Golden Jubilee; (vi) Monograph entitled *'Lithostratigraphy, Biostratigraphy and Paleogeography of the Eastern Karakoram, India'* authored by Dr. K.P. Juyal; (vii) Abstract volume of the 2nd National Geo-Research Scholars Meet-2017; (viii) Consultancy Report by Dr. Sushil Kumar for NHPC Ltd., JKSPDC & PTC India Ltd. on *'MEQ Studies of Kuru, Kwar, Pahul Dul Hydroelectric Project, J&K, India'*.

The section provided the facility & 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 Institute's 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) has also been started from this year. Journal is indexed in Thomson Reutors (US), Elsevier (Netherlands), and in Indian Citation Index (India). 12 new members got registered under the Life Time Subscriber Scheme (LTSS) Membership for Himalayan Geology journal bring the total registered number to 476.

LIBRARY

The Library of Wadia Institute of Himalayan Geology has special library status because of its finest collection of books, monographs, journals, and e-books on the mountain building process, geological and geophysical phenomenon with special reference to Himalaya. The collection and services offered makes it one of the best libraries in the field of earth sciences in India. The scientists, researchers and projects staff make full utilization of the Library while publishing their research work in the reputed peer-reviewed journals. The Library has always remained best information access to the researchers for their specialized research pursuits. Specialists and professionals across the country also visited the Library to consult thematic and rare collections available in it.

The Library has subscribed to 70 International and 38 Indian Journals. The Library also purchased 20 reference books, while 137 books are received as gratis. In addition to this, a total number of 167 books have been added to the Hindi Collections. The Library has more than 4000 selected e-books from different publishers and learned societies on the thrust areas of research of the Institute. This year the existing collections have been added with new e-books collections from (i) Springer: Earth and Environmental Science updated by adding 796 titles e-books collection. The WIHG scientists as and when required were also provided with books/journals on inter-library loan basis from the Libraries of other organizations situated at Dehra Dun.

The Library for the easy access and exclusive publications of the research work by WIHG, further digitized them for its incorporation into the Institutional Repository (IR) which is essentially developed using DSpace (OSS). The Institute repository has been brought under the open source automation environment KOHA this year. Also, the articles published by Institute scientists in various journals have been digitized. The repository consists of 1975 PDFs of WIHG Scientist's publications along with 97 full PDF text of Prof D.N. Wadia's publications, which are placed on the intranet within the Institute.

The Institute Library is a member of NKRC and continue to receive the support of Consortia towards online access to Elsevier's "Earth and Planetary Science collection", Wiley's "Earth, Space & Environmental Sciences"; Springer "Earth and Environmental Science and Chemistry" collections. In addition to this, WIHG Library has access to the publications of American Institute of Physics, American Physical Society, Derwent Innovation Index (with Web of Knowledge), Emerald Group Publishing, IEEE, NPG: Nature-Main Journal, NPG: Nature Geoscience, Royal Society of Chemistry, Science magazine, Springer Journals, Taylor & Francis, Web of Science, Wiley & Blackwell. All these publishers contribute online access to more than four hundred journals' titles, apart from our own subscription.

The Library has the small hub of computers for the users for accessing the e-books and e-journals and other e-resources available, either subscribed by WIHG Library or available through NKRC. This facility was also extended to the summer trainees. The hub is also being used for conducting several exams towards the recruitment of administrative and technical staff of the Institute. The Library further serves as a central facility for the reprography demand of the Institute.

S.P. NAUTIYAL MUSEUM

The Institute's Museum named of Prof. S.P. Nautiyal is a major axis of education, and continues to generate awareness among the students and public, not only from the distant corners of India but also from overseas. Museum as usual remained the main center of attraction for the national and international visitors. The exhibits and the information provided in the Museum continued to attract the students and general public. This year too students from different schools, Universities, colleges and from other Institutions visited the museum, guided tours were provided to them. More than 2,500 people visited the Museum from different parts of country. Some of the educative exhibits displayed in the Museum include, Drifting Continents, Volcanoes, Earthquakes, Origin and Evolution of Life, Himalayan Glaciers, Landslides, Flash floods, etc. One of the major and effective additions was the display of a Geological clock at the entrance wall of the museum. It is 10x7 feet three-dimensional model that depicts the life through ages. It shows the distribution of life in the different epochs. The fossils shown in the model were prepared by the fiberglass. It is the center of attraction for all, and is highly appreciated by the scientific community as well as by the students and by the public. The exhibit were also received wide appreciation by the general public who visited the Institute during the science outreach programme.

Museum observed Open Days on National Technology Day (11th May). Foundation Day (29th June), Founders Day (23rd October) and National Science Day (28th February). Like preceding years, enormous number of students and public visited the museum on these open days. The print media gave a wide coverage of the function. Also, in order to give a general 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 in English are distributed free of cost to them.

TECHNICAL SERVICES

Analytical Services

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

Instrument	Samples analyzed		
	WIHG Users	Outside Users	Total
Palyonology Lab (microscope)	144	-	144
XRF Lab	787	536	1323
ICP-MS Lab	1104	659	1763
Elemental Analyzer	940	-	940
Gas Bench	271	61	332
TL/OSL lab	171	17	188
Sedimentology lab: Laser Particle Size Analyzer	1060	-	1060
Vibratory Sieve Shaker	132	-	132
XRD Lab.	294	30	324
LINTAB™ 6 Tree- ring station	185	-	185
LA MC ICPMS	55 (~3100 U-Pb spots)	7 (~183 U-Pb spots)	62 (~3300 U-Pb spots)
Mineral Separation Lab	75	15	90
Paleomag Lab.	1428	-	1428
Water Chemistry Lab	499	153	652

Photography Section

During 2017-18, approximately 6500 images were clicked using SLR digital cameras to cover the various functions organized in the Institute from time to time, including Foundation Day, Founders day, National Science Day, National Technology Day, New Year's Day, Republic day, Independence Day, Seminars/Symposia (e.g., 2nd National Geo-Scholars Meet-2017; Golden Jubilee lectures), cultural programme, and superannuation parties of the Institute staff etc. Apart from this around 800 snaps were clicked for rock and fossil specimens. The colour printing of around 350 digital images was arranged from the market. No new cameras/lenses/flash guns were procured during the reporting year as a majority of scientists already have cameras issued permanently to them for use in the field and laboratory. The remaining scientists and research scholars are provided cameras from a 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 2017-18, the section has provided 25 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 done. 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 2017-18, the laboratory provided 1483 thin and polished sections to various users for carrying out microscopic, fluid inclusion and EPMA studies. The laboratory also processed crushing/grinding of 1752 rock samples for carrying out major, trace and REE analysis by ICPMS, XRF and XRD methods.

CELEBRATIONS

Independence Day

Independence Day was celebrated in the Institute on August 15, 2017, and Prof. Anil K. Gupta, Director unfurled the National flag. To mark the occasion many sports events were organized for the staff and children of the Institute's employees. Dr. Meera Tiwari, Scientist G of the Institute distributed the prizes to the winners

Independence Day Celebrations in the Institute

3rd International Yoga Day

3rd International Yoga Day was celebrated in the Institute on June 21, 2017. On this occasion, more than 60 Scientists, employees and research students practiced Yoga between 7:30 and 8:30 AM under the directive and guidance of Yoga Instructors Shri Hemant Kundra and Smt Madulika Kundra of the 'Art of Living'.

Foundation Day

The 49th Foundation Day of the Institute was celebrated on June 29, 2017. On this occasion Dr. V. K. Saraswat, Member NITI Aayog and Former Secretary DRDO was

(Top) Chief Guest Dr. V. K. Saraswat delivering the Foundation Day Lecture. (Bottom) Chief Guest, the Guest of Honour Prof. Ajit Kumar Chaturvedi, Director of the Institute and Dr. Meera Tiwari releasing the Compendium of 50 years of Institute Activities.

the Chief Guest and Prof. Ajit Kumar Chaturvedi, Director, IIT Roorkee, Roorkee was the Guest of Honour. Dr. V.K. Saraswat delivered the 'Foundation Day Lecture' on *'Pursuit of Science for Humanity'*.

The Chief Guest has also given out the 3rd Prof. R.C. Mishra Memorial Gold Medal to Dr. Priyeshu Srivastava of School of Environmental Sciences,

Chief Guest Dr. V.K. Saraswat giving away the 3rd R.C. Mishra Gold Medal Award to Dr. Priyeshu Srivastava of JNU.

Jawaharlal Nehru University, New Delhi. This award is given annually to the young scientists below the age of 35 years.

The occasion was also marked by the distribution of awards by the Chief Guest to the best research papers published by the Institute scientists as well as to the best workers in the various categories of the Institute. Institute's 'Best Paper Award-2016' was jointly given for two papers (i) *'Stable isotopes ($\delta^{13}C_{DIC}$, δD, $\delta^{18}O$) and geochemical characteristics of geothermal springs of Ladakh and Himachal (India): Evidence for CO_2 discharge in northwest Himalaya'* authored by S.K. Tiwari, S. K. Rai, S. K. Bartarya, A.K. Gupta, M. Negi and published in 'Geothermics', and (ii) *'Paleoseismic evidence of a giant medieval earthquake in the eastern Himalaya'* authored by R.L. Mishra, I. Singh, A. Pandey, P. S. Rao, H. K. Sahoo, R. Jayangondaperumal and published in 'Geophysical Research Letters'.

The Best Worker Awards were given to Sh A.S. Negi (Administrative Officer) and Sh C.B. Sharma (Assistant Engineer) for their dedicated service to the Institute. Director's Letter of Appreciation were also given to Sh Naresh Kumar Juyal (Technical Officer), Sh S.S. Bhandari (Librarian), Sh Rambir Kaushik (Asstt. Pub. & Doc. Officer), Smt. Neelam Chabak (UDC), Sh Vijai Ram Bhatt (LDC), Sh Rajeev Yadav (LDC), Sh Rahul Sharma (Assistant), Sh Deepak Tiwari (FCLA), Sh Raghuveer Singh Negi (Field Attendant), Sh Prateek Negi (Artist-cum-Modeller), Sh Harish Kumar Verma (M.T.S.), Sh R.S. Rana (M.T.S.), Sh Manmohan (Driver-Contractual) and Sh L.S. Bhandari (Chowkidar-Contractual).

International Fossil Day

The Institute observed October 16, 2017 as 'International Fossil Day'. Dr. R.J. Azmi, Ex-Scientist of the Institute delivered the 'Fossil Day Lecture' on *'Fossils: Importance and some Indian context'*. Apart from talking about fossils, in general, Dr Azmi

Dr. R.J. Azmi, Ex-Scientist of the Institute delivering the 'Fossil Day Lecture'

explained on his palaeontological findings from the Vindhyan succession.

The Founder's Day

The Institute observed October 23rd as Founder's Day as a mark of respect to Dr. D.N. Wadia. The Chief Guest on

Prof. V.P. Dimri delivering the 'Founder's Day Lecture'

the occasion was Padma Shri Professor V.P. Dimri who delivered the 'Founders Day Lecture' on the topic *'Carbon Dioxide Geosquestration to Protect Pahad: A Non-linear System'*.

Republic Day

Dr. Meera Tiwari, Director hoisted the National Flag on the Republic Day, January 26, 2018. As a mark of

Republic Day Celebrations in the Institute

Republic Day Celebrations in the Institute

Republic Day celebrations various sports and cultural activities were organized in the Institute for the employees and their children. Prizes were distributed to the winners of various events.

Science Week

Science week has been observed in the Institute in the last week of February as part of the 'National Science

(Top) On the National Science Day, students and teachers visited various labs and the Museum. (Bottom) School children including the blind children participating in the essay writing completion conducted by the Institute.

Day' celebrations. 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.

Prof. Durgesh Pant, Director, Uttarakhand Science Education and Research Centre, Uttarakhand was the Chief Guest for the National Science Day, i.e. on 28th February and delivered the 'National Science Day Lecture'. 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.

The Institute also observed 'Open Day' on February 29, 2018, wherein laboratories were kept open to students and public. A large number of school children, college students and other public from Dehradun visited the Laboratories. Scientists as well as the technical staff and research scholars explained the functioning of the various scientific instruments and its uses to the visitors. Museum was kept open for the visitors, in which various exhibits related to the Himalayan glaciers, Earthquakes, Landslides, Origin of Life, Volcanoes, Rocks Minerals, etc., were displayed and explained to the visitors.

Other Activities

- A book written by Padma Bhusan Prof. K.S. Valdiya on the life of Padma Vibhusan, Sh. Sundar Lal Bahuguna, noted environmentalist and leader of Chipko movement was released by Sh. Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand at a function held in the Institute on September 7, 2017. Sh Sundar Lal Bahuguna ji was personally present on the occasion of the book release.

Hon'ble Chief Minister of the Uttarakhand Sh. Trivendra Singh Rawat releasing the book on Sh. Sundar Lal Bhaguna written by Prof. K.S. Valdiya. Dr. Meera Tiwari, Director WIHG also joins them in the book release ceremony.

- Institute has observed *'Swachhta Hi Seva'* fortnight campaign from September 15, 2017 to October 2,

Institute employees taking oath towards cleanliness, and in action during the Government of India's *'Swachhta Hi Seva'* fortnight campaign

2017 in line with Government of India campaign. Under this campaign, all the employees of the Institute took a pledge to remain committed towards cleanliness and devote time for this, and also made voluntary cleaning of premises from Wadia Institute to Ballupur.

- The IMA Blood Bank of Uttarakhand has organizing a blood donation camp in the Institute on June 13, 2017, wherein Institute staff actively participated and donated blood. A lecture was also delivered on the topic *'Voluntary Blood donation for Society and for individual with an ultimate purpose to save Human life'* by IMA.
- The employees of the Institute took a pledge for a New India on the occasion of anniversary of the *'Quit India Movement'* on August 10, 2017.
- Institute on October 26, 2017 organized half-day workshop for *'Studies on various aspects of landslides and mitigation measure thereof'* to the delegates of joint Indian Academy of Highway Engineers, Noida and Japan International Cooperation Agency, Japan. The delegation mainly comprises of senior road engineers (Chief Engineer/Additional Chief Engineer/equivalent) representing across the country.
- Hon'ble Prime Minister, Shri Narendra Modi inaugural curtain raiser ceremony speech was telecasted through video conferencing mode in the Institute Auditorium on the occasion of the 125th Birth of Satyendra Nath Bose National Centre for Basic Sciences, Kolkata Anniversary celebrations of Professor S.N. Bose's.
- Institute scientists conducted Mock drill on November 7, 2017 for earthquake preparedness involving the students of Eklavya Adarsh Residential School located in Kalasi, Chakrata.

Students of Eklavya Adarsh Residential School were explained about the do and don't during an earthquake, and a mock drill how to protect themself during an earthquake is demonstrated by the scientists of the Institute.

DISTINGUISHED VISITORS TO THE INSTITUTE

- Sh. Trivendra Singh Rawat, Hon'ble Chief Minister of Uttarakhand
- Sh. Sundar Lal Bahuguna a noted Garhwali environmentalist and Chipko movement leader of Uttarakhand
- Padma Bhushan Prof. K.S. Valdiya, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advanced Scientific Research, Bengalore
- Padma Shri Prof. V.P. Dimri, ex-Director and Bhabha Chair Professor at Centre for Earth, Ocean and Atmospheric Sciences, University of Hyderabad, Hyderabad
- Hon'ble Anil R. Dave, Retired Justice of Supreme Court of India
- Hon'ble S.N. Srivastava, Retired Justice of Allahabad High Court
- Dr. V.K. Saraswat, Member NITI Aayog and Former Secretary DRDO, Government of India
- Prof. Ajit Kumar Chaturvedi, Director, IIT Roorkee, Roorkee
- Prof. Ashok Sahni, Professor Emeritus, Lucknow
- Sh. R.K. Shukla, ex-Director, KDMIPE ONGC, Dehradun
- Brig. S. Tha Raja, National Defence College. New Delhi
- Sh. S.K. Das, ex-Chief Secretary, Government of Uttarakhand
- Prof. Durgesh Pant, Director, SERC, Uttarakhand
- Prof. Jai Krishna, ex-Professor of Geology Department, BHU, Varanasi
- Prof. V.K. Gairola, ex-Professor of Geology Department, BHU, Varanasi
- Prof. Sankar Chatterjee, University of Texas, USA
- Prof. Barbara Romanowicz, College of France, Paris
- Sh. Sarin Bansal, Additional Secretary, Disaster Management, Government of Uttarakhand
- Sh. Kamal Kant Jaswal, former Secretary, Government of India

STATUS OF IMPLEMENTATION OF HINDI

In order to promote use of Hindi as Raj Bahasa in official activities and mutual communication in office and outsides deeds, Hindi Pakhwara was celebrated in the Institute during 14-28, 2017. The inauguration of the Pakhwara on September 14, 2017 was done by Hon'ble Vice Chancellor Dr. Uday Singh Rawat of Sri Dev Suman Uttarakhand University. In his inaugural lecture he emphasized the use of Hindi language in scientific writings and personal communication in everyday life. As a part of the celebrations invited guests like Dr. Muniram Saklani, former director, Uttarakhand Bhasa Sansthan and Dr. Ram Vinay Singh, DAV (P.G.) College, Dehradun have delivered interesting lectures narrating the importance of Hindi language for the national building and sustainable progress of the nation.

Institute scientists Dr. Sushil Kumar delivered a talk on *'Earthquake and animal behaviour'* and Dr. Santosh Kumar Rai on *'Himalayan River and national security'*; while Shri Tajendra Ahuja an employee delivered lectures on *'Information technology and our changing life style'*. Various other activities like essay and debate competition were organized for school children. Besides this self-written poem and recitation, essay writings, debate, slogan activities were conducted for Institute employees. The research scholars of the Institutes also enacted a skit highlighting the ease of communication and teaching in Hindi would be.

(Top) Chief Guest Dr. Uday Singh Rawat is greeted with a sapling by Dr. Meera Tiwari, Director on the Inaugural Day of Hindi Pakhwara. (Bottom) On the dais are Dr. Muniram Saklani and Dr. Ram Vinay Singh along with Director, Dr. Meera Tiwari

(Top) Institute employees participating in the Hindi and English slogan completion. (Bottom) Research scholars of the Institute performing a skit.

To make Hindi language more interesting and useful in everyday life, poets of national repute Padam Shri Leeladhar Jagoori, Dr. Atul Sharma, Dr. Vidhya Singh, Dr. M.R. Saklani, and Dr. Sudhir Gairola were invited for a 'kavi samelan', which was witnessed and enjoyed by invited guests, Institute employees and their family members. The valedictory lecture was delivered by a prominent scientist and Hon'ble Vice Chancellor, Prof. L.M.S. Palni of Graphic Era University. The talk of his lecture was '*D.N.A finger printing'*. After lecture distribution of prizes was done amongst the winners of various events conducted during the Hindi Pakhwara.

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 Committee consisting of five members including Scientists and Asst. Finance and Accounts Officer for the redressal of employee's grievances. Four requests regarding grievances of the employees were received and considered during the year by the Grievances Committee.

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 2017-18.

6. Status of Vigilance Cases

There is one vigilance case pending during the year 2017-18.

7. Information on the RTI cases

Six applications for seeking information under the Right to Information Act, 2005 were carried forward from the previous year 2016-17.

The details of information on the RTI cases during the year 2017-18 are as under:

Details	Opening balance as on 01.04.2017	Received during the year 2017-2018	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	06	40*	00	Nil	43
First appeals	Nil	03	Nil	Nil	03

*Four applications under the Right to Information Act, 2005 were carried forward to the next financial year 2018-19.

8. Sanctioned Staff strength (category wise)

Group/ Category	Scientific	Technical	Administrative	Ancillary	Total
A	63	-	2	-	65
B	-	4	14	-	18
C	-	63	22	40	125
Total	63	67	38	40	208

9. Sanctioned and released budget grant for the year 2017-2018

Plan	:	Rs. 3212.83 lakhs
Non-Plan	:	NIL
Total	:	Rs. 3212.83 lakhs

STAFF OF THE INSTITUTE AS ON 01.04.2018

Scientific Staff

1	Prof. Anil Kumar Gupta	Director (Repatriate on his parent Dept. IIT Kharagpur on 29.08.2017)
2	Dr. (Mrs) Meera Tiwari	Scientist 'G' & Director (Addl. Charge)
3	Dr. Kishor Kumar	Scientist 'G'
4	Dr. Rajesh Sharma	Scientist 'G'
5	Dr. G. Philip	Scientist 'G'
6	Dr. D. Rameshwar Rao	Scientist 'G'
7	Dr. S.K. Bartarya	Scientist 'G'
8	Dr. S.K. Parcha	Scientist 'G'
9	Dr. H.K. Sachan	Scientist 'F'
10	Dr. Sushil Kumar	Scientist 'F'
11	Dr. A.K. Mahajan	Scientist 'E' (On Lien)
12	Dr. D.P. Dobhal	Scientist 'E' (On Deputation)
13	Dr. Vikram Gupta	Scientist 'E'
14	Dr. Suresh N.	Scientist 'E'
15	Dr. Pradeep Srivastava	Scientist 'E'
16	Dr. Ajay Paul	Scientist 'E'
17	Dr. S.S. Bhakuni	Scientist 'E'
18	Dr. R. Jayangondaperumal	Scientist 'E'
19	Dr. A.K.Singh	Scientist 'E'
20	Dr. (Mrs) Kapesa Lokho	Scientist 'E'
21	Dr. K.S. Luirei	Scientist 'E'
22	Dr. P.S. Negi	Scientist 'D'
23	Dr. A.K.L. Asthana	Scientist 'D'
24	Dr. Gautam Rawat	Scientist 'D'
25	Dr R.K. Sehgal	Scientist 'D'
26	Dr. Jayendra Singh	Scientist 'D'
27	Dr. B.K. Mukherjee	Scientist 'D'
28	Dr. Santosh Kumar Rai	Scientist 'D' (Lien Vacancy)
29	Dr. Naresh Kumar	Scientist 'D'
30	Dr. Devajit Hazarika	Scientist 'D'
31	Dr. Dilip Kumar Yadav	Scientist 'D'
32	Dr. Koushik Sen	Scientist 'D'
33	Dr. Satyajeet Singh Thakur	Scientist 'D'
34	Dr. Rajesh S.	Scientist 'C'
35	Dr. (Mrs) Swapnamita Choudhuri	Scientist 'C'
36	Dr. Narendra Kumar Meena	Scientist 'C'
37	Dr. Param Kirti Rao Gautam	Scientist 'C'
38	Dr. Manish Mehta	Scientist 'C'
39	Dr. (Ms.) Aparna Shukla	Scientist 'C'
40	Dr. Vikas	Scientist 'C'
41	Shri Som Dutt	Scientist 'C'
42	Dr. Anil Kumar	Scientist 'C'
43	Shri Saurabh Singhal	Scientist 'C'
44	Dr. Narendra Kumar	Scientist 'C'
45	Dr. Sudipta Sarkar	Scientist 'B'
46	Dr. M. Prakasam	Scientist 'B'
47	Shri Vinit Kumar	Scientist 'B'
48	Dr. Aditya Kharya	Scientist 'B'
49	Dr. Paramjeet Singh	Scientist 'B'
50	Dr. (Ms) Suman Lata Rawat	Scientist 'B'
51	Dr. (Mrs) Chhavi Pant Pandey	Scientist 'B'
52	Dr. Parveen Kumar	Scientist 'B'
53	Dr. Aliba AO	Scientist 'B'
54	Dr. Sameer Kumar Tiwari	Scientist 'B'
55	Dr. Pinkey Bisht	Scientist 'B'
56	Dr. C. Perumalsamy	Scientist 'B'
57	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 Ravindra Singh	Sr. Technical Officer (Retired on 30.06.2017)
7	Shri N.K. Juyal	Technical Officer
8	Shri T.K. Ahuja	Technical Officer
9	Shri C.B. Sharma	Assistant Engineer
10	Shri S.S. Bhandari	Librarian
11	Shri Rambir Kaushik	Asstt. Pub. & Doc. Officer
12	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
13	Shri Bharat Singh Rana	Librarian
14	Dr. Jitendra Bhatt	Sr. Tech. Assistant
15	Shri Pankaj Chauhan	Jr. Technical Officer (On Deputation)
16	Shri Lokeshwar Vashistha	Sr. Lab.Technician
17	Dr. S.K. Chabak	Sr. Lab.Technician
18	Shri R.M. Sharma	Sr. Lab.Technician
19	Shri C.P. Dabral	Sr. Lab.Technician
20	Shri Shiv Pd. Bahuguna	Sr. Lab. Assistant
21	Shri Sashidhar Pd.Balodi	Sr. Lab. Assistant (Retired on 28.02.2018)
22	Shri Rajendra Prakash	Sr. Lab. Assistant
23	Shri Tirath Raj	Sr. Lab. Assistant
24	Shri Nand Ram	Elect.cum-Pump.Optr.
25	Shri Balram Singh	Elect.cum-Pump.Optr.
26	Smt. Sarita	Technical Assistant
27	Shri Rakesh Kumar	Technical Assistant
28	Km. Sakshi Maurya	Technical Assistant

29	Smt. Disha Vishnoi	Technical Assistant
30	Shri Abhimanyu Yadav	Technical Assistant (Lien Vancancy)
31	Shri Prateek Negi	Artist cum Modeller
32	Shri Rahul Lodh	Lab Assistant
33	Shri Nain Das	Lab Assistant
34	Shri B.B.Saran	Draftsman (Retired on 31.01.2018)
35	Shri Tarun Jain	Draftsman
36	Shri Pankaj Semwal	Draftsman
37	Shri Santu Das	Section Cutter
38	Shri Puneet Kumar	Section Cutter
39	Shri Ram Kishor	Field-cum-Lab-Attendant (Retired on 31.08.2017)
40	Shri Ansuya Prasad	Field-cum-Lab-Attendant (Retired on 31.01.2018)
41	Shri Hari Singh Chauhan	Field-cum-Lab-Attendant
42	Shri Ravi Lal	Field-cum-Lab-Attendant
43	Shri Preetam Singh	Field-cum-Lab-Attendant
44	Mrs. Rama Pant	Field Attendant
45	Shri R.S.Negi	Field Attendant
46	Shri Ramesh Chandra	Field Attendant
47	Shri B.B.Panthri	Field Attendant
48	Shri M.S.Rawat	Field Attendant
49	Shri Sanjeev Kumar	Field-cum-Lab-Attendant
50	Shri Deepak Tiwari	Field-cum-Lab-Attendant
51	Shri Ajay Kumar Upadhaya	Field-cum-Lab-Attendant
52	Km. Sangeeta Bora	Field-cum-Lab-Attendant
53	Shri Deepak Kumar	Field-cum-Lab-Attendant
54	Km. Anjali	Field-cum-Lab-Attendant

Administrative Staff

1	Shri Pankaj Kumar	Registrar
2	Ms. Deepti Datta	Finance & Accounts Officer
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)
7	Smt. Rajvinder Kaur Nagpal	Stenographer
8	Shri M.C. Sharma	Office Superintendent
9	Shri S.K. Chhettri	Accountant
10	Shri Rahul Sharma	Assistant
11	Shri S.K.Srivastava	Assistant
12	Shri R.C.Arya	Assistant
13	Mrs. Prabha Kharbanda	Assistant
14	Mrs. Kalpana Chandel	Assistant
15	Km. Shalini Negi	Stenographer
16	Smt. Richa Kukreja	Stenographer
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	Km. Rachna	Lower Division Clerk

Ancillary Staff

1	Shri Sohan Singh	Driver
2	Shri Shyam Singh	Driver
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

Contracutal 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	Sh. 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
14	Shri Sang Bam Kach	Chowkidar

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

Governing Body
(during 2017-18)

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 (UP)	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 (UP)	Member
7.	Dr. D.S. Ramesh	Director, Indian Institute of Geomagnetism, Plot No. 5, Sector 18, New Panvel, Navi Mumbai-410218 (Maharashtra)	Member
8.	Dr. Rajiv Nigam	Chief Scientist, CSIR-National Institute of Oceanography, GOA-403004	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

Research Advisory Committee
(during 2017-18)

Sl.	Name	Address	Status
1.	Prof. D.C. Srivastava	Head, Department of Earth Sciences, Indian Institute of Technology-Roorkee, 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, Next 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

Sl.	Name	Address	Status
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

Finance Committee
(during 2017-18)

Sl.	Name	Address	Status
1.	Prof. M.P. Singh	124, Chandganj Extension, (Opp. CN-7, Sector-B), Aliganj, Lucknow-226024 (UP)	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

Building Committee
(during 2017-18)

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 Corporation, 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

STATEMENT OF ACCOUNTS

M/S P.S. SETHI & CO.
CHARTERED ACCOUNTANTS

10, INDRAPRASTHA ENCLAVE, SHIMLA BYE PASS, MAJRA
DEHRADUN – 248 171 (U.P.)

TEL: 9837562985
9528173229
emails: pssethiddn@gmail.com,rkguptasre@gmail.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, 2018 which comprises Balance Sheet ,Income and Expenditure Account, Receipt and Payment Account and summary of significant accounting policies.

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

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

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

P.S. SETHI & CO. Chartered Accountants DEHRADUN

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, 2018;
b) in the case of the Income and Expenditure Account of the deficit for the year ended on that date; and
c) in the case of the Receipt and Payment Account, of the cash flows for the year ended on that date.

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
M.COM, LL.B.,FCA, DISA (ICAI),FAFP,CCAD

FRN: 004545C
M.NO: 402349

Date: 24th September, 2018
Place: Dehradun

Action Taken Report on observations of the Chartered Accountants – Annexure – 1 to the Consolidated Annual Financial Statement/Account for the Financial Year 2017-18

Sl. No.	Comments/Observations by Chartered Accountants	Replies and Action taken by the Institute
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.	Para 1 & 6 : Tally.Erp.9 generally accepted/recognized software system of accounting has been installed in the Accounts Section for maintaining the account which is easily available to all the members of staff of the section through terminals provided to them. Basic training to all the members of the staff of the Section has been imparted. Uploading of the day to day data relating to receipts and payments is being done. To strengthen the working knowledge of the system and maintain the record by all other segments of the administration is required for fully conversion to accrual system of accounting. Efforts are being made to the effect by imparting necessary in-house (preferably) training to the members of staff. On fully conversion to tally system of accounting work of maintaining of financial accounting on FOXPRO database which is an obsolete software, will not be required.
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.	Provision has been made for retirement benefit while revised estimate for the financial year 2018-2019 and budget estimate for the financial year 2018-2019 is prepared/finalized. Observation of the audit is noted for future compliance and the benefits/ liability will be worked out and reflected in the annual account for the financial year 2018-2019.
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 year 2017-18 has not been undertaken.	Observation noted. Necessary action will be taken and outcome will be reported in next audit.

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 h not been carried out by the verifying officer till d Reason of not doing the needful may be specified.

Physical verification of library and wet canteen not conducted.

While auditing the accounts pertaining to the Library as well as wet canteen 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. Similarly the furniture utensils and other items available in the wet canteen have also not been physically checked. The reason for not complying with the rule laid down in GFR regarding physical verification of Assets may be specified.

4. During the course of audit it was observed that the Institute has not deducted TDS While making payment for professional for instances:

Non-deduction of TDS from the due payment of Professional Translator

Name	Nature	Amt. of Payment
Rohit Dubey	Professional	61317/-

While auditing the above-mentioned voucher it is observed that a payment of Rs. 61317 was paid to Mr. Rohit Dubey, Translator on A/c of carrying out translation work of Annual Report 2016-2017 in Hindi. The payment was made to the above-named

While making the payment of Rs. 61317/- towards translation charges to Mr. Rohit Dubey, income tax was not deducted due to over sight. Mr. Dubey has been requested to deposit the income tax applicable in the case. The due amount will be deposited into Govt. account shortly.

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	Being a professional service TDS was required to be deducted from the due payment of the translator. However, the requisite TDS was not deducted from the due payment of the Professional. The same may now be deposited in to the concerned head after calculating the amount of TDS as per the provisions of Income Tax Act.	
5.	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.	E-Tendering process as Govt. of India procurement rule has already been adopted recently and one tender of publication has been finalized through E-tendering. One more case of Procurement of Computer is in pipe line through E-tendering.
6.	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 a software which is more user friendly to al 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 and current year (2017-18) records of financial statements/Balance sheet etc shall be prepared on tally Software. But, necessary training of staff in account section for working on Tally Software is not provided.	Please refer comments/reply under para 01 above.
7.	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.	Mr. Uttam Singh has not completed codel formalities to enable the office to pay his final accumulation in his CPF account. He has been informed to do the needful and on completion of the required action due amount will be paid to him.
8.	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**	Books of accounts for the reported projects are not being maintained as the tenure of the same has been completed. Completion report by each of the project investigator is

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	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.	required to be submitted to the funding agency to enable the office do the needful. Project investigators concerned have been informed to comply.
9.	During the course of audit it was observed that there is outstanding demand of Rs.34362.58 in traces website the year wise and form wise break is as follows: F.Y: Form Type: TDS demand Prior Year: 26Q: 1209.00 2016-17: 26Q: 12859.58 2017-18: 26Q: 20294.00	Full tax has been deducted at source and has been deposited. However the matter of reconciliation of the amount mentioned by the audit is in process with the authority to get it matched with.
10.	**Inordinate delay of 4 months made in initiating the Purchase of sophisticated equipments worth Rs. 325 lakh: Equipments issued after a gap of two months from the date of receipt** Voucher no 902 dated 22.11.2017 for Rs. 13823022/-Assets register no 5 page 169 While auditing the above Assets Register it was observed that following sophisticated equipments were found recorded at page no 169 of the stock register:- 1.Broadband Seismometer 2.Strong motion Accelerometer 3.Data Acquisition System It was further observed that the equipments were further described as under:- 1.Broadband seismometer contains 11 sub items 2.Strong motion Accelerometer contains one item. 3.Data Acquisition system was not found recorded in the above Assets Register. It was also observed that as per Project Completion Certificate the equipments were shown installed/commissioned for training at 10 remote sites and one CRS at WIHG was successfully completed by M/s CHRISVIN Geomet Service Private Ltd 826, Tarapur Towers Chennai. The above certificate was furnished by Dr. Sushil Kumar Scientist 'F' as on 21.03.2018. On further verificatiom of the concerned records following points of irregularity were noticed:- 1.The Director WIHG had accorded a sanction on 16-11-2016 to incur an expenditure of Rs. 325 Lakh for the purchase of 5	Observation noted. Matter will be investigated and necessary action will be taken and outcome will be reported in next audit.

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	sophisticated equipments including the above named equipments. However an inordinate delay was made in initiating the process on the purchase of the requisite equipments. As a matter of fact the purchase order for the above equipment was issued as on 09.03.2017 after a delay of 4 months. The reason for initiating the process of purchase after a long delay may be specified. II.It was observed as per issue register Indent for the above-mentioned equipments was received by the Store Section as on 12.01.2018 vide Indent No. 093/063. However the equipments were shown issued after a delay of two months. The above name equipments are very sophisticated and they cannot be preserved without use for a long time. The reason for issuing the equipments after a long gap may be specified. III.It was also noticed that as per serial no. 8 of the purchase order dated 09.03.2017 it was provided that necessary warranty certificate must accompany the supply. However, no such Warranty Card was found on record. The reason for not receiving the requisite warranty card for the precious equipments from the supplier may be specified. IV.It was further observed that a Security Deposit worth Rs. 9,86,659 dated 25.10.2017 shown in the form of FDR issued by HDFC bank favouring WIHG was pledged by the firm as Security Deposit. The validity of the FDR was shown as dated 25.10.2017 to 25.12.2019. However as per serial No. 8 of the Purchase order it was provided that the ordered materials must be warranted for a period of 24 months from the date of satisfactory installation and acceptance of supply. In the instant case the equipments were commissioned/installed up to the period 21.03.2018 as per Project Completion Certificate dated 21.03.2018 furnished by Dr. Sushil Kumar, Scientist 'F'. As a matter of fact FDR's validity was required w.e.f. 21.03.2018 to 20.03.2020 for covering the period of 24 months of the equipments warranty. The reason for not covering the validity period of the warranty of the above equipments by the necessary FDR's issued by the supplier may be specified.	
11.	**Rule 161 of GFR not followed while floating tenders of the high valued Instruments: adequate time not offered for the invitation of tenders** **RAC** Sanctioned a fund of Rs. 325.00 Lakh for the purchase of instruments under the non-recurring head as on 21.10.2016 for the financial year 2016-2017. Accordingly global tenders (two bid system) were floated as on 09.11.2016 along with detailed terms and conditions. In response to the floating of tenders a sole tender was received from M/s Thermo Fisher Scientific India Ltd. Mumbai as on 09.12.2016. Accordingly an extension of 15 days period was approved by the	Observation noted. Matter will be investigated and necessary action will be taken and outcome will be reported in next audit.

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competent authority for the receipt of more tenders. The date of submission of the tenders was extended up to 28.12.2016 at 13.00 hrs. However no additional bid was received up to 28.12.2016 in spite of floating the Tender Notice in the leading newspapers as well as making the same available on the concerned website. It was further observed that the Store and Purchase Officer made a recommendation for accepting the bid received from M/s Thermo Fisher Scientific India Ltd on single tender basis as on 28.12.2016. The same was accepted by the CFA (Director) as on 02.01.2017 on the recommendation of the National Technical Evaluation Committee. In pursuance to the acceptance of the single bid, purchase order was issued to the above named firm for the purchase of the following instruments.

(i) I R M S model= MAT 253 Plus along with accessories Euro 3,17,097.

(ii) Purifier Panel

(iii) Imported Regulators

(iv) Gas Cylinders Rs. 1125000

A perusal of the concerned records reveals the following points of irregularity:-

(i) Rule 161 of GFR lays down "where the Ministry or Department feels that the goods of the required quality, specifications etc., may not be available in the country and it is necessary to also look for suitable competitive offers from abroad, the Ministry or Department may send copies of the tender notice to the Indian Embassies abroad as well as to the foreign Embassies in India. The selection of the embassies will depend on the possibility of availability of the required goods in such countries. In such case e-procurement as per Rule 160 may not be insisted." However in the instant case instead of following the procedure given in the above rule, the Institute published the ad of the tender in the five National dailies including a journal published from Calcutta and uploaded in the CPPP portal. Since the ad of the high valued equipment could not have a wide global publicity, consequently only one tender was received. As such it lacked the adequate competitiveness. The reason for not sending copies of the tender notice to the Indian embassies abroad may be specified.

(ii) It was further observed that an extension of 15 days period was approved by the Competent Authority up to 28.12.2016 for the receipt of the tenders. As a matter of fact 15 days time was not

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	sufficient period for the receipt of tenders. In terms of rule 161 it is laid down 'ordinarily, the minimum time to be allowed for submission of bids should be three weeks from the date of publication of the tender notice or availability of the bidding document for sale, whichever is later. Where the Department also contemplates obtaining bids from abroad, the minimum period should be kept as four weeks for both domestic and foreign bidders'. The reason for not adhering to the above laid down rule for granting sufficient time for the invitation of the bids after retendering may be specified.	
12.	**Unauthorized amendments carried out by the three transporters on their quotations in a highly irregular manner: Members of the Committee ignored the unauthorized amendments while recommending the lowest quotation** Hiring of Vehicle Vr.no 366 C-124 A payment of Rs. 48505 was passed for payment as hiring charges for M/s Chanchal Gupta Transporter on a/c of hiring of buses for local journey. It was noticed that approval and sanction for hiring of private buses during 2nd National Geo-Research Scholars meet was accorded by the Competent Authority on the recommendation of the committee constituted for the purpose. It was further observed that three quotations were received for 52 seater bus for the meet to be held between 17 to 20 may 2017. Details of the quotations received are shown below:- (A) Mayank Gupta – (i) Local visits in Dehradun- Rs 7200 per day (ii) Wadia to Mohand & back- Rs 13500 per day (iii) Wadia to Mussorie & Kampty fall & back- Rs 13500 Above rates include tolls, packing, taxes etc. Service tax @ 9% extra (B) Chanchal Gupta- (i) Local visits in Dehradun- Rs 6500 per day (ii) Dehradun to Mohand & back- Rs 12500 per day (iii) Dehradun to Mussorie & Kampty fall & back- Rs 12000 Service tax @ 9% extra (C) Ashok Kumar Gupta- (i) Local visits- Rs 6900 per day (ii)Dehradun to Mohand -Rs 13200 per day (iii) Dehradun to Mussorie & Kampty fall- Rs 14000 In this	Payment of the sum was made to the transporter concerned on the recommendations of the duly constituted committee and approval of the authority competent in exigency of Institute work. However observations made by the audit are noted for future compliance.

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	connection following points of irregularity were noticed:- (i) Comparative chart for the three quotations was not made by the Committee before according the approval by the Competent Authority. (ii) It was observed that Service Tax No. and PAN nos were also not mentioned on the three quotations received by the Committee. (iii) A perusal of the quotations submitted by Mayank Gupta revealed that the bus owner mentioned the rate Rs. 13500 by making unauthorized overwriting at serial No B of his quotation. It was originally written as Rs 11500. Unauthorized amendments in the quotations are not accepted in audit. The reason for overlooking the unauthorized amendments effected by the Transporter in his quotation rates needs to be specified. (iv) It was observed that M/s Chanchal Gupta had originally quoted the rate as Rs 10200 from Dehradun to Mohand for bus fare. The fare was written both in figures as well as in words. Later on the amount was altered from 10200 to 12500 by making overwriting both in figures as well as in words. However the unauthorized amendment was not rejected by the Committee. (v) M/s Alok Kumar Gupta amended the figure from Rs. 11200 to 13200 at serial no 2 Dehradun to Mohand in his quotation in a highly irregular manner. It is interesting to note here that all the three bus owners were allowed to change the rates of fare in connivance with the members of the Committee an irregular manner. Accordingly the quotation of M/s Chanchal Gupta was accepted in an irregular manner. (vi) It was further observed that hiring charges of 2 buses for 1 day for Mohand & back on 19.05.2017 were shown as Rs 12500 x 2= Rs 25000. However bus numbers hired were not mentioned on the bill. (vii)Papers of the hired buses were not verified. (viii) Driving licenses of the drivers were not verified. The irregularity may now be got condoned under the orders of the CFA.	
13.	**Expenditure of Rs 83414 booked to incorrect head of expenditure** Vr.no 639 C-24 dt 19-09-2017 While auditing the above-mentioned voucher under the head 'Building Maintenance a/c' it was observed that total expenditure of Rs. 83414 was incurred on the purchase of Diesel & petrol for Gen set and Grass Cutting machine during the month of Aug 2017. CFA of the Institute accorded	As suggested expenditure incurred has been transferred to the appropriate head of account "Electricity Charges" and "Maintenance of Garden". As far as observations with regard to maintenance of register is concerned, the Officer-in-charge has been informed to

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	financial sanction of Rs. 83414 under the head 'Purchase of Diesel and Petrol' as on 11-09-17. In this connection following points of irregularity were noticed:- (i) As per the cashbook above expenditure was factually booked under the head 'Building Maintenance A/c' whereas the same was required to be debited to the appropriate head 'Purchase of Diesel and Petrol' The reason for not debiting the appropriate head of expenditure in the instant case may be specified. (ii) Log book of the Diesel & Petrol was verified. On verification of the same it was revealed the Log book was prepared on an ordinary register instead of the prescribed performa. (iii) Opening balances as well as closing balances were not calculated on day to day basis. (iv) The log book register was not countersigned by the Verifying Officer.	comply.
14.	**Receipt of ordered chemicals after a delay of 6 months: Chemicals received less than the demanded chemicals: Items other than the demanded ones received in stock: Two contradictory approvals- The first for one year and the other for 6 months issued by the Competent Authority for the same work** Vr. No. 638 dt 19-09-2017 While auditing the Chemicals account it was observed that Purchase Order for the purchase of carborandum powder was forwarded to M/s Geologists syndicate PVT Ltd. Kolkata as on 30.11.2016 vide P.O. No. 1876 dt. 30.11.2016. Details of the Purchase Order are shown below:-	Observation noted. Matter will be investigated and necessary action will be taken and outcome will be reported in next audit.

Sr.No	Description of item	Qty	Rate	Cost
1	Mesh 220	100Kg	225 per kg	22500
2	Mesh 400	50 Kg	240 per kg	12000
3	Mesh 600	50 Kg	225 per kg	12750
				47250
Add Vat/Cst@ 14.5%				6851.25
Total cost				54101.25
Or say				54101

It was mentioned in the P.O that the supply of the chemicals should be made within 3-4 weeks from the date of receipt of the Purchase Order. A Scrutiny of the concerned records revealed the following points of irregularity:-

(i) Supply of the chemicals was required to be received in the

P.S. SETHI & CO. Chartered Accountants DEHRADUN

Institute up to the end of Dec 2016. However the firm failed to supply the required chemicals within the stipulated period. As a matter of fact the same were received in the stock as on 27-06-2017 in two batches as per the stock entry no 19/142 made on the suppliers bills after a delay of 6 months. The reason for the late supply by the firm has not been clarified. In this connection invoice no. 50/17-2018 dated 26-05-2017 for Rs. 18377 and invoice no. 234/16-2017 dt.27-2-17 for Rs.35724 may be referred.

(ii) It was also observed that quantity of the chemicals was received much less than the actual demanded quantity. 15kg of Mesh 400 was received against Mesh-600 and the actual quantity demanded was 50 Kg. It is not clear as to why re-quotations were not invited due to failure of supply by the erring firm.

(i) It was also observed that the firm supplied a quantity of 20 Kg of Mesh-500 against the demand of Mesh 600. The chemical Mesh-500 was not demanded by the Institute. It is not clear as to why the store keeper accepted an item other than the demanded one in the store without obtaining prior approval from the Competent Authority.

(ii) It was further observed that the old rate contract expired as on 24-06-2017 whereas work order to the tune of Rs. 56323 was issued as on 28-06-2017. Line 3 of the opening paragraph of the work order reads "The Competent Authority has granted an extension of the prevailing rate contract for a further period of one year on the same terms & conditions as specified in the quotation mentioned above". The same was approved by the Director as on 28-06-2017 on the work order itself. It was further observed that on the note sheet an extension of 6 months period was approved by the Director as on 18-07-2017. As such there is contradiction in both the approvals. The reason for granting contradictory approval on two different occasions for the same work needs to be specified.

(iii) Sanctions and approvals should be granted on the note-sheet in the beginning of each file. However the same are being obtained on the work orders or at other places other than the beginning space of the file.

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15.	**Delay 0f more than 4 months in the receipt of items: Items issued 14 days prior to the date of receipt from the supplier** Vr.no 788 C-81 dt 26-10-2017 for Rs. 735528 While auditing the Chemical Glassware a/c it was observed that a purchase order for the purchase of 7 different generic chemical items was issued to M/s Katyuri Chemicals & Instruments Dehradun as on 07-03-2017 by the Institute vide P.O. No 2016-17/100/4691 dated 07-03-2017. There was a rate contract in existence with the above mentioned firm. A scrutiny of the concerned records revealed the following points of irregularity. (i) As per para 3 (Delivery period) of the purchase order for the above chemicals issued as on 07-03-2017 supply was required to be obtained within 3 weeks i.e. before 31-03-17. However the actual delivery was received as on 12-09-2017. The reason for a delay of more than 5 months may be specified. (ii) Chemicals were not subjected to Technical Inspection at the time of receipt. (iii) It was further observed that the chemicals were received in stock as on 26-09-2017 whereas the same were issued to the concerned labs as on 12-09-17 & 14-09-17 i.e. in advance as per the concerned consumable stock register. It is not clear as to how the above items happened to be issued before the receipt from the supplier.	Observation noted. Matter will be investigated and necessary action will be taken and outcome will be reported in next audit.
	for P.S. Sethi & Company **Chartered Accountants** **CA Rakesh Gupta** **(FCA,DISA(ICAI))** **Dated: 24th September,2018**	**(Manju Pant)** **Astt. Fin. & Accts. Officer** **(Pankaj Kumar)** **Registrar** **(Dr. (Mrs.) Meera Tiwari** **Director (Addl. Charge)**

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31ST MARCH 2018)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	90,09,45,252	88,68,83,511
Reserves and Surplus	2	-	-
Earmaked/ Endowment Fund	3	16,94,704	14,83,516
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	77,97,706	67,63,614
TOTAL		**91,04,37,662**	**89,51,30,641**
ASSETS			
Fixed Assets	8	42,01,92,828	41,62,47,002
Investments from Earmaked/ Endowment Funds	9	47,115	47,115
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	49,01,97,719	47,88,36,524
TOTAL		**91,04,37,662**	**89,51,30,641**
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. MEERA TIWARI)
A F & A.O	Registrar	Director

Date : 24th September, 2018
Place : Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31ST MARCH 2018

(Amt in Rs...)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12	-	-
	Grants/ Subsidies	13	27,24,90,958	30,96,74,788
	Fees/Subscription	14	22,000	13,000
	Income from Investments	15	8,35,524	7,43,924
	Income from Royalty, Publication etc.	16	1,01,396	61,107
	Interest earned	17	2,89,13,765	2,96,39,036
	Other Income	18	42,94,625	59,85,164
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**30,66,58,269**	**34,61,17,019**
B	**EXPENDITURE**			
	Establishment Expenses	20	18,86,14,970	21,97,65,049
	Other Research & Administrative Expenses	21	7,58,61,070	6,65,57,966
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	80,18,401	76,96,060
	Depreciation Account	8	6,54,92,175	6,97,21,683
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	(59,025)	10,740
	Loss / (Profit) on sale of Assets	A-19	(6,360)	(27,920)
	TOTAL (B)		**33,79,21,231**	**36,37,23,578**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		(3,12,62,962)	(1,76,06,559)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	BALANCE BEING SURPLUS /(DEFICIT) CARRIED TO CORPUS FUND		**(3,12,62,962)**	**(1,76,06,559)**

AUDITOR'S REPORT

"As per our separate report of even date"

FOR P.S. SETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
(PARTNER)

(MANJU PANT)
A F & A.O

(PANKAJ KUMAR)
Registrar

(DR. MEERA TIWARI)
Director

Date : 24th September, 2018
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2018)

(Amt In Rs. .)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	22,32,58,909	21,76,45,252
Grants - in - Aids	26	35,70,93,255	36,79,57,788
Grants - in - Aids/Other Receipts (Ear Marked	27	4,30,68,133	4,34,602
Loan & Advances	28	18,60,02,345	21,58,03,958
Loan & Advances (Ear Marked)	31	-	8,000
Fees/Subscription	14	22,000	13,000
Income from Investments	15	8,35,524	7,43,924
Income from Royalty, Publication etc.	16	1,01,396	61,107
Interest earned	17	1,60,54,330	1,39,72,080
Other Income	18	42,94,375	59,85,164
Investment (L/C Margin Money)	34	3,97,02,823	2,22,00,000
		87,04,33,090	**84,48,24,875**
PAYMENTS			
Establishment Expenses	20	18,86,14,970	21,97,65,049
Other Administrative Expenses	21	7,58,61,070	6,65,57,966
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	80,18,401	6,054
Loans & Advances	29	17,47,88,411	22,85,86,729
Loans & Advances (Ear Marked)	32	-	3,82,211
Investment (L/C Margin Money)	35	2,49,55,000	4,97,00,000
Fixed Assets	36	6,94,31,641	5,53,17,803
Ear Marked Fund Expenses	33	4,30,61,653	-
Grant - in - Aid (Ear Marked) Refunded	30	-	12,50,154
Closing Balance	25	28,57,01,945	22,32,58,909
		87,04,33,090	**84,48,24,875**

AUDITOR'S REPORT

"As per our separate report of even date"

FOR [illegible]ETHI & CO
CHARTERED ACCOUNTANTS

CA RAKESH GUPTA
(FCA, DISA (ICAI))

(MANJU PANT)
A F & A.O

(PANKAJ KUMAR)
Registrar

(DR. MEERA TIWARI)
Director

Date : 24th September, 2018
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, 33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2018

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.

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. Meera Tiwari)
A.F. & A.O	Registrar	Director

Date : 24th September, 2018
Place: Dehradun

P. S. SETHI & CO. Chartered Accountants DEHRADUN

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2018

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)	34362.58
	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

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. 2017 -18 is as follows:**

Remuneration to auditors		
i)	As Auditors	33,040/-
	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, 2018, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2018.

(Manju Pant)	(Pankaj Kumar)	(Dr. Meera Tiwari)
A.F. & A.O	Registrar	Director

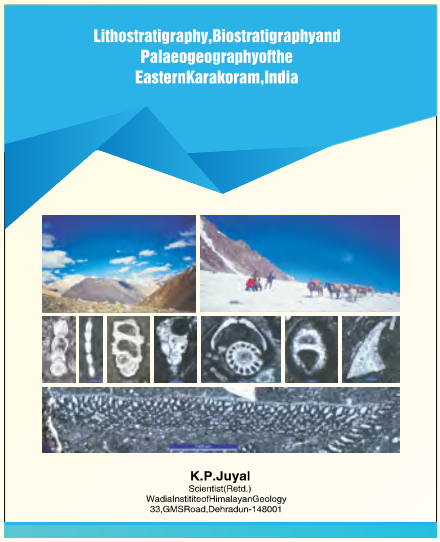
Date :
Place: Dehradun

P. S. SETHI & CO. Chartered Accountants DEHRADUN

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

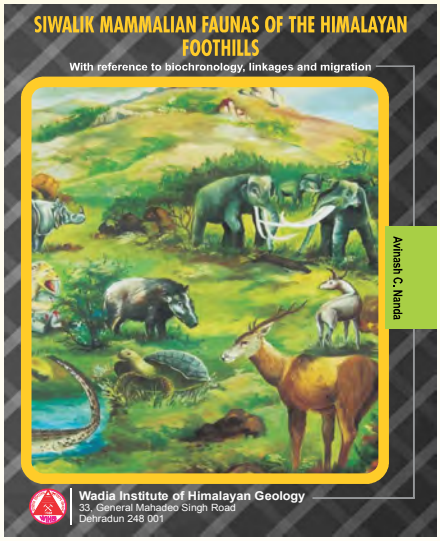
Latest Publications

2018



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

2015



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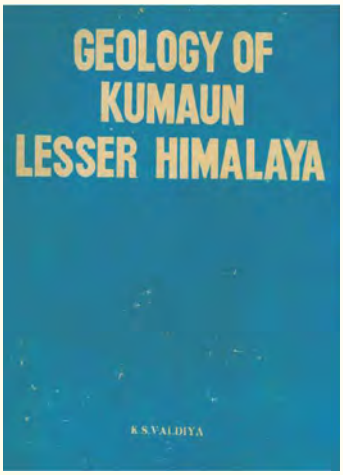

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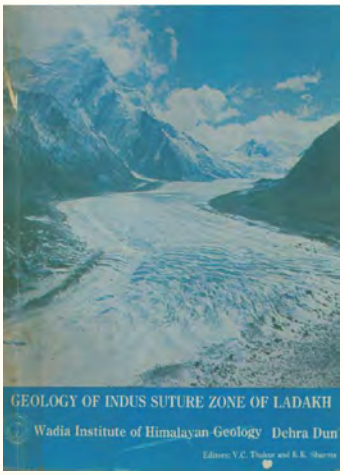

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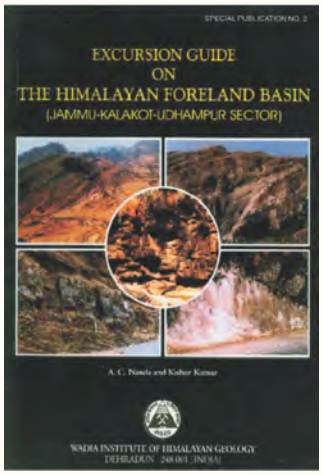

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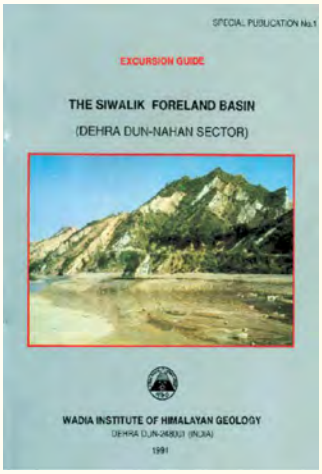

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Volume 13*	(1989)	1000.00	100.00
Volume 14* (in Hindi)	(1993)	600.00	-
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OTHER PUBLICATIONS

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
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