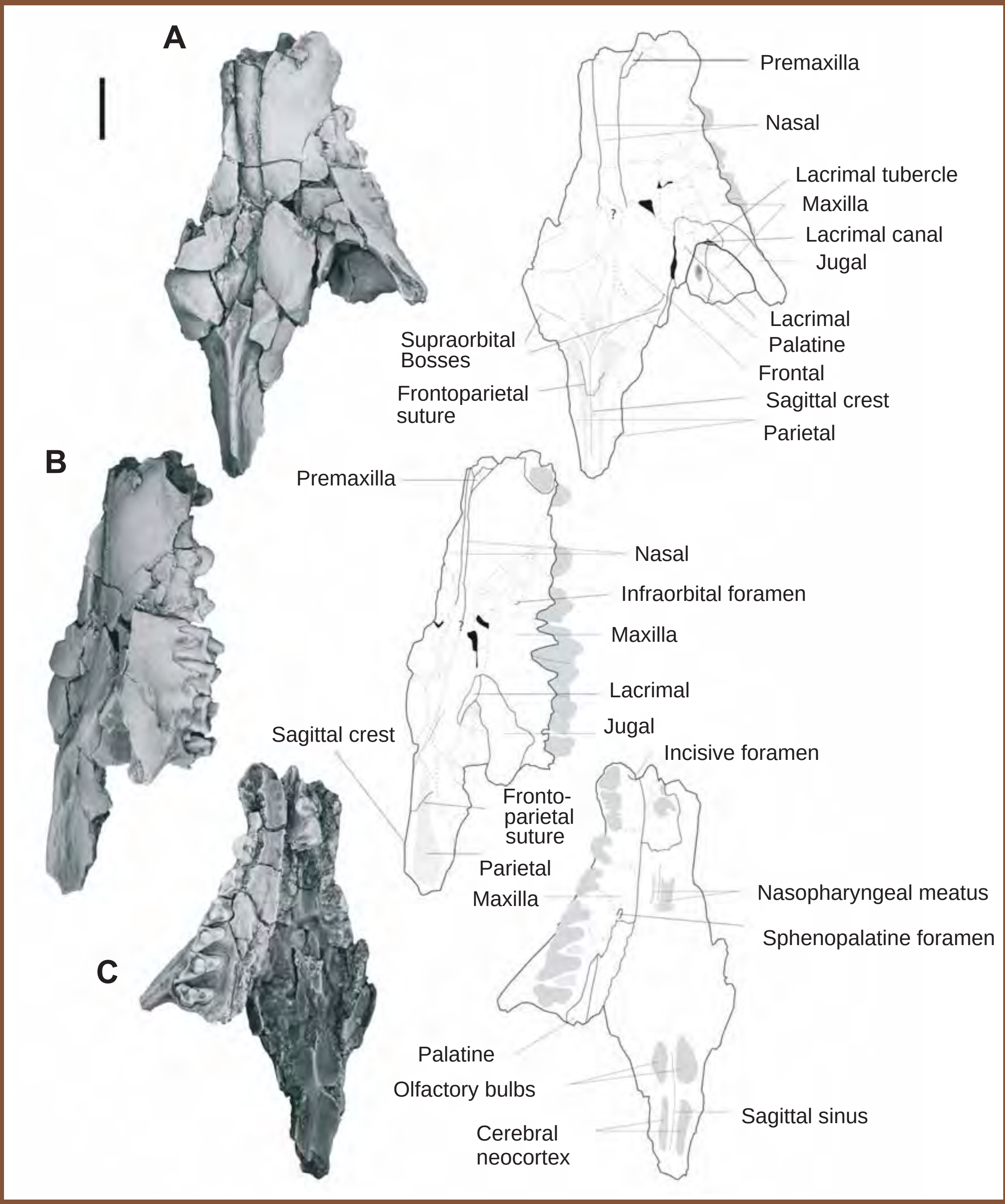
ANNUAL REPORT 2015-16



WADIA INSTITUTE OF HIMALAYAN GEOLOGY
DEHRA DUN

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

Cover photo: Skull of *Indohyaenodon raoi*. Photographs (left) and interpretive drawings (right) of the partial skull with complete right P2-M3, C and P1 alveoli, and left P1 in A, dorsal, B, lateral, and C, ventral views. Scale bar equals 10 mm.

(Courtesy: Kishor Kumar)

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RESEARCH ACTIVITIES

RESEARCH GROUPS

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

THRUST AREA THEMES

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

UNITS ANCILLARY TO RESEARCH

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

ADMINISTRATION

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

INSTITUTE'S RESEARCH ACTIVITIES

The Wadia Institute of Himalayan Geology has a mandate to study scientific issues related to the Himalaya including its evolution, geodynamics and climate. The Institute plays a lead role in geological and geophysical investigations of the Himalayan region to understand earthquake activity, the glacial-monsoon linkages, the climate-tectonic interactions and in-depth study of the crust-mantle boundary across the India-Eurasia plate.

An important step initiated during the year was to prepare a systematic glacier lake inventory based on satellite images for the Uttarakhand Himalaya, which included 1,266 lakes. The idea is to understand the state and fate of glaciers, including the disaster potential (GLOF) in the region. Further, for the first time in the country, the tapping and using of the geothermal energy for room heating was demonstrated in the Chumathang region of Ladakh by the Institute scientists. A survey was also carried out by Institute Scientists after the Jammu & Kashmir flood, on the request of district administration, to demarcate the safer areas for rehabilitating people in the Udhampur districts. The Institute Scientists organized five days training programme for the officers of the Rail Vikas Nigam Ltd (RVNL) that has the responsibility of making 110 km rail route (mostly through tunnels) in the Himalayan terrain between Rishikesh and Karanprayag (Garhwal Himalaya). The Institute had also brought out the book entitled *'Siwalik Mammalian faunas of the foothills with references to biochronology, linkages and migration'*.

With an objective to provide the necessary infrastructural facilities to produce internationally competitive data base research, instrumental facility like 'LA-MC-ICP-MS' has been added to the existing high end instrumental facilities of the Institute. Shri Y.S. Chowdary, Hon'ble Minister of State for S&T and Ministry of Earth Sciences inaugurated the unit on October 9, 2015. The continuous growth in the analytical laboratory facilities, field equipments and inter-linkages with other academic institutions has ensured significant progress in all the on-going projects. An overview of the on-going activities in 5 Thrust Area Themes (TAT) showed that major research activities in

Shri Y.S. Chowdary inaugurating the LA-MC-ICP-MS Lab.

the thrust areas have progressed well towards the projected goals. Significant achievements in each of the thrust areas for the year 2015-16 are highlighted below.

TAT - 1: Geodynamic Evolution of the Himalaya and Adjoining Mountains

- The receiver function analysis study reveals a prominent intra crustal low velocity layer (IC-LVL) beneath the Tethyan Himalaya, and inferred 4-8 % partial melt and/or aqueous fluid at mid-crustal depth.
- The magneto-telluric response at few stations along the Satluj River valley section, Himachal Pradesh indicates the presence of a smooth northward dipping conducting layer along the profile with a possibility of break or jump below the zone of Himalayan Seismic Belt.
- Monitoring the Frontal Thrust systems and other allied major Thrusts in the Dehradun and Kangra re-entrants in the Northwest Himalaya through GPS measurements and Gravitational Potential energy (GPE) suggest that, in comparison with the Dehradun re-entrant, the horizontal stress component is two orders of magnitude higher in the Kangra re-entrant, especially between the HFT and the Jwalamukhi Thrust.
- A P-T pseudo section modeling approach of the Main Central Thrust Zone (MCTZ) and Higher Himalayan Crystalline Sequence (HHCS) in the Alaknanda valley, NW Himalaya yields peak metamorphic

conditions of 6.3-7.5 kbar and 550-580°C in the MCTZ, and 8-10 kbar and 610-650°C in the basal part of the HHCS. The results indicate continuity in the P–T field gradient across the contact between the MCTZ and HHCS, and show an inverted metamorphic sequence from biotite to garnet zones to the basal part of the HHCS.

- The inferred P-T evolution of the Sapi-Shergol blueschists in Ladakh, ca. 470°C and 19 kbar, is characterized by a clockwise hairpin loop along low thermal gradients (8-9°C/km), and is consistent with a cold subduction zone system in an intra-oceanic subduction setting.
- The geochemical data of Nagaland-Manipur Ophiolites of Indo-Myanmar Orogenic Belt, NE India show that they were initially generated in the seafloor spreading regime at the eastern margin of the Indian plate which was then thrusted over the continental margin of the Indian plate during its collisional and subduction process with the Myanmar plate.
- The U-Pb zircon geochronology application on the rocks of Higher Himalayan Crystallines using the newly installed LA-MC-ICPMS facility in the Institute suggest that, the Vaikrita Thrust that is considered as MCT by many, is indeed a terrain boundary with contrasting detrital zircon ages and characteristics. Zircons from Munsiari Formation are indistinguishable from that of Inner Lesser Himalaya (Berinag Quartzite) suggesting affinity with Lesser Himalaya.

TAT-2: Indian Monsoon-Tectonic Interaction and Exhumation of the Himalaya

- Speleothem proxy records from Mawmluh Cave, Meghalaya reflect abrupt increase in Indian Summer Monsoon strength during the Bølling-Allerød and early Holocene periods and pronounced weakening during the Heinrich and Younger Dryas cold events.
- The sedimentation rate of the Rewalsar Lake, Himachal Pradesh was measured on the top 2 m core samples using isotopes of ^{137}Cs and ^{210}Pb dating techniques, which reveal that the lake has experienced an average sedimentation rate of 3.35 cm/yr during the last ~50 yrs which is the highest in comparison to the other lakes in the NW Himalayan region and is attributed to the enhanced human interference in the catchment area.
- New data on Alaknanda-Mandakini and other Rivers indicate that floods in the Himalaya largely occur during the warm and wet climatic phases, and that the Indian Summer Monsoon front may have penetrated into the Ladakh during the post glacial climatic optimum.
- The sustained treeline rise in Mandakini Valley is represented by some cold/snow regime resistant plant species such as *Betula utilis*, *Sorbus acuparia* and *Rhododendron companulatum,* and is indicative of climate change implication, especially the continuous decrease in snow regime/snow precipitation in alpine ecosystem.
- Major ions, stable isotopes ($\delta^{13}C_{VPDB}$) and silica measured in the samples in Indus River waters covering Ladakh region, show that the alkalinity in these rivers is linked with silicate weathering.

TAT-3: Earthquake Precursors Studies and Geo Hazard Evaluation

- The paleoseismological investigations carried out at Nalagarh in the Pinjaur Dun has revealed Late Pleistocene earthquakes along the Nalagarh Thrust that separates the Palaeogene rocks from the Neogene Siwaliks. Similar studies carried out in NW Frontal Himalaya at Kala Amb shows two large earthquakes of magnitude ≥7.6 between 34.1 ka and 17 ka, and of magnitude 8 to ≥ 8.5 between 5.78 ka and 2 ka.
- The synthesis of the seismic records of BBS stations run by WIHG suggests that the hypocenters of the earthquakes are mainly distributed at shallow depth of up to 20 km.
- The frequency-dependent attenuation of *P* and *S* waves in Garhwal Himalaya indicate that the Garhwal region falls under tectonically active areas of the world with dominancy of scattering attenuation.
- The slip distribution evaluation from waveform modeling of earthquakes in the Garhwal-Kumaun region of Himalaya on the fault plane show that the large slip regions cover a very small area as compared to the total area of fault plane.

TAT-4: Biodiversity - Environment Linkage

- The independent evidence of acanthomorphic acritarchs has been employed as a proxy for paleogeographic reconstructions. The report of *Tianzhushania spinosa* from Infrakrol Formation suggests that this fossiliferous horizon is coeval with the Lower Doushantuo Formation (Member II) of South China.

- New fossils of the early Eocene hyaenodontid *Indohyaenodon raoi* were described from the Cambay Shale Formation (western India), including the first known rostrum, upper dentition, and postcrania, substantially expanding our knowledge of the species and providing insights into its functional morphology and relationships. The new phylogeny is consistent with either an African or an Asian origin for the group
- An elephant skull, the *Elephas* cf. *namadicus* was discovered from the late Pleistocene strata of Marginal Ganga plain.
- The $\delta^{13}C$ values from both pedogenic nodules and gastropod shells from a part of the fossiliferous Pinjor Formation exposed near village Nadah, Panchkula clearly indicate the dominance of C_4 vegetation in the area at that time. The $\delta^{18}O$ values, in general, suggest persistence of warm and humid climate conditions.
- A shallow marine to near shore environmental condition followed by different stages of regression and transgression is inferred on the basis of identified calcified green algae in the carbonate beds from the Ordovician-Silurian successions of Pin valley of the Spiti Basin.
- The recent discovery of *Wengania exquisita* from the phosphate beds of Birmania Formation near Jaisalmer, Rajasthan shows the fossiliferous nature of the basin, and indicates an Ediacaran age for the formation.

TAT-5: Himalayan Glaciers: their role in Indian Monsoon variability and Hydrological changes in the Ganga Basin

- The study of Dokriani glacier reveal that the snout is continuously retreating with varying rates. Monitoring by GPS with reference to permanent survey point made on both the sides of the glacier front showed that the total frontal retreat determined was 17 m for the year 2014-15 which is comparatively less than previous year retreat of 21 m.
- The calculation of ablation for debris-covered and clean ice of Dokriani Glacier using thirty stakes observed over a period of 4 years suggests that thinning glacier rapidly becomes debris-covered over the ablation area, which reduces the rate of ice loss.
- Study of two glaciers, namely Pensilungpa in Suru River basin and Durung-Drung in Zanskar River basin, Ladakh having present snout at altitude of 4,121 m and 4,674 m respectively, reveal glaciers retreats by ~707 m and ~336 m as with an average rate of ~15 ma^{-1} and 7 ma^{-1} respectively.
- Hydrogeological studies undertaken around Tehri reservoir reveals that groundwater mainly occurs in disconnected bodies of aquifer and is available through secondary porosity and permeability of the rock formations. A map was prepared in which four zones (high, moderate, low, and very low) of potential groundwater prospects are identified.
- Landslide susceptibility map of the township of Mussoorie has been prepared integrating frequency ratio and weight of evidence modelling methods. It is observed that there is higher potential for landslides in the area covering terrace deposits, old landslide deposits and along road cuts.

Academic Pursuits

The Institute made its presence felt in Academia and under the on-going research programs pursued during the year, the Institute has published 54 papers, with around 67 papers being in press or communicated. Five research scholars were awarded Ph.D. degrees, while three theses were submitted for the award. Eleven scientists have also visited abroad to participate in various seminar/symposia/ workshop/training courses.

The Institute had the privilege of organizing the 30th Himalaya-Karakoram-Tibet Workshop (HKT-2015) at its premises in Dehra Dun during October 6-8, 2015, which was inaugurated by Hon'ble Governor of Uttarakhand, Shri. Krishna Kant Paul. A total number of 264 participants including 46 foreign participants presented their research work in the conference. As a part of the event, a four days post-workshop field excursion tour along the Rishikesh-Joshimath-Malari section was organized. The post-field workshop was of great success as around 24 foreign delegates and 13 Indian delegates participated in it. A kick off meeting of the Indo-Norwegian Project at National Geotechnical Facility (NGF), Dehra Dun was also organised during April 24-25, 2015. Presentations were made during this meeting by the participants, and a course of action for future research work was planned.

One of the Institute scientists, Dr. T.N. Jowhar received the honour of becoming the *'Sessional President for Earth System Sciences'* in the 103rd Indian Science Congress held at Mysore University, Mysore from January 3-7, 2016. In the other aspects of academic pursuits, the Institute made the laboratory facilities accessible to researchers from national institutions and universities. It continued the publication of '*Himalayan*

Geology', journal and brought out the volumes 36(2) and 37(1), along with newsletter 'Bhugarbh Vani' volume 5 (in four parts).

Other Highlights

Institute has participated and displayed its scientific exhibits at various forums in different parts of India. The Institute employees participated in the *'Swacchata Abhiyan'* on October 2, 2015. It had also organized *'Free Heart Check-up Camp'* and *'Free Eye Test Camp'* for its employees in the Institute premises.

Hindi pakhwara was celebrated in the Institute during September 14-28, 2015. During this period Hindi essay competition and debate for school children and Institute employees was organized. 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. The Annual Report of the Institute for the year 2014-15 was published in bilingual form (Hindi and English). Various incentive schemes for encouraging progressive use of Hindi were also implemented. The Hindi Magazine *'Ashmika'* volume 21 was also published.

Anil K. Gupta
Director

TAT - 1: GEODYNAMIC EVOLUTION OF THE HIMALAYA AND ADJOINING MOUNTAINS

TAT - 1.1
Himalayan Deep Image Profiling (HIMDIP) along defined transects

(*S.S. Bhakuni, Gautam Rawat, Naresh Kumar, Dilip Kumar Yadav and Devajit Hazarika*)

Structural analysis across eastern limb of Nahan salient

The structural data generated across the Himalayan Frontal Thrust (HFT), Main Boundary Fault (MBF), Main Boundary Thrust (MBT), and Jutogh Thrust zones were analysed to understand the geometry and kinematics of eastern limb of the Nahan salient along the Tons-Giri River valley section, Himachal Himalaya. The HFT is a NNE-dipping structure with development of bedding-parallel shears, and gentle to very steep-dipping normal faults (dipping towards both north and south directions) recognized at base of hanging wall. It is revealed that there was no influence of pre-existing salient architecture on the subsurface geometry of the Main Himalayan Thrust (MHT) or detachment during propagation of the Himalayan mountain physiographic front along the HFT. In the Giri river valley section, across the vertical to steeply-dipping MBF, the Upper Tertiary footwall comprising reddish mudstone of the Siwalik rocks has been thrust over by the Lower Tertiary hanging wall consisting of olive green calcareous shale and slates of the Subathu Formation. A fault ridge has developed along the base of hanging wall of the MBF. The Giri river flows along top of the footwall of the MBF.

In another section, north of Nahan, the MBF dips moderately towards NW where rocks of the Subathu Formation are characterized by development of a large number of normal fault planes dipping gentle to moderate towards NNE. This formation in particular is deformed by the extensional tectonics that has widened the width of the Lower Tertiaries towards the apex of the Nahan salient. Towards end point of the eastern limb of the Nahan salient, the MBF merges with the MBT near the inflection point between the Nahan salient and Dehradun recess. Here the width of Lower Tertiaries is condensed near branch point of the MBF. Across the MBT, the hanging wall massive and thickly bedded Krol limestone has thrust over the Subathu calcareous and carbonaceous shales with basic rocks at the top of the footwall (Fig. 1). The MBT is a sub-vertical structure with frequently developed left-lateral strike-slip faults recognized at the base of hanging wall of the MBT. Large sub vertical pinch and swell structures with transverse tension release fractures are observed at top of the footwall, where layer-parallel stretching is observed. Much of the deformation across the MBT has been accommodated by incompetent Subathu rocks. Southeast-dipping discrete shear zones are common at base of the hanging wall of the MBT. These shear zones have been offset by a normal faults dipping moderately towards WSW. A new intraformational thrust fault within the Dagshai Formation is recognized that may be the younger splay of the MBT in addition to the MBF. There is an intimate relationship between thrust tectonics and evolution of landscape in the MBT zone. Towards west along another transect the mylonitic carbonate rocks with pinch & swell-, and boudin-structures have developed at base of hanging wall of the MBT. In this section the width of the Lower Tertiaries exposed between the MBF and MBT is less. The base of the hanging wall of the Jutogh Thrust is demarcated by development of a shear zone that is cut by steep-dipping faults along which gauge material has formed within shear zones in pulverized and weathered quartzite dipping towards west (Fig. 2). Away from the thrust schsitosity in garnet-bearing phyllite-quartzite sequence dips gently towards NW. Normal faults cutting the main foliation dip moderately towards ESE are common. Large schistosity-parallel pinch and swell

Fig. 1: Vertical-dipping Main Boundary Thrust (MBT) between the Krol Limestone and Subathu shales. NW-SE trending strike-slip faults (S-SF) are common at base of hanging wall of the MBT.

Fig. 2: The base of hanging wall of the Jutogh Thrust is sheared with fault gauge developed with shear zones observed with quartzite. Away from the Jutogh Thrust, normal faults are commonly developed at basal part (garnet-mica schist) of the hanging wall of the Jutogh Thrust.

structures have developed within phyllites at and near top of the footwall of the Jutogh Thrust. At the base of the hanging wall of the Jutogh Thrust, the presence of isoclinal reclined folds and pinch and swell structures indicates rotation of early folds along the down-dip stretching lineation formed as a result of propagation of thrust sheet. Hanging wall of the Jutogh Thrust forms a linear, large and high ridge.

Magnetotelluric response studies along the Satluj river valley section, H.P.

The magnetotelluric response at few stations along the Satluj River valley section, Himachal Pradesh indicates the presence of near source effect. The electric field recordings at these stations were very noisy perhaps due to various hydro-electricity projects and unbalanced power network of the region reflecting larger error bars in some of estimated impedance tensors. Therefore, the apparent resistivity curves were analyzed for dimensionality and decomposition. Swift skew and bahr's phase sensitive skew indicate the complexity of geoelectrical structure as none of site response of entire period band can be classified as strictly 2-D except sites at the southern end of the profile. Variation of skew parameters therefore suggests that dimensionality of subsurface geoelectrical structure is band limited and varies depth-wise. The preliminary results of the pseudo-section upto 10 sec period suggest the presence of a smooth northward dipping conducting layer along the profile with a possibility of break or jump below the zone of Himalayan Seismic Belt (Fig. 3).

Pseudo section for XY polarisation　　Pseudo section for YX polarisation

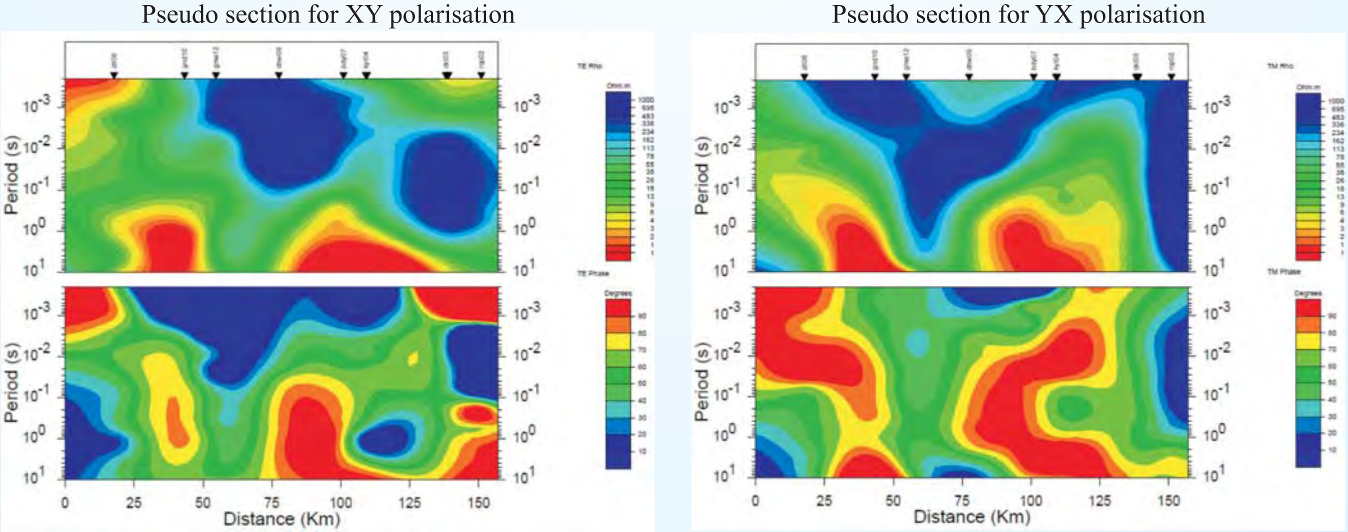

Fig. 3: Pseudo section of apparent resistivity and phase of XY and YX polarisation of MT Transfer function along the Satluj River valley.

Seismicity pattern in the Satluj River valley section, H.P.

Seismicity to micro-earthquakes level and higher intensity are assessed for the Kinnaur region, northwest Himalaya in and around the Satluj and Spiti river valleys (Fig. 4). The earthquake events in the magnitude range of 1.0 to 4.2 located using local velocity model are mostly concentrated within the upper part of the crust. The epicentre and hypocentres of the seismic events are plotted with filled red circles in figure 4 with geo-tectonic background. These seismic events are confined within the Central Crystallines and to the south of the Tibetan zone. The seismological data was integrated with the available geological, geophysical, and geomorphological aspects to understand the geophysical processes of India-Eurasia collision zone. Most of the earthquake sources are associated with the Main Himalayan Thrust (MHT) or detachment and with local tectonics active above it.

The investigation suggests multi seismo-genesis zones that can be broadly divided into two parts. There is high concentration of micro-earthquake seismicity in the epicentre zone of M6.8 Kinnaur earthquake of 19th January, 1975. The seismicity, focussed to the west of the Kaurik-Chango Fault Zone (KCFZ), is aligned nearly N-S direction and is related with the seismo-genetic fault of the Kinnaur earthquake. This is in the northeast part of the study region and in depth section the hypocentres are located in the upper 20 km crustal part. The seismicity is generated by the local tectonic faults and concentrated above the MHT. In the southern part of the study region, the seismicity is aligned nearly NW-SE direction, which is along the Main Himalayan Seismic Belt (MHSB) coinciding with the trend of its southeast Garhwal region and northwest Kangra-Chamba region, Himachal Pradesh. The well located seismic events of northwest Kangra-Chamba region (Kumar et al., 2009) are plotted with filled magenta colour. In this part of the Nahan salient zone, the Main Central Thrust (MCT) is curved and is convex towards SW, however, the seismicity is not along the surface trace of this tectonic fault as observed towards east and

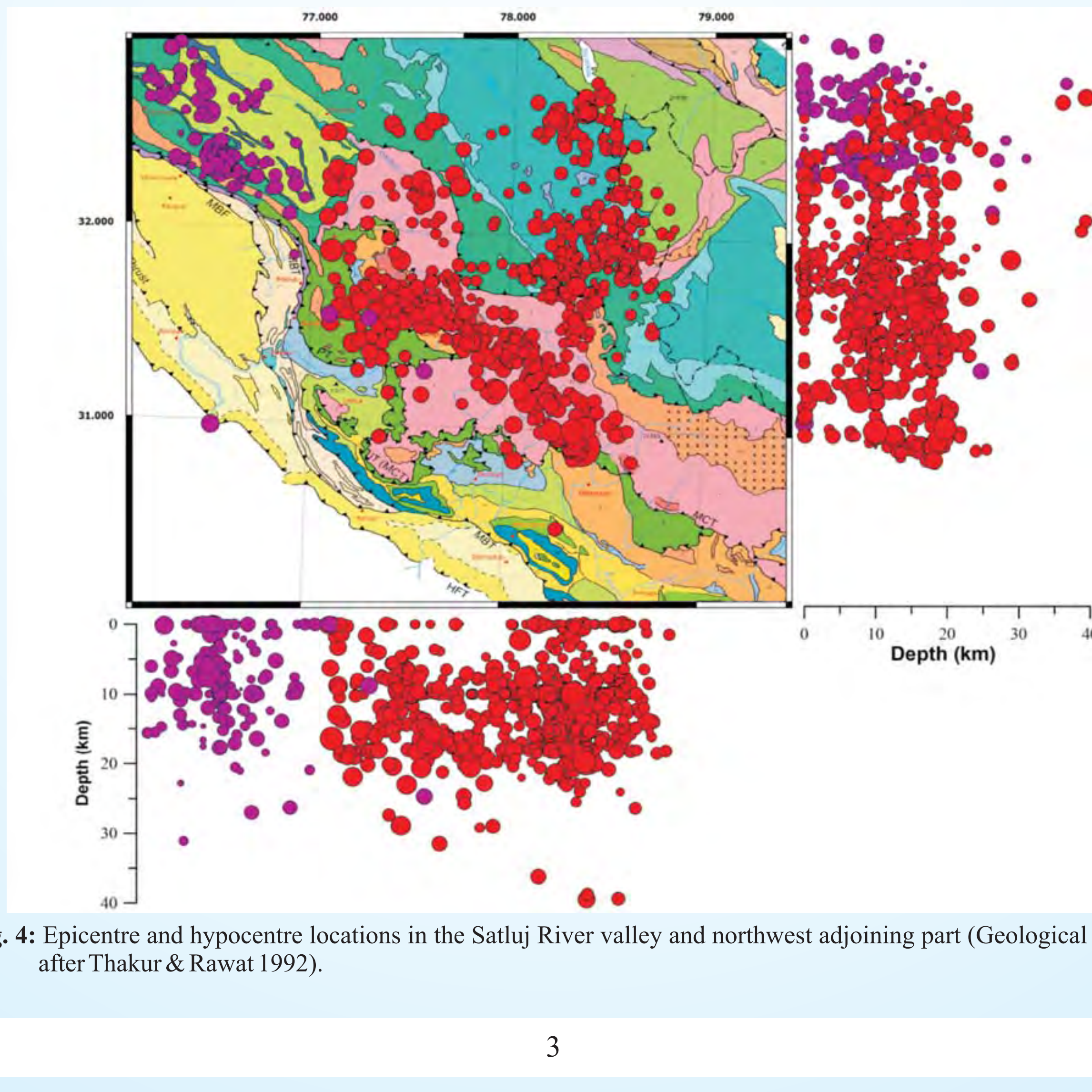

Fig. 4: Epicentre and hypocentre locations in the Satluj River valley and northwest adjoining part (Geological map after Thakur & Rawat 1992).

west directions. Also, the hypocentres along the longitude are deeper than ~5 km for localised zone of the Nahan salient, which highlights the unique feature of seismicity. Continuous data of this network and other stations of the northwest Himalaya are combined to perform the seismic tomography to investigate the sub-surface structure.

The earthquake data of the seismic stations: Garurganga (GUR), Uttarkashi (UTK) and Tehri (TEH) seismic stations in the Garhwal Himalaya are collected, processed and analyzed for the determination of fault plane solution (FPS). The earthquake events with magnitude ≥3.0 are used for this purpose, so that it can have maximum numbers of P-wave first motion arrivals. Towards north, the earthquake events recorded by Kinnaur seismic network of WIHG for the period of 2013-2015 are also added to get better accuracy in the locations. Beside this the moment tensor solutions determined by USGS are also incorporated in this work. From the strike, dip and rake of fault plane solutions, pressure (P) and tension (T) axes of respective earthquake events with their plunges are determined. Further the stress tensor inversion studies are carried out to get the maximum (σ1) and minimum (σ3) compressional axis orientations in this part of the Himalaya. In continuation of the previous study in the Kinnaur region, the hypocentral parameters of earthquake events in southern part of Kinnaur region are also analyzed to get the FPS. Consequently from the population of FPS, the stress pattern in this southern part near the MCT is determined. In this part stress tensor inversion results show compressional stress regime in comparison to the east-west trending extensional stress regime for the Kinnaur region. In the Chamoli district of Uttarakhand an earthquake of magnitude 4.9 occurred in the east southeast of Pipalkoti on 1st April, 2015, at a depth of 10 km. This event, widely recorded by Kinnaur and Garhwal networks of WIHG seismic network, is being processed and analysed for further study.

Geometry of Main Himalayan Thrust and Moho beneath Satluj River valley section, H.P.

The receiver function analysis method was applied to the teleseismic data recorded by 18 broadband seismographs stations located in and around Satluj River valley, H.P. The receiver function data were stacked at each recording station, and inversions have been carried out to obtain shear wave velocity models. The seismological stations cover the geotectonic units between the HFT and TH. The study reveals low dipping MHT towards NE between the Sub-Himalaya and Higher Himalaya rather than flat-ramp-flat geometry as reported in the Nepal Himalaya and Garhwal Himalaya. In contrast, large change in depth of the MHT is observed from the South Tibetan Detachment (STD) towards the TH. The depth of the MHT varies from ~15 km in the Sub-Himalaya to ~22 km in the Higher Himalaya whereas it increases from ~25 km near the STD up to ~40 km beneath the TH. The inverted shear wave velocity models show ~46 km thick crust at the stations near the HFT and the crustal thickness increases to ~60 km beneath the TH. The shear wave velocity models estimated at stations near the HFT show extremely low velocity (~0.7-1.2 km/s) in the upper most 3-4 km thick crust indicating effect of the sedimentary column of the Indo-Gangetic plain south of the HFT. A prominent intra crustal low velocity layer (IC-LVL) is detected beneath the TH and inferred 4-8 % partial melt and/or aqueous fluid at mid-crustal depth. The IC-LVL is less prominent beneath the Higher Himalaya and is negligible south of the Larji-Kulu-Rampur window.

The geometry of the MHT is essential for characterizing earthquake hazard and understanding the nucleation of great earthquakes in the Himalayan Seismic Belt (HSB), a narrow zone straddling the northern Lesser Himalaya and southern Higher Himalaya. As the seismicity in the HSB is largely correlated with ramp structure in the MHT, the spatial distribution of local earthquakes (M≥3.0) occurred during 1964 - August 2015 have been studied in and around Satluj River valley, and the hypocentral information of local earthquakes for this period have been obtained from catalog of International Seismological Centre (ISC) **(**www.isc.ac.uk**).** Usually, small and moderate magnitude earthquakes in the NW Himalaya are confined in the HSB. The spatial distribution pattern of epicentres in the present study area shows three well defined along-strike segmentation patterns namely Kangra-Chamba region the seat of the great 1905 Kangra earthquake, Satluj River valley region and the Garhwal Himalayan region (Fig. 5). Absence of both large and moderate magnitude earthquakes are obvious in the HSB that belongs to the southern part of the Satluj River valley intervening Shimla region. This segment of the HSB is located west of the Delhi-Hardwar Ridge and east of rupture zone of 1905 Kangra earthquake (M 8.0) (Fig. 6). The absence of seismicity is correlated with absence of ramp structure where under-thrusting Delhi-Hardwar Ridge interacts with the Himalaya arc.

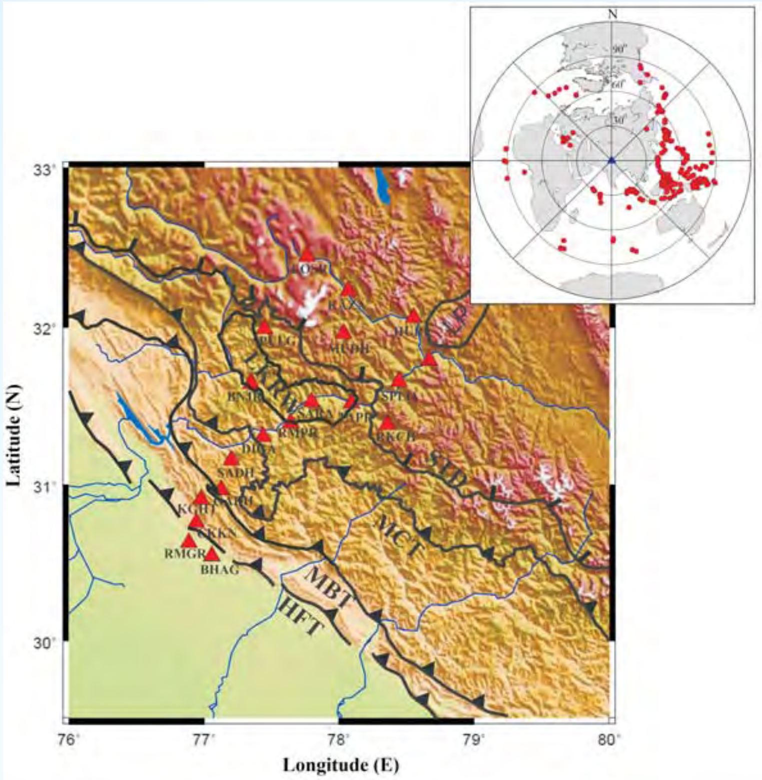

Fig. 5: Topographic map of the Northwest Himalaya with major tectonic features: (1) Himalayan Frontal Thrust (HFT), (2) Main Boundary Thrust (MBT), (3) Main Central Thrust (MCT), (4) South Tibetan Detachment (STD), (5) Larji-Kulu-Rampur Window (LKRW) (6) Leo Pargil (LP) Dome, (7) Vaikrita Thrust (VT), (8) Munsiari Thrust (MT). The red triangles represent seismological studies used in the present study and blue triangle represents stations used by Hazarika et al. (2014). The inset in the top right corner shows distribution of teleseismic earthquakes (red filled circles) used for *P*-wave receiver function analysis.

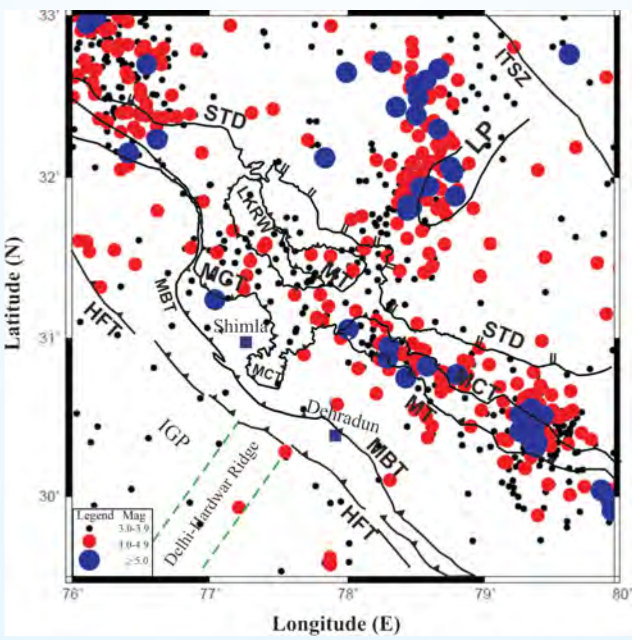

Fig. 6: Distribution of earthquakes (M≥3.0) in the northwest Himalaya for the period of 1964-2015 (source: ISC catalogue) are shown in relation to major tectonic features existing in the region. The tectonic features are same as mentioned in figure 5. ITSZ represents Indus Tsangpo Suture Zone. The Delhi-Hardwar Ridge in the Indo-Gangetic Plains (IGP) is marked by dashed lines following Arora et al. (2012). The red star indicates epicentre of 1905 Kangra Earthquake (M 8.0).

TAT-1.2

Present day Uplift or Subsidence and Gravitational Potential energy change in NW-Himalaya and the NE Himalayan Syntaxis: Crust-mantle density in homogeneity using Satellite Geodesy/Gravimetry and Seismology

(S. Rajesh, Sushil Kumar and V. Sriram)

We have been monitoring the Frontal Thrust systems and other allied major Thrusts in the Dehradun and Kangra re-entrants in the Northwest Himalaya through GPS measurements and processed the data by constraining with twenty five IGS stations in ITRF08 reference frame. Our results show that the HFT close to the Nahan salient is not showing any surface deformation, although it shows SE trend. The magnitude of such deformation of HFT increases towards the Dehradun re-entrant. In general, the baseline length shortening rate increases with respect to the LCK2 station towards south-east. This suggest there exist along the arc movement of HFT from the east of Nahan salient towards SE. The baseline shortening rate between Dehradun and south of HFT is abysmally small around 0.06 mm/yr. Forward modeling of the velocity data from HFT to north of MCT across the Dehradun re-entrant shows an overall 16 mm/yr shortening. At the west from Nahan salient the frontal velocities are predominantly SW towards the Kangra re-entrant. Thus, the Nahan salient acts as a velocity divide in the surface movement of the southern plate boundary fault.

We interpret the observed GPS velocities along the Arc of HFT in the Sub-Himalayan region on the basis of radial mass flow induced by the Gravitational Potential Energy (GPE), and is shown in figure 7. By assuming a thin lithosphere the overall columnar vertical stress component integral was partitioned according to the effect of topography and the crust lithospheric effects. The integral was solved to get an analytical expression of topographic effect with constant crustal density. A two layer crust-mantle combined lithospheric density function was defined to solve the integral equation. We used SRTM (3 Arcsec) and Crust1.0 model for the case of topography and crustal thickness. We assumed a lithospheric thickness of 125 km and used the EGM08 model for the computation of lithospheric part of GPE. While including the topography part the GPE raised more than 125 x 10^{11} N/m.

In general high overall GPE is observed in the higher Himalayan region. In Sub-Himalayan region the topo and lithospheric component of GPE falls to 15 x 10^{11} N/m, especially at the south of HFT. The GPE driven radial flow constitutes both along the Arc and perpendicular to the Arc velocity components.

We considered the GPE variations across the Arc component at Nahan Salient and Kangra and Dehradun re-entrants. In the Dehradun re-entrant the overall GPE variation is less than 2 x 10^{12} N/m up to the MBT zone and then sharply changes to 6 x 10^{12} N/m towards higher Himalaya. We also computed the GPE gradient throughout the length of the profile by assuming that the whole block will be deformed across the total length of a given stretch of crust. The across the Arc GPE gradient is equivalent to the horizontal stress acted over the

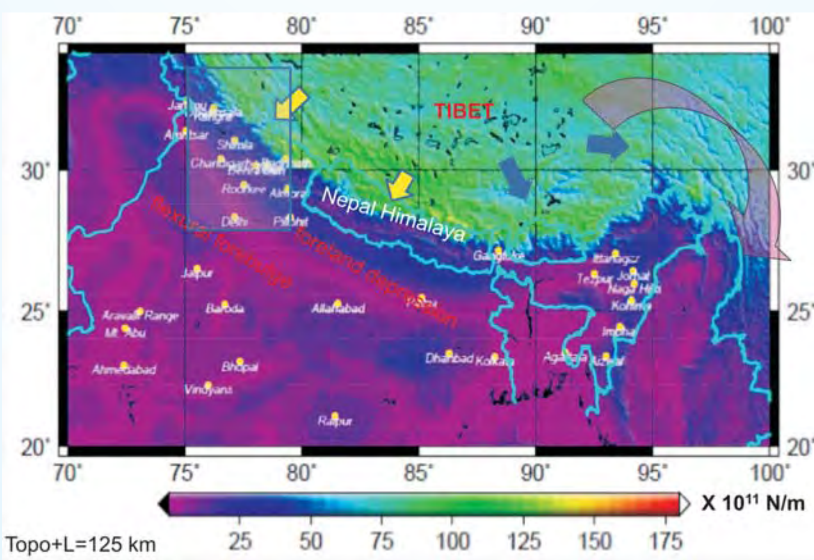

Fig. 7: The gravitational potential energy distribution (including the topography and a lithosphere of thickness 125 km) in the Himalaya-Tibet region shows the regional radial mass flow towards the Frontal side of the collision.

overall length of the block and its magnitude varies from 2 to 14 MN/m^2 from the south of HFT to north of MCT in the higher Himalaya. In Dehradun re-entrant the HFT is experiencing a horizontal stress of 4.21 MN/m^2 with respect to the reference and it increases to 23 MN/m^2 between MCT and the MBT. Similarly, in the Kangra re-entrant between the HFT and the Jwalamukhi Thrust the horizontal stress component is two orders of magnitude higher than the case of Dehradun re-entrant. Our analysis shows that plausibly the Kangra HFT is one of the most stressed portions of HFT in the NW Himalaya.

We studied the site effects in the Dehradun valley and at its topographic boundary high near the MBT, where the site effect is controlled by the fluvial erosion and deposition and topographic slope instability, respectively. Results show a bimodal distribution of site amplification characteristic of top soil near the MBT, where unique dual peak resonant frequencies (1.11 and 1.38 Hz) and amplification factors (1.69 and 1.51) are observed. This highlights that erosion due to topographic slope instability is prominent near the MBT. We also extracted the dynamical shear strain. Results show that the effective shear strain in the valley, which is a measure of plasticity of soft soil under strong motion conditions of short and long term recurrence interval of a Great Magnitude earthquake is 20 to 30 milli strain. This is reasonably higher than the plasticity limit (10 milli strain) that lead to liquefaction. Moreover, the estimation of peak shear strain with depth under different strong motion conditions at various borehole locations in the valley is higher than the threshold shear strain of 0.01%, this emphasize that the soft soil in the Dehradun Valley is vulnerable for liquefaction.

TAT-1.3
Tectonics of the Shillong Plateau, northeastern India

(Swapnamita C. Vaideswaran)

The northern front of the Shillong Plateau had been taken up for GIS based study of geomorphic indices, such as topographic breaks supported by longitudinal profile analysis, stream length gradient index (SL), ratio of valley floor width to valley height (V_f), steepness index (k_s). In the Kulsi Basin, results indicate that the upstream basin is more tectono-dynamic than the downstream segment. The Chandubi Lake is located where the river enters the Brahmaputra alluvium and represents remnant of an old, wide paleo-channel of the Kulsi River. The lake, which has been shrinking in size with time, also houses old submerged tree trunks from which samples were collected. These samples were used for radiocarbon dating. The results show inundation episodes in the lake area around the years 160±50 AD, 970±50 AD, 1190±80 AD and 1520±30 AD. Landsat satellite data from 1972 to 2003 shows migration in a segment of the river representing the last strand of the Kulsi paleo-channel which was seen to have been abandoned around 1991-92. The river shifted corresponding to high discharge in the area between 1980 and 1990. The geomorphology of the area shows that the Chandubi Lake represents a paleochannel which has been inundated several times is evident from the Holocene dates of tree trunk samples refuting speculations that the lake was created by the 1897 earthquake.

TAT-1.4
Tectonic evolution of Shyok Suture and Karakoram Fault Zone rocks and their bearing on Tibet uplift

(Koushik Sen and Barun K. Mukherjee)

We have carried out outcrop-scale, petrographical and geochemical analysis of one migmatites body present within the Ladakh Batholith near Upshi, along the Indus Suture Zone. As, deformation and remobilization of the Ladakh Magmatic Arc would result from the collision between the Indian plate and Ladakh Arc, this migmatites body is of extreme importance as the timing of partial melting (and source characterization) would provide insight in the timing of continental collision as well as probable assimilation of material from the Indian continental margin and the Ladakh Magmatic Arc. Initial U-Pb geochronology analysis of this migmatite show bi-modal age distribution of ~60 Ma and ~50 Ma. This result would suggest that the Ladakh Batholith crystallized at ~60 Ma and got remobilized at ~50 Ma, which happens to be the timing of accretion of the Indian continent with the Ladakh Magmatic Arc. Our ongoing geochronological analyses of this migmatites and intrusives will provide a complete picture of the collision, accretion and post-collisional thickening/underthrusting along the Indo-Eurasian collisional zone.

TAT-1.5
Fluid evolution and formation condition of Migmatites of Karakoram region as well of Ophiolitic rocks of western Ladakh

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

The field-work has been carried out in the in Nidar, Tso-Morari and Nubra valleys, and samples of ultramafic rocks, eclogite, albitite and volcanics were collected. The petrography, and the generation of the mineral chemistry data of ultramafic rocks were done. The ultramafic rocks are comprised of olivine, orthopyroxene, clinopyroxene and Cr-spinel. The XRF analysis of ultramafic rocks were also carried out to do thermodynamic modelling. Further interpretation of the data is in progress. We have separated zircons from the eclogite rock for U-Pb dating. The major & trace element analysis of Nubra volcanics is completed.

New occurrence of albitite is first ever recognized in Nubra valley of Ladakh region in the Trans-Himalaya area within Indian Territory at 34° 44' 46" N and 77° 33' 8" E before Panamik (in the wish pond, local name of the area). The albitite has been documented by petrography, mineral chemistry, XRD and whole rock geochemistry (i.e. major, trace and REE). The albitite in this study is comprised of 80-90% albite and amphibole. Whereas apatite, zircon, and ilmenite occur as accessory minerals. The textural relationship of whole rock and geochemical data advocate for its igneous origin. The albitite contain about 5-6 ppm U and Th, which may possibly host of U-REE mineralization.

In Western Himalaya, the best occurrence of blueschist is that of the Sapi-Shergol Ophiolitic Mélange in Ladakh. This unit is dominated by volcanoclastic sequences rich in mafic material with subordinate interbedding of metasediments, characterized by very fresh lawsonite blueschist-facies assemblages. We have petrologically investigated lawsonite blueschist-facies metasediments Our results indicate that (i) the Sapi-Shergol blueschists experienced a cold subduction history along a low-thermal gradient, with peak conditions ca. 470°C and 19 kbar of temperature and pressure, respectively. Additionally, in order to preserve lawsonite in the studied lithologies, exhumation must have been coupled with significant cooling, i.e., the resulting P-T path is characterized by a clockwise hairpin loop along low thermal gradients (8-9°C/km). The inferred P-T evolution is consistent with a cold subduction zone system in an intra-oceanic subduction setting. Moreover, the estimated peak P-T conditions roughly coincide with the maximum P-T estimates predicted by thermomechanical models for the metasediments exhumed in accretionary wedges, and with the maximum P-T conditions recorded by natural occurrences of blueschist accretionary complexes worldwide.

TAT-1.6
Metamorphism, Migmatization and Magmatism in Higher Himalayan Crystalline: Geochemical and Geochronological constrain on Leucogranite Granite melt generation and emplacement

(*P.K. Mukherjee and Saurabh Singhal*)

Laser Ablation Multi-Collector ICPMS (LA-MC-ICPMS) facility was successfully installed in the Institute to give optimum performance. Test runs carried out using standard solutions gave satisfactory results, and at times exceeded the specification under solution mode. Following the proper tuning under solution mode, U-Pb zircon geochronology application was standardized, and about 150 zircon grains from 8 samples were analysed at a spot size of 20 µm. Some interesting trends of age relationships were found in defining the characteristics of HHC compared to LHS and MCT zone (Baijnath/Munshiari Fm) across the MCT. Following are the salient observation made from the new geochronologic data.

- *Lesser Himalayan Sequence (LHS)*: The zircons from Berinag Quartzite show variable ages, with older cores of Late Archean (~2600 Ma), while the rims and some of the cores cluster around Paleoproterozoic ~1800 Ma. However, no younger zircons were distinctly observed.
- *MCT zone/Lesser Himalayan Crystalline/Munshiari/ Baijnath*: The age ranges similar as that of LHS. They are marked by extensive Pb-loss. Two distinctive discordia trends with upper intercepts of 1945±13 Ma and 1850±8 Ma were observed. Both these trends have a nearly common intercept at 27.9±8.2 Ma. The upper intercept ages represent magmatic zircon ages, while the lower intercept age of 28 Ma represents a major thermal event, and in all probabilities it may represent peak tectonic activity along MCT.
- *At HHC-Joshimath Formation (Hanging wall of MCT)*: It marks the first appearance of Neo-proterozoic (871±18 Ma and 1043±26 Ma) magmatic zircons. Older zircons mostly define an upper intercept age of 1900±18 Ma with a minor late Archean (2648±8 Ma) is also observed.
- *Suraithota Formation (HHC)*: Three distinct zircon population are identified. The characteristic Neoproterozoic component (871±7 Ma) becomes more populous. Other two older component are of Paleoproterozoic (1850 Ma), and a minor late Archean 2600 Ma).

The above results suggest that Vaikrita Thrust that is considered as MCT by many is indeed represent a terrain boundary with contrasting detrital zircon ages and characteristics. This also corroborates the work of Ahmed et al. (2000, GSA Bull) who found a contrasting Nd-isotopic signature across Vaikrita Thrust, and is indeed the true MCT. Further, the Hf isotopic finger-printing studies are in progress, and combined with the above zircon geochronologic data would provide much better understanding of the nature and provenance of HHC.

TAT - 1.7

Geochemical and crustal evolution of the Himalayan orogenic belt in Himachal NW Himalaya, and in the Eastern Syntaxial Belt, NE India

(S.S. Thakur, A.K. Singh, D.R. Rao and Rajesh Sharma)

NW Himalaya

In the Lahaul-Spiti region of Himachal Pradesh the two-mica granite body, the Jaspa granite of lower Palaeozoic age, has intruded into the low-grade Haimanta Group of rocks. The common mineral assemblage observed in granite is ms-bt-pl-microcline-qtz with accessory ep, ap and opaque. The Haimanta Group of Tethyan Himalayan sequence rocks are composed of mineral assemblage such as, ms-bt-pl-qtz-ilm-ttn, grt-ms-bt-ep-pl-qtz and ms-bt-pl-qtz-ttn and ms-bt-ep-pl-qtz. The analysis of the garnet which is observed to develop in the contact zone shows that, they are grossular to spessartine rich with end member composition in range of 35-44 mol. % of grossular, 23-26 mol.% of spessartine, 30-38 mol. % of almandine, and 1-2 mol. % of pyrope. Biotite is Mg rich with X_{Mg} value in range of 0.55 to 0.60. Geothermometric calculations show the metamorphic temperature of ~450°C. Fluid inclusion studies have been initiated on Jaspa granite and the enclaves present within it to compare the fluid participated in evolution and to constrain the *P-T*. It is observed that the fluid inclusions present in the granites are more abundant than in enclaves, although they are small. The study showed two distinct fluid inclusion types: liquid rich saline aqueous inclusions with 80 to 90 vol% are primary, which from our preliminary studies suggest to represent the late stage of granite formation. Polyphase halite bearing inclusions are uncommon. Others are CO_2 and coexisting CO_2-H_2O inclusions which has also been confirmed by the micro Raman spectroscopy which occur in clusters and at times in trails. Based on their occurrence, these inclusions are considered to characterize the post granite metamorphism. The enclaves also consists of CO_2 and coexisting CO_2-H_2O inclusions. The fluid inclusions in granite suggests that water rich saline fluid was present during granite crystallization. Further synthesis and interpretation of the data of geothermobarometric and fluid inclusions data is in progress.

Studies have been carried out on the mafic xenoliths which sporadically occur in the Lower Palaeozoic Kinnaur Kailash Granite (KKG) of Sutlej valley, NW Himalaya. Amphiboles are common constituent minerals in these xenoliths. These mafic xenoliths contain mineral assemblage of opx-cpx-hbl-pl±qtz. Amphiboles (Cummingtonite and hornblende) and garnets bearing corona around cpx and opx have been observed. The *P-T* calculation of hornblende based on substitution mechanism shows that the amphiboles of the study area have equilibrated in the temperature and pressure ranges of 550-650ºC and 3.0-7.5 kbar, respectively. From the studies carried out it is suggested that, the retrograde hornblende were formed in the mafic xenoliths during the cooling of the terrain. The *P-T* path shows that hornblende has undergone retrograde *P-T* trajectory. Further, the geochemical studies of mafic xenoliths are processed and the results are communicated for publication.

The studies on the MCT zone of the Alaknanda valley have also been taken-up during the year to understand the tectonometamorphic evolution of MCTZ and its relation with HHCS. A continuous increase in the inverted metamorphic field gradient across the contact between the Main Central Thrust (MCT) and Higher Himalayan Crystalline Sequence (HHCS) with increasing structural level (Fig. 8) is established (Thakur et al., 2015, Contribution to Mineralogy and Petrology). The Main Central Thrust has been defined based on first appearance of kyanite, chemically homogeneous garnet and garnet with random inclusion trails. *P-T* pseudosection modelling approach has been used to understand the metamorphic evolution of the Main Central Thrust Zone (MCT) which suggest peak metamorphic *P-T* condition in range of 6.3-7.5 kbar and 550-582°C (Fig. 9). A comparative study of the metamorphic history of the MCTZ rocks in NE Himalaya (Siyom valley, Nandini and Thakur, 2011), Sutlej valley of NW Himalaya (Caddick et al. 2007) and Alaknanda valley in NW Himalaya show complex tectono-metamorphic evolution varies from one section to other. In NE Himalaya MCTZ has undergone peak metamorphism of sillimanite-kfeldspar grade with clockwise *P-T* path (Nandini and Thakur, 2011) whereas in Sutlej valley, NW Himalaya LHCS has undergone sillimanite grade metamorphism with clockwise *P-T* path (Caddick et al.

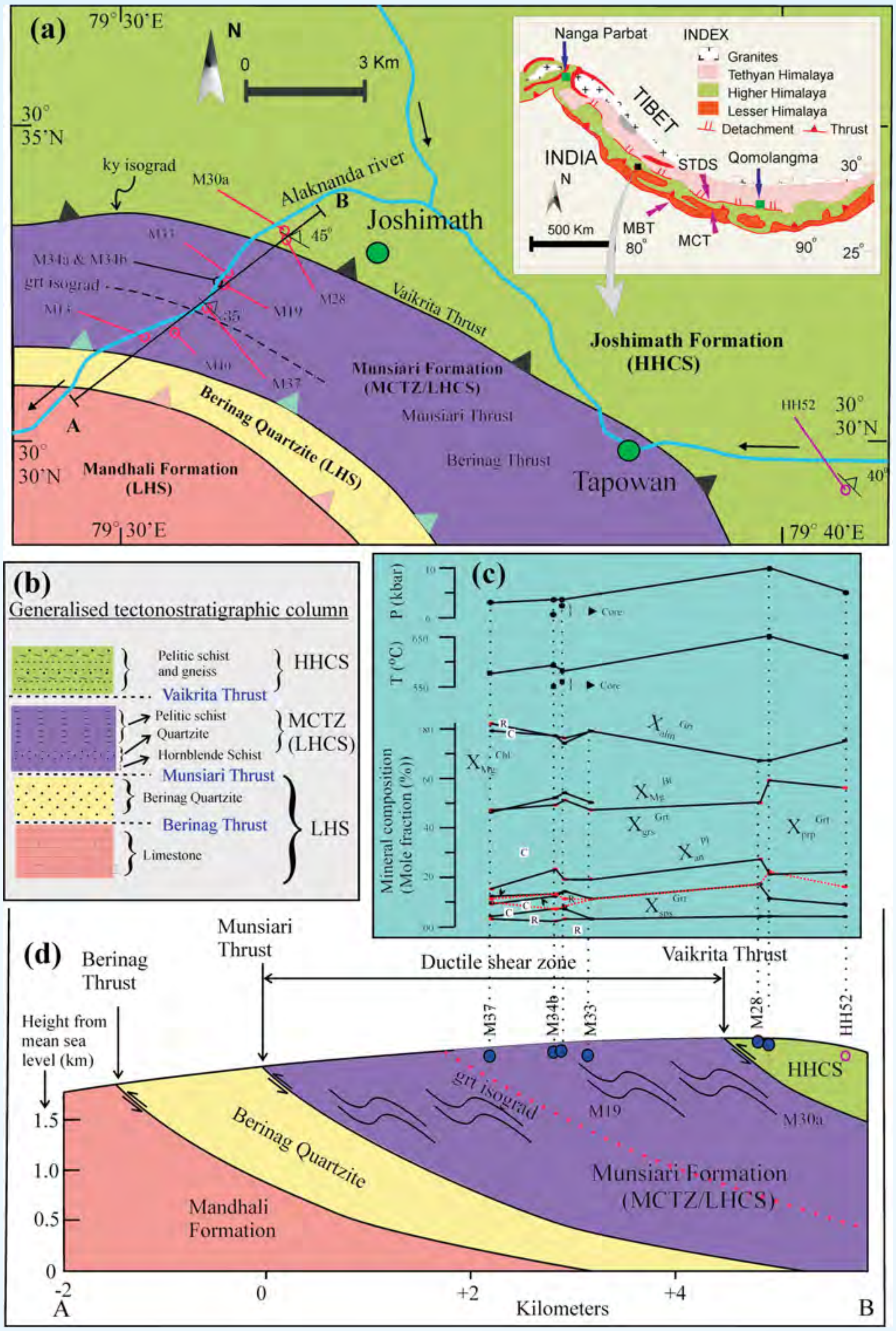

Fig. 8: (a) Geological map of Alaknanda valley modified after Valdiya (1980) and Celerier et al. (2009). Kyanite isograd coincides with the Vaikrita Thrust and marks the beginning of the HHCS. Sample locations are marked by red circles. Inset shows regional map of the Himalayan orogenic belt. (b) tectonostratigraphic column of the study area; (c) spatial profile of pressure, temperature and mineral chemical variation across MCTZ. *P-T* results from isopleth thermobarometry are shown as isolated points for garnet core composition and as a line connecting the points for garnet rim compositions. In the mineral compositional plot, composition of the same mineral in different samples is joined by a line. Variations in both core (C) and rim (R) compositions of garnet are shown; (d) cross section along the line A-B in (a). *Abbreviations: HHCS = Higher Himalayan Crystalline Sequence; LHS = Lesser Himalayan Sequence; LHCS = Lesser Himalayan Crystalline Sequence; MCTZ = Main Central Thrust Zone.*

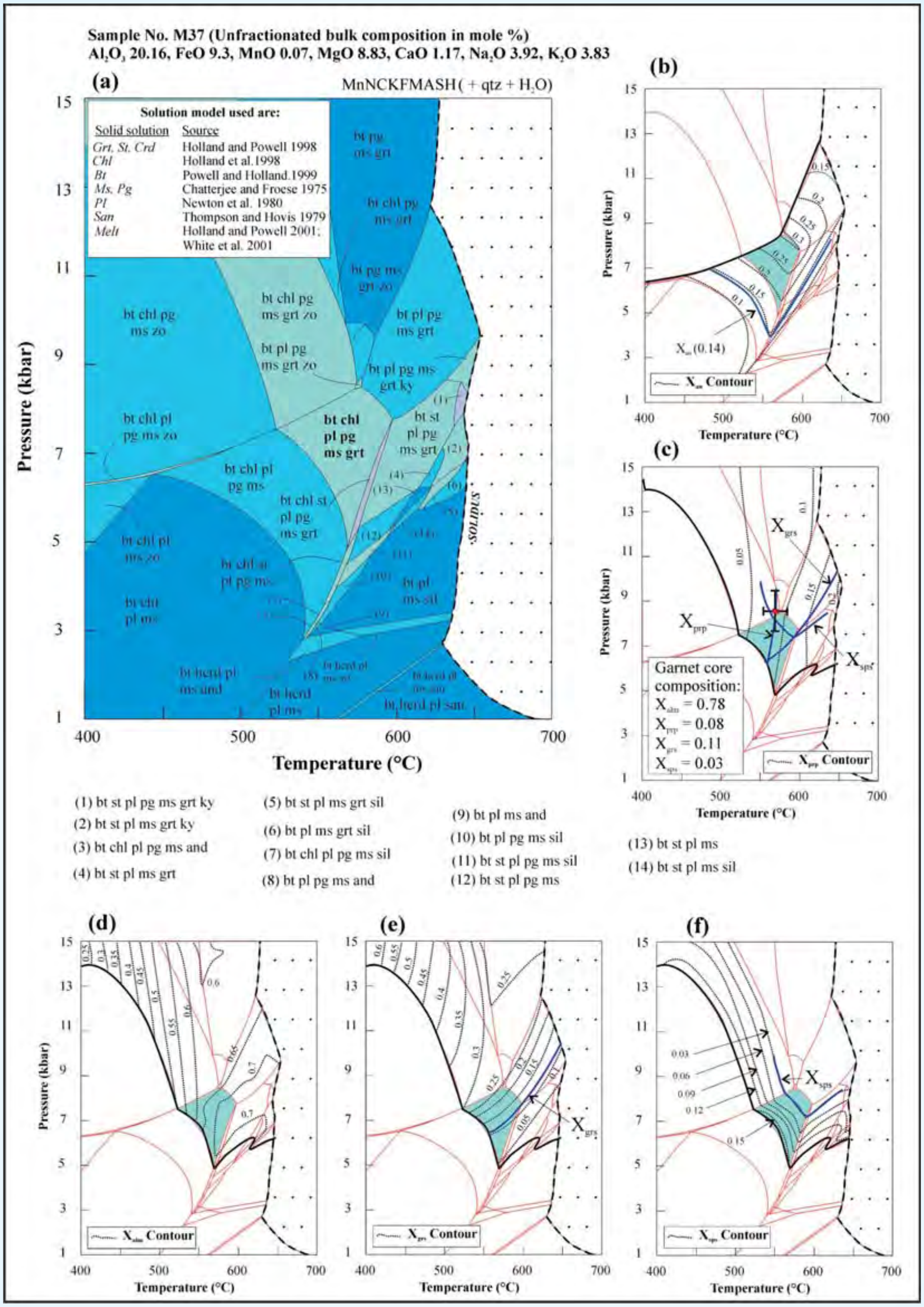

Fig. 9: *P-T* pseudosection in the MnNCKFMASH system (+qtz +H_2O) at a_{H2O}=1 for unfractionated bulk rock composition of the MCTZ sample M37. (a) Stability fields of different mineral assemblages below the solidus are shown, solution models used in pseudosection calculation are given in the inset; (b) Isopleths of X_{an} in plagioclase; (c-f) Isopleths of X_{prp}, X_{alm}, X_{grs} and X_{sps} in garnet, respectively. Thick violet line represents isopleth of the measured garnet composition. The stability field of grt-bt-chl-pl-ms-qtz assemblage in the rock is shaded in (b) - (f). In (c), compositional isopleths of X_{prp}, X_{grs} and X_{sps} corresponding to the measured garnet core composition are plotted which intersect to form a triangle inside the stability field of the above mineral assemblage. *P-T* result from multi-equilibria thermobarometry is also plotted with error bar.

2007). In contrast to this, in Alaknanda valley, NW Himalaya, MCTZ has undergone garnet grade prograde metamorphism (Thakur et al., 2015, Contribution to Mineralogy and Petrology).

NE Himalaya

The Nagaland-Manipur Ophiolites (NMO) of Indo-Myanmar Orogenic Belt, NE India forms a part of the Tethyan ophiolites and are considered as southward extension of the Indus Tsangpo Suture ophiolites, while others considered it as a separate ophiolitic suite. We have carried out geochemical and petrological studies of the NMO in order to compare the Tidding-Tuting ophiolites that are exposed in the eastern syntaxial belt. The NMO are comprised of peridotites, cumulate mafic-ultramafic sequence, felsic intrusives, oceanic pelagic sediments along with minor podiform chromites. However, sheeted dykes which are considered as a significant component of ophiolites are absent in the NMO. The geochemical studies of peridotites and pyroxenites suggest different origin.

The studies showed that, the peridotites have Cr number [Cr# = Cr/(Cr+Al)] in the range of 0.14 to 0.29, Mg number [Mg# = Mg/(Mg+Fe^{2+})] in the range of 0.71-0.76, show gradual decrease in REE concentrations from HREE to MREE (Sm_N/Yb_N = 0.285-0.460) with slight increase in LREE (La_N/Sm_N = 0.721-2.201). The estimated equilibration temperature range from 971 to 1156°C. The olivine-spinel equilibrium and Cr-spinel chemistry data suggest that these tectonite peridotites are residual mantle after limited extraction of basaltic melts and have experienced low degree of partial melting (<15%). Conversely, the pyroxenites show Cr number in the range of 0.27-0.48, Mg number in the range of 0.44-0.53, exhibit nearly flat MREE to HREE (Sm_N/Yb_N = 0.622-0.756) and depleted LREE (La_N/Sm_N = 0.380-0.759). The estimated equilibration temperatures in these rocks range from 890 to 931°C. The presence of highly magnesian opx and cpx in these pyroxenites in conjunction with their geothermometry suggests that they were formed at high pressure and temperature in the form of deeply originated cumulates after magmatic fractionation from the basaltic melt.

The geochemical data together with field and petrographical evidences indicate that both the tectonite peridotites and cumulate pyroxenites are essentially spinel-bearing, and free from any plagioclase, suggesting their derivation from a deep source in the mantle beyond the stability limit of plagioclase in a mid-oceanic ridge tectonic setting. We envisage that, the mantle section in the NMO was initially generated in the seafloor spreading regime at the eastern margin of the Indian plate which was then thrusted over the continental margin of the Indian plate during its collisional and subduction process with the Myanmar plate (Singh et al. 2016, Geological Journal).

TAT-1.8
Mineralization and Metallogeny in, northwest Himalaya: Emphasis on the role of complex fluids in magmatic and mineralization processes

(Rajesh Sharma)

The field-work has been carried out in sulphide mineralized localities namely: Amba Khala (30°64'14"N, 78°07'45"E), in Sirmour Dist. (H.P.), and Chamri (H.P.) and Amtiyar gad (30°57'37"N, 77°55'16"E) in Tonse river valley in Uttrakhand. The mineralisation are localized to the shear zone. Sulphide mineralization of Amba Kala is hosted in slates and phyllites, and is enriched in galena with subordinate chalcopyrite. This mineralization is noticed in veins along the axial planes (Fig. 10). Textures shows fracture fillings by the sulphide minerals and replacement of chalcopyrite by galena. Sulphur isotope analysis of three samples indicate that $\delta^{34}S$ of galena varies from 11.1 to 11.4 which do not clearly point to magmatic sulphur, and are not comparable to $\delta^{34}S$ values of sulphides from Askot and/or Kullu. Three types of inclusions in gangue quartz are filled with biphase aqueous, aqueous-carbonic and monophase low density carbonic fluid. At Amtiyar gad, the ore assemblage consists of pyrite, galena, sphalerite and minor chalcopyrite. Galena shows banding of the cleavage planes indicating post deposition deformation. Ore textures are complex with mutual replacement of galena and sphalerite and exsolution between chalcopyrite and sphalerite. A hydrothermal nature is generally apparent,

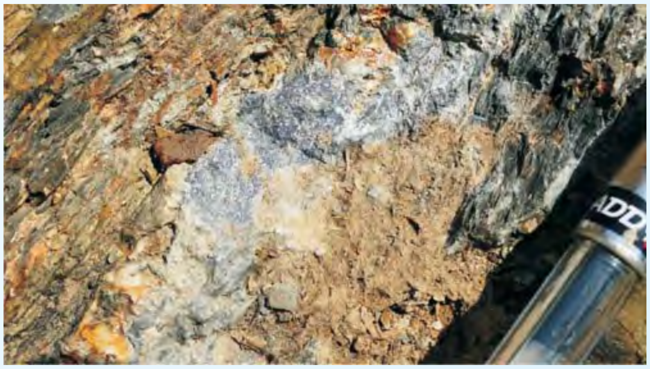

Fig. 10: Galena mineralization in quartz vein present along the S2 schistosity in Amba Khala area.

however, further work underway on ore chemical and microthermometry would be helpful in understanding origin of these sulphides.

Barite is found associated with Neoproterozoic Nagthat siliciclastic rocks at various places in Sirmour District, Himachal Pradesh and in the Tons valley of Lesser Himalaya. Field-work was also recently carried in one of the mineralized location near Kaffota, H.P. Veins, lenticles and pockets of barite microscopically show two types of grains, (i) the barite porphyroclasts representing the original deposition of barite, and (ii) the fine polycrystalline aggregate formed after recrystallization of porphyroclasts. The fabric and fluid inclusion studies of barites were also carried out. The studies suggest that the fluid inclusions in barite grains are saline aqueous. Type 1 aqueous inclusions in undeformed porphyroclasts are earliest representing initial barite deposition. These inclusions homogenize at 112 to 208 ºC with salinity ranging from 3.71 to 11.9 wt % eq NaCl. Their T_h vs salinity infer mixing of two fluids in barite deposition during primary barite formation stage, of which one may be basinal brine. Deformation features including bending of the grains and granulation pattern of the barite suggests that the barite deformation is linked with tectonics. A partial re-equilibration is inferred from fluid inclusion data. The characteristic textures and morphology of re-equilibrated Type 4 fluid inclusions, and the position of various isochors substantiate that the barite deformation and recrystallization is related to Himalayan tectonics and exhumation.

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

TAT-2.1
Sediment production and sedimentation in Drier Himalaya: Patterns, time scales and palaeoclimatic in trans-inferences

(Pradeep Srivastava, Koushik Sen and Anil Kumar)

Developed a record of past floods from the Indus River (Ladakh, NW Himalaya), the Alaknanda-Mandakini Rivers (Garhwal Himalaya), and the Brahmaputra River (NE Himalaya) from new paleoflood deposits, which are characterized by sand-silt couplets, massive sand beds, and organic debris flows. The chronology of paleoflood deposits, established by Optically Stimulated Luminescence (OSL) and ^{14}C AMS dating techniques, indicates the following:

- the Alaknanda-Mandakini Rivers experienced large floods during the wet and warm Medieval Warm Phase (MWP); pollen recovered from the paleoflood deposits, located in the headwaters of Mandakini River, also showed presence of warmth loving tree and marshy taxa
- the Indus River experienced at least 14 large floods during post-glacial climatic optimum, when flood discharges were likely an order of magnitude higher than those of modern floods (Fig. 11); and
- the Brahmaputra River experienced a megaflood between 8-6 ka.

Magnetic susceptibility of flood sediments indicates that 10 out of 14 floods on the Indus River originated in the catchments draining the Ladakh batholith, indicating the potential role of glacial lake outbursts (GLOFs) and/or landslide lake outbursts (LLOFs) in compounding flood magnitudes.

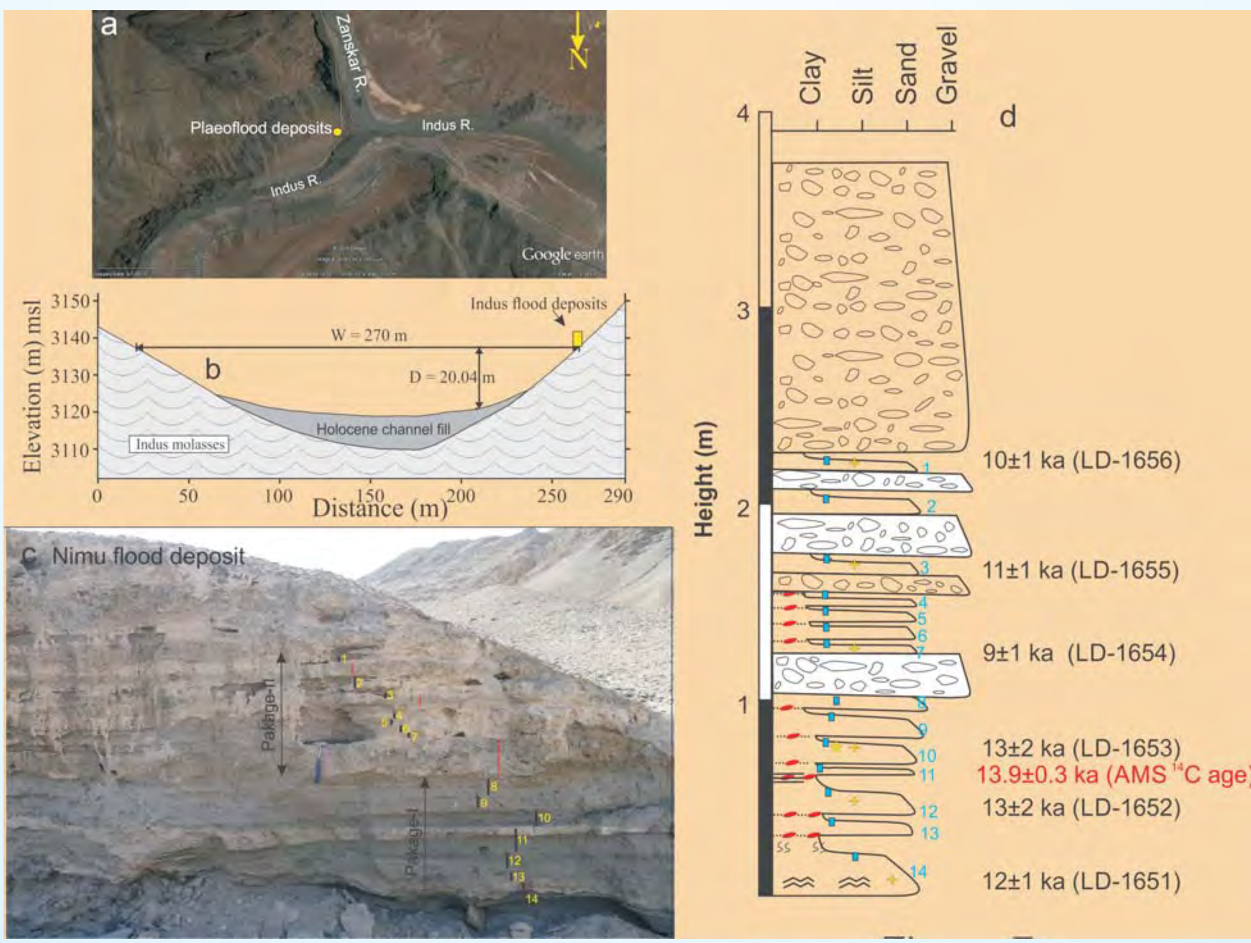

Fig. 11: Paleoflood deposits at Nimu and their chronology.

Collectively, our new data indicate that floods in Himalaya largely occur during the warm and wet climatic phases. Further, the evidence supports the notion that the Indian Summer Monsoon front may have penetrated into the Ladakh during the post glacial climatic optimum.

The studies of two new sections of paleofloods in Zanskar and Indus rivers are in progress.

TAT-2.2
Fossil findings from Mohand Anticline and Dharmsala Group of Himachal Pradesh

(a revised project approved by RAC).

(B.N. Tewari)

- Miocene taxa from Siwalik and Dharmsala horizons of the Himalaya and the ones being recovered from Kutch, western India are similar; these terrestrial taxa inhabited huge bioprovince that was capable of sustaining folivorous beasts. Earlier studies based on rare and scattered occurrences of mammals suggested that only Early and basal Middle Miocene terrestrial mammals were represented in the region, but the new researches extend the fossil register into the Late Miocene, with taxa such as *Hipparion, Parachleuastochoerus salinus* and *Tetraconodon indicus* being represented at some localities such as Tapar and Pasuda.
- Hipparionine dental remains are typical component of the Siwalik Miocene assemblages and now these are also known from Miocene horizons of central Kutch, Gujarat. These immigrant extinct horses evolved in North America and came to ancient world with the opening of land route in Miocene. In India they are well known from Sub-Himalayan Siwalik Group horizons; their record from non-Siwalik Neogene horizons of Kutch is significant as it relates the stratigraphies in Siwalik and Kutch non-marine foreland and coastal basins.
- Outer western Himalayan early Miocene terrestrial fossils from Jammu and Kashmir and Himachal Pradesh have been studied by number of teams because of (i) the exposures being more accessible, and (ii) application of bulk maceration techniques in developing fossil assemblages as a rule. Our focus on paleontological studies in the exposures of Dharmsala Group in Kangra Valley in the Outer western Himalaya has rewarded with enormous number of microscopic cyprinid fish pharyngeals, chara gyragonites, ostracods, etc besides dental remains of larger animals including deinothere and crocodiles.

TAT-2.3
River response to allogenic forcing and late Quaternary landscape evolution: Punjab re-entrant

(N. Suresh and Rohtash Kumar)

In the Satluj valley, in all six levels of terraces (T1-T6) were identified between Ogli (north of MBT) and Ropar (south of MBT). Litho-sections were constructed and OSL samples were analysed from representative litho-units to establish the chrono-stratigraphy. The measured litho-sections show that the litho-units, in general, are dominated by gravel and sand, but the oldest and topmost terrace (T6) is dominated by thick sequence of medium to very coarse sandy facies. To the north of MBT, the topmost terrace is extensively developed around Bali, Aut and Ogli areas. The terrace depositional sedimentary sequence is dominated by thick sequence (~70 m) of medium to coarse massive sand, locally faint trough cross-stratified and parallel laminated, and associated with locally 20 to 50 cm thick lacustrine facies. The bulk mineralogy by XRD shows dominance of quartz followed by feldspar, calcite and clay minerals (illite and chlorite). Quartzite bearing gravels are rare or absent. All this suggest that they were derived from the physical weathering of granite gneiss, exposed particularly north of MCT. The Optically Stimulated Luminescence (OSL) chronology suggests that the thick sandy sequence was deposited between 69±10 ka and 49±6 ka. Similar thick sandy sequence is also observed in the paleo-exist of the Satluj River in the outer margin of Sub-Himalaya, near the vicinity of Himalayan Frontal Thrust. These sandy facies are fine to medium grained, multistoried, and internally consist low angle trough cross-stratifications and parallel lamination. The quartz OSL ages suggest that they were deposited between 70±5 ka and 50±4 ka. The deposition of thick sandy facies, traced for hundreds of kilometers, suggests that the sediments were produced under relatively stable condition during late Quaternary period, when extensive weathering and rapid exhumation of granite in the Higher Himalayan catchment. Its transport to the valley between 70 and 49 ka resulted extensive aggradation and/or it represents extreme climatic events.

The subsequent lower terraces in the hanging wall of MBT are however dominated by gravel facies which are clast to matrix supported, poorly sorted, fining upward and imbricated. They consist of quartzite, granite gneiss, volcanics and limestone and/or slate clasts. From this locality younger terraces formed around 27±5 ka and 2.5±0.7 ka were also documented. In the Sub-Himalaya around 45 ka, thick sequence of gravel facies, resting directly over the thick sandy units in the vicinity of the Himalayan Frontal Thrust, is also documented. However, in the Inner Sub-Himalaya, immediate south of the MBT, a terrace surface formed after 45±7 ka was identified. In addition, three younger terraces formed around 26 ka, 11 ka and 6 ka were also well developed.

The major periods of aggradation coincided with Quaternary cold phase, and dissection with periods of lower sediment supply during warmer phases. The climatic change controls water and sediment supply, probably synchronous with river response. The stream incision and absence of sedimentation in the valley suggests reduced sediment supply, however, with relatively high stream power. As mentioned earlier, the sandy facies is observed in the wider valley and during catastrophic flooding, gravel load remains in the channel, whereas sandy load is deposited in the floodplains. On the other hand, sandy facies in the Outer Himalaya was deposited in the mountain front with decrease river gradient on a wider channel area.

The studies thus suggest that, during late Pleistocene major extreme events was responsible for their development. The deposition of thick sequence of gravel facies around 45 ka might be correlated to the reported major tectonic episode around 45 ka in the Himalaya. The observed two termination phases of deposition around 26 ka and 11 ka have occurred in the reported increased monsoon phases (29-23 ka and <10 ka), and hence are correlated to climate change. The non-deposition of sediments between 11 and 6 ka indicate prolonged incision phase, and are in agreement with less erosional products in the mountain slopes due to increased vegetation cover during the humid inter-glacial period. The stratigraphy of these terrace deposits together with chronology is under progress and will through light on the evolution history with respect to Quaternary tectonic deformations and climatic variations.

TAT-2.4

Late-Quaternary paleomonsoon study in Ladakh, North western Himalaya and Indo-Gangetic plain, India

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

The project deals with the reconstruction of high resolution paleoclimate records from the north-western Himalayan region and Ganga Plain, India. The Ladakh Himalayan region, moreover, has scarcity in paleoclimatic data, and to achieve this goal, following work has been carried out during the reporting year.

A multi-proxy data set for Tso-Moriri Lake cores has been developed. Grain size analysis of 75 samples from ~3 meters lake cores has been performed using the Laser Particle Size Analyzer (LPSA) at WIHG, Dehradun, to study the down-depth grain-size variation and climate control. The bulk sediment analysis from 22 samples from cores of about 1.5 meters below lake floor was carried out using XRF at WIHG, Dehradun, to study distributions and variations of major oxides and trace elements down the depth. In order to study the clay mineralogy down the ~3 meters of Tso-Moriri lake cores, XRD analysis was performed on 34 clay slides at WIHG. The extraction of organic phosphorus (OP) and inorganic phosphorus (IP) for 31 samples of Tso-Moriri Lake were carried out to understand the climatic signatures encoded within the lake sediments following standard protocol. The data generated reveals interesting events of paleoflood records during the ~1700 years of paleoclimatic variations in the north-western Himalaya. The role of Indian Summer Monsoon (ISM) and Westerlies can also be understood from these records.

The Rewalsar Lake cores have been analysed for reconstructing climate, sedimentation, and pollution etc. from the mid-altitude region of the Himalaya. Grain size analysis of 62 samples from ~5 meters lake core has been performed by LPSA at WIHG to study the down-depth grain-size variation and climate control. It has also been observed that the Rewalsar Lake experienced a higher rate of the sedimentation history during the last ~50 years as compared to the other north-western Himalayan lakes. On the other hand, the geochemical studies also revealed low to moderate heavy metal pollution in the lake during the past ~50 years.

Around ~8 meter of Ganga River cliff section at Ramnagar, Varanasi was studied for paleoclimatic reconstruction of the Ganga Plain. A multi-proxy data set (grain size and magnetic mineralogy) were already generated during the previous years, while the data on major oxides and trace elements have been generated during this reporting year. The findings of this work indicate a gradually drier climatic condition during the late Quaternary with intermittent wet phases.

TAT-2.5

Climate Variability and Treeline Dynamics in Western Himalaya

(P.S. Negi and Jayendra Singh)

Thirty days field work has been conducted to accomplish various objectives related to the treeline dynamics, dendrochronological study and aerosols monitoring. In order to monitor aerosols i.e., black carbon (BC) and CO_2 concentration in pristine localities of high Himalayan region, two sets of aethalometers and CO_2 sensors were procured. After intensive field investigation, suitable site has been identified for the installation of the instruments. And one set of instruments successfully installed near Chirbasa at 3600 m *asl* in Gangotri Valley (Fig. 12a-d) and accordingly monitoring is in progress. During the instrument testing phase the black carbon concentration was reported from 36 to 1311 ng/m^3 (20.10.15), 03 to 346 ng/m^3 (21.10.15) and 0.0 to 16 ng/ m^3 (22.10.15). The unusual high value of BC is surprising for such a pristine locality and attributable to the use of LPG/Kerosene oil and fire wood by the various tourists, and the BC value may not be so high during non-tourist season and it needs to be checked by further monitoring.

In order to carry out intensive sampling for treeline rise in Mandakini Valley, field work has been conducted. The current average of treeline altitude with earlier 26 treeline points is 3453.33 m *asl* with rate treeline rise @ 10 m/year since the year 1962. From the present field work, two more treeline sample points has been reported at the altitude of 3510 m and 3450 m *asl*. The higher most elevation of the treeline is represented by some cold/snow regime resistant plant species such as *Betula utilis*, *Sorbus acuparia* and *Rhododendron companulatum*. Other species reported from main floristic composition of treeline/ecotone area are *Quercus semicarpifolia*, *Q.floribunda*, *Abies spectabilis*, *Juuniperus squamata*, *Juuniperus indica*. The sustained treeline rise is indicative of climate change implication, especially the continuous decrease in snow regime/snow precipitation in alpine ecosystem. Also, some of the prominent locations in Mandakini Valley such as Gaurikund, Rambara and Kedarnath were investigated to understand the geomorphological, especially landscape and forest changes during the Kedarnath disaster in 2013.

In order to carryout, the dendrochronological studies around 300 tree cores were collected from 3 conifer and 4 deciduous species for palaeoclimatic studies in different locations of Din Gad valley (Tela camp) area. Ring-widths of two conifer species were

Fig. 12: (a) Insulated Aethalometer behind the solar panel, (b) Aethalometer covered by solar panel, (c) Observation site with Bhagirathi peaks in the background, and (d) Treeline 3,752 m asl, near Chirbasa.

measured with an accuracy of 0.001mm, and successfully dated each growth ring to the level of calendar year for 41 tree cores of Abies and 32 tree cores of Spruce. Ring-widths of 18 tree cores of one deciduous species were also measured and the dating of growth rings is in process. Tree-ring chronologies of these two conifer species were prepared for further dendroclimatic studies. Besides, annual growth rings of two conifer species was separated for stable isotope analyses. Ring widths of 11 tree cores of deciduous species were also measured and dated to the level of calendar year of their formation. Ring width measurement of *Betula utilis* samples collected from Bhagirathi valley and Chorabari glacier valley are in process.

TAT-2.6
Geochemical and isotopic studies as tracers of weathering and erosion processes in the NW Himalaya

(Santosh K. Rai, S.K. Bartarya, Anil K. Gupta and A.K.L. Asthana)

Major ions, stable isotopes ($\delta^{13}C_{VPDB}$) and silica measured in the samples in Indus River waters covering Ladakh region, show that the alkalinity in these rivers is linked with silicate weathering. However, co-variation of [HCO_3+SO_4] with [Ca+Mg] indicates that the alkalinity in these rivers may be originated with silicate weathering mediated by H_2SO_4 or dissolution of halites. Thus it is presumed that, the silicate weathering serve as a dominant mechanism to produce the alkalinity in these Rivers. This observation is also supported by the fact that the silicates (granites, gneisses, schists etc) in the Indus valley comprise mainly of minerals including quartz, plagioclase, alkali feldspar, biotite and muscovite and dissolution of these can produce silica and alkalinity together in solution. These results find support as the Indus River flows through the Indo-Tsangpo Suture zone characterised with tectonic activity and highly fractured/sheared rocks which are prone to weathering. This work hints for the plausibility of silicate weathering in the Indus catchment which may be mediated with the H_2SO_4.

Analytical studies carried on the landform development of the Ramganga basin incorporate the quantitative analysis of its catchment in the Garhwal Himalaya Uttarakhand. The drainage parameters (linear, areal and relief) of the Ramganga Basin from Dudhatolidhar peak its origin point to Kalagarh from where the River Ramganga enter into the plain are covered. The impact of the morphological characters on the terrain is reflected by the drainage basin of the area.

TAT-2.7
High resolution Paleoclimate records from the Himalaya and adjoining regions

(Anil K. Gupta, Jayendra Singh, Santosh K. Rai and Suman Lata Rawat)

In order to reconstruct floristic composition and Indian summer monsoon variability during the Holocene period four sediment cores from the Ganga basin and two palaeolake profiles from the Pinder valley, Garhwal Himalaya have been collected and being analysed to generate multi-proxy records (pollen, grain size, loss on ignition and stable carbon isotope). In addition, ring-width chronology of *Pinus wallichaina* from Kinnaur region, Himachal Pradesh was also prepared and climate signal of the ring width chronology was identified for further reconstruction of past climate records. Besides, 100 tree cores of two conifer species (*Cedrus deodara* and *Pinus gerardiana*) were processed and annual growth-ring width of trees are being measured for the further climate change studies.

TAT 2.8
Variability of Indian Monsoon during the Quaternary period since MIS-3 using the high resolution speleothem records from Himalayan regions and sediment records from Ganga plain lakes

(Som Dutt, Anil Kumar, Anil K. Gupta, Suman Lata Rawat and Saurabh Singhal)

In order to reconstruct the variability of Indian summer monsoon (ISM) in the Indian subcontinent during the late Quaternary, the sub-sampling of some speleothems, collected from the NE Himalaya have been carried out. The results of one speleothem MWS-1 from Mawmluh cave, Meghalaya indicate a strong wet phase between 33,500 and 32,500 years B.P. followed by a weak/dry phase from 26,000 to 23,500 years B.P. The weakest phase of ISM lies between 17,000 and 15,000 years B.P. These records also suggests abrupt increase in ISM strength during the Bølling-Allerød and early Holocene periods and pronounced weakening during the Heinrich and Younger Dryas cold events.

The chronology of sediment core from Rewalsar Lake (Mandi, Himachal Pradesh) have been developed by 15 AMS ^{14}C ages. The preliminary results of grain size variability suggest very high erosional events in the lake catchment around 2,900, 1,750 and 1,250 years B.P., which indicate the strong flood events.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEOHAZARD EVALUATION

TAT-3.1

Seismological, seismotectonic and subsurface related studies seismic hazard evaluation from the Ladakh, Kinnaur, Kangra and Garhwal-Kumaun regions of the NW Himalaya

(Sushil Kumar, Ajay Paul, Dilip Kumar Yadav and Devajit Hazarika)

Strains resulting from the continued collision between India-Asia plates are manifested in number of large earthquakes along the Himalayan arc. In the NW Himalaya, adjustments and activation of crustal blocks to accumulating/decaying strains continuously trigger micro-earthquakes. The understanding of earthquake source processes and the medium characterization provides the base tools for the assessment, mitigation and reduction of seismic hazards. Towards obtaining these objectives a regional network of seismic stations are being operated in the NW Himalaya. Around 40 Broad Band Seismographs (Fig. 13), along with other Geophysical equipments were operated in the NW Himalaya. The data is being acquired and analyzed continuously by the network. The earthquake events for period during April 2015 and March 2016 were analyzed for understanding the spatio-temporal variations, source mechanisms, source parameters, Shear Wave Splitting (SWS) properties, 1D and 3D velocity structure, evaluation of strain energy budget and stress orientations in the Garhwal-Kumaun region of Himalaya. The epicentral location map indicates that Munsiari Thrust, which is located south of the Main Central Thrust, is more active. From the slip distribution evaluation on the fault plane from waveform modeling of earthquakes, it has been found that the large slip regions cover a very

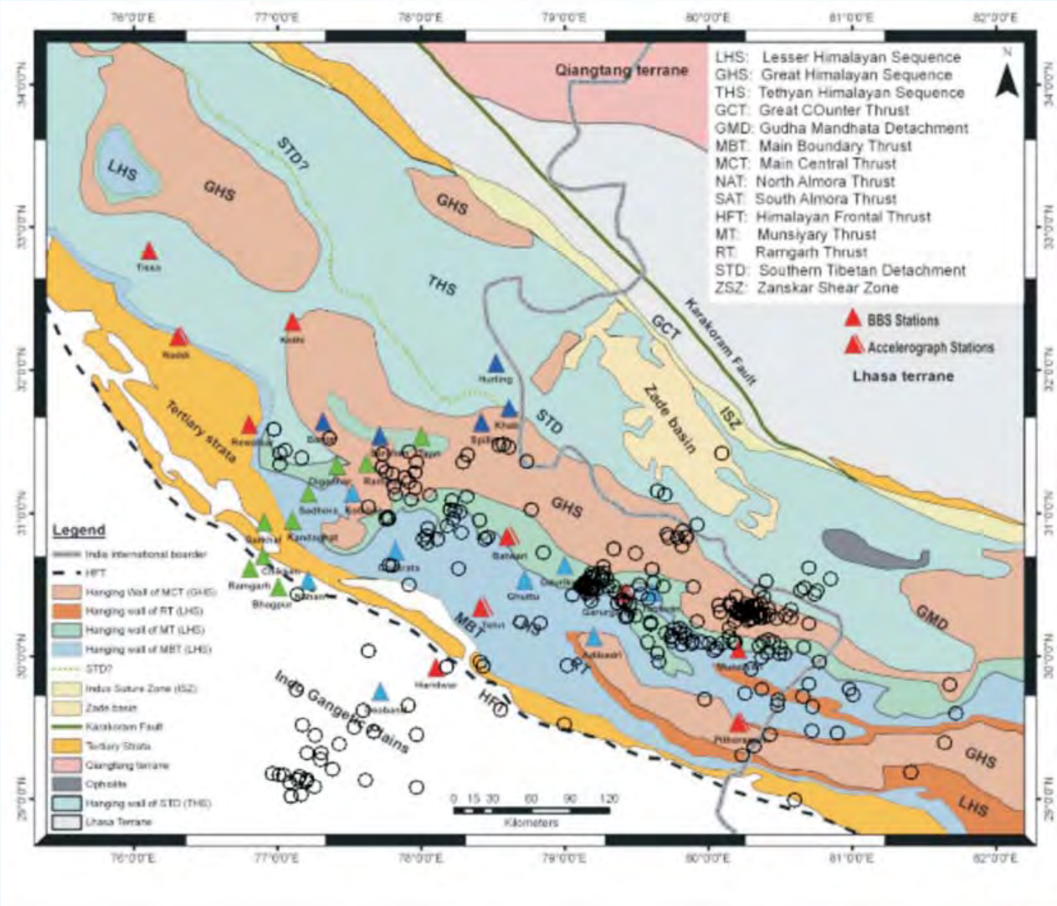

Fig.13: Broadband seismographs and accelerographs locations are shown with triangles and epicentral locations of local earthquakes triggered during 2015-16 are shown with black circles on the seismotectonic map of NW Himalaya.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEOHAZARD EVALUATION

small area as compared to the total area of fault plane. Some of the fault plane shows multiple asperities and the focus lie close to the nearby thrust.

Attenuation characteristics of coda waves in the NW Himalaya

From the NW Himalaya (Fig. 14), digital seismogram data of 82 earthquakes were recorded at different stations during 2004-2006 and were analyzed to study the seismic coda wave attenuation characteristics in this region. We used 132 seismic observations (Fig. 15) from local earthquakes with a hypocentral distance <240 km and a magnitude range of 1.2-4.9 to study the coda Q_C using the single isotropic scattering model. These earthquakes were recorded at 20 temporary seismic stations (Fig. 15) installed in the NW Himalaya by the WIHG. The Q_C values were estimated at 10 central frequencies: 1.5, 3, 5, 7, 9, 12, 16, 20, 24, and 28

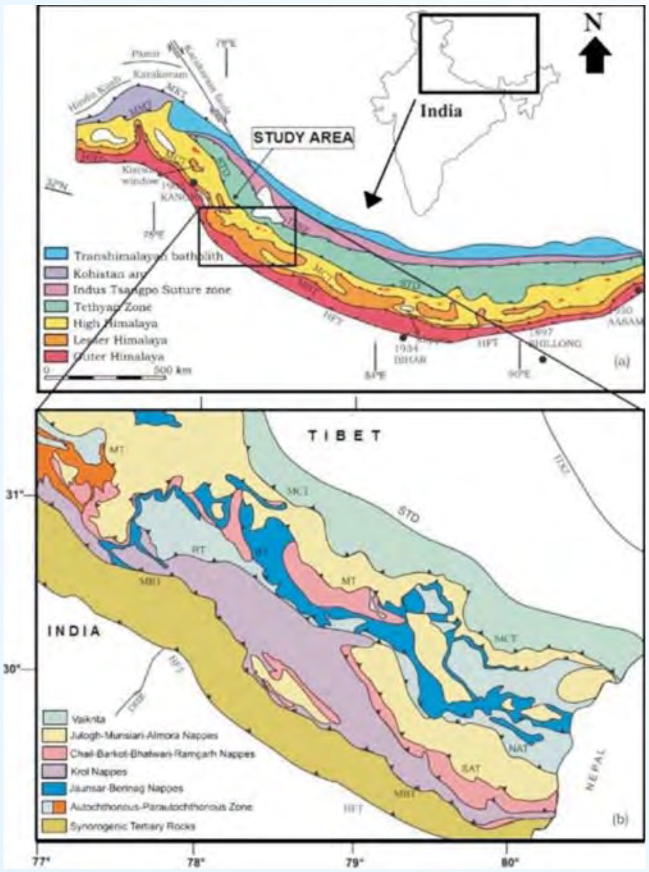

Fig. 14: (a) Simplified map of the Himalaya. (b) Map of the study area modified after Valdiya (1980). *Abbreviations:* Black dots - location of the four great earthquakes, MKT-Main Karakoram Thrust, MMT-Main Mantle Thrust, ITSZ-Indus Tsangpo Suture Zone, STD-South Tibetan Detachment, MCT-Main Central Thrust, NAT-North Almora Thrust, BT-Berinag Thrust, MT-Munsiari Thrust, RT-Ramgarh Thrust, DHR-Delhi Haridwar Ridge.

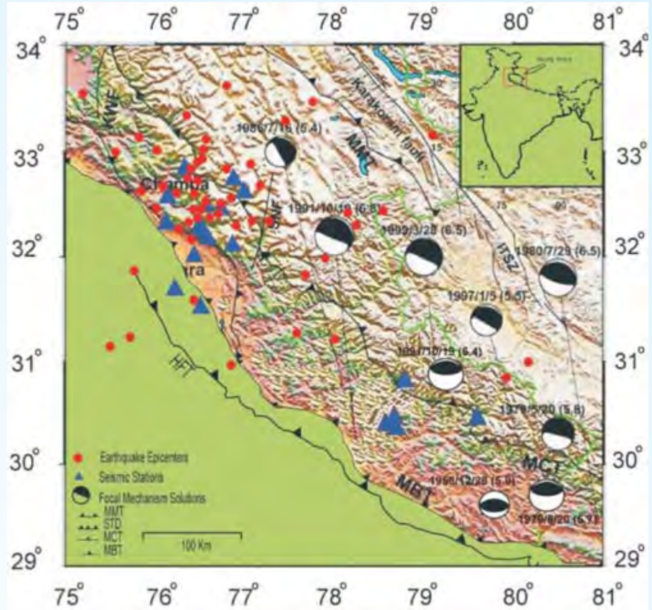

Fig. 15: Station locations are shown with the blue triangles and events used in the study are shown with red circles. HFT, MBT, MCT, STD, and MMT are abbreviations for the Himalayan Frontal Thrust, Main Boundary Thrust, Main Central Thrust, South Tibetan Detachment, and the Main Mantle Thrust, respectively. The focal mechanisms of some strong earthquakes are also shown in the figure, and the date and magnitude of the events are given above the beach ball. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Hz using starting lapse-times of 10, 20, 30, 40, 50, and 60 s and coda window-lengths of 10, 20, 30, 40, and 50 s. The Q_C fits the frequency dependent power-law, $Q_C=Q_0 f^n$. For a 10 s lapse time with a 10-s coda window length $Q_C=47.42f^{1.012}$ and for a 50 s lapse time with a 50 s coda window length, $Q_C=204.1f^{0.934}$. Q_0Q0 (Q_C at 1 Hz) varied from ~47 for a 10 s lapse time and a 10 s window length, to ~204 for a 50 s lapse time and a 50 s window length. An average frequency dependent power law fit for the study region may be given as $Q_C=116.716f^{0.9943}$. The exponent of the frequency dependence law n ranged from 1.08 to 0.9, which correlates well with values obtained in other seismically and tectonically active and heterogeneous regions of the world (Fig. 16). In present study region, Q_C increases both with respect to lapse time and frequency, i.e., the attenuation decreases as the quality factor is inversely proportional to attenuation. The low Q_C values or high attenuation at lower frequencies and high Q_C values or low attenuation at higher frequencies suggest that the heterogeneity decreases with increasing depth in our study region.

Sikkim earthquake of 18th September 2011

The attenuation characteristics of seismic wave energy around the source region of the Strong Sikkim earthquake, India (Mw: 6.9) of 18 September 2011 is estimated using coda waves analysis. Total 105 aftershock events (Fig. 17) have been selected and analysed for estimation of Qc values at central frequencies ranging from 2-16 Hz using five lapse-time

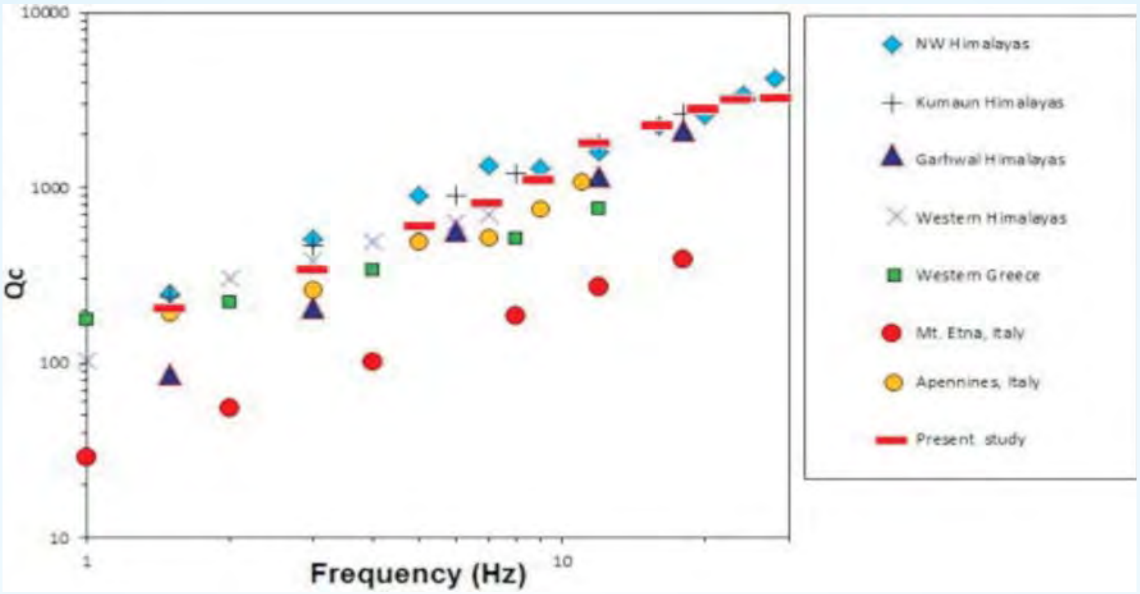

Fig. 16: Comparison of the study results with estimates from various regions in the world. *Data References:* NW Himalayas (Tripathi et al., 2012); Kumaun Himalayas (Singh et al., 2012); Garhwal Himalayas (Gupta et al., 1995); western Himalayas (Mukhopadhyay and Tyagi, 2007); western Greece (Tselentis, 1998); Mt. Etna, Italy, (Pezzo et al., 1995); Sikkim Himalayas (Hazarika et al., 2013); Apennines, Italy (Bianco et al., 2002); and this study. View the MathML source (LT=50,WL=30).

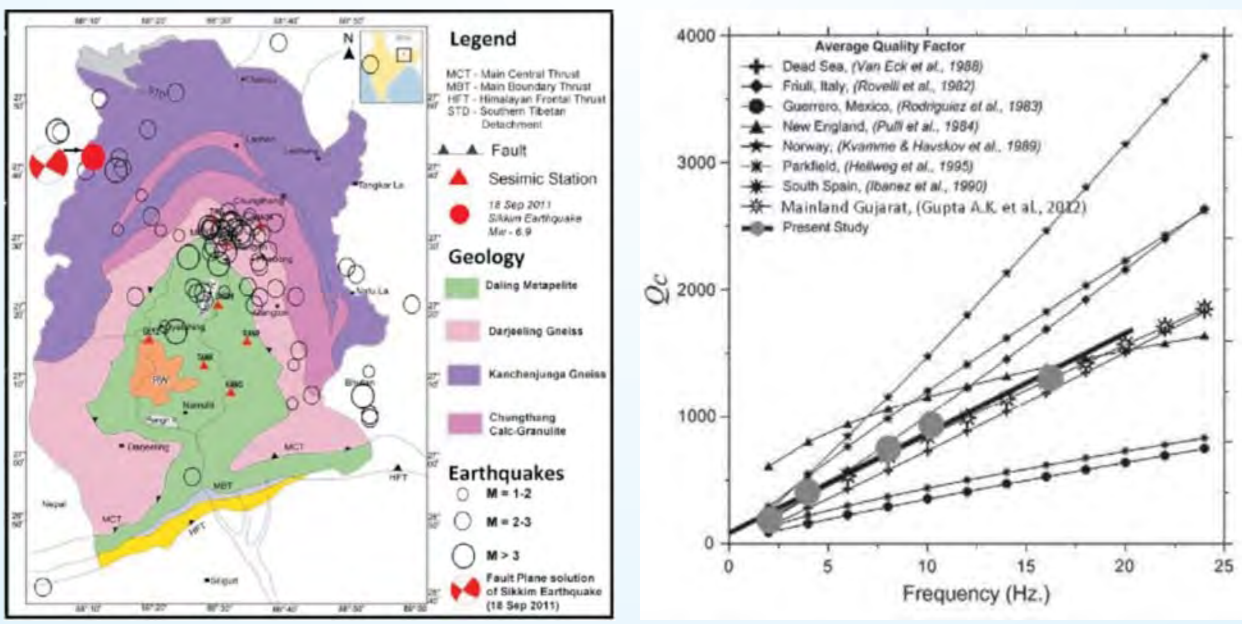

Fig. 17: Tectonic map of the Sikkim Himalaya, India depicting 8 broad band seismic stations (marked with red triangles), 105 aftershock events (marked with open black circles, size varying with magnitude) used in the study, geology of the area and the epicentre location of the 2011 Sikkim earthquake with its fault plane solution. Different tectonic boundaries as MCT, MBT, HFT and STD are also marked. In the adjacent figure comparison of Q_c values for Sikkim Region, India with the existing attenuation studies worldwide.

windows from 25 to 50 s starting at twice the travel time of S-wave. The obtained average Qc values are frequency dependent that indicates that the area is tectonically and seismically more disturbed. Results shows that Sikkim area has lowest Qc values at all frequencies in comparison to the reported Qc values for the adjacent areas in northeast India and other parts of India (**Fig. 17**). Obtained Qc values in this study are also significant for seismic hazard analysis by simulating the strong ground motions in the concern region.

TAT-3.2
Earthquake precursory studies in the Himalaya through Multiple Geophysical Approach

(Naresh Kumar, Gautam Rawat, P.K.R. Gautam)

Precursory changes and Seismic hazard

Multi-Parametric observatory, Ghuttu, Garhwal Himalaya has continuous recording of different geophysical field at one site on the earth's surface and also sub-surface measurement in a 68 m deep borehole. All time series report a seasonal variation with high effects of hydrological changes, atmospheric effects and external terrestrial interferences. We are putting more efforts to remove these effects and also eliminate the background noise for searching anomalous changes related to the ongoing local regional seismicity. Analysis is focused on anomalous behaviour relative to the occurrence of moderate and higher magnitude earthquake (M>=4.0) mainly of epicentre distance within 200 km. However, for the big size earthquake events the extent of the epicentre distance is increased in which for this year a detailed study associated with Mw7.8 Nepal earthquake of 25th April, 2015 is conducted. Co-seismic changes associated with this event are also evaluated.

To characterise the anomalous changes in different time series, it is also important to understand the regional aspects of seismicity, earthquake source behaviours, geo-tectonic aspects and sources of seismogenesis regimes. The strong motion data of Ghuttu and other local stations is assimilated to assess the seismic hazard of the region based on observations from M5.7 earthquake of western Nepal region. A comparative study of the GPS data and the gravity measurement using SG is also performed. The strong motion records of different sites are important to understand the seismic hazard and seismic energy attenuation behaviour.

It is imperative to analyse the data generated due to the occurrence of strong magnitude and higher size earthquake. In this context we studied the strong motion data recorded in the Garhwal Himalaya during the occurrence of M5.7 earthquake of 4th April, 2011 located in the western Nepal earthquake. Data recorded by a dense local network of 24 strong motion accelerograph stations is used to estimate horizontal and vertical component of the peak ground acceleration (PGA) and estimated the attenuation characteristic. The results are interesting to better understand its bearing on the seismic hazard scenario of the Central Himalayan region. Based on *H*/*V* ratio, the attenuation trend of

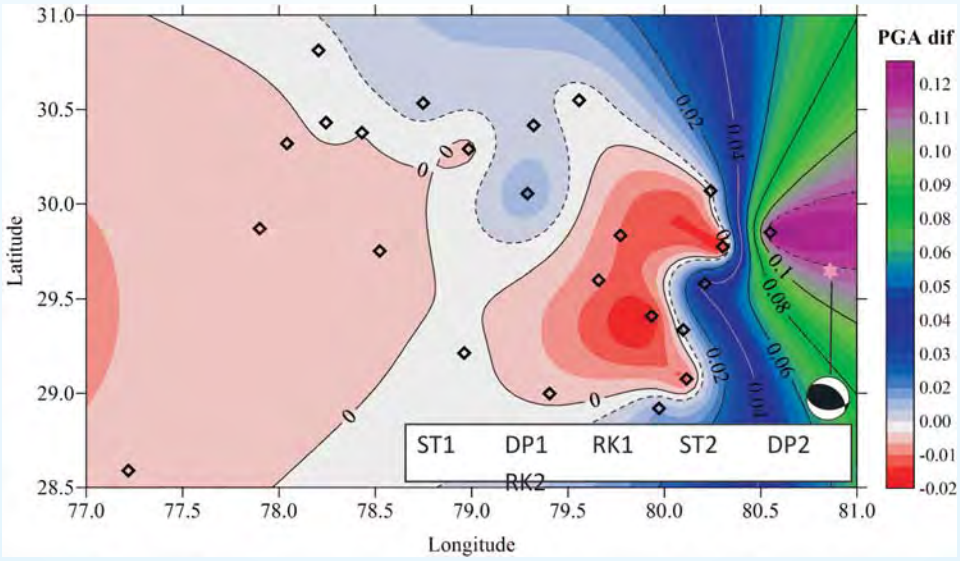

Fig. 18. Deviation of recorded PGA values from the obtained attenuation characteristic curve at specific distance is plotted for vertical component data. Star denotes the epicentre location, the Focal Mechanism solution of USGS is plotted and its parameters are also mentioned.

strong seismic waves detected to be bimodal with one trend for closer distance up to 100-120 km, while the other trend corresponds to regional distances. These two different PGA trends have close bearing on the major tectonics and structural set-up of the region. The present results may improve the concept of ground motion model for evaluating seismic hazard evaluation for the Himalaya. The analysis highlight that the hetero-geneous region where the geological and tectonic elements are having drastic variation may cause maximum deviation in the source geometry (Fig. 18). Therefore if the strong motion effect varies depending upon source mechanism for strong earthquakes then it may also have consequences upon anomalous changes in different geophysical parameters.

Seismo-Electromagnetic

During the year 2010, the earthquakes of magnitude M >3.5, within 150 km radius from MPGO Ghuttu occurred in the first half period of the year (Table 1 and Fig. 19). It is therefore considered best time frame to scrutinize different parameters of MPGO, which were considered and reported as an earthquake precursors by researchers worldwide. The study has its significance in understanding the evolution of seismogenic processes, in absence of difficulty of establishing one to one relationship of these widely reported parameters to a particular earthquake. Polarisation ratio and variability of fractal dimension considering earthquake process as SOC system. Initially, daily ULF data of local mid night from19:00-20:00 hrs (UT) from 1st January, 2010 to 31st December, 2010 is used to show the changes in first half and second half of the year. Later to confirm these changes, the study extended to May 2009 to May 2011.

From the temporal variation of polarization ratio, presence of seismo-magnetic disturbances superposed upon background geomagnetic variations are inferred. Fractal dimension variability indicates that average fractal dimension for first half of the year is increased as compared to average fractal dimension of second half of the year and there is gradual increase in the fractal dimension before earthquakes. In order to see that this feature is not periodic, the fractal dimension variability is shown for a period of two years from (June 2009 to May 2011) in figure 20.

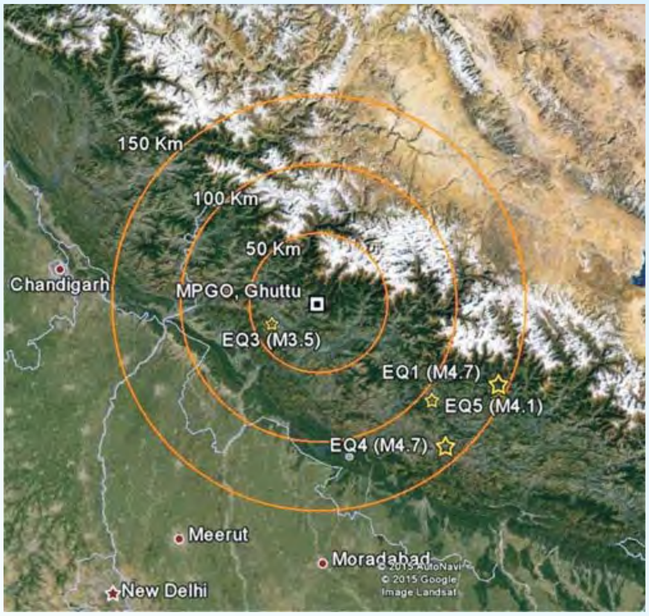

Fig. 19: Location map of earthquakes listed in table 1.

Crustal Deformation using GPS studies

Under-thrusting of the Indian tectonic plate beneath Eurasian plate resulting gradual ongoing tectonic activity produces a continuous stress which is responsible for seismic hazard in the Himalaya and surrounding regions. These seismic activities can be attributed to slip deficits where the Indian and Eurasian continent plates are locked during inter seismic periods. The geodetic measurements can help to discriminate the distribution of the interlocking areas and the gradually slipping areas beneath the Himalaya. With the objective

Table 1: List of earthquakes within 150 km radius of MPGO Ghuttu observatory.

S. No.	Date	Julian Day	Time (UTC)	Lat.	Long.	Depth (km)	Magnitude	Epicentral Distance (km)	Preparation zone radius (km)
1.	22.02.2010	53	17:23:43	30.0°N	80.1°E	02	4.7	143.29	104.95
2.	01.05.2010	121	22:36:25	29.9°N	80.1°E	10	4.6	148.27	95.06
3.	03.05.2010	123	17:15:08	30.4°N	78.4°E	08	3.5	35.65	31.99
4.	22.06.2010	173	23:14:08	29.6°N	79.7°E	18	4.7	138.67	104.95
5.	10.07.2010	191	03:16:20	29.9°N	79.6°E	10	4.1	108.33	57.94

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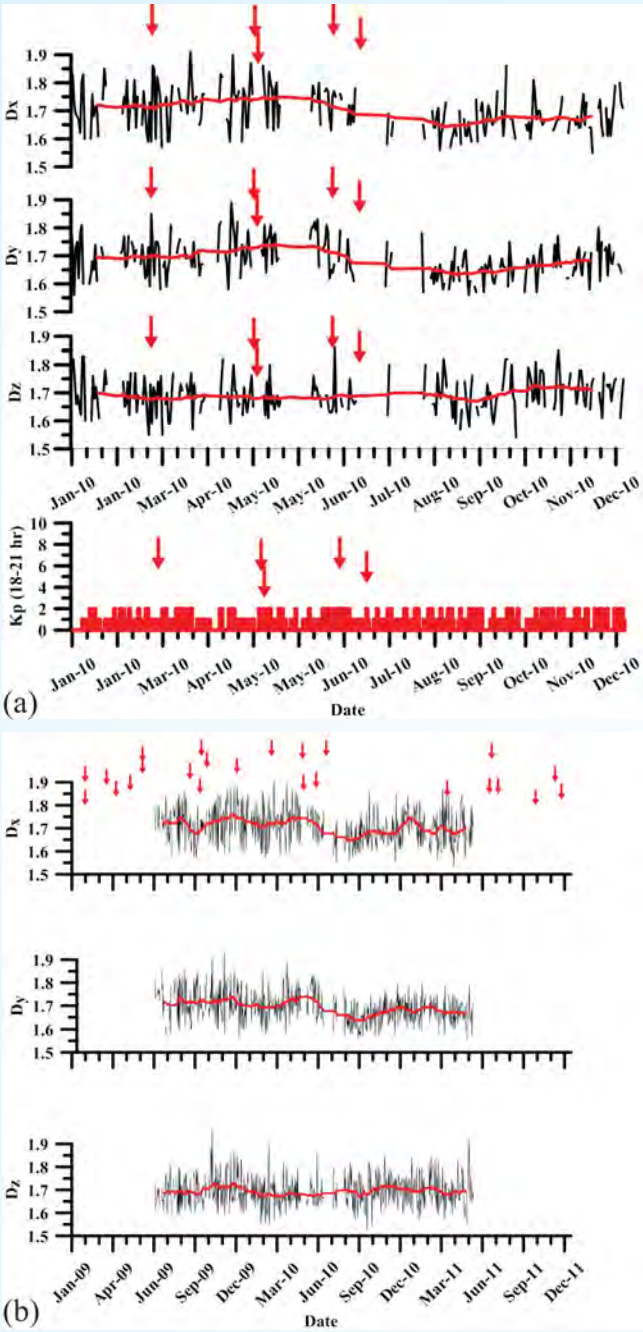

Fig. 20: (a) Fractal dimension variability during year 2010 for days having Kp<3. (b) Variability of fractal dimension from June 2009 to May 2011. The red arrows indicate the earthquake within 150 radius from MPGO Ghuttu.

of earthquake precursor and ongoing deformation study in the Himalaya, we are using multi-geophysical approaches with GPS as one component of them. For the contribution of GPS component in achieving the goal of the project and for estimating the strain pattern in the

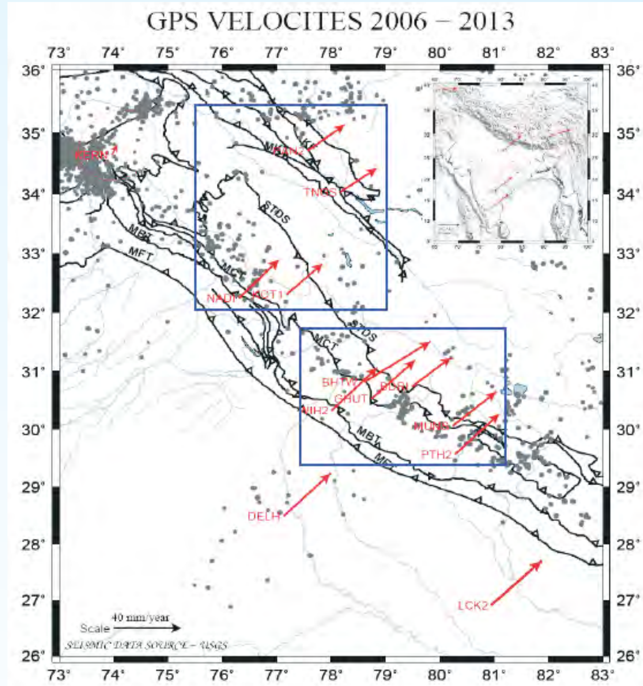

Fig. 21: The velocity field in the North-West Himalaya.

Himalaya, we have established a network of permanent GPS stations in different parts of the Himalaya. The continuous data from these stations is being acquired on 1 sec and 30 sec sampling interval simultaneously. As the crustal deformation is a main concern to the plate boundary phenomenon, it was observed by the earlier workers that a convergence zone is taking place along the Himalaya. We are also working to see the effect of Terrestrial Ground Water (TWS) on the Himalayan seismicity for which we combined the seismicity, GPS and TWS data simultaneously. The GPS velocity vectors of NW Himalayan region obtained using local GPS data of ~8 years (2006 to 2014) is shown in figure 21. The study highlight two zones of deformation (covered by rectangles) where deformation in the Garhwal Himalaya towards southeast of the study region is more compared to the adjoining northwest part.

TAT-3.3

Active tectonics and paleoseismological studies within the zones of Himalayan Frontal Thrust and Main Central Thrust in Uttarakhand and Himachal Himalaya

(G. Philip and N. Suresh)

Trench Excavation across Logar Fault

The Logar Fault delineated at Logar village in northwestern Kumaon Sub-Himalaya, vertically displaced the Quaternary alluvial fan and is considered to be a normal fault with minor strike slip component. The geomorphic features such as the abandoned courses of tributaries indicate the pre-faulting scenario at Logar. A trench excavation survey was carried out at Bairasari village across the Logar Fault scarp for paleoseismic investigation. The distribution of various units in the trench suggest deposition of sediments immediately after the faulting. The samples collected from the top surface of the south side-up scarp of the fan as well as the bottom unit of the trench show the OSL age as ~20 ka that indicate the upper age of the fan before the faulting, and suggest rapid post faulting deposition of the units in the trench.

The merging of Quaternary fault of the Logar mega fan with the MBT is exposed at Logar Gad bridge. The highly jointed, sheared and fractured Tertiary rocks exposed along the Logar Fault in the river section confirm the recent tectonic activity. The geomorphic south side up expression of the Logar Fault, which also coincides with the Himalayan mega thrust therefore suggest succeeding tectonic activity along the MBT. At the same time the nature of faulting, the length of the Quaternary fault and shearing of the basement rocks suggests its genetic link with seismic related tectonic activity in this region. The mappable length (~9.5 km) of the relatively a small Logar Fault indicate that it was not long enough to produce a great earthquake (Mw>8) and may be one of the several secondary hanging wall structures initiated to accommodate rupture during large magnitude Himalayan earthquakes. Tectonic activity along the MBT substantiates high seismic potential of the Sub-Himalaya and calls for more extensive study of paleoearthquakes of this vastly populous mountainous region. Based on paleo-seismological investigations, large magnitude multiple paleoearthquakes that have produced surface rupture along the MBT strongly indicates that large magnitude earthquakes greater than those events took place in the historical past is highly possible along the MBT.

Trench Excavation across Bhauwala Fault

The Bhauwala fault is one of the major E-W trending faults in the central Doon valley. The fault in the Quaternary Doon fan was identified on satellite image by earlier workers. Based on further field work we have traced the degraded fault scarp near Bhauwala. To understand the nature of the fault and its relation with paleoearthquake, a trench excavation survey has been carried out across Bhauwala fault. However the trench (30x5x5 m) could not expose the fault plane since further excavation was not possible due to limitations in the availability of the land. Nevertheless the exposed trench shows distinct deformation features due to faulting. While the study is in progress, this fault in the vicinity of the MBT in northwestern Himalaya is considered to be the result of multiple reactivations of the faults after giant earthquakes.

Geophysical Surveys at HFT near Kala Amb, Doon valley and Trans-Yamuna regions

Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) surveys were employed across three different active fault systems in the northwestern frontal and Sub-Himalaya.

A 50 m GPR profile acquired along the river bed clearly differentiated two major lithological boundary created due to displacement at the HFT zone near Kala Amb. Electrical resistivity profiles performed with 2 m spacing show a general lateral increase of resistivity from north to south limited to shallow depth of around 16 m. The profile obtained using Wenner configuration showing both vertical and lateral variations in resistivity, show the north dipping low angle faults.

Geophysical surveys have also been carried out across Bhauwala fault and Donga Fault in Doon valley and Bharli Fault in the Trans-Yamuna segment of the NW Doon valley. The depth of GPR profiles acquired across fault scarp vary from 3 to 10 m depending on the antenna frequency and subsurface soil condition. With 200/600 MHz dual frequency antenna, high resolution subsurface image with penetration depth up to 5 m were obtained. The GPR section shows a prominent offset in all profiles especially in Bhauwala and Kala Amb at variable depth feature. Delineation of subsurface tectonic features using geophysical methods has corroborated our surface observations and should help us in integrating geological and geophysical means to establish the active fault systems in the study areas.

TAT-3.4

Timing, size, and lateral extent of earthquake ruptures along the Himalayan Frontal Thrust *(TSLER-HFT)*

(R. Jayangondaperumal and Pradeep Srivastava)

Paleoseismic investigation in from Sub-Himalayan range of Himachal Himalaya

Results of a paleoseismic trenching investigation on a backthrust in the northern margin of Janauri hill, at Mehandpur (31°18'11.37"N, 76°18'31.47"E), Sub-Himalayan range of the Himachal Himalaya are presented (Figs. 22 and 23). The active backthrust revealed the last event took place after 0.8±0.03 ka ago

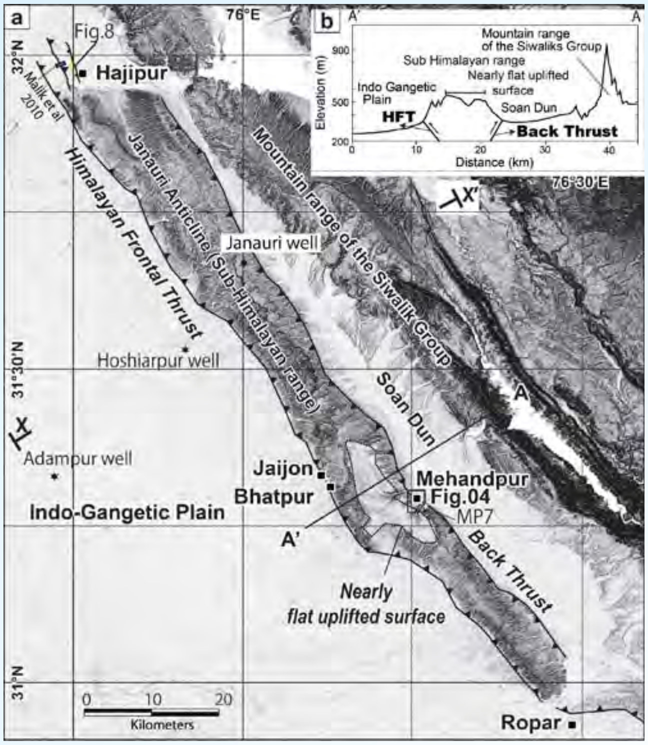

Fig. 22: SRTM showing Janauri anticline bounded with fore-backthrust along with Soan Dun.

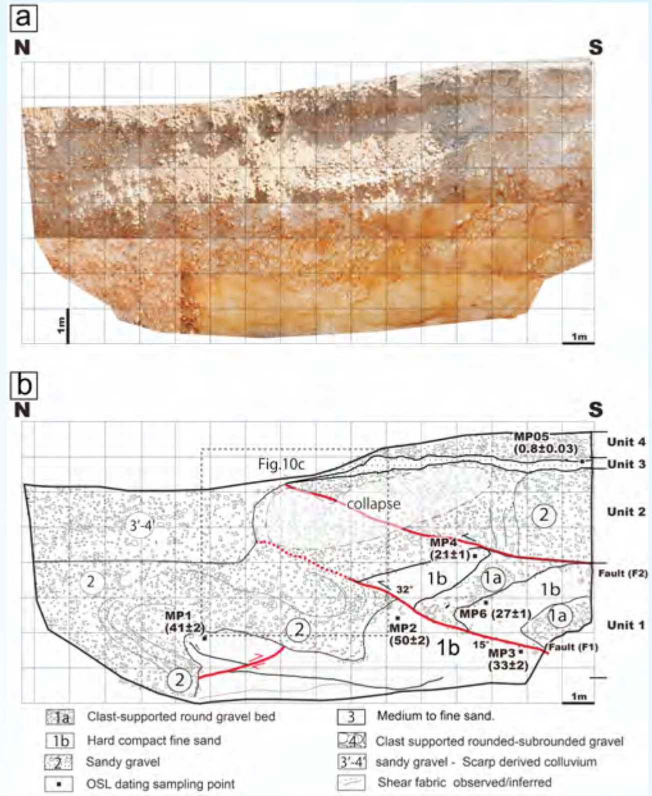

Fig. 24: a) Photo-mosaic of trench log of east wall at Mehandpur. (b) Interpreted geologic boundaries and faults, OSL dating samples and the mean age (ka).

(i.e. post A.D. 1200). The age of the last earthquake with a minimum fault slip ~1 m along F1 fault and presence of single colluvium on the back thrust nearly matches with an earthquake event previously documented on the Bhatpur forethrust of the Himalayan frontal thrust system (Fig. 24). Uplifted and truncated fluvial terraces due to displacement on the backthrust are preserved along several north flowing river valley sections in the northern limb of Janauri anticline. The long-term vertical uplift rate calculated through dividing difference between current elevation and elevation of current river grade is 1.08±0.08 mm/yr. Field evidence shows fore and backthrusts are active and they form simultaneously, but displacements are episodic suggesting the backthrust develops either due to locking of forethrust or to accommodate a large amount of fault slip due to magnitude of earthquake event along the forethrust. Further, the backthrust may be used as an

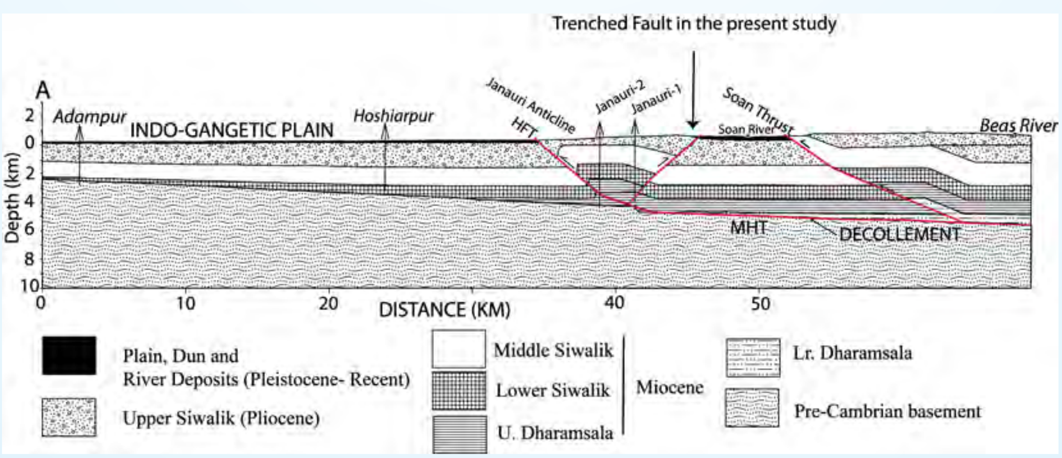

Fig. 23: Geological cross-section along X-X' (location shown in figure 22) showing the Januari anticline along with fore and backthrust.

indirect method of inferring the age of the last event that took place along the forethrust.

TAT-3.5

Morphotectonic evolution of the Himalayan frontal belt between Kosi and Kali rivers, Kumaun Himalaya

(Khayingshing Luirei)

Kosi valley represents a varied geomorphology with respect to structure of the bedrock from the South Almora Thrust (SAT) downstream to the Himalayan Frontal Thrust (HFT) zones where Kosi River exit into the Gangetic plain. Morphotectonically the Ramnagar area in Kumaun Sub-Himalaya is characterized by four levels of terraces (Fig. 25). Terrace (T_4) at 415 a msl, T_3 at 390 a msl, T_2 at 365 a msl; T_1 at 350 a msl and present river bed (T_0) at 347 a msl. T_4 is strath terrace with fluvial deposit over inclined Upper Siwalik conglomerate and the strath bedrock forms a part of broad syncline. Tectonic fabrics in the HFT zone in the bedrocks are indicated by number of reverse and normal faults. The reverse faults are oblique to the trend of the HFT. The gently NW to N dipping bedrocks in the hanging wall becomes SE dipping in the footwall of the HFT. Between Ramnagar and Garjiya the valley is very wide, the widest being at Amdanda-Terha section where the valley measures about 3.5 km, further upstream the valley becomes very narrow northwest of Garjiya where the width measures about 140 m. The HFT is defined by almost E-W running escarpment and two to three levels of terraces indicating uplift along the terrain defining thrust.

Upstream along the Kosi river section at Ukhaldunga in the Main Boundary Thrust (MBT) zone, the ~30 m wide Kosi river course developed just north Ukhaldunga the valley becomes a wide flood plain of about 1,300 m in the hanging wall of the MBT. Wide development of aggradational landform such as terraces and fans are observed. Valley profile indicates broader valley of Kosi River at the time of deposition of terrace at Basela-Bawa area and upstream when Kosi River was flowing through Ukhaldunga. Terrace at Basela is about 120 m above present river bed where the valley is vertical to deep gorge and is observed as strath terrace. Ukhaldunga is inhibited in the old Kosi River channel remnant being represented by 140 m wide wind gap. Rejuvenation of the terrane has led to incision of the bedrocks and overlying sediments leading to development of steep to vertical valley and changing the course of Kosi River. Four broad levels of terraces are observed at Ukhaldunga, T_4 at 630 a msl, T_3 at 610 a msl, T_2 at 596 a msl, T_1 at 585 amsl and T_0 at 580 a msl. Older terraces T_4 and T_3 are composed of sub to well rounded

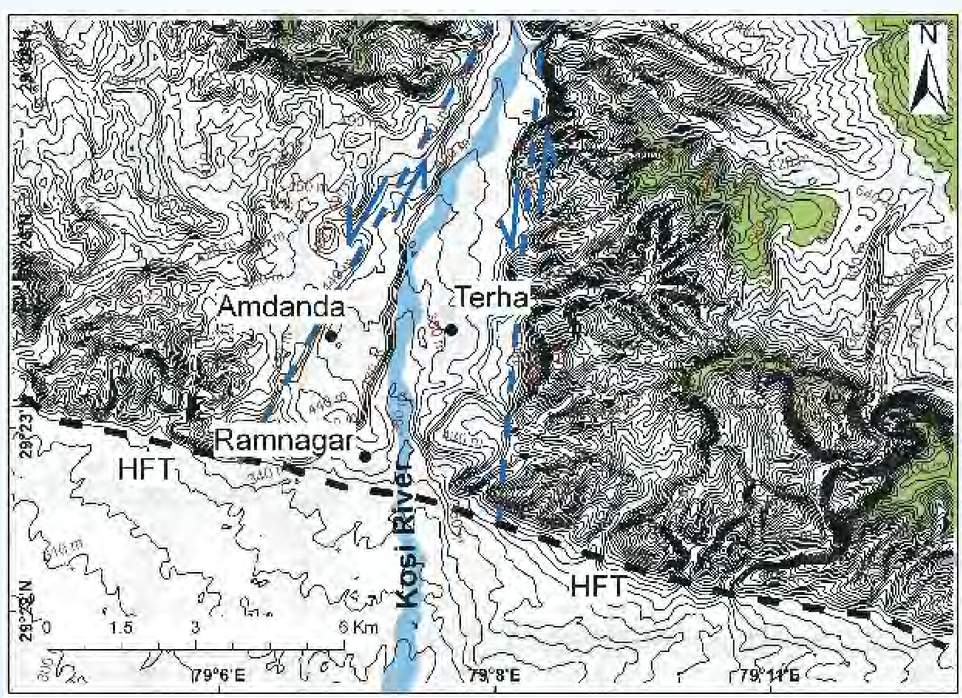

Fig. 25: DEM of Ramnagar area characterized by closely spaced contours in the Himalayan Frontal Thrust (HFT) zone. The wide valley at Amdanda-Terha narrows down at Ramnagar as a result of uplift along the HFT.

pebbles and boulders of riverine and angular rock fragments of landslide and slope generated. T_2 is a strath terrace (the bed rock is composed of phyllite) and is overlain by 2 to 3 m thick fluvial deposit showing stratification. The youngest terrace is made up mainly of medium grained sand. The MBT zone is defined by depression or trough in Amgari-Parewa section; the depressions are observed where black shales of Lower Siwalik form the top portion of the footwall. In Ukhaldunga-Dabara the hanging wall of the MBT zone is characterized by huge fan deposit. The fan deposit exposed Gaunchhil Gadhera shows gently (1-2°) dipping towards the N while the lower younger terrace deposit is tilted by about 5-7° towards N. At Amgari pre-Tertiary rocks are observed thrusting over landslide debris along the MBT at the new road cut section. In this area across the MBT sudden change in slope is observed, slope profile drawn across the MBT also indicate the same evidences. Similar observations are also reported (Valdiya, 1988) from Patkot-Amgari area. Dhikala Thrust an intraformational thrust within the Siwalik is neotectonically active as indicated by uplift of the Syat surface in the Kotabagh area. The fault scarp trends NW-SE and the scarp measures about 50 m and is best observed between Rurki and Selsiya. Stream longitudinal profile of Kosi River from the hanging wall of the South Almora Thrust (SAT) down to the footwall of the Himalayan Frontal Thrust (HFT). Knick points are observed along the longitudinal profile at SAT, MBT and HFT. Stream length gradient (SL) index have high values at MBT and HFT. Steepness index (Ks) also has high values at MBT and HFT and the concavity (⊖) value is 0.723.

TAT-3.6

Geoengineering studies and the petrophysical characteristics of rocks in the selected transects of Uttarakhand and Himachal Himalaya

(Vikram Gupta)

Field work has been carried out in the Satluj valley, Yamuna valley and Mandakini valley for the extraction of field based inventory of active landslides during the year 2015-16. The landslide inventory for the Satluj valley has been prepared and compared with the previous inventory for the year 1993 and 2006. It has been noted that there is a radical increase in the spatial coverage of landslides along with their frequency in the valley. This spatial increase in the landslides is dominantly confined, (i) along the Pawari Landslides Zone, and (ii) the area between Moorang-Pooh section. These areas were studied in details for their change in geomorphological condition, landuse pattern, anthropogenic and environmental factors, along with the extraction of the geotechnical characterization of rocks and soils.

Pawari Landslide Zone

Pawari Landslide Zone (31º33'20"N; 78º16'49"E) is an old and chronic landslide and is active possibly prior to 1962. The landslide zone is of strategic importance as, (i) numerous villages like Kothi, Kashmir, Khawangi, Telangi, Boktu along with Reckong Pio, the district headquarter of Kinnaur district, are located in the main body of the landslide zone, whereas Yuwarangi, Kalpa, Putka Dogri and Mewar Dogri are located in the crown portion of the landslide, and (ii) the toe portion of the landslide passes through the National Highway (NH-05) which is a lifeline for the people living in the area. The landslide is endangering all the townships as well the national highway. The failure events of the landslide as recorded during 2004-2014 is depicted in the following table indicating an increase in its frequency, particularly after 2009.

In order to evaluate the stability of this landslide slope and to understand its behavior in future, plain strain Finite Element Modelling (FEM) along with Shear Strength Reduction (SSR) technique has been performed in static as well as in pseudo-static conditions on two slope sections using Phase^2 (ver. 6.0) software. The sections were selected such that, the first section (located to the northern part of the landslide zone) outlines only rockmass, and in the second section (located in the central part of the landslide zone) the rock mass was overlain by the debris cover. The Generalized Hoek-Brown (GHB) failure criterion for the rockmass and the Mohr-Coulomb (M-C) failure criterion for the debris were applied in the models. The results show that the central part of the landslide zone develops higher displacement than in other parts. Further displacement have been observed to be confined in both the sections, in the toe portion of the landslide as well in the elevation range between 2,000 and 2,200 m above msl. These modelling results have well be corroborated in the field, with the broken or

Years	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
No. of slope failure events	8	11	4	6	7	5	10	23	6	31	28

bulged retaining walls and tilted trees. This demands an appropriate mitigation measures at the above mentioned locations/elevation range.

Moorang-Pooh section

The Moorang-Pooh section encompassing about 20 km long stretch along NH-05, in the present day climatic scenario, witnessed higher precipitation in the form of rainfall which during previous years, had witnessed dry conditions. Thus, the slopes in this section which were earlier dry and stable, however, with the onset of the rainfall in the area, the slopes started to move. It is further envisaged that the slopes in the area will continue to slide, until the repose angle of the slopes will be maintained. The concentrated landslides in the Moorang-Pooh section are thus mainly rain-induced, and is related mainly to the shift in the climatic pattern.

TAT - 4: BIODIVERSITY - ENVIRONMENT LINKAGE

TAT-4.1

Geobiological study of the Neoproterozoic-early Cambrian sequence of carbonate belt, Lesser Himalaya including study of microbiota and microbiotic processes and their interpretation in terms of palaeo-environment and correlation of evolutionary trend with global bioevents

(Meera Tiwari and Santosh K. Rai)

Covering a time span from Ediacaran (base of pink carbonate of Blaini) to Early Cambrian (Tal Group), the Krol Belt in the Lesser Himalaya of India, occurs as a series of synclines from Solan, Himachal Pradesh in the north-west to Nainital, Uttarakhand in the southeast. Biostratigraphic division of the belt have been encumbered by the lack of radiometric constraints and absence of reliable biostratigraphic markers. Various lithostratigraphic division of this belt reveals many palaeobiological entities namely cyanobacteria, algae, acritarchs trace fossils and sponge fossils. For the global correlation of Ediacaran deposits Large Acanthomorphic Acritarchs (LAA) are used as significant biostratigraphic tools. Recently, well-preserved acanthomorphic acritarchs identified as *Tianzhushania spinosa*, *T. polysiphonia* and *Papillomembrana compta* were discovered from chert nodules of Infrakrol Formation exposed in the Nainital Syncline of Kumaun Lesser Himalaya. A biostratigraphic correlation of the deposit of Doushantuo Formation in south China and the Krol Group suggests that the Infrakrol deposits are correlatable with the *Tianzhushania* dominated lower zone of Doushantuo Formation. LAA are reported from Ediacaran period globally, including south China, Australia, Eastern European Platform, Siberia, India and Svalbard. In spite of limitations caused by facies control, taphonomic bias and taxonomic problems, some of the well-documented and globally distributed large acanthomorphic acritarchs are proved as potential tool for biostratigraphic subdivision and global correlation of Ediacaran strata, currently available evidence suggests that acanthomorphic acritarchs are most useful in lower-middle Ediacaran stratigraphic correlation. Like Yangtze Gorges area, *Tianzhushania spinosa* bearing horizon in Infrakrol Formation occurs within a few meter above the cap carbonate and just below Krol 'A' Formation.

Tianzhushania and its type species *T. spinosa* are large acanthomorphs characterized by very thin cylindrical processes without vesicle sculptures (Yin and Li, 1978). Van Waveren et al. (1993) suggested that the spiny outer wall of *Tianzhushania* is comparable to that of planktic copepod eggs thus indicating a pelagic nature of the form, whereas these structures are also represented as animals resting eggs and embryos (Xiao and Knoll, 2000; Yin et al., 2004, 2007). The thin-section examination of chert samples of Infrakrol Formation reveal the dominance of *Tianzhushania* and support the notion that acanthomorphic acritarchs offer a strong tool for regional and global correlation of the Ediacaran period. The recovered biota is a significant addition to the record of earliest Ediacaran acanthomorphic acritarch from India.

Stratigraphic similarities and similar fossil record noted by previous workers (Jiang, 2014; Liu et al., 2013, 2014; Shukla & Tiwari, 2014; Tiwari & Knoll, 1994; Tiwari & Pant, 2004) suggests a paleogeographic connection between South China and India during the Neoproterozoic times. In the present study, the independent evidence of acanthomorphic acritarchs has been employed as a proxy for paleogeographic reconstructions. The report of *Tianzhushania spinosa* from Infrakrol Formation suggests that this fossiliferous horizon is coeval with the Lower Doushantuo Formation (Member II) of South China.

The genus *Papillomembrana compta* originated in the Cryogenian Interglacial epoch with FAD older than 635±18 Ma (Vidal and Moczydłowska, 1995) and *is* also present in Doushantuo Formation of China. Zircon U-Pb ages from interbedded ash beds in Doushantuo Formation have yielded age between 635.2±0.6 Ma and 551.1±0.7 Ma (Condon et al., 2005). The Infrakrol Formation is hence bracketed within the same age range. The similarity in the mode of preservation also indicates similar palaeoenvironmental conditions that was suitable for the origin and early diversification of the metazoans just after the snowball Earth period. The abundance of the form *Tianzhushania spinosa* indicates that either this species was more in population or is more resistant to degradation in comparison to other forms. The present record is very important to understand the phylogenetic diversity and evolution of early multicellular eukaryotes. The relationship of fossil record of Ediacaran and Cambrian period has to be studied simultaneously to understand the then prevailing favourable conditions that caused the Cambrian explosion of life. The recovered Ediacaran acritarchs have proved to be potential independent evidence for construction of both biozonation scheme and paleogeography.

TAT-4.2

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

(S.K. Parcha)

Stratigraphy of the Paleozoic succession of the Zanskar region

The Zanskar basin constitutes the southern part of the Ladakh Himalaya and geologically it represents the north-western extension of the Spiti basin. The Zanskar basin comprises a sequence ranging in age from Proterozoic to Mesozoic. It provides a rich repository of pre- and post-collision history which is preserved in the sedimentary sequences spanning in time period ranging in from Proterozoic to Eocene. The Higher Himalayan crystalline and all the sedimentary sequences are present in the Zanskar valley. The Tethyan sedimentary sequence were deposited in the passive continental margin. Zanskar basin has also preserved the Panjal traps, the first sedimentary sequence following Permian rifting is represented by shallow water arenaceous, argillaceous and bioclastic rocks belong to Kulung Formation under the progressively subsidizing passive Indian Margin. The present studies were concentrated in the Paleozoic succession of the Zanskar Basin the detail studies of the succession ranging from Cambrian to Permian was carried out. The Paleozoic succession here is litho-stratigraphically represented by Phe Formation, Karsha Formation, Kurgiakh Formation, Thaple Formation, Muth Formation and Lipak and Po Formation. The fauna was collected from the different sections the detailed studies of the same is under progress.

Geochemical studies of the Lower Cambrian succession of Kunzum La Formation

The Geochemical studies have been carried out in the sedimentary sequence of Lower Cambrian succession of Kunzum La Formation. The studies reflected that the siliciclastic sediments are mainly enriched in clay minerals and a positive correlations of Co and Zn with Al_2O_3 and K_2O is observed which indicates that Co and Zn are to be the adsorbed constituents of clay minerals. The positive correlation between Ce/Ce* and Eu/Eu* suggests effect of diagenesis process on the REE concentrations is high. The K_2O/Na_2O vs. SiO_2; SiO_2/Al_2O_3 vs. K_2O/Na_2O plots suggests the sediments of Lower Cambrian succession were deposited along active continental margin to passive continental margin, and were derived from quartzose sedimentary provenance and to some extent from the felsic igneous provenance. Chemical weathering evaluations (CIA and CIW) indicated moderate to strong weathering of source rock, and also reflects the change in climate towards warm and humid conditions. The results derived from the Ni/Co and U/Th plot suggest well oxygenated depositional environment and abundance of organic productivity throughout the succession. Parcha and Pandey (2011) also suggested dysaerobic to aerobic depositional environment of Lower Cambrian on the presence of trace fossil assemblage reported from siliciclastic rocks.

Faunal assemblages of the Cambrian succession from the Spiti Basin

The Spiti Basin exposes well preserved Cambrian successions in the Tethys Himalaya. The present study is focused on the trilobite assemblage reported from the Middle Cambrian succession. The Middle Cambrian is the most extensively fossiliferous succession in the Spiti Basin, particularly in the Parahio Valley. The trilobite in this succession ranges from informal Stage 5 of Cambrian Series 3 and goes up to the Guzhangian Stage of Series 3. The Middle Cambrian trilobite fauna of the Spiti Basin broadly correlates with that of Chinese fauna, particularly by the presence of *Pagetia*, *Kunmingaspis* and *Oryctocephalus*. Whereas, the same forms as well as other forms are also correlated with Australian, America and Kazakhstan for the presence of *Pagetia*, *Opsidiscus*, *Oryctocephalus* and *Ptychoparia*, and with Iran for the presence of *Hundwarella*. The *Oryctocephalus indicus* is one of the key international stratigraphic marker species. The FAD of *Oryctocephalus indicus* (Reed) at present is considered as one of the criteria proposed for defining the base of the (as-yet-unnamed) global Stage 5. The faunal studies reveals that the fauna recovered from the different sections at generic level, is likely of cosmopolitan nature, representing deep to shallow water environment suggests that during the Middle Cambrian the Spiti Basin was gradually shallowing. The trilobite faunal records reveal that, with an exception a few species a large part of Himalayan trilobite fauna shows affinity with that of China, Australia and Iran.

Microbially induced sedimentary structure and trace fossils

Microbially induced sedimentary structures were observed in fine grained sandstone in Spiti Basin along with trace fossils. The presence of microbial mat structures along with trace fossils help to understand the

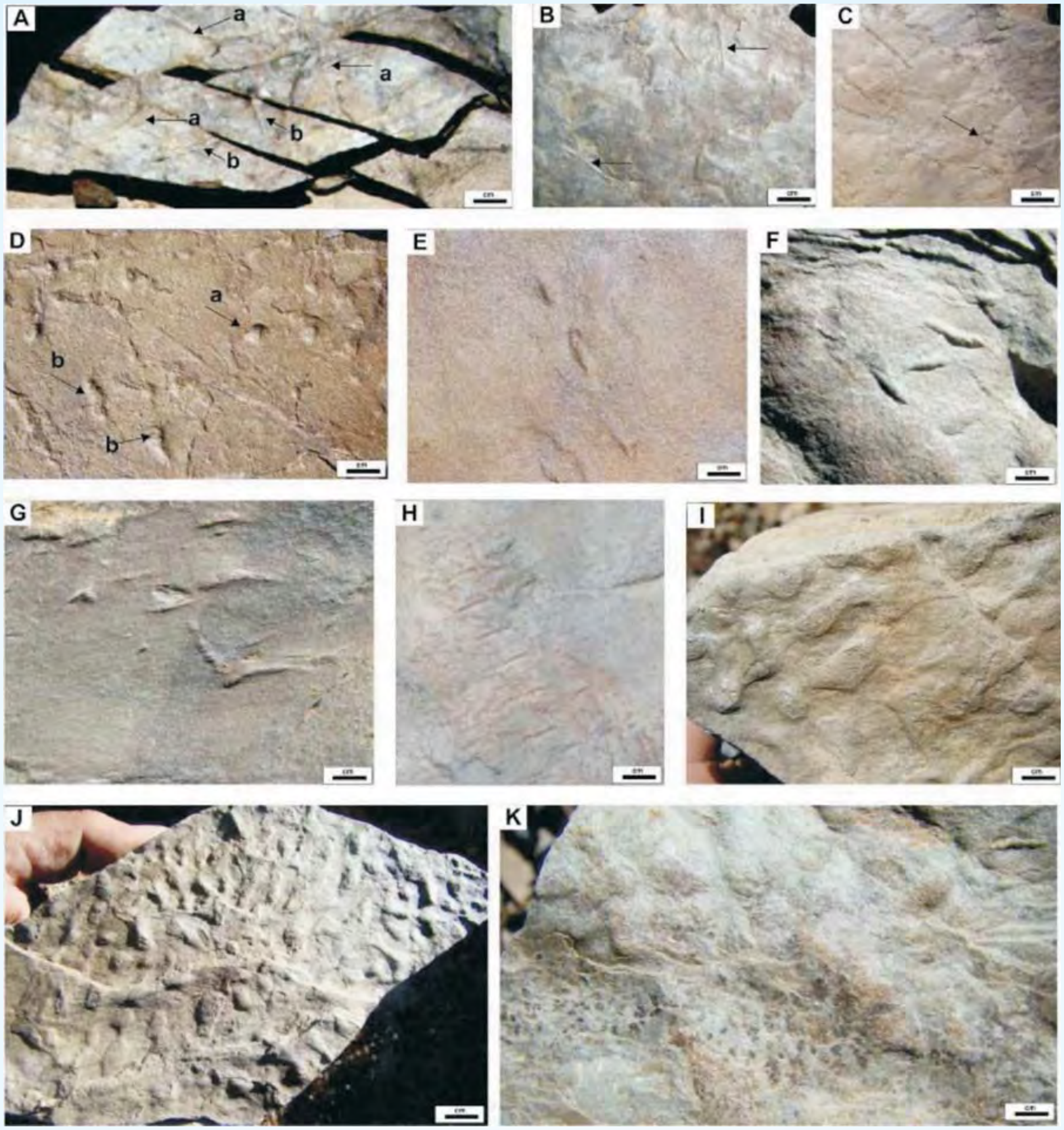

Fig. 26: Trace fossils from the early Cambrian succession of Chandratal section. A a, *Palaeophycus* isp. A b and B, *Planolites* isp. C and D a, *Skolithos* isp. D b, E and F, Burrow. G- H, Scratch marks. I- K, Microbially induced structure.

interaction between the biota and early life. The microbially induced sedimentary structures are mostly formed in shallow marine settings by interaction of microbial mats with the physical dynamics of sediments. They reflects that deposition has taken place within the photic zone. These structures exhibit a regular or irregular pattern, and have a distinctive morphology which represents changes in the depositional environment. Also, the presence of the microbially induced sedimentary structures in the basal part of the early Cambrian succession is ascribed to the absence of grazing organisms during that time.

On the other hand, 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. The early Cambrian benthic palaeo-community preserved in the Chandratal section (Fig. 26) shows the dominance of arthropods, annelid and polychaetes all are living principally within the sediments, indicating transition from an anaerobic to aerobic condition, and faunal change from endobenthic, soft-bodied, deposit feeders to epibenthic grazers. The trace fossils assemblages indicates that the Kunzum La

Formation was deposited in the deep to shallow shelf setting. Thus, the presence of Cruziana ichnofacies in the Chandratal section reflects low to high energy environment, whereas, microbially induced structures present in the fine grained sandstone reflects deposition of sediments has taken place under shallow marine conditions within the photic zone.

TAT-4.3

Paleogene and Neogene foraminiferal biostratigraphy, sedimentation and paleoclimate change of the Assam-Arakan Basin, northeast India

(Kapesa Lokho)

Rocks samples were collected from the Cretaceous to Miocene sedimentary rock succession of Nagaland and Manipur for the recovery of microfossils. Around 150 rock samples were processed for the recovery of microfossils, and picking of microfossils, SEM microphotography, identification and description of the recovered fossils were also carried out in the lab.

The study of Cretaceous and Tertiary microfossils, ichnofossils and fossil leaves with regard to their biostratigraphy, paleoenvironment and paleobiogeography from the Indo-Myanmar suture zone, Northeast India is continued. In the course of field work while in search for microfossils, ichnofossils and fossil leave impressions were encountered in the outcrops from the Barail Group of Naga Hills. The fossils recovered have been identified and described for the reconstruction of paleoenvironmental and paleogeographic setting. Recovery of Paleogene foraminifera from the Disang Group of Manipur, Indo-Myanmar Range is significant in view of the biostratigraphy and paleoenvironmental reconstruction. So far, detailed foraminiferal biostratigraphy data is poorly recorded and studied. Robust stratigraphic correlations are essential to decipher early history. Foraminifera have many characteristics ideal for biostratigraphy because of their distinct morphology, diversity, evolve rapidly, highly abundant, globally distributed and have high preservation potential. As such, they are extensively used for the biostratigraphy of marine sediments.

TAT-4.4

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

(K. Kumar)

The study of Eocene vertebrates from the Himalayan and Peninsular sections and their palaeogeographic implications was continued. Fossils that received focus during the year include those of rodents, creodonts and tapiroids among Mammalia, and snakes among Reptilia.

Two new early Eocene rodents, *Subathumys solanorius* gen. et sp. nov. and *Subathumys globulus* gen. et sp. nov., and three others (*Birbalomys* cf. *sondaari, Birbalomys* sp., cf. *Chapattimys* sp.) were recorded, based on upper cheek teeth, from the lower-middle part of the Subathu Formation of the type area in Himachal Pradesh, NW Sub-Himalaya. The teeth of new rodents exhibit morphological features most similar to the unified ctenodactyloid family Chapattimyidae (including Yuomyidae), which is also represented in the assemblage from the upper part (middle Eocene) of the Subathu Formation (Fig. 27). The associated lower cheek teeth are provisionally referred to three indeterminate chapattimyids. The new Subathu rodents are somewhat younger than the previously documented early Eocene assemblages from the Indian subcontinent, and are chronologically intermediate between the early Eocene ailuravines from western peninsular India and the middle Eocene chapattimyids from northwestern India and Pakistan. They suggest that chapattimyids originated in the Sub-Himalayan region during the Ypresian, which is earlier than previously believed. The absence of ailuravines in this as well as younger rodent assemblages from the subcontinent seems to suggest that ailuravines (Ischyromyidae), within a relatively short time after their appearance in the Peninsular India in the early Eocene, may have been replaced by the indigenous chapattimyids. The co-occurrence in the early Eocene Subathu assemblage of three or more chapattimyids indicates their early radiation and dominance during the early and middle Eocene. This record of rodents opens the possibility of recovery of other small mammal remains in older levels of the Subathu Formation, which will be important for understanding linkage with early Eocene faunas from Peninsular India, Europe and North America (*J. Earth System Sci.,* 2015).

New fossils of the early Eocene hyaenodontid *Indohyaenodon raoi* were described from the Cambay Shale Formation (western India), including the first known rostrum, upper dentition, and postcrania, substantially expanding our knowledge of the species and providing insights into its functional morphology and relationships (Figs. 28 and 29). Craniodental morphology suggests that *I. raoi* had a broad diet, including non-vertebrate material as well as flesh of a diversity of prey species. Postcranial morphology is broadly similar to that of other early hyaenodontids and

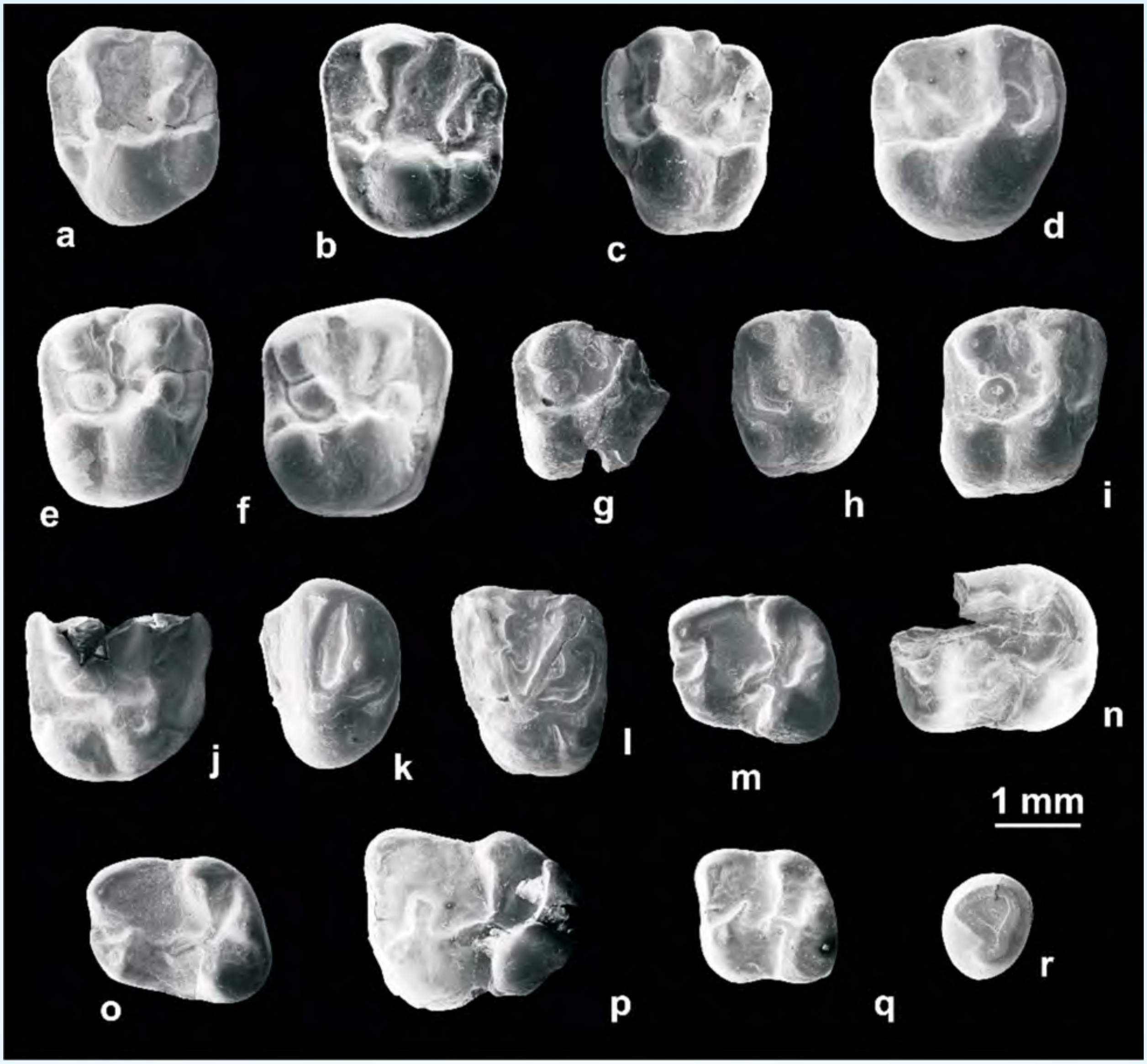

Fig. 27: Isolated cheek teeth of chapattimyid rodents from the early Eocene older Subathu red beds, lower-middle part of the Subathu Formation, Subathu, Himachal Pradesh. Scale bars represent 1 mm. a-c: *Subathumys solanorius* gen. et sp. nov. (a, c) compared with cf. *Petrokoslovia* sp. indet. 1 (b) from the younger Subathu red beds, a, left M1-2; b, left M2; c, right M1, reversed; d: *Subathumys globulus* gen. et sp. nov., right M2; e-f: *Birbalomys* cf. *sondaari* (e) compared with *Birbalomys sondaari* (f) from the younger Subathu red beds, e, right M1; f, left M1-2, reversed; g-j: *Birbalomys* sp. g, right P4; h, left M1-2, reversed; i, right M2; j, right M1-2; k, l: cf. *Chapattimys* sp. k, left P4; l, left M1; m-n: Chapattimyidae indet. 1 m, left m1; n, partly damaged right m3, reversed; o-p: Chapattimyidae indet. 2 o, left m1; p, left m3; q: Chapattimyidae indet. 3 left m2; r: Rodentia indet. P3.

suggests a scansorial locomotion. Dental morphology indicates that *I. raoi* is closely related to other South Asian hyaenodontids, with shared features including strong cingula, narrow premolars, and a reduced P4 protocone. The most comprehensive phylogenetic analysis of Hyaenodontidae to date was undertaken which corroborates this relationship, but finds South Asian hyaenodontids to be the stem of a group that includes most African hyaenodontids. This and other higher-level relationships within Hyaenodontidae are however weakly supported, and substantially different alternative hypotheses of relationships are not significantly less parsimonious, reflecting strong character conflict. Factors contributing to this conflict include the isolation of hyaenodontid faunas on different continents during much of the Eocene,

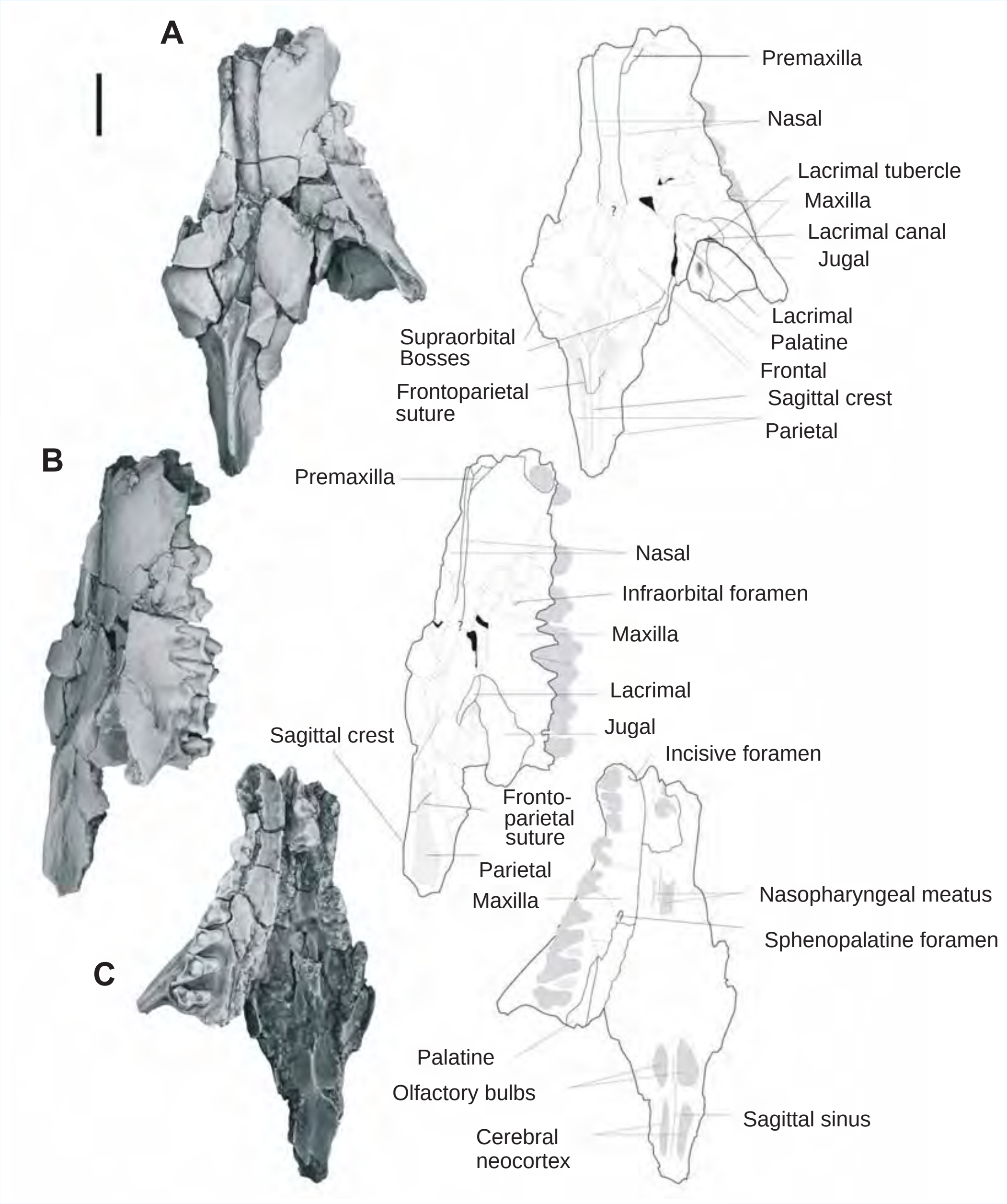

Fig. 28: Skull of *Indohyaenodon raoi*. Photographs (left) and interpretive drawings (right) of the partial skull with complete right P2-M3, C and P1 alveoli, and left P1 in A, dorsal, B, lateral, and C, ventral views. Scale bar equals 10 mm.

canalization and simplification of carnivorous dentitions, and a lack of non-dental material for critical hyaenodontid groups. The new phylogeny is consistent with either an African or an Asian origin for the group (*J. Vertebrate Paleontology,* 2015).

Fossils of the first early Eocene tapiromorph perissodactyls, recovered from the Cambay Shale Formation (c. 54.5 Ma) of western India, were allocated to a new genus and species, *Vastanolophus holbrooki*. They exhibit plesiomorphic characters typical of the paraphyletic "Isectolophidae," such as small size and weak lophodonty (Fig. 30). However, the weaker hypoconulid and paralophid, higher cusps, lower cristid obliqua, and the lingual opening of the talonid are found in Helaletidae, the most primitive tapiroid family. *V. holbrooki*, gen. et sp. nov., may be the oldest and the most primitive tapiroid suggesting that at least tapiroid perissodactyls originated on India. Recently Rose *et al.* (2014) proposed an Indian origin for the Perissodactyla

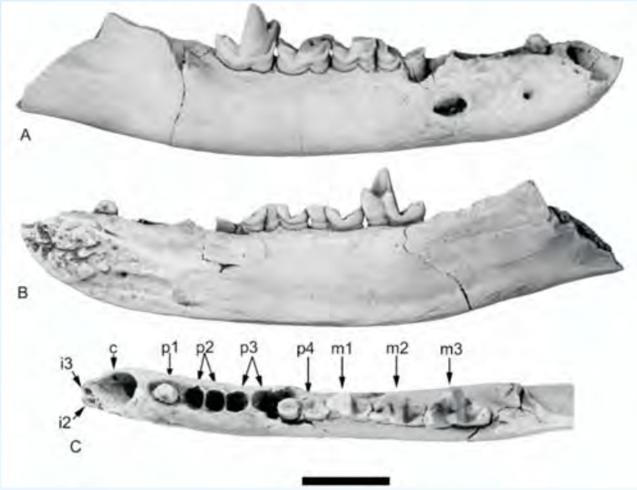

Fig. 29: Dentary and lower dentition of *Indohyaenodon raoi*. Right dentary with p4-m3, root of p1, and alveoli for i2, i3, c, and p2-3 in A, buccal, B, lingual, and C, occlusal views. Scale bar equals 10 mm.

based on the basal position of the cambaytheres from Vastan, reviving the out of India hypothesis originally proposed by Krause & Maas (1990). The helaletid *Vastanolophus* indicates the presence in India of definitive primitive Perissodactyla, and its age and plesiomorphic morphology suggests that Tapiroidea might have originated in India (*Palaeovertebrata,* 2015).

Several important fossil remains, including cambaytheres, primates, rodents and snakes were also collected during the field work carried out in the Paleocene-Eocene sections of western India.

TAT-4.5
Vertebrate faunal studies of the Neogene Siwalik Group (NW Himalaya) with reference to migration history and Himalayan uplift

(R.K. Sehgal)

The studies related to vertebrate faunal of the Neogene Siwalik Group (NW Himalaya) with reference to migration history and Himalayan uplift were continued. The mudstone samples collected during field-work from the Lower Siwalik of Udhampur region and Upper Siwaliks in the vicinity of Chandigarh were macerated for microvertebrate potential (nearly 400 kg). A few significant rodents and gastropods were recovered near Chandigarh from the Patiali Rao section of Pinjor Formation of the Upper Siwalik subgroup. These rodent fossils belong to murid family, while the generic and specific identity of the samples is yet to be finalised.

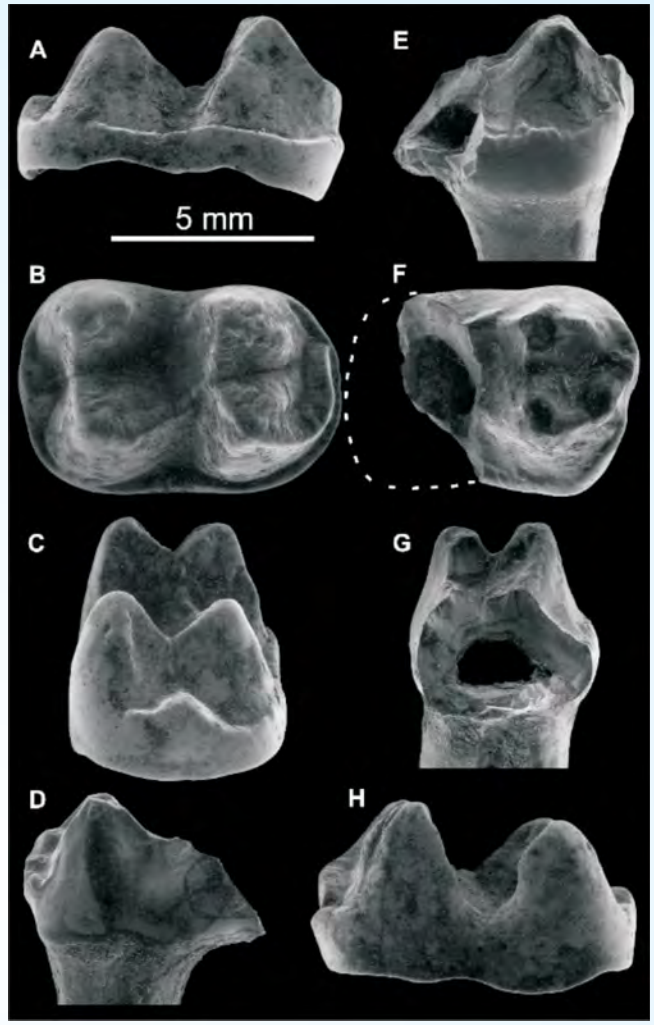

Fig. 30: *Vastanolophus holbrooki* nov. gen. et sp. from the early Eocene of Vastan mine, India. A-C, H: right m1 in labial (A), occlusal (B), distal (C), and lingual (H) views. D-G: right fragmentary p4, in labial (E), occlusal (F), distal (G), and lingual (D) views.

Short ranging fossil rodents were described from the Chinji Formation of the Lower Siwalik subgroup of Udhampur area (Quaternary International, 2012), and during the recent field-work, fresh samples were collected from the surrounding areas for micro-vertebrate prospective. On maceration it yielded a few dentitions of rodents belonging to Cricetidae and Murinae families. In addition to it, an isolated molar Sivapithecus *simonsi* (Primate) was also found. A detailed study of this material is under way. Also, from several localities of the Murree Formation, samples were processed for microvertebrate potential, but no significant fossils could be found.

Further detail studies related to the Cenozoic faunal migration and uplift of the Himalaya were carried out.

The Cenozoic successions in the Outer Himalaya are represented by the marine and continental Subathu Group (Paleocene-middle Eocene), the continental Dharamsala or Murree Group (Oligo-Miocene) and the fresh water Siwalik Group (Middle Miocene-Middle Pleistocene). The intermontane deposits of the Ladakh Himalaya, referred as Ladakh Molasse Group (Oligo-Miocene) has also yielded significant mammalian fauna. In addition, the Bugti Fauna belonging to the Chitarwata Formation (Oligo-Miocene), and the faunas from the Manchar Formation (Middle to Upper Miocene) are well known from Pakistan and these lie far away from the Himalaya, in the Sind Province. The stratigraphic correlation of the the Cenozoic successions of Indo-Pakistan region is given in table 2.

The Cenozoic mammalian dispersal patterns show that, in the initial stage of its development, the Himalaya was not an immediate barrier for faunal migration across its width. Several terrestrial genera occur on both the sides of the Himalaya during the span of Subathu Group, the Bugti Fauna (Oligo-Miocene), the Kargil Fauna (Oligo-Miocene), and the fauna of the Murree Group (Oligo-Miocene). For this study, the degree of similarity of mammalian genera were taken into consideration. It was during the deposition of the Siwalik Group that the Himalaya started acting as a formidable barrier for faunal migration across its width.

The mammalian assemblages of the Lower Siwalik Subgroup (18-10 Ma) show good faunal links with central Asian localities. At the time of Nagri Formation (10-8 Ma) the Himalaya gained a sufficient height to act as a barrier between India and central Asia and the faunal migration between the two landmasses almost ceased. With the uplift of the Himalaya, the monsoonal conditions started in the Indian subcontinent.

A collaborative palaeontologic and chronologic work was carried out on a fossilized elephant skull specimen collected from a cliff section of Dhasan river of Southern Ganga Plains (sample collection courtesy Dr. Pradeep Srivastava and his team). The dental morphology and cranial features of the skull were compared with the known species of *Elephas* from the Indian subcontinent. Although it shows very near resemblance to *Elephas namadicus,* but being an isolated specimen its specific identity cannot be proclaimed with certainty. As such, the specimen was provisionally referred as *E.* cf. *namadicus*. The Optically Stimulated Luminescence ages place this find at ~56 ka BP. This is the first chronologically well constrained report of *E.* cf. *namadicus* from the Ganga Plain.

Stable isotopic studies, carbon and oxygen combined with palaeontological studies were carried

Table 2: Stratigraphic correlation of significant continental Cenozoic succession of Indo-Pakistan region.

AGE		PAKISTAN			INDIA: Ladakh	INDIA: Foreland basin	
		Upper Siwalik Subgroup	Boulder Conglomerate Formation			Upper Siwalik Subgroup	Boulder Conglomerate Formation
Pleistocene			Pinjor Formation				Pinjor Formation
Pliocene			Tatrot Formation				Tatrot Formation
Miocene	Upper	Middle Siwalik Subgroup	Dhok Pathan Formation			Middle Siwalik Subgroup	Nurpur Local Fauna (=Dhok Pathan Fauna)
			Nagri Formation	Manchar Group			Haritalyangar Local Faunas (=Nagri and Dhok Pathan faunas)
	Middle	Lower Siwalik Subgroup	Chinji Formation			Lower Siwalik Subgroup	-Ramnagar Local Fauna (=Chinji Fauna)
			Kamlial Formation				
	Lower	Murree Group Bugti Fauna (Chitarwata Formation)			Kargil Formation (Ladakh Molasse Group)	Murree/Dharmsala Group =(Dagshai and Kasauli formations)	
Oligocene							
Eocene	Upper					Subathu Group having Kalakot Fauna	
	Middle	Kuldana Formation (Ganda Kas Fauna) Mami Khel Formation (Banda Daud Shah Fauna)					
	Lower						

out for the first time from a part of the fossiliferous Pinjor Formation exposed near village Nadah, Panchkula (Haryana). The analysis were done on pedogenic nodule (soil carbonate) and fossilized gastropod shells. $\delta^{13}C$ values from both pedogenic nodules and gastropod shells clearly indicate the dominance of C_4 vegetation in the area at that time, while $\delta^{18}O$ values, in general, suggest the persistence of warm and humid climate conditions.

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

TAT-5.1

Mass balance and snout fluctuation studies of Dokriani and Chorabari glaciers, Garhwal Himalaya

(D.P. Dobhal)

Under the ongoing long term glacier monitoring programme on the Himalayan Glaciers, the mass balance, snout retreat and meteorological observations of Dokriani and Chorabari glaciers were carried out for the period October, 2014 to October, 2015. The field data collected with the help of CFG Project staffwere computed, analysed and were summarized as follows:

Mass balance

For the mass balance of Dokriani Glacier ablation/accumulation stakes were placed in October 2014, and were monitored in the first week of June to estimate the net winter balances for the period 14th November, 2014 to 15th June, 2015. Snow/firn and ice densities measurement were done at several locations in the accumulation zone. These ablation stakes were measured at 15 days interval till the end of ablational season (i.e., till October, 2015), and monthly and total summer melting is calculated. The net winter accumulation measurement was made by probing of snow depth and snow pits at several locations in the accumulation zone. The data obtained from the stakes measurement was used in final calculation of net annual mass balance for the budget year 2014-2015 (Fig. 31). The results reveals that during the study period maximum melting (4.70 m w.e.) recorded between the altitude 3,900 and 4,000 m near the snout whereas, the minimum (0.01 m w.e.) melting was found at an elevation of 5,000-5,100 m near equilibrium line/snowline. Net annual balance for the year 2014-15 was calculated (-) 1.52 × 10^6 m^3 w.e. with specific balance of (-) 0.24 m w.e. The Equilibrium Line Altitude (ELA) demarcated at the height of 5,050 m a.s.l. and AAR calculated was 0.60 for mass balance budget year 2014-15

For the mass balance measurement of Chorabari Glacier 12 ablation stakes were installed along the center line of ablation zone in October 2014, and 24 stakes were placed with the help of steam drill machine in June 2015 to strengthen the stake network in the entire ablation area. The accumulation measurement were made by snow pits and probing of snow depth in the accumulation zone. Based on the ablation stakes and snow pits measurement net annual ablation and

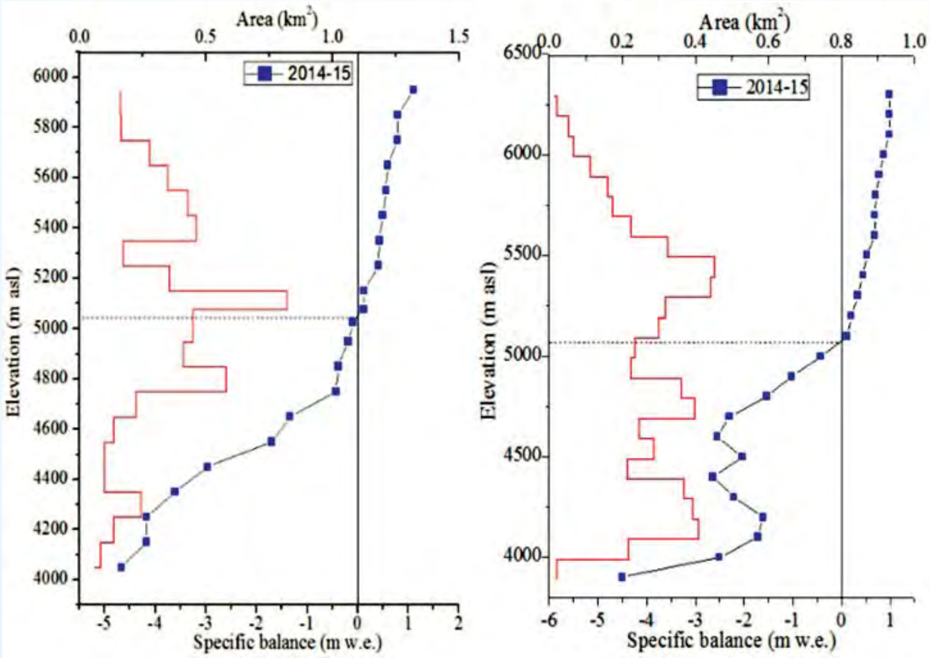

Fig. 31: Mass balance gradient (altitude versus specific mass balance) of Dokriani (left) and Chorabari (right) glaciers for the mass balance budget year 2014-2015.

Table 3: Summary of Mass balance and snout retreat of monitoring glaciers during the budget year, 2014-2015.

Glacier	Net Balance (10^6 m^3 w.e.)	Specific Mass Balance (m w.e.)	ELA (m asl)	AAR	Snout Retreat (m)	Snout Position (m asl)
Dokriani	-1.52	-0.24	5,050	0.60	17	3,955
Chorabari	-4.15	-0.63	5,030	0.45	-	-

accumulation is calculated (Fig. 31). The results shows a negative mass balance with specific balance amounting (-) 0.63 m w.e. The equilibrium line (ELA) was delineated at an elevation of 5,030 m and AAR calculated was 0.45 for the budget year 2014-15 (Table 3).

The study reveals that both the glaciers possessing negative mass balance trend but amount of net mass loss during the period is less compared to the previous years. It is also observed that overall melting recorded was comparatively less to the previous years owing to the higher winter accumulation that delayed the early expose of glacier surface. Moreover, summer monsoon was quite prominent that increases the accumulation in the higher altitude of glacier areas.

Snout Recession

The snout of Dokriani glacier was monitored by GPS with reference to permanent survey point made on both the sides of the glacier front. The total frontal retreat determined was 17 m for the year 2014-15 (from Oct 2014 to Oct 2015) which is comparatively less than previous years (21 m). The study reveals that the snout of Dokriani glacier is continuously retreating with varying rates. The progressive retreat of glacier snout indicates that it has undergone marked change in the shape and position due to the debris entrainments. The snout of the Dokriani glacier is deep and narrow bounded by huge and vertical lateral moraines. Because of the unconsolidated sediments and fragile nature, they are always susceptible to debris flows in the valley. The observed retreat rates varying annual could be attributed to the sudden debris flow from the lateral moraines, which badly damaged frontal area of the glacier or accumulate a huge amount of debris in and around the glacier termini, results enhance or retard the process of snout retreat. Such processes have also been reported in other glaciers of the Himalaya. The snout recession of Chorabari glacier have not been monitored owing to loss of stable reference points and also risky to approach after the lake outburst flood in the area.

Reconstruction of Equilibrium Line Altitude (ELA) and paleo-temperature reconstruction

The glacial ELA is the position of the glacier where mass accumulation is equal to mass loss. It is very sensitive to climate so that it could be used as a climate proxy to reconstruct the balance of glacier whether it was positive or negative. It measures directly the climate sensitivity in comparison to other glacial properties such as length, area, loss of volume and have less erroneous. An attempt is made to evaluate/ reconstruct the mass balance trend of Dokriani glacier using ELA and Accumulation Area Ratio (AAR). The study is based on assumption that accumulation area of the glacier is of fixed proportion and takes the mass balance gradient into account. The AAR is estimated with Terminus to Head Wall Ratio (THAR) method,

Table 4: Reconstruction of ELA using AAR, THAR and associated temperature decline.

Stage	Terminus (m asl)	Head (m asl)	distance from Snout (km)	AAR (0.56)	AAR (0.72)	THAR (0.4)	THAR (0.5)	THAR (0.6)	AVERAGE AAR	AVERAGE THAR	MEAN (m asl)	std	Δ ELA (m)	TEMP DEC-LINE (°C)
Stage I	2831	6400	8.3	4120	3760	4259	4616	4972	3940	4616	4278	478	210	0.96
Stage II	3200	6400	4.5	4370	3980	4480	4800	5120	4175	4800	4488	442	224	1.03
Stage III	3445	6400	1.7	4700	4300	4627	4923	5218	4500	4923	4711	299	150	0.69
Stage IV	3646	6400	1.6	4520	4880	4748	5023	5298	4700	5023	4862	228	124	0.57
Stage V	3733	6400	1.5	4790	5020	4800	5067	5333	4905	5067	4986	114	114	0.53
Present day	4000	6400	0	4920	5080	4960	5200	5440	5000	5200	5100	141	N/A	N/A

which assumes that the glacier can be approximated by some constant ratio between the altitude of terminus and head of glacier. The ELA and AAR were measured to each of the glacial stages, identified and mapped in the glacial regime. Further, the terminus position, head of the wall and distance from the present snout position were measured for individual stage and AAR was calculated by different methods. Reconstructed ELA with the apparent temperature reconstruction, derived through lapse rate of Dokriani glacier and associated loss in volume for each glacial stage is given in the table 4. The AAR of 0.56 and 0.72 has been applied for ELA reconstruction and THAR values of 0.5 and 0.6 has been used for error reduction, and the reconstructions has been checked for present day glacier. The studies of the reconstruction of mass balance trend of Dokriani Glacier and also ice mass lost from Stage I to present day are still being continued.

TAT-5.2
Assessment of potential hazards in the Glaciated regions: its causes and consequences

(Vikram Gupta, D.P. Dobhal and Swapnamita C. Vaideswaran)

The Gangotri catchment is highly glaciarised region as the winter snow-line descends down to about 2,200 m asl. Between 2,200 and 4,000 m the valley is composed of loose unconsolidated glacier material and is the source of several hazards like rock-fall, debris flow and flood, particularly during the summer period when the snow/ice melting is at its peak coupled with monsoon rains. Similarly, above 4,000 m asl (the present snout of the glacier) the area is highly snow covered with ~10-15 % permanent snow/ice cover and with number of glacial lakes developed in the valley. In order to assess the various hazards, inventory of avalanches and their path along with various mass movement activities have been prepared.

TAT-5.3
Hydrogeology of Himalayan springs

(S.K. Bartarya and S.K. Rai)

Geohydrological studies undertaken around Tehri Reservoir reveals that groundwater mainly occurs in disconnected bodies of aquifer and is available through secondary porosity and permeability of the rock formations. Three hydrogeological units may be recognized in the study area, (i) Fractured hard rocks, (ii) Fluvial and Colluvial deposits, and (iii) Karst Aquifer.

The fracture-joints and lineaments serve as easy conduits for infiltrating water and its further movement. The major recharge events for the aquifers in the region are the monsoon rains. For most of the springs, the discharge increases with the onset of the monsoon showers and declines in the post-monsoon season. In the study area, three types of springs are dominant**:**

- Fracture joint related springs
- Colluvial springs and seepages
- Contact springs

Twenty one springs were chosen for the detailed study. Old landslide deposits being porous and permeable hold good quantity of water proving to be a good localized aquifer. The hydrographs of the springs show a periodic rhythm with the rainfall pattern. The spring discharge is generally high in the monsoon months, thereby attaining a peak value. Few springs show a good discharge in the pre-monsoon months, in spite of very less rainfall indicating the high storage nature of the underlying formation. On comparing the average annual discharge of the springs, it is found that the fracture joint related springs yield more water (average 17 LPM) in comparison to the colluvial type of springs (average 10 LPM). The average discharge of the fracture joint related spring vary between 13.8 LPM to 20.51 LPM while the colluvial spring discharge vary with a minimum of 1.9 LPM to maximum of 18.6 LPM.

A groundwater prospecting map prepared show which four potential zones, (i) high, (ii) moderate, (iii) low, and (iv) very low zones. The high potential zone covers nearly 1.7% area in the Bhagirathi and Bhilangana valley. This zone is characterized by the presence of fluvial terraces which exists generally adjacent to the reservoir rim. The possibility of occurrence of groundwater in this zone is about 70-120 LPM. The moderate potential zone comprise of two geomorphic units which are alluvial fans and colluvial deposit covering an area of 0.3 and 3% of area respectively. The alluvial fans have the possibility of occurrence of groundwater of about 50-70 LPM while the expected discharge of colluvial deposits is about 20-50 LPM. The low potential zone is formed by the residual hills which covers the maximum portion in the study area (87%). The recharge conditions in this zone are low and the expected possibility of groundwater is about 5-20 LPM. The fourth prospect zone is the very low potential zone, and is characterized by the geomorphic unit denudational hills. It covers 8.0 % of the study area, and is distributed in small pockets over the entire study area. The water prospect of this zone is very low about 5-10 LPM, and therefore it is not suited for groundwater exploration.

For studying the hydrochemistry and assessing the water quality, water samples were collected from springs and reservoir. The spring-water of the study area is dominated by bicarbonate, the range of which varies between 14.6 to 372 mg/L. The chemical analysis results shows the abundance of the major cations Ca> Mg > Na > K and the abundance of anions in the order HCO_3>Cl>SO_4>NO_3>Br>PO_4. The relatively higher ionic concentration in ground water in comparison with the reservoir water samples indicates longer contact time of water with aquifer material. Weathering of the rocks in the study area is the main process responsible for the major sources of ions in the spring water. All the chemical parameter analyzed are well within the desirable limit of BIS (IS 0500:2012). The total Coliforms and E coli variation in the spring samples is <1 to 1011, and <1 to 206, respectively. The presence of Coliform bacteria in spring water shows infiltration of sewage water.

TAT-5.4

Glacier Surface Changes and Mass Fluctuation of Pensilungpa and Durung-Drung Glaciers, Ladakh, Western Himalaya, India

(Manish Mehta, Aparna Shukla, Vinit Kumar)

Two glaciers namely Pensilungpa (18 km^2) in Suru River basin and Durung-Drung (73 km^2) in Zanskar River basin, Ladakh, Western Himalaya, India have been selected for long term glaciological studies (Fig. 32). The preliminary study is based on satellite data, maps and ground base measurements which were used to obtain the snout retreat, area vacated and Equilibrium Line Altitude (ELA) changes of the glaciers. The study reveals that Durung-Drung and Pensilungpa glaciers retreated by ~707±75 m and ~336±36 m as with an average rate of 15±1.6 ma^{-1} and 7±0.6 ma^{-1} respectively. Between 1966 and 2014, Durung-Drung glacier lost ~16% (~14 km^2), while, Pensilungpa Glacier lost ~20% (~4 km^2) total glacier surface area. Total frontal area vacated during this period was calculated to be 0.036 km^2 for Durung-Drung Glacier and 0.14 km^2 for Pensilungpa Glacier. However, from 1977 to 1980, the right flank (EW) of Durung-Drung Glacier advanced ~155 m at the rate of 52 ma^{-1}, while the left flank (NS) of the glacier was retreat only 4 m. This rapid advancement of the glacier seems like a surging phenomenon. Similarly, in 1971 to 1977, the Pensilungpa Glacier retreated only by 8 m with an average rate of 1.4 ma^{-1}, showing the slow retreat or remained in a quasi-stagnant state. The estimated ELA rise between 1966 and 2014 was ~96±45 m for Durung-Drung Glacier and ~70±50 m for Pensilungpa Glacier. The study also shows that the glaciers in these valleys have smaller accumulation area and large ablation areas in comparison to other Himalayan glaciers. The present Area Accumulation Ratio (AAR) of the Durung-Drung and Pensilungpa glaciers are ~0.37 and ~0.31 respectively. The present finding shows that the ablation as well as accumulation area of the glaciers of the region has significantly reduced. This increased retreat rate of the glacier is probable a direct consequences of the global climate change. The present snout of the glacier located at altitude of 4,121 m and 4,674 m asl for Durung-Drung and Pensilungpa glaciers.

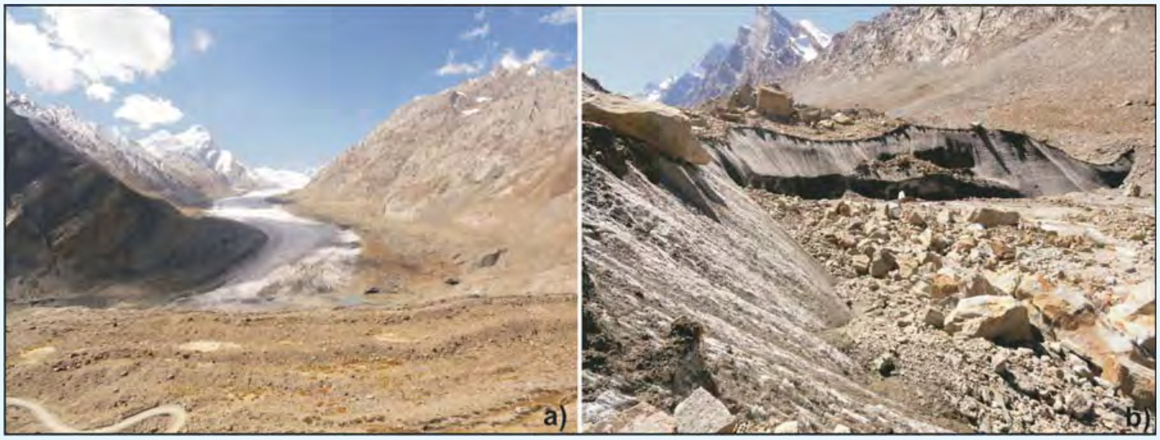

Fig. 32: Field photographs of Durung Drung and Pensilungpa glaciers. a) Panoramic view of the Durung Drung glacier. b) Ice wall at the snout of Pensilungpa glacier.

SPONSORED PROJECTS

MoES Sponsored Project

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

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

The central part of the Nepal Himalaya was hit by a devastating earthquake (M7.8) on 25th April, 2015 at 06:11:26.27 (UTC), located at 15 km depth from Earth's surface. It strongly hit Nepal and surrounding region causing destruction of building and causalities. The epicentre zone has also recorded many aftershocks, the strongest aftershocks of M7.3 occurred on May 12, 2015. Multi-Parametric Geophysical Observatory (MPGO), Ghuttu, Garhwal Himalaya is located at 636 km towards west from the epicentre of this earthquake. The observatory is equipped with simultaneously operated multiple geophysical equipments of radon, seismic, magnetic, gravity, GPS along with atmospheric observation.

Monitoring of radon, rainwater and underground water during Nepal Earthquake 2015

A careful scrutiny of radon data during April 2015 revealed prominent anomalous changes associated with this strong earthquake. The radon emanation is likely to vary in the crust during earthquake preparation and occurrence period based on well-accepted dilatancy-diffusion model of earthquake generation mechanism. Figure 33 shows temporal variation of soil radon, underground water radon, rainfall and water level during April 2015. On 16th April at 06:45 (UTC), that is 10 days before the occurrence of Nepal earthquake, the soil radon concentration (brown solid line) suddenly starts increasing with an increasing trend up to 28th April. Initially the increase is abrupt, however after 22nd April, there is a gradual enhancement during pre-, co- and post-seismic period till 28th April (unfortunately, on 28th April the radon probe malfunctioned and there is a gap of data until the instrument is repaired). In this period, the effect of rainfall and underground water level changes is negligible and therefore, the observed significant variations during a short span of time indicate that the variations are largely due to the occurrence of the earthquake with minor influence of meteorological parameter.

Underground water radon measured at 50 m depth (pink dots) using gamma probe shows prominent pre-seismic temporal changes similar to soil radon. The radon measurement in soil using alpha probe is also utilised which shows large variations for pre-, co- and post-seismic period (solid purple line). Hence, in all these data set precursory changes are imprinted followed by co- and post-seismic variation. Immediately after the occurrence of Nepal earthquake the radon concentration suddenly dropped and then high fluctuation is observed with a shift in base to lower

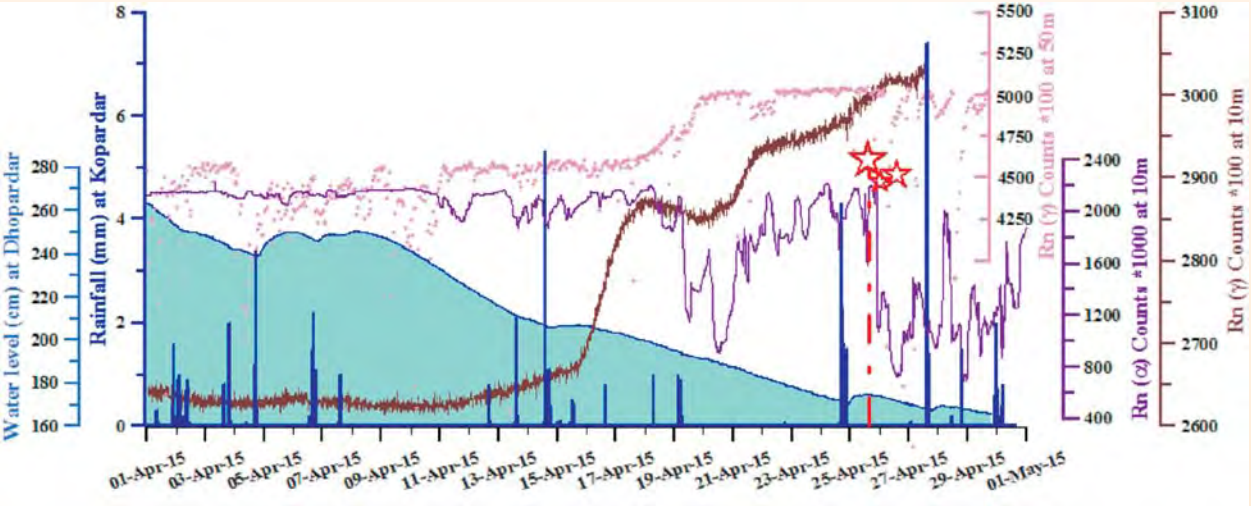

Fig. 33: Continuous records of different time series. The variation of the soil radon using gamma probe (brown solid line), alpha probe (solid purple line) and underground water radon through gamma probe (pink dots). Rainfall (blue bars) and water level records in 68 m deep borehole (blue solid line) are also shown.

level. These variations can also be hardly related with the rainfall, underground water level and other meteorological effects.

Monitoring magnetic field variations during Nepal Earthquake 2015

The three component magnetic field variations, recorded for the month of April 2015 are shown in figure 34. Diurnal changes in magnetic field variations are clearly observed. In the horizontal north component (X-component), there are intermittent high frequency variations from April 10-16, 2015. Due to the high frequency content of these variations, they may be linked with lightning activity. Also, at the same time, the sum Kp variation is quite high, signifying dominant contribution of solar ionospheric current system. Moreover, the main shock of Nepal earthquake is ~636 km away from the observatory.

The data is further analysed for fractal dimension and polarization ratio variability (Fig. 35) to see if any tectono-magnetic signature is observed or not for Nepal earthquake. In figure 35, bottom plot of red vertical bars represent daily sum Kp values from 1st January, 2015 to 30th April, 2015. Colour plots in top three panels represent Higuchi fractal dimension, averaged for a day from hourly values. As it can be clearly observed that the evolution of fractal dimension for two horizontal components is having a longer period, which can be well correlated with the increasing Kp values for this period. In figure 35, the black solid lines (scale given in left side) represent Z/x, Z/y and Z/H ratio from top to bottom. Z/H represents polarisation ratio of vertical to total horizontal component. Polarization ratio represents the presence of near field. Polarization ratio for entire three months remained below 1, indicating that there is no period in these months where vertical field have dominance over horizontal field, i.e., absence of near magnetic field variations is observed at Ghuttu. Thus, it is concluded that there is no precursory signature in magnetic field variations. The temporal evolutions of fractal dimension and polarization ratio (Fig. 36) for the April month also do not indicate any signature of tectono-magnetic field of precursory nature for the Nepal Earthquake of April 2015.

Measuring strong local earthquake events

During this reporting period total 11 strong motion earthquakes were recorded by accelerograph station under operation in MPGO, Ghuttu (Table 5, Fig. 37).

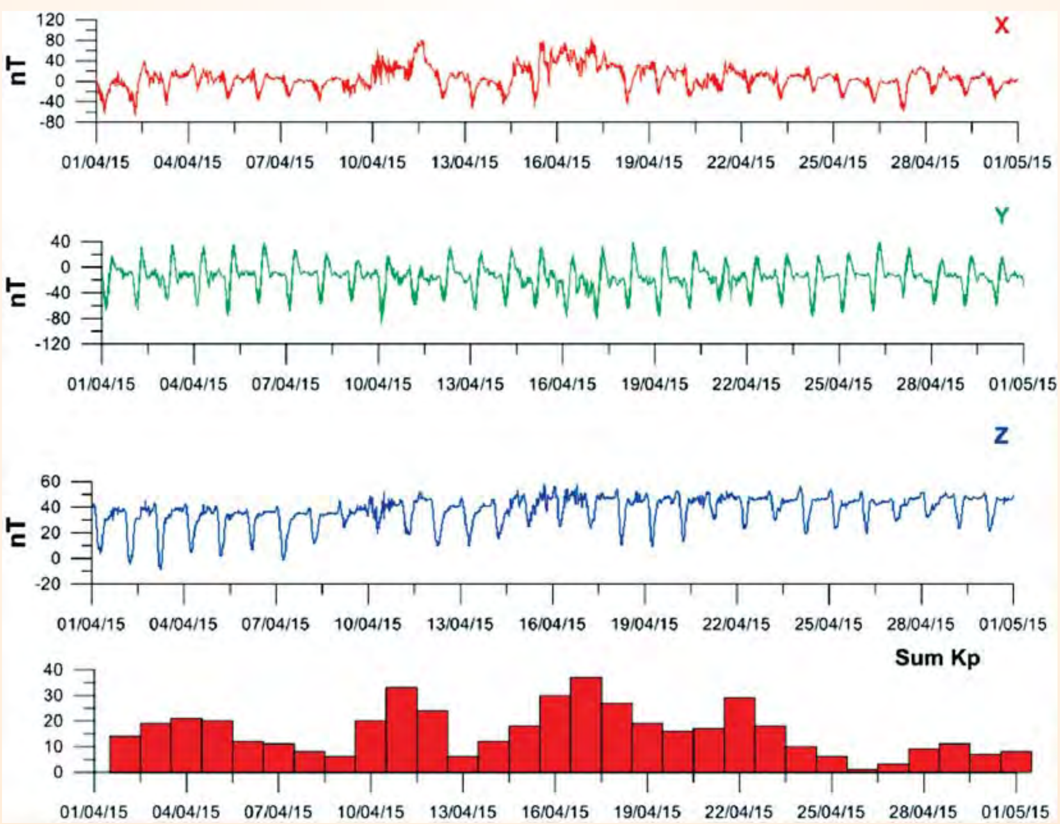

Fig. 34: Magnetic field variations as recorded in MPGO Ghuttu by fluxgate magnetometer.

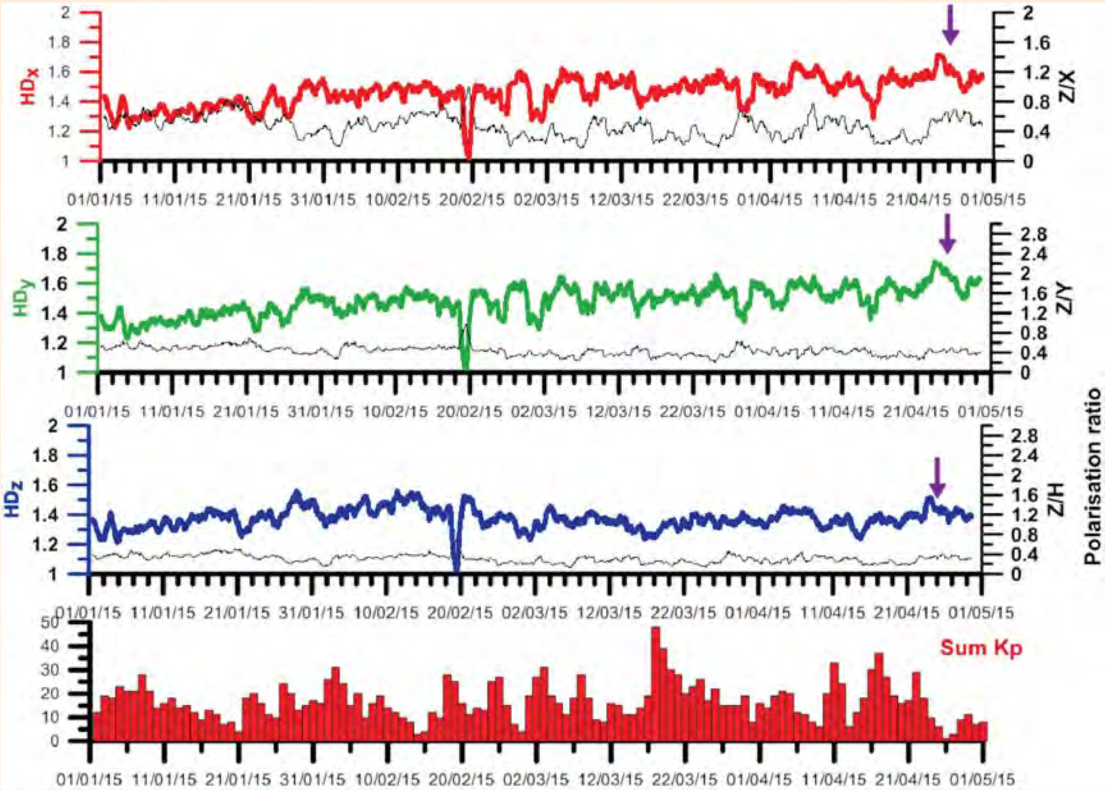

Fig. 35: Evolution of fractal dimension and polarisation ratio for a period from January 1, 2015 to April 30, 2015.

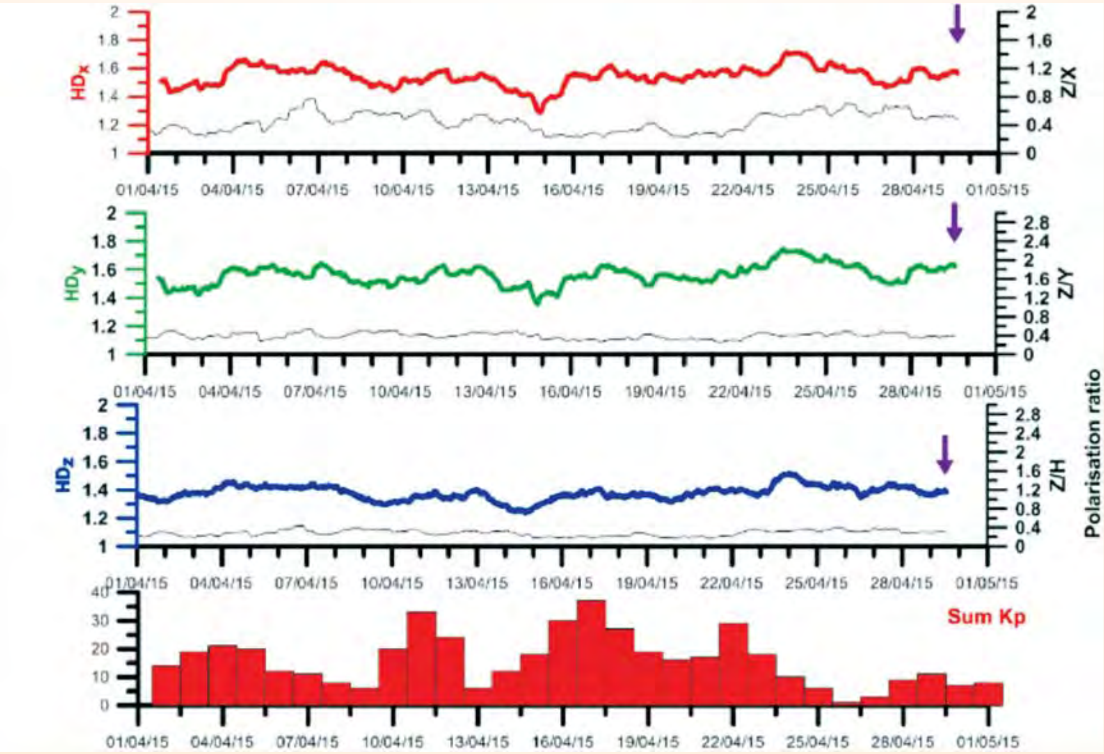

Fig. 36: Evolution of fractal dimension and polarisation ratio for the month of April, 2015.

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Table 5: Hypocentral parameters of earthquakes recorded by accelerograph station of MPGO Ghuttu along with epicentral distance and estimated PGA values.

DD/MM/YY	IME(UT)	TIME(IST)	LAT	LONG	Depth	Magnitude	Distance	PGA	Region
01-04-2015	21:23:54	02:53:54	30.2	79.4	10	5.1	73.184958	4.68	Chamoli
25-04-2015	06:11:25	11:41:25	28.1	84.6	10	7.9	629.00936	4.73	Nepal
26-04-2015	07:09:08	12:39:08	27.6	85.9	10	6.9	768.15628	2.58	Nepal
25-04-2015	06:45:20	12:15:20	28.1	84.8	10	6.6	646.56553	2.27	Nepal
23-05-2015	11:53:57	17:23:57	30.4	79.2	10	3.2	46.397143	0.78	Chamoli
18-07-2015	23:48:07	05:18:07	30.5	79.1	13	4.3	34.646794	6.6	Uttarakhand
29-09-2015	09:27:17	14:57:17	29.7	80.3	33	4.8	176.15792	2.34	Distt.Pithoragarh
24-10-2015	04:35:00	10:05:00	30.3	80	20	3.9	123.50071	0.31	Distt.Pithoragarh
29-11-2015	02:47:38	08:17:38	30.6	79.6	10	4	82.707313	2.13	Chamoli,Uttarakhand
29-12-2015	15:50:22	21:20:22	32.2	79.3	10	2.9	193.15646	0.59	Chamoli,Uttarakhand
04-02-2016	07:10:27	12:40:27	32.7	75.7	10	4.1	375.58234	0.8	HP-J&K Border Region

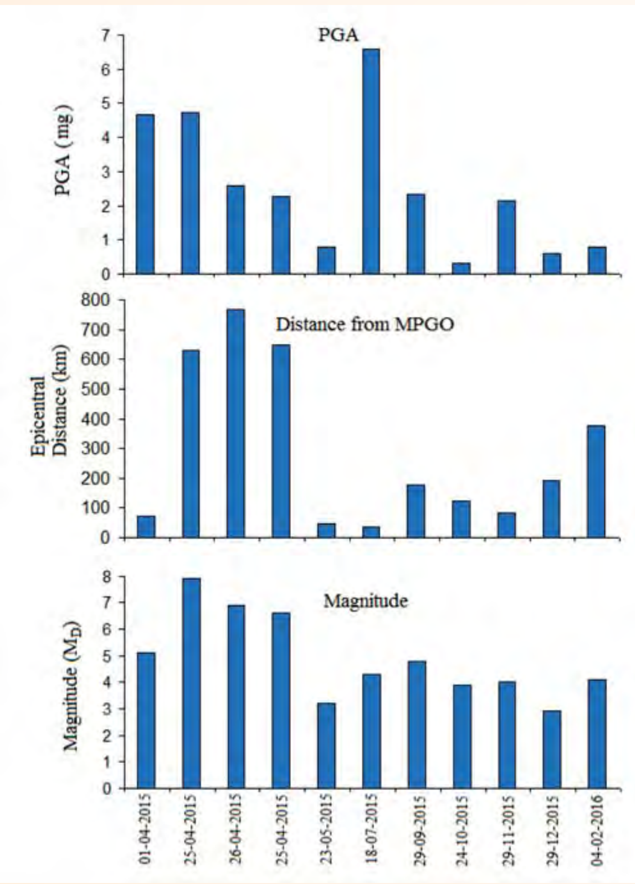

Fig. 37: Plot showing variation of estimated PGA values with epicentral distance and magnitude for 11 earthquakes. The date of occurrence of the earthquakes is shown at the bottom panel in X-axis.

Out of 11 earthquakes, 8 earthquakes are local earthquakes (epicentral distance mostly within ~200 km) of Uttrakhand and Himachal Pradesh and 3 earthquakes are the main 2015 Nepal earthquake (Mw 7.8) and its aftershocks. The Peak Ground Acceleration (PGA) values for all the earthquakes were estimated which ranges from 0.31 to 6.6 mg. The PGA values are plotted with magnitude and epicentral distances of the earthquakes to observe the variation of PGA values with magnitude and epicentral distance. Although PGA values increases with increase in magnitude of an earthquake, it largely depends on epicentral distance. During this period highest PGA value (~6.6 mg) was observed for an earthquake of magnitude 4.3. This was the nearest earthquake from MPGO Ghuttu with epicentral distance ~34 km. This PGA values obtained during this period will be input to ongoing catalog of PGA values which will be finally utilized for constructing PGA value map in and around MPGO Ghuttu.

GPS measurements for Crustal deformation

As the higher seismicity is being observed along the MCT, the MPGO has been established just south of MCT in the Higher Himalaya. We are operating GPS station (CORS) for continuous observations along with multi-geophysical instruments for the purpose of earthquake precursory and crustal deformation study. To investigate the behaviour of deformation pattern around the MPGO, we analyzed the five years data of GPS station Ghuttu through the latest version of GAMIT software in ITFR08 reference frame. The results are obtained in terms of variation of horizontal as well as vertical deformation with time and velocity field on 95% confidence level. During the processing of data of our local network, we also included the data of IGS GPS stations, LHAZ is one of them. In the study, we estimated the deformation of Ghuttu station

'GHUT' with IGS station 'LHAZ'. The comparative analysis indicates convergence between GHUT and LHAZ with the rate of convergence ~15 mm/yr and ~23 mm/yr respectively. In the effort, we have also examined anomalous changes in the time series of GHUT before, after and during the occurrence of local earthquakes for both cases when the earthquake lies within or out of strain radius, and tried to detect any relation of such changes with the occurred earthquake. For this purpose we considered seven local earthquakes with magnitude range of 4.5 to 5.7 that are selected on the basis of strain radius equation given by Dobrovolsky et al. (1979). In the analysis, we inferred the significant parameters that are responsible for the anomalous behaviour in the GPS time series.

MoES sponsored project

Seismicity monitoring and evaluation of active faults in Garhwal Himalaya and adjoining Shimla Hills region

(Ajay Paul)

Seismic Monitoring of Garhwal region

This project shoulders on the earlier MoES Sponsored Project *'VSAT linked seismic network for seismic hazard studies in Garhwal Himalaya'* wherein a seismic network of nine Broad Band Seismograph (BBS) were installed in June/July 2007. Each station is equipped with Trillium-240 (broadband) seismometer of high dynamic range (>138 dB) and Taurus Data Acquisition system (DAS). The data acquired from all the stations are analysed at the Central Recording Station (CRS) at Dehradun. The remote stations are located 5 in Uttarakhand, 3 in Himachal Pradesh and 1 in Uttar Pradesh (Fig. 38).

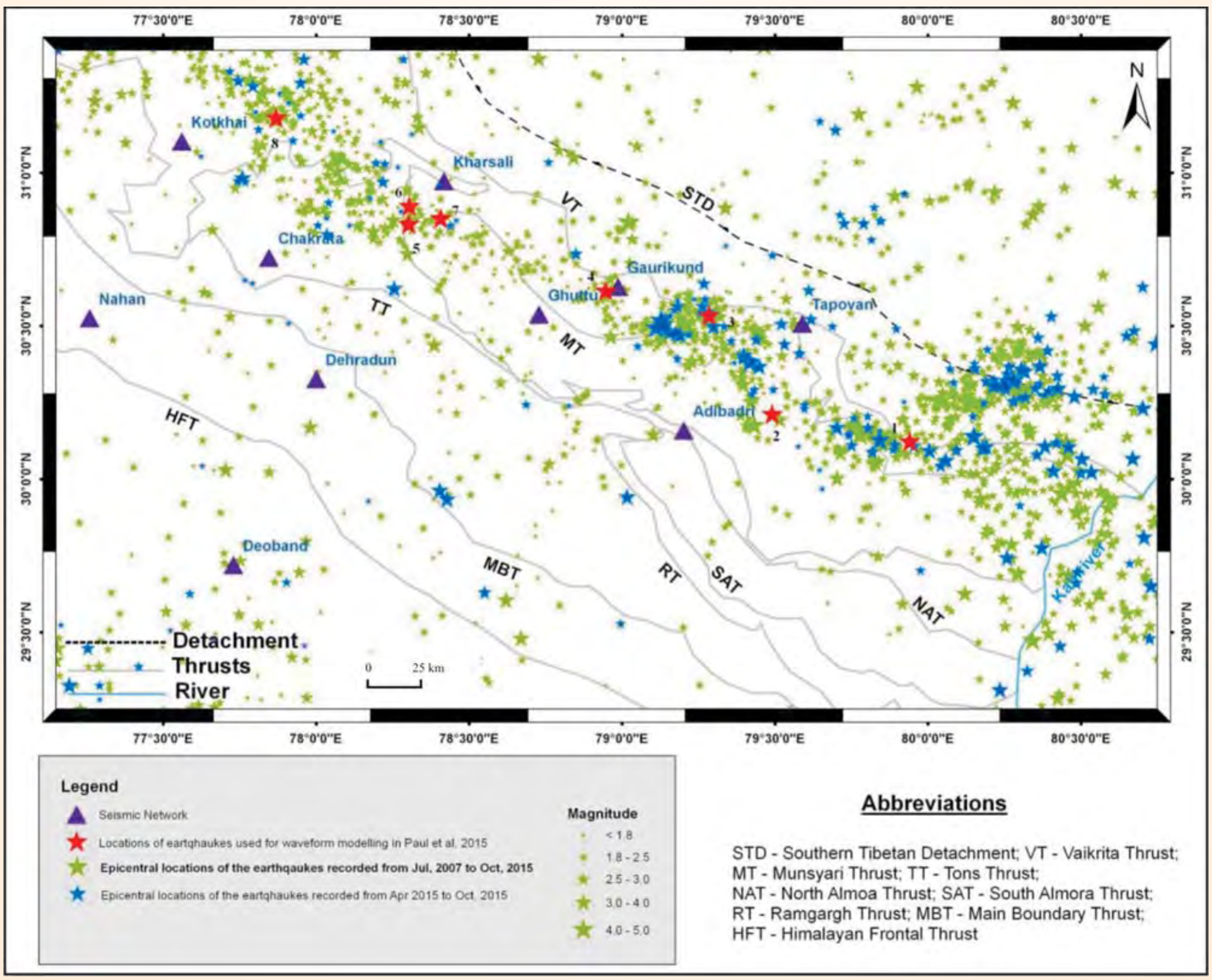

Fig. 38: Epicentral locations of the earthquakes plotted on the tectonic map of the region (modified after Valdiya 1980), recorded between July, 2007 to October, 2015 by the seismic network and the events used (no. 1-8) for waveform modelling in Paul et al., 2015 (listed in Table 6).

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The network has recorded a total of 33,251 events from the installation period i.e from July, 2007. This includes 5,297 local events, 15,698 regional events and 12,256 teleseismic events. 4,922 events have been detected for the period April 2015 to October, 2015, which includes local (560), regional (2,822) and teleseismic (1,540) events. The hypocentral parameters have been evaluated using Seisan software. The epicentre location map (Fig. 38) shows that the earthquakes are occurring in a narrow zone, south of MCT. The magnitude ranges between 1.8 to 5.1 and majority of events lie within 25 km depth.

The earthquakes of M >4.0 have been used to solve the Moment Tensors (MT) to achieve their moment magnitude, seismic moment and source fault mechanisms like strike, dip and rake using ISOLA (Isolated asperities) program. The results show that a majority of the earthquakes of M>4.0 have thrust mechanism. The results further suggest that the location of the cluster of earthquakes in this region coincides with the mid-crustal-ramp structure in the detachment with 10-20° dip angle which connects the seismically active detachment in the south and aseismically slipping detachment in the north. This result supports the seismically active mid-crustal-ramp beneath the region (Garhwal Himalaya).

The slip heterogeneities have been evaluated on the source faults for eight earthquake events (Table 6, Fig. 38) using geometric ray theory and green's function approach. It has been found that the earthquakes source have more than one asperities. The area contributing to slip is small compared to the total area of the fault surface.

Also, to understand the upper crustal anisotropy of Garhwal region, shear wave splitting (SWS) measurements has been carried for the events M_L>2.2 near Chamoli region in Garhwal Himalaya for the period November 2014 to July 2015. During the analysis of SWS measurements, a significant temporal variation in delay time (δt) has been observed at Ghuttu (GTU) seismic station with respect to the moderate earthquake of magnitude M_L4.9 which occurred in the Chamoli region on 1st April, 2015 at 21:23:55 hrs (UTC). The preliminary observations of variation in SWS measurements at GTU station show the increase in delay time before the occurrence of the earthquake and it decreases gradually with time. This method is helpful to monitor variations in the crack geometry and stress building up in the region before an impending moderate to large earthquake.

Nepal Earthquake

A massive earthquake of Mw7.8 occurred on 25th April 2015. The epicentre lies in Central Nepal (Fig. 39). The epicentre of the main shock occurred

Table 6: Details of source fault obtained from waveform modelling (Paul et al., 2015).

S. No.	Earthquake parameter	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8
1	Date 10/07/10	22/02/10	2006/11	06/04/13	22/07/07	09/02/12	27/11/12	28/05/10	
2	Origin time (UTC)	03:16:20	17.23.46	06:27:17	22:29:31	23:02:13	19:17:30	12:15:15	07:25:00
3	Latitude (°N)	30.213	30.123	30.535	30.615	30.833	30.892	30.852	31.18
4	Longitude (°E)	79.492	79.942	79.285	78.948	78.304	78.306	78.408	77.871
5	Depth (km)	4	10	7	15	9	15	15	6
6	RMS 0.3	0.37	0.43	0.22	0.15	0.26	0.35	0.2	
7	Magnitude	4.1	4.2	4.9	4.2	4.9	4.5	4.3	4.3
8	Fault type	Thrust	Normal	Strike	Thrust	Thrust	Normal	Thrust	Thrust
9	Strike 360	180	179	20	60	180	99	20	
10	Dip 60	50	62	40	50	20	40	20	
11	Rake 90	-90	-11	90	59	-90	90	90	
12	Slip angle	85	95	141	91	121	101	81	41
13	Average Slip (cm)	18	33	22	20	40	23	14	25
14	Maximum Slip (cm)	175	175	140	165	195	175	175	175
15	Station showed in figs (3&4)	Adibadri	Adibadri	Chakrata	Kotkhai	Chakrata	Chakrata	Kotkhai	Chakrata
16	Length of the fault (km)	13	13	11	13	13	13	13	13
17	Width of the fault (km)	6	11	5	7	9	12.5	9	9
18	T_{S-P} In observed (sec)	9 sec	10 sec	15 sec	18 sec	6.5 sec	8 sec	13.5 sec	8 sec
	T_{S-P} In synthesized (sec)	7.5 sec	12 sec	10 sec	17 sec	7 sec	7 sec	13.7 sec	8.3 sec
19	Rupture	1.70	1.50	1.70	1.00	1.70	1.60	1.72	1.55

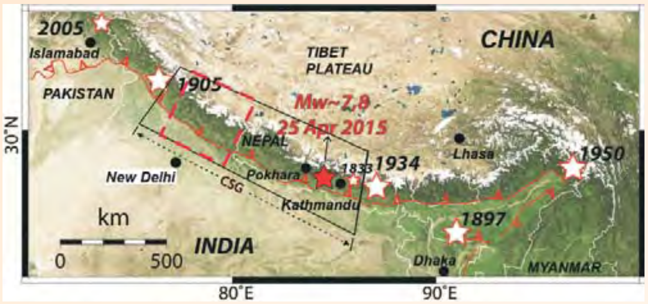

Fig. 39: Epicentral location of four great earthquakes i.e. 1897 Shillong, 1905 Kangra, 1934 Bihar-Nepal Border, 1950 Assam earthquake, along with Nepal earthquake and the area location of Central Seismic Gap (CSG) for great earthquake (between 1905 and 1934). The red dotted box shows the network area (map modified after Sapkota et al., 2013).

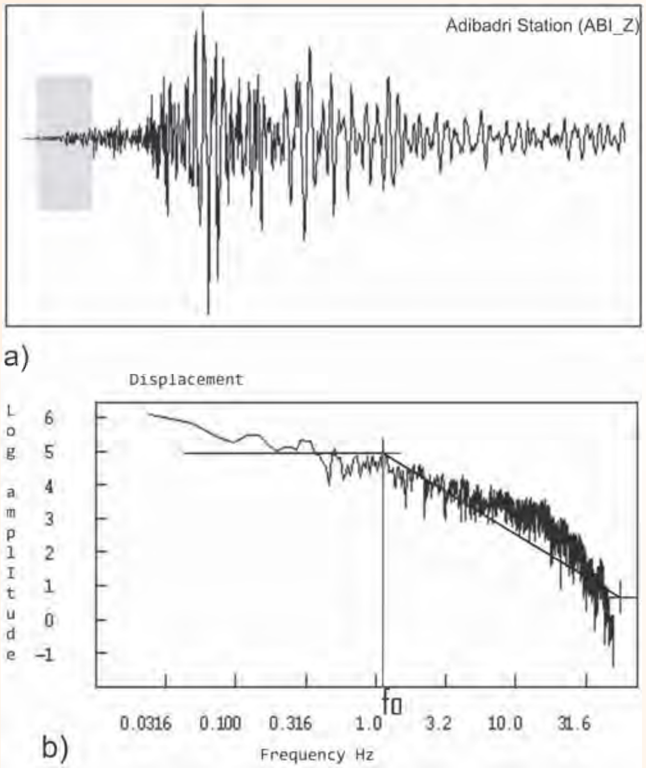

Fig. 40: The recorded waveform of vertical component and its spectrum for the 25th April 2015, Mw 7.8 Nepal earthquake recorded at seismic station Adibadri.

approximately 50 miles from the capital, Kathmandu near Lamjung region which caused tremors in northern India as well. The broadband network in Garhwal recorded the main shock (Fig. 40) and 45 aftershocks M>4.5 in next two days which includes two major aftershocks of M6.6 and M6.7. On May 12, 2015 another earthquake of magnitude M_w7.3 was also recorded which occurred to the eastern zone of the main shock with the same source mechanism as that of main shock. Source parameter studies and its implications have been undertaken.

WIHG - ISRO/IIRS Project

Geodynamics and seismicity investigations in the Northwest Himalaya

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

Monitoring of current seismicity in the gap areas

The work initiated with the compilation of a seismic catalogue of the northwest Himalayan region. Seismic activity of the NW Himalaya is extracted from the IMD website for all events of magnitude greater than 3.0. Altogether about 144 earthquakes are collected that occurred during 2006-2014 of magnitude ranging from 3.0 to 5.8 (epicentres shown in figure 41). To further improve the location of these events, the extraction of waveform data of corresponding earthquake has been initiated for the Garurganga (Chamoli district) seismic stations. The epicentres of these events are mainly concentrated around Main Central Thrust and most of the epicentres lies to the north of this tectonic line. These events are concentrated in the High Himalayan Seismic Belt where the density of past seismicity is high. Many events have high error and poorly constrained, mainly in

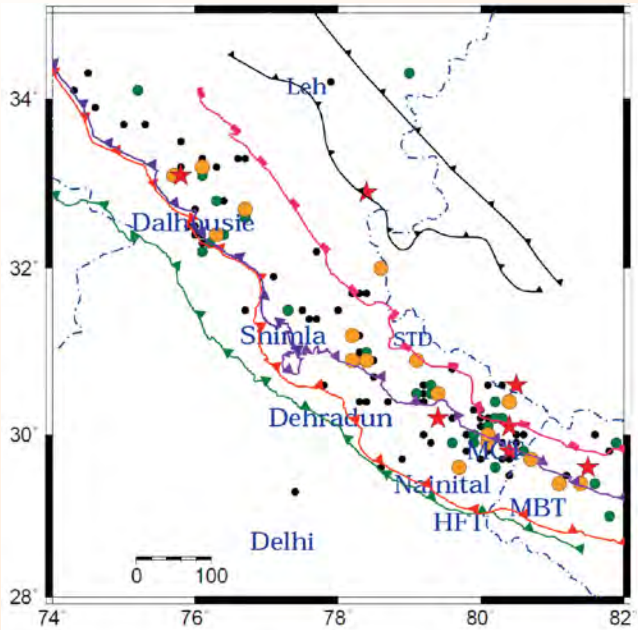

Fig. 41: Distribution of seismic events for the period 2006 to 2014 (M≥3.0). The black, green, orange dots represent magnitude range 3.0-4.0, 4.1-4.5, 4.6-5.0 and the red stars represent magnitude range 5.1-6.0.

Table 7. Earthquakes of M > 6.0 in Garhwal and Kumaun region.

	Date		Magnitude	Lat °N	Long °E
September	1,	1803	8.0	30.3	78.8
May	26,	1816	6.5	30.9	79.0
June	6,	1902	6.0	31.0	79.0
July	27,	1926	6.0	30.4	80.4
October	8,	1927	6.0	30.5	80.5
March	5,	1935	6.0	29.7	80.2
June	4,	1945	6.5	30.0	80.0
December	28,	1958	6.2	29.5	80.0
December	31,	1958	6.0	30.1	80.7
September	26,	1964	6.2	29.6	80.9
June	27,	1966	6.0	29.6	80.9
October	19,	1991	6.6	30.75	78.86
March	19,	1999	6.8	30.01	79.42

depth location. Almost all the events are located in the upper crust with maximum focal depth of 35 km. The IMD catalogue locate maximum events at 10 km depth which seems to be the default depth location and the inclusion of waveform data of WIHG stations network will improve the locations. The past seismicity (Table 7) in the northwest Himalayan region indicates that there were earthquakes of magnitude ≥6.0 at frequent intervals.

The region between two great earthquakes of 1905 Kangra earthquake and 1934 Bihar-Nepal earthquake, need to be monitored more precisely as it has been found that this region has sufficient stored potential energy to cause the occurrence of great earthquake. The recent M7.8 earthquake of April 25, 2015 has reduced a little bit part of this gap to the best of 1934 earthquake but even then still the so called seismic gap is large.

Based on the preliminary analysis, four new stations planned and proposed viz. Almora, Munsiari, Pong dam and Pangi, (Fig. 42) for getting good azimuthal coverage which are required for improving the location of seismicity of the NW Himalayan region. These locations were marked keeping in view of the existing network of WIHG in the NW Himalaya. For further enhancement the seismic monitoring capacity, preferably two new locations (at Jharipani and Pantnagar) are required and in addition another location Munsiari, if required, will be introduced in later stage. The new stations, Pong dam and Pangi in the Himachal Pradesh will be installed in the second phase (Fig. 42). The installation of these five stations will give a good azimuthal coverage along with existing network of WIHG.

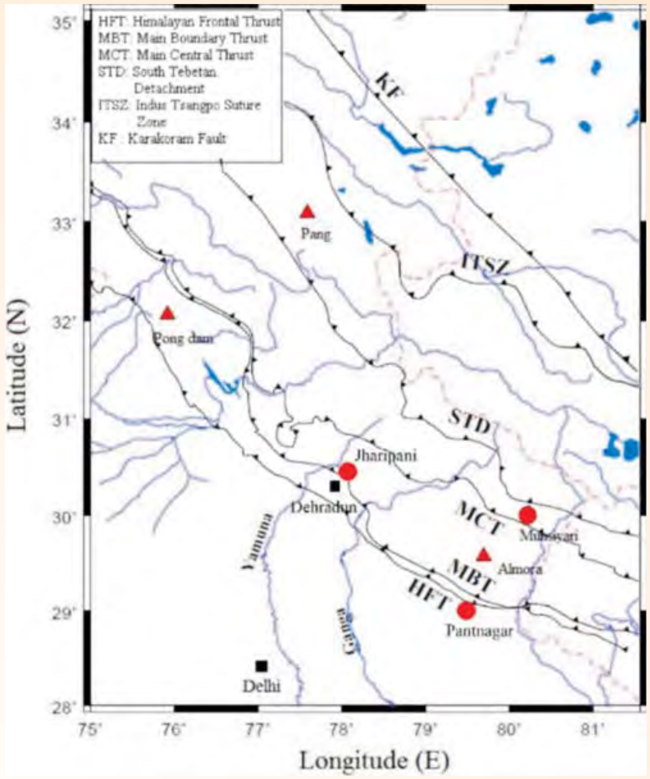

Fig. 42: Map showing the Location of Seismic stations to be installed in the First Phase (red circles) and in the Second Phase (triangles).

Deformation monitoring, strain modelling and earthquake precursor studies using TEC

Under this program one of the objectives was to establish a permanent GNSS data acquisition system for crustal deformation monitoring. A site on the way to Mussorie at a height of around 1,900 m in Oak Groove School at Jaripani has been selected with the intention to fill the existing gap at the north of the Main Boundary Thrust (MBT). Another site for the installation of permanent GNSS system has been established at Pantnagar University campus in Pantnagar, to understand the ongoing kinematics of Himalayan Frontal Thrust (HFT) at the east of Ganga Tear Fault. Analysis of existing GPS data acquired by WIHG has been carried out. This has helped to identify certain transects across the Plate Boundary Thrusts. One of the major observations was that, there exist an azimuthal variation in the GPS measured velocity vectors across the thrust systems ranging from the frontal HFT to the MCT. Thus in totality a good aerial coverage in data acquisition is required to understand the block wise rotation along the thrust systems. However, a network can be build up by taking multiple transects across the structures by considering the feasibility. As of now, one transect is proposed in the Garhwal region.

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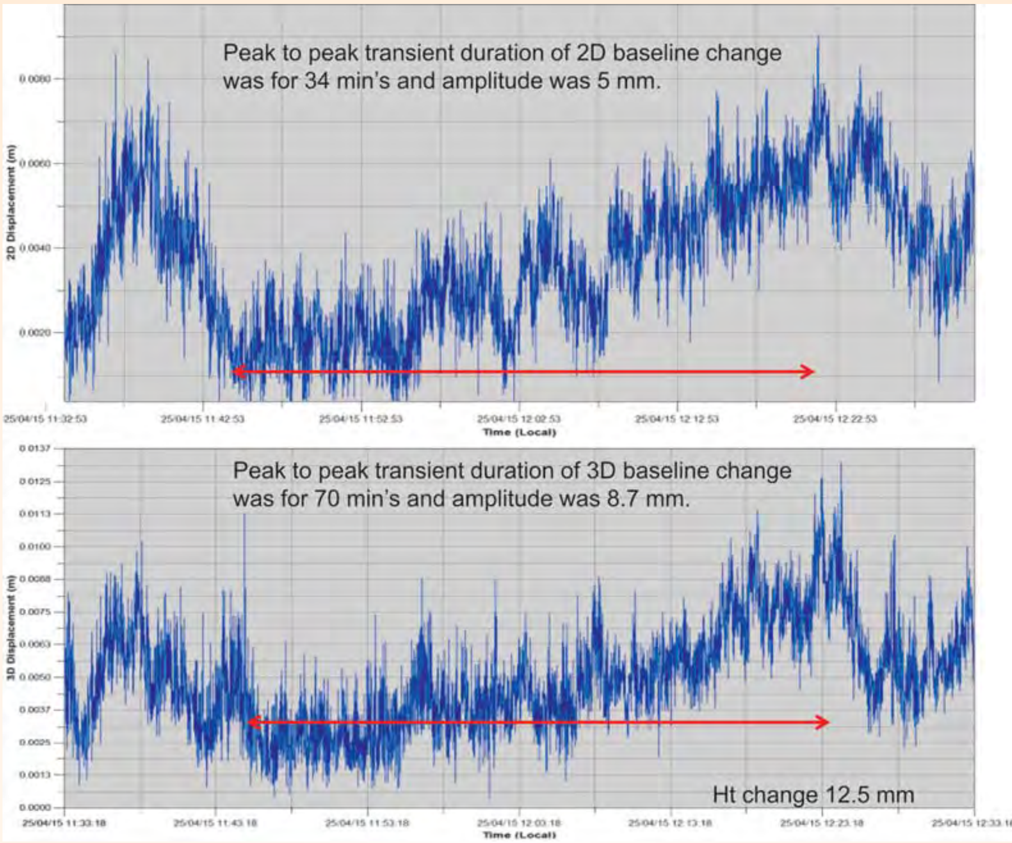

Fig. 43: Shows the 2D and 3D transient displacement anomalies observed in Dehradun followed by the 25th April 2015 M_w 7.8 Gorkha earthquake.

The 7.8 Magnitude Gorkha (Nepal) earthquake on 25th April 2015 gave us an opportunity to understand the GPS response to such Great earthquake at high sampling rate of 1 Hz. Our initial processing of data from WIHG, Dehradun station shows transient offsets in its position at all three components, rather than any static offsets. The 2D baseline change between an antenna pair during the time of Nepal Gorkha earthquake shows 5mm transient offset that last for a duration of around 34 minutes (Fig. 43). There were no static offset between the antenna pair as the station is almost 900 km away from the epicentre of Gorkha earthquake. Apart from distance the direction of fault rupture is also important to get any substantial static offset. The direction of rupture was towards SE at a length of around 160 km from the epicentral location in Lamjung District at Central Nepal. The transient 3D baseline length change of around 8.7 mm, which last for more than an hour (Fig. 43).

For the precursory research, one of the goals was to understand the TEC anomalies. We identified a few significant past earthquakes occurred in this region and observed that in general the diurnal signal variation is prominent rather than finding the near zero or very feeble TEC precursors. Based on a theoretical study it is understood that the response of ionospheric system to pre-, co- and past-seismic scenario could not be identified by using only the GPS 'L' band signals. Since, the 'L' band could sample only up to 30 TECU in the ionospheric layers, unlike the Ku or Ka band. In general altimetric missions use such bands and hence there is a need to explore such mission data in tandem with the GPS 'L' band signals to find the faint precursory signals.

Active fault mapping using high resolution EO data and geophysical investigation

The major objective of this component is to map active faults and paleoearthquake ruptures of NW Himalaya between HFT and MCT within the geographical limits of Uttarakhand and Himachal Pradesh. This is essentially to understand the implication of earthquake precursors and seismic hazard assessment in the study area. The seismic hazard evaluation in the tectonically active Himalaya is very crucial because earthquakes pose a continual threat to the safety of the people inhabiting in this gigantic mountain system of

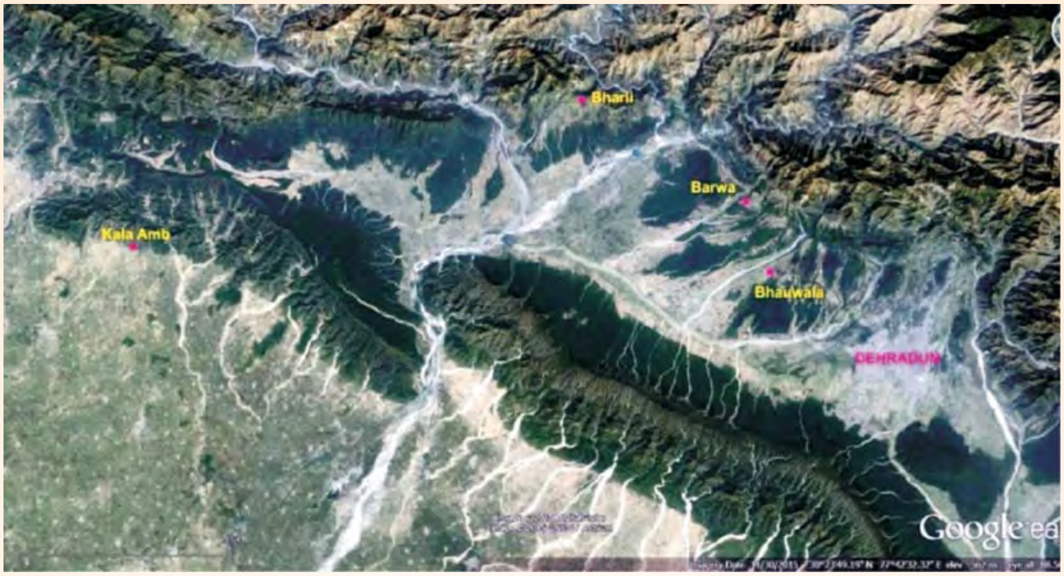

Fig. 44: Google Earth Imagery of the NW Doon Valley showing locations of active faults and geophysical survey.

Himalaya. It is now widely accepted that more than 80% of the earthquakes are due to the active faults. Keeping this in view, in the present study we have selected Doon Valley to map some of the fault systems identified by the previous workers.

Ground Penetrating Radar (GPR) surveys have been used to understand the existence of Bhauwala Fault, which is an E-W normal fault in the central part of the main Doon valley. Field evidences are very clear in delineating the degraded scarp. Attempts have also been made to extend these fault systems further into the main Doon fan. However, because of the intense modification for agricultural practice has limited the scope of interpolation of the faults on either side. The antennas of 50 and 100 Megahertz has shown subsurface features however, found to be less useful in discretely delineating the expression of Bhauwala.

Parallel to the Bhauwala fault, another fault system at Barwa has been identified in the satellite images (Fig. 44). No detailed study on the existence of this fault system has so far been carried out. Hence, GPR was employed to verify the existence of such a fault system in the NW Doon Valley. The survey shows that there exists subsurface displacement of the lithounits, which indicates the existence of fault. We plan to carry out complementary geophysical methods such as electrical resistivity besides identification of suitable trench locations and excavations for confirming its attitude and existence.

Bharli fault system is another active fault with predominantly strike slip component, which cut across the NW-SE trending MBT. Hence, this younger fault system has displaced the pre-Tertiary lithounits at Bharli manifested with prominent (pre-Tertiary) shutter ridge and sag ponds. The fault system is considered to be displacing the Chandpur Phyllite and the present location of the fault is prrsently covered with thick volume of slided material, which belongs to the southerly slopes of the pre-Tertiary. Although the field requirements for the GPR is not satisfactory, we have carried out a preliminary survey to establish the fault system.

Electrical resistivity survey has also been carried out to understand the subsurface lithological distribution. The different array of electrodes pole-dipole, dipole-dipole, Schlumberger and Wenner arrangements of electrodes have been laid in the field. Lithological units based on their electrical resistivity could be delineated. However, there was no clear manifestation of fault that could be delineated of the Bhauwala Fault Profile. The study is in progress and in the coming years it is planned to make an inventory of the active fault systems using geological and geophysical techniques, which will be also supplemented with wherever trench excavation survey are feasible.

MoES 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)

To understand the paleoearthquake history and recurrence interval of Himalayan earthquake and to quantify the long-term uplift rate two months of field

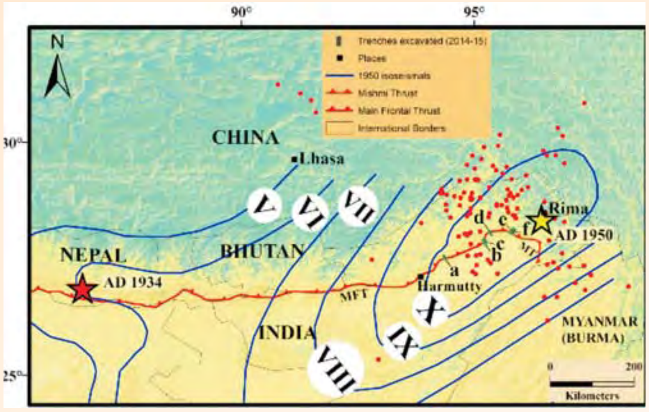

Fig. 45: Isoseismal map of the A.D. 1950 Assam earthquake showing the aftershocks (red dots) along with trench location green-black solid lines with alphabets 'a' through 'f' (a, Hemibasti; b-c, Niglok T1 and T2; d, Pasighat; e-f, Roing park trench) excavated in the preset project during the first year. *Note:* Locations of our entire trench lie in the maximum damaged zone of the A.D. 1950 Assam earthquake. MFT, Main Frontal Thrust or HFT, Himalayan Frontal Thrust.

work was carried out. Four photo-mosaic logs from Pasighat, Niglok and Hemi Basti trenches in Arunachal Himalaya were constructed (Fig. 45). About 48 charcoal samples were dated from these trenches. The radiocarbon age along with displaced stratigraphic units suggests the occurrences of great earthquakes in 17th and 20th Century. However, the latter events result is getting constrained robustly by using ^{137}Cs fallout isotopes, LOI, grain size analysis, and the work of which are in progress.

MoES Project

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

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

Published maps for area of study and adjoining areas were compiled in the digital format. Using different imageries (30 DEM cartosat imagery, etc) we mapped disjointed terraces/fan/surfaces and active fault scarp along the active faults in the Ravi and Chakki Valleys, and their way points are noted. Field work was performed in the months of May and June 2015, wherein structural data and litholgical boundary were systematically mapped. Wherever terraces were found, they were mapped using high resolution survey instruments to know whether the geomorphic surfaces were mimicking with respect to underlying dipping bed rocks. OSL samples were collected along Ravi and Chakki Khad river valley sections by making pit on the top of the disjointed or abandoned terrace surfaces. Further, to understand the rock strain or bulk strain of associated with SMA, oriented block samples were collected for magnetic fabric studies to infer the kinematic history of the anticline, and thus the evolution of folds. The AMS (magnetic fabric) samples were collected from the forelimb, hinge and the backlimb of the anticline. Also, since no escarpments were found in the frontal region of the anticline in the satellite data, the area was closely examined in the field in pursuit of escarpments in the region. Our preliminary field study in the east of Beas River reveals that the MFT is not emergent unlike other segment along HFT (or MFT).

Project

Geodynamic evolution of the Indian Plate through high resolution Geoid/Gravity from SARAL/ ALTIKA altimeter

(S. Rajesh, T. J. Majumdar, SAC/ISRO)

The project has been completed and the project completion report was submitted to the Project Director, Head, ASD/AOSG/EPSA/SAC. The high resolution data has been obtained after processing the IGDR. However, across track resolution was less and need to be integrated with other follow-on mission like JASON-3. In future new project will be submitted to merge SARAL with more cycle GDR data along with other foreign missions, such that the inter track density would be augmented for the high resolution geodynamic studies for fracture zone mapping etc., Processing with high sampling rate data would also be taken up in the new project. To this wave form data processing methodology will be considered.

Indo-Norwegian Collaborative Project

Earthquake Hazard and Risk Reduction on the Indian Subcontinent (RRISC)-Towards an earthquake-safer environment

(Vikram Gupta)

This is a joint collaborative project involving institutions like NORSAR, Norway and NGI Norway, Geological Survey of Bhutan, Bhutan, Indian Institute of Technology, Roorkee, C-MMACS, Bangalore, Assam Engineering College, Guwahati and Wadia Institute of Himalayan Geology, Dehra Dun. Under the ambit of this project, the Wadia Institute of Himalayan Geology had planned to study earthquake risk and loss assessment in the hilly areas, particularly in Mussoorie and Nainital townships (Uttarakhand), along with seismic hazard

Fig. 46: a and b showing the slope wash material transported downslope through the narrow passage between the Everest hotel and India hotel get deposited on the Mall road.

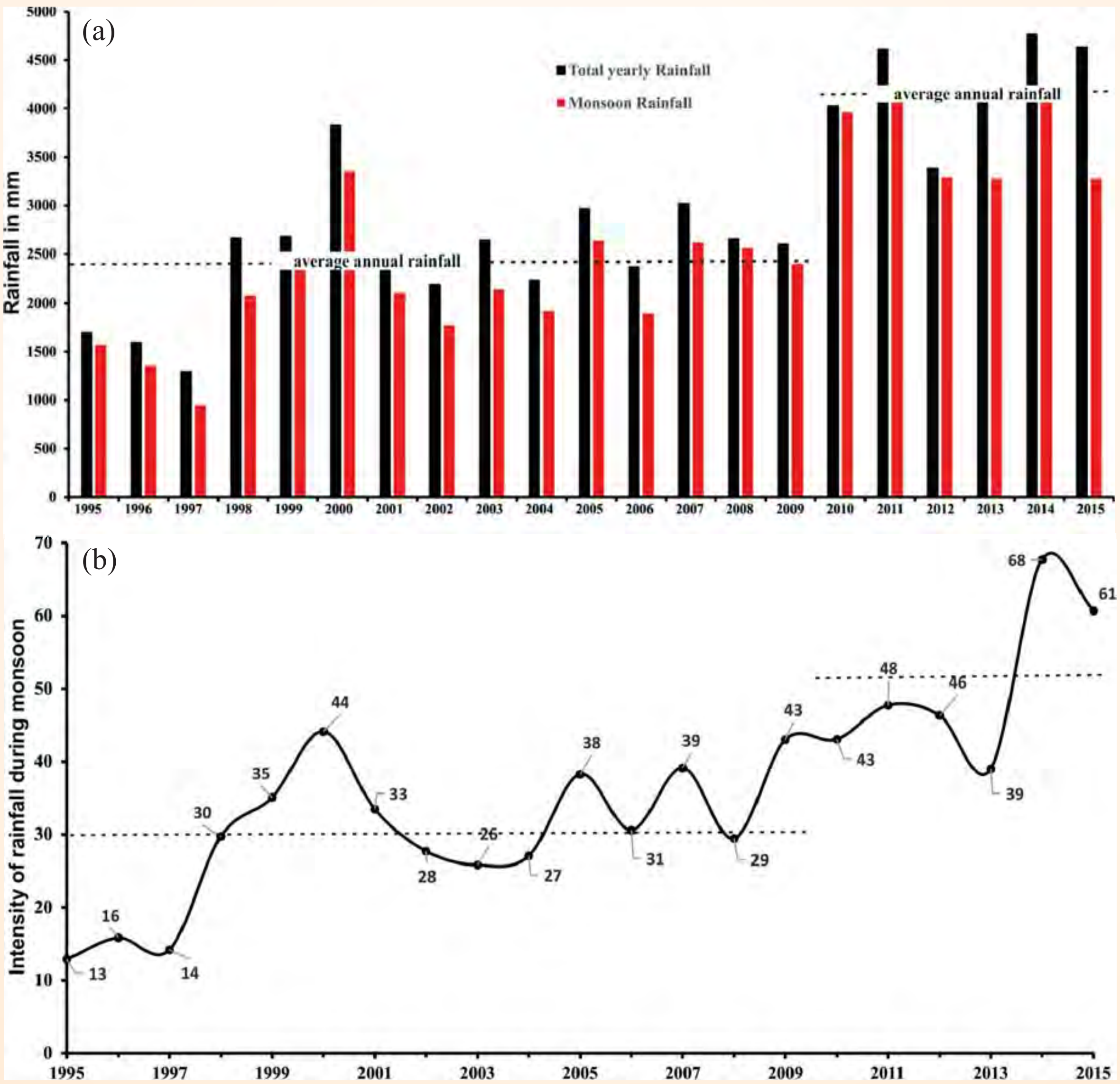

Fig. 47: (a) Total annual rainfall and the total rainfall during monsoon season (June-September) of the Nainital town during 1995-2015 (b) intensity (total rainfall/number of rainy days) of rainfall during 1995-2015 for the monsoon period.

potential between Kangra and Chamba (Himachal Pradesh).

During the year, active landslides that had occurred during 2015 on the Sher-ka-Danda hill in the Nainital township had been studied, besides the preparation of the landslide susceptibility map of the Mussoorie township. The studied landslide is a debris flow that had occurred on the southwest facing slope of the Sher-ka-Danda hill on July 5, 2015 between 3 and 7 PM after the incessant rainfall. The slide had damaged the narrow link road connecting Birla Vidya Mandir School with the town mall road. The rainfall has mobilised the debris cover on the bedrock generating huge volume of debris, exposing the bedrock. The slope wash material was transported downslope towards the lake. Since there is no proper drainage to drain off the water from the hill, and the lower part of the slope is occupied with commercial activities, the debris material finds its way through a narrow passage of about 2 m wide, between two buildings namely, Everest Hotel and India Hotel and accumulated on the Mall road (Fig. 46a-b). It has been estimated that about 1,500 m^3 debris has been deposited on the road and part has been transported into the lake. Rainfall data indicate that, the year 2015 had recorded the second highest annual rainfall (4,641 mm) during 1995-2015, of which about 71% had fallen during the monsoon season (Fig. 47). Though, on the day of occurrence of landslide, meagre 5 mm of rainfall had been recorded, but preceding the day, 416 mm rain had fallen during July 1-4, of which just 300 mm fell on July 01, 2015. Thus all the slopes were saturated.

It has been observed that the rainfall pattern in the township has noted appreciable change, particularly after 2009 (Fig. 47). There is an increase of average annual rainfall, average rainfall during monsoon months i.e. June-September each year, and the intensity of rainfall during monsoon months by a factor of ~73% during 2010-2015 cf. 1995-2009. This has the major implication on the slope stability in the area, as the slopes that had acquired a particular angle of repose become metastable under a particular set of climatic regime when prevalent for quite a long time in the area, and are now moving so as to adjust itself under a new set of climatic regime. It is expected that the increased rainfall patterns will cause more landsliding in the area till the slopes acquire the angle of repose.

Landslide susceptibility map of the township of Mussoorie has also been prepared integrating frequency ratio and weight of evidence modelling methods. For this ten thematic maps/causative factor maps were generated using high resolution satellite data and bivariate statistical approach is applied to under the weight of evidence of each causative factor. All the maps were generated in ArcGIS. It is observed that there is higher potential for landslides in the area terrace deposits, old landslide deposits and along road cuts.

DST Project
Centre for Glaciology

(Anil K. Gupta, D.P. Dobhal, Indira Karakoti, Rakesh Bhambri, Amit Kumar, Akshaya Verma, Reet Kamal Tiwari, R.S. Ahluwalia, Sameer Tiwari, Nilendu Singh)

The Centre for Glaciology is extensively involved in the strengthening the network for long term glacier monitoring in the Himalaya to evaluate and understand the changes in glacier health and dynamic process vis-a vis climate change. Currently four glaciers namely Dokriani, Chorabari, Dunagiri and Gangotri glaciers in the upper Ganga catchment in Uttarakhand are being monitoring and developing as full-flagship research stations. During the period an attempt has also been made to monitor few glaciers in the part of Himachal Himalaya and the study was initiated with snow cover assessments and their contribution in the river discharge by using isotope techniques. A field work has been carried out in upper Chandra River, Lahual & Spiti district of Himachal Pradesh in the month of June, 2015. In order to strengthen the network of instrumentation for real time data collection, an Aethalometer (Black carbon) and portable AWS are installed at Dokriani and on Chorabari glaciers catchment, respectively. During the summer period of 2015 (May-October) extensive field work to generate high quality time series data on glacier dynamic, snout fluctuation, meteorology, glacial hydrology and sediment transfer, melt-water chemistry, isotopic characterization of glacier melt, precipitation (snow and rain) and glacial geomorphology remote sensing has been carried out. Data collected during the period were compiled and analysed. Besides the in-suite measurements, the study on glacier surface changes, snow cover assessment and Glacier Lake inventory are also done by using remote sensing techniques. The major findings of the project are summarized below:

GPR Profiling

One of the key objective of the project is the estimation of glacier ice thickness of Himalayan glaciers to evaluate the total volume of glacier. Dokriani glacier is one of the glacier where ice thickness measurement was done in 1995, using pulse EKKO IV sensor software with 12.5 MHz central frequency and 2 m step size. The glacier ice thickness measured by GPR ranged from 15m 120 m and computed total volume of glacier ice

Fig. 48: Longitudinal and cross GPR profiles over the Ablation zone of Dokriani glacier.

was 283.6 x 10^6 m^3. To assess the changes in glacier mass/volume of Dokriani glacier between the period 1995 and 2015 (20 year), an attempt has been made to estimate the ice thickness by GPR survey. In this study a low-frequency antennas (12.5 and 25 MHz) with step size 4 m and one longitudinal (along the centre line) and four cross profile are used in the ablation zone of the glacier (Fig. 48). The data collected were analysed with the help of software Ekko-View. The preliminary results obtained from the profiles show substantial thinning in the ablation area of the glacier. It is also observed that, the present glacier snout is located at an altitude of 3,985 m, and the thickness estimated is about 25-30 m.

Glacier melting

In order to test the sensitivity of surface melting and its impact on annual mass balance, a study has been carried out to study the relationship between surface melt variations and meteorological parameters by using two enhanced Temperature-index (T-index) models with incorporating meteorological parameters viz. temperature, precipitation, relative humidity, wind speed and net radiation. Weather data recorded at Chorabari Glacier during 10th July to 10th September, 2010 and 10th June to 25th October, are used for this study. The modelled surface melt is validated against the measured point surface melting at few ablation stakes during the same period. Performance of the developed models is evaluated by comparing with basic temperature-index model and is quantified through different efficiency criteria. The results (Fig. 49) suggests that the proposed models yield considerable improvement in surface melt simulation. Consequently, the study reveals that glacier surface melt depends not

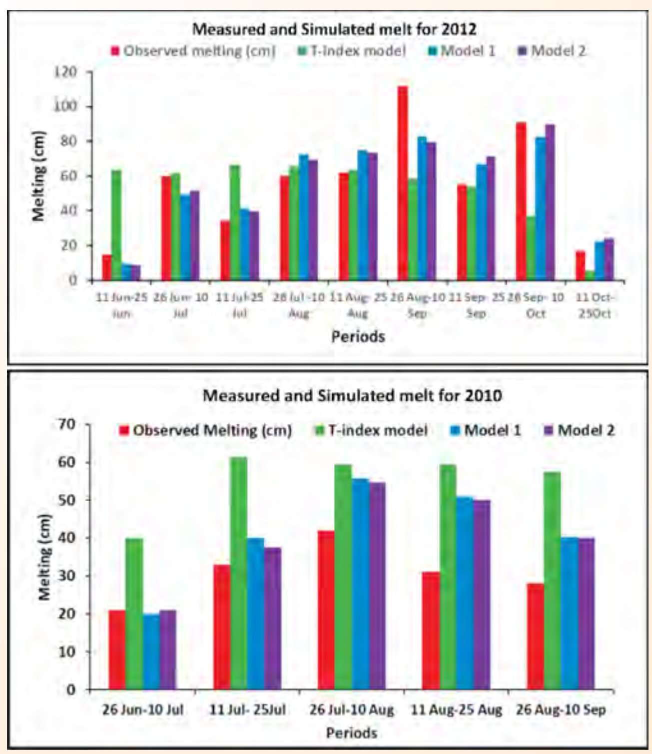

Fig. 49: Observed and simulated glacier ice surface melting in the ablation area of Chorabari Glacier (2012 and 2010).

only on temperature but also on weather parameters viz. relative humidity, wind speed and net radiation play a significant role in glacier surface melting. This approach provides a major improvement on basic T-index method and offers an alternative to energy balance model.

Meteorological observations

Monitoring of the Himalayan glaciers are important to quantify the changes that occurred due to variability in local weather and its awful effect on the glaciers health. Over the past decades, some meteorological observations have been carried out by using conventional method at high altitude regime of the Indian Himalaya, restricted only for summer period. It is understood that poor accessibility, rugged terrain and harsh weather conditions make it considerably more difficult to install the instruments, and regularly monitor the climatic records. Consequently, pattern of precipitation, temperature and other meteorological parameters are not well known except for a few glaciers. Lack of such information on climatic phenomena contributes to a poor understanding of melting and other flow generation processes in the high altitude regions. In this study, a comprehensive meteorological analysis has been made for the Chorabari Glacier, Alaknanda Valley, Garhwal Himalaya and the Dokriani Glacier, Bhagirathi Valley, Garhwal Himalaya using observed records from October 2014-September 2015. The meteorological data (air temperature, relative humidity, wind speed, net radiation, snowfall and rainfall) collected through Automatic Weather Station Network (Table 8; Fig. 50 and 51).

Table 8: Seasonal average of meteorological parameters.

Element	Winter (Oct –Apr)			Summer (May-Sep)		
	K1* **(4270 m a.s.l.)**	**D1#** **(4364 m a.s.l.)**	**D2#** **(3763 m a.s.l.)**	**K1*** **(4270 m a.s.l.)**	**D1#** **(4364 m a.s.l.)**	**D2#** **(3763 m a.s.l.)**
Temperature (ºC)	-3.2	-4.3	-0.6	5.2	4	8.1
Relative Humidity (%)	49	44	42	78	77	68
Wind Speed (m s^{-1})	1.6	2	1.5	1.3	1.5	1.4
Net Radiation (W m^{-2})	-6	11	18	64	69	95
Precipitation (mm)	1875¥	1654¥	-	1052†	-	938†

*AWS at Chorabari Glacier   #AWS at Dokriani Glacier   ¥Snowfall   †Rainfall

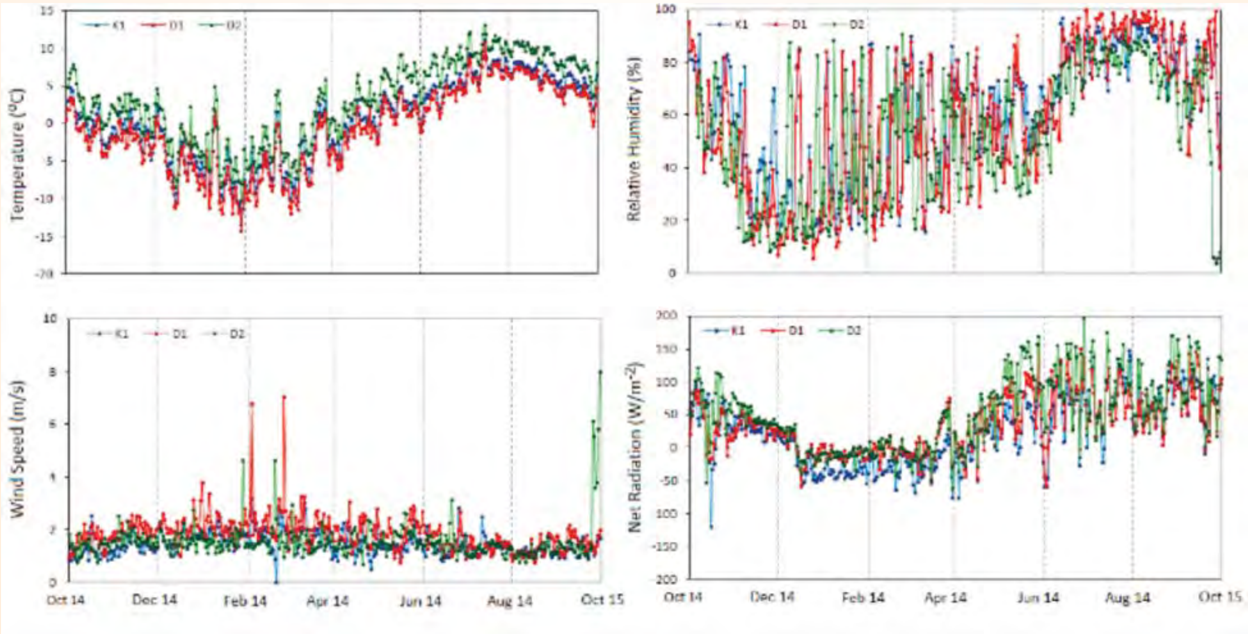

Fig. 50: Time series of daily mean temperatures, mean relative humidity, mean wind speed and mean net radiation observed at Glacier camp site (K1) of Chorabari Glacier (4,270 m a.s.l.), Advance Base camp site (D1-4,364 m a.s.l.) and Base camp site (D2-3,763 m a.s.l.) of Dokriani Glacier during 1st October 2014 to 30th September 2015.

SPONSORED PROJECTS

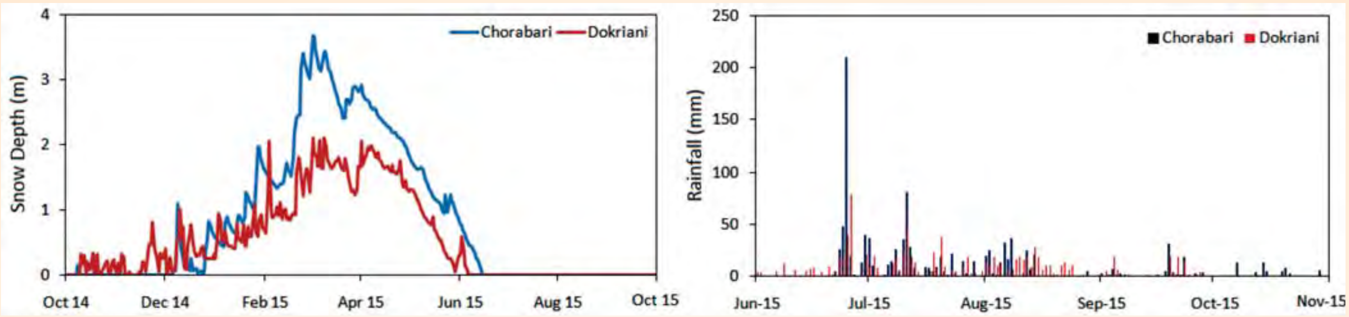

Fig. 51: Daily mean snow depth and observed total rainfall at Glacier camp site (K1) of Chorabari Glacier (4,270 m a.s.l.) and Advance Base camp site (D1-4,364 m a.s.l.) of Dokriani Glacier.

Snow Cover Assessment (SCA)

Snow Cover Assessment (SCA) and variability during summer months at different elevation zones of Chorabari glacier basin (elevation range ~3,799 - 6,893 m.a.s.l, and basin area 17.8 km^2) has been carried out using Landsat TM 5 satellite data (acquired from the Earth Explorer site) for the years 2009 and 2010. Results show that nearly 97% of the catchment area is covered with snow during winter months, out of that only ~46% remains at the end of summer. Subsequently, the SCA for each elevation zone is plotted against the elapsed time in order to construct the depletion curves for the different elevation zones. The high variability found in SCA (Cv = 0.03 to 1.98) between higher and lower elevation zones (Fig. 52). At higher elevations it is significantly less (above 5,500 m.a.s.l) in comparison to lower elevation zones (below 5,000 m.a.s.l), indicating depletion of SCA more rapidly melt during summer months.

Glacier surface ice velocity is one of the important parameters which determines the glacier dynamics. If the surface ice velocity is high in upper zone (accumulation zone) of the glacier, more ice is brought to the lower zone (ablation zone) of the glacier where it melts more rapidly. The surface ice velocity depends on multiple factors, like geomorphology of a glacier valley, ice load, orientation, slope and debris cover. In this study, we have used latest Landsat-8 satellite images from different dates to calculate the surface ice velocity of 190 glaciers of the Himachal Pradesh and Jammu and Kashmir Himalaya. The standard procedure has been implied to estimate the glacial velocity using COSI-Corr-an add-on module of ENVI software. The geo-morphometric parameters of the glacier surface have been derived using SRTM 90 m global DEM. It has been observed that the slope of the glacier is one of the main factors on which the velocity is dependent i.e. higher the slope higher is the velocity and more ice is brought by the glacier to the ablation zone. The debris cover over the glacier and at the terminus also affects the velocity of the glacier by restricting ice flow. Thus, observations (Fig. 53) suggest that the geomorphology and geo-morphometry of the glacier has a considerable control on the surface ice velocity of the glacier.

Isotopic Characteristics of flash flood in Kedarnath

During middle June 2013, Kedarnath valley in Rudraprayag district of Uttarakhand, India, was affected by catastrophic rainfall episode that caused massive loss of human lives and damage to the properties and livestock. In the present study, isotope approach ($\delta^{18}O$ and δD) is used to understand this catastrophic flash flood in Kedarnath valley. In order to analyse the isotopic signatures of the Mandakani River,

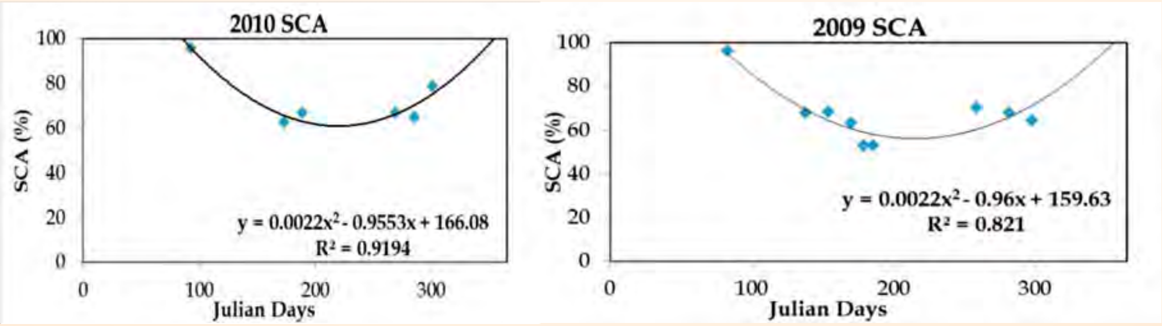

Fig. 52: Snow cover assessment and variability in Chorabari Glacier catchments.

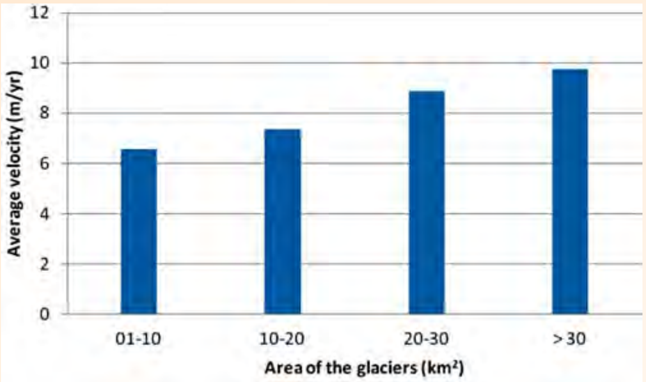

Fig. 53: Graph showing the comparison of mean velocity and the glacier area. *Note:* as the glacier area increases the mean velocity of the glacier is also high.

a sampling site was set up above the Shri Kedarnath Temple and collection of samples of river water, snow/glacier melt water and rainfall was started from 24th May, 2013 and continued till 16th June, 2013. Few samples including 16 June sample of rain and river flow were in good condition with appropriate labels which were brought for analysis by the field team when some communication was established in the valley after flash flood. Isotopic signatures of rainfall, snow/glacier melt water and river water of Mandakani River were measured and used to estimate the contribution of rainfall-derived runoff and snow/glacier melt runoff on flooding day. The result indicates that during the course of flood in Mandakani River, isotopic signature of river water was -15.97 %, whereas average isotopic signature of river before the flood shows -10.39 % (Fig. 54). A two-component mixed model was applied for the pre-event (flash flood) and syn-event in the Kedarnath valley as river flow was contributed only with two components, i.e. rainfall-derived runoff and snow/glacier melt runoff. By using the two-component mixed model, the contribution of rainfall-derived runoff

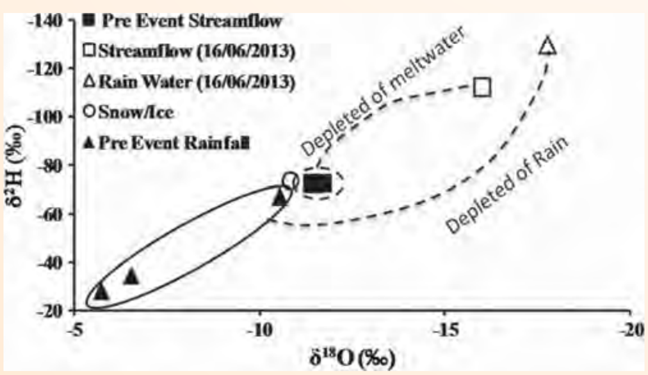

Fig. 54: Isotopic signature of rainfall, snow and river flow water during flash flood and pre-event (flood) storms.

is found to be 78 % and the contribution of snow/glacier melt runoff is 22 % during the flash flood in Mandakani River surrounding the Shri Kedarnath Temple, Central Himalaya, India.

Project

Reconstructing palaeoclimate and landscape history in Lahaul and Spiti, Himalaya using cosmogenic radionuclides (^{10}Be and ^{26}Al)

(Archna Bohra)

Late Quaternary glaciations in the Himalaya are poorly defined due to lack of the chronological control. The expansion and contraction of glaciers and timings of their events are important parameters to understand the past climate changes and derive valuable information for developing the predictive futuristic models in the evolution of glacial landscapes. The present study includes three major glaciated valley, (i) the Sonapani, (ii) Chattaru valley and (iii) Losar from Lahul and Spiti and lie adjacent to each other from Khoskar towards Kaza. The geo co-ordinates of these glaciated valleys lie between 31°44'N - 32°59'N latitude and 76°46'E - 78°41'E longitude, and cover an area of ~13,833 km^2 with an elevation ranging from 3,070-6,400 m above msl.

Moraine samples were collected for surface exposure dating (^{10}Be and ^{26}Al) from these glaciated valley during 2014-2015, to understand the past glaciation history of few million years. A total of 26 moraine samples were collected from these locations. Of which, fourteen samples were crushed, and fractions of 80-120 mesh were taken for chemical analysis. Quartz were isolated at 1.2 amp current with reverse slope using magnetic separator. They were treated with 2% HF to remove the surface inclusions if present on the grains. Sample digestion was done using concentrated HF, and was followed by fuming with conc. HNO_3 for complete removal of fluoride complex. The samples were passed through anion column followed by cation column. Beryllium was finally collected in 45 ml vial by eluting with 1.2N HCl in a cation column. The solutions were dried, and precipitated as $Be(OH)_3$ using NH_4OH at 7.8 pH. The $Be(OH)_2$ was later converted to BeO by heating to 900°C for 8 hours. The BeO powder with Nb powder in 1:1 ratio is loaded in cathode tubes before its analysis in the Accelerator Mass Spectrometry (AMS). The chemical separation of the samples from the three glaciated valley was carried out at ISSER, Kolkata and IUAC, New Delhi, and the already prepared target sample (cathode tubes) will now be measured for ^{10}Be analysis using AMS at IUAC, New Delhi.

DST-Young Scientist Project

Micrometeorological measurements and modelling experiments in the Pindari glacier

(Nilendu Singh)

Himalaya has its own peculiar energy-water fluxes and balance behaviour, further, the studies on energy-water exchange over the glaciers of the Himalaya are rare. It is thus proposed to carry out a first-of-its-kind micrometeorological study in the one of the fastest receding, mid-altitudinal, western Himalayan glacier named 'Pindari'. The objectives of the study will be, to understand the surface energy and mass exchange processes. The characterization of glacial surface energy and mass exchange processes can predict melt-driven stream flow, peak/extreme flows and will improve the temporal resolution of melt models. Micrometeorological profiling studies shall also help in analyzing the atmospheric boundary layer (ABL) structure that will help in better understanding the climate-glacier-vegetation responses, and feedbacks in larger perspectives.

The station consists of the following set of sensors for continuous and automated measurements of radiation and energy-water balance components: (1) four-component net radiometer, (2) soil heat flux plates at two-depths, (3) three-height air temperature – relative humidity probes and anemometers for wind speed and direction, (4) three-depth soil thermometers, (5) rain-gauge, (6) pan evaporation meter, and (7) soil moisture sensor. A 30-channel data logger logs data every second which is averaged over 15 minutes and stored in the logger.

Project

National Geotechnical Facility (NGF)

(Anil K. Gupta, Rajesh Sharma, B. Venkateshwarlu and Ruchika Tandon)

Field work was carried out during November 2015 in the Dungel landslide, Tons Valley to study the behaviour of slope and to assess the depth of overburden. The rock and soil samples were collected from the area for determining their geotechnical properties in the laboratory. Till date, all the geotechnical properties of soil, and the preparation of core samples from rock blocks have been completed to understand various geotechnical parameters. Field work was also carried out in the Surbhi landslide, Mussoorie in November of the reporting year. The development of a new scarp adjacent to the older landslide area have been recognized in the field. The GPR was operated along the three bands of roads at Surbhi landslide zone, and profile showed the signatures of subsidence. The Laboratory data was also generated for the numerical modelling and to investigate the factor of safety along new scarp.

One day training to 20 Officers of the Geological Survey of India was conducted in June 2015 on *'Rock Mechanics and Engineering Geology'* in the premises of National Geotechnical Facility. Lectures were arranged during forenoon session followed by demo for the various soil/rock testing experiments in the afternoon. Couple of meetings in months of April and October were also organized between the scientists of Norwegian Geotechnical Institute (NGI) and officials of the DST. The pupose was to strengthen the cooperation between NGF and NGI, and to initiate the research program on the Himalayan landslides. The meeting of the Program Advisory Committee of NGF took place on December 27, 2015, Dr Rajesh Sharma, Project Director, presented the progress of the activities of NGF in the meeting. Total four summer trainees completed two months dissertation work at NGF in the months of June-July. Their training dealt with engineering geology, applications of GPR and landslides in Himalayan region.

Indo-ISOR, Iceland-NGI, Norway collaborative Project

Commissioning of Pilot project for the use of geothermal energy

(S.K. Bartarya, Guatam Rawat and S.K. Rai)

The Chumathang geothermal area is located in the Indus Valley in eastern Ladakh region of the North West Himalaya, and is considered part of the Puga-Chumathang geothermal field. It is a considered as very potential area for the near term development of geothermal energy in the region. The Chumathang hot spring zone, is located toward north side of the Indus Suture Zone. AMT data has been collected in the Chumathang area to know the depth and geometry of geothermal source. From the data it is quite evident on first approximation that, the conductive regime start just beneath the river and start dipping northward. In figure 55 the features marked with letters 'A' to 'E' imaged as low resistive features, are the alluvial cover in the Chumathang area, mainly consists of recent talus, aeolian sand, fluvioglacial sediments and glacial moraines encrusted with borax, sulphur and other hot spring deposits. As observed from the model, the thickness of this cover is increased toward north east side and this deposit is having depth of

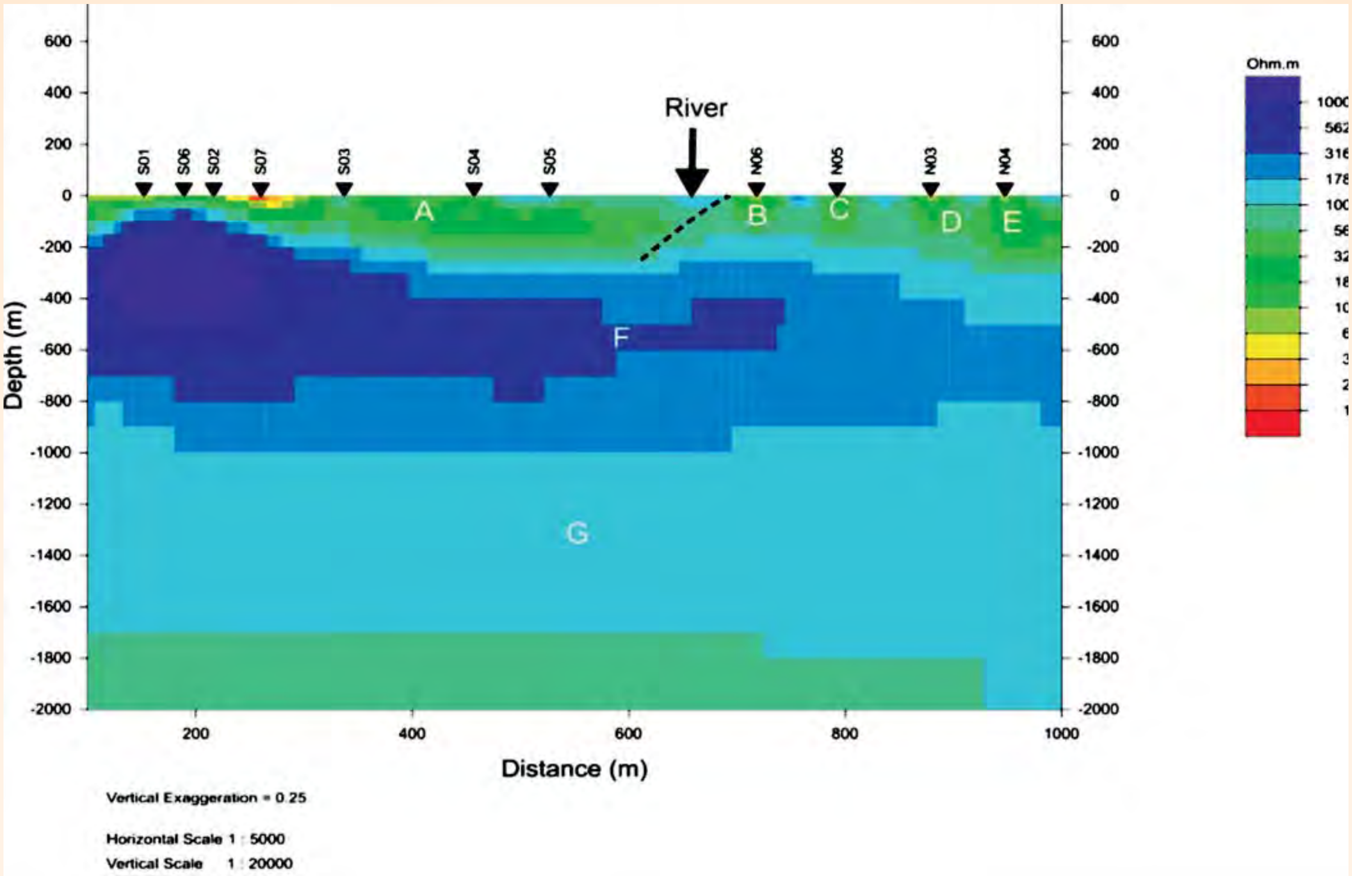

Fig. 55: Geoelectric model (TM Mode) of Chumathang geothermal field.

approximately 200 m. The resistivity of this cover is in the range of 10-30 ohm-m indicating that these deposits are water saturated. The important feature of this cover, imaged as low resistive feature, is that toward south side of river this cover is continuous and broken at one place below site S03, whereas toward north of the rivers these deposits are in pockets and are delimited with intrusion of granitic rocks (i.e., those represented from 'B' to 'E' in figure 55). Perhaps hot conduits are moving upward through the boundaries of these pockets, and therefore most of the geothermal exposure is visible toward north of the river. The 'F' and 'G' features (Fig. 55) are resistive features, where 'F' is more resistive that 'G' and represent granite rock of different stages.

Young Scientist Project

Hydro-climatic Response and Isotopic Characterization of Glacier Melt-runoff from Dunagiri Glacier, Dhauli Ganga Basin, Garhwal Himalaya

(Amit Kumar)

Dunagiri Glacier (30°33'20"N, 79°53'36"E) a north-facing glacier, situated in the Dhauliganga River basin, Chamoli District, Uttarakhand has been selected for hydrological, meteorological and isotopic studies. It occupies an area of 2.56 km^2 and length of about 5.54 km with altitude ranging between 5,100 m at the head and 4,200 m at the terminus of the glacier.

Meteorological Observations and Analysis

A conventional meteorological observatory was established about 500 m downstream from the glacier termini and meteorological observations were made continuously. The observatory for record parameters like temperature (minimum, maximum, dry and wet bulb), relative humidity, rainfall and wind velocity (Fig. 56a). Daily precipitation was recorded for year 2015 during different months June, July, August and September was 92.5, 103.7, 46.6 and 41.5mm, respectively. The total annual rainfall was observed to be 284.0 mm. The maximum amount of rainfall experienced in the valley during the month of July followed by June. Distribution of daily rainfall for the year is shown in figure 56b. Air temperature is one of the most important meteorological variables required for estimation of melt rate of a glacier. The pattern of mean monthly maximum and minimum air temperature in

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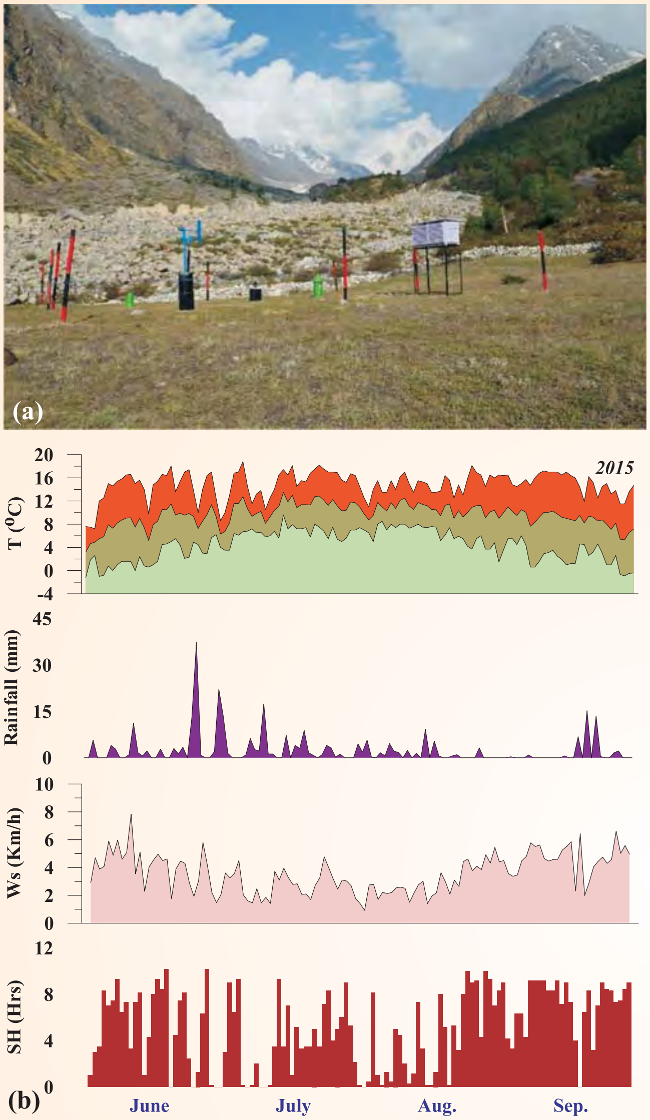

Fig. 56. (a) Location of meteorological observatory, and (b) daily distribution of meteorological data collected near the Dunagiri glacier termini.

different months i.e. June, July, August and September was observed 14.1, 15.3, 14.8 and 15.1 and 2.3, 6.4, 6.5 and 2.4°C, respectively. Mean monthly temperature for ablation season 2015 was observed to be 8.2, 10.8, 10.6 and 8.8°C, respectively. In general, temperature follows increasing trend from the month of June and starts decreasing in the month of September onwards. The observed maximum, minimum and mean temperature for the whole melt season is 14.8, 4.4 and 9.6°C, respectively. Further, day to day variability in minimum air temperature is less than that of maximum temperature. In the high altitude regions wind plays an important role in transport of moisture, formation of clouds, and occurrence of precipitation and melting of glaciers. The daily mean wind speeds for June to September were 4.1, 2.8, 2.9 and 4.6 km/h, respectively, and the average wind speed for the whole season was found to be 3.6 km/h. Some observations were made round the clock using automated instruments, sunshine recorder are used to calculate total sunshine hours during the whole day. Total monthly values of sunshine hours for different months during the melt period 2015 in June, July, August and September were 153.6, 122.95, 125.25 and 214.3 h, respectively. Maximum bright sunshine hours observed in the month of June, July, August and September are 10.15, 9.30, 10.0 and 9.15 h, respectively. Thus, maximum mean monthly bright sunshine hours are observed in the month of June followed by August.

Hydrological Observations and Analysis

A gauge and discharge site has been established at River near the snout of Dunagiri glacier (Fig. 57). In order to measure the water level data, an automatic water level recorder was installed on the artificial well installed near the river bank. A stage-discharge relationship for the gauging site was developed analysing the observed gauge and corresponding discharge data. A typical stage-discharge relationship developed for ablation season 2015 (Fig. 58). Monthly mean values of the discharge were computed from the daily mean values for each month of the ablation season, and the values for the months of June, July, August and September are 2.4, 8.6, 5.5, and 2.6 m^3/s, respectively. The mean monthly discharge was observed to be 4.9 m^3/s. Mean monthly suspended concentration for June, July, August and September during the study period was 1168.1, 1290.5, 1208.2 and 961.5 mg/l, respectively and show variation over the melt season. Mean monthly total suspended loads for same months during the study period were 262.5, 988.7, 588.4 and 211.8 tonnes respectively. Daily distribution of discharge and sediment concentration and load are given in figure 59.

Also, the samples of rainfall, snow, ice and discharge were collected during summer 2014-2015 for isotopic analysis of each component (Rain and Snow) at discharge measuring site. Apart from this, hydrology and hydrochemistry of melt-water discharge, measurements of physical properties of streamflow components (pH, EC and temperature), snow cover assessment, glacial hazards and geomorphological study have also been initiated at Bangni glacier. Freely available LANDSAT and ASTER images have been used for such type of analysis.

Fig. 57. Locations of discharge gauging site at various time intervals near the Dunagiri Glacier termini.

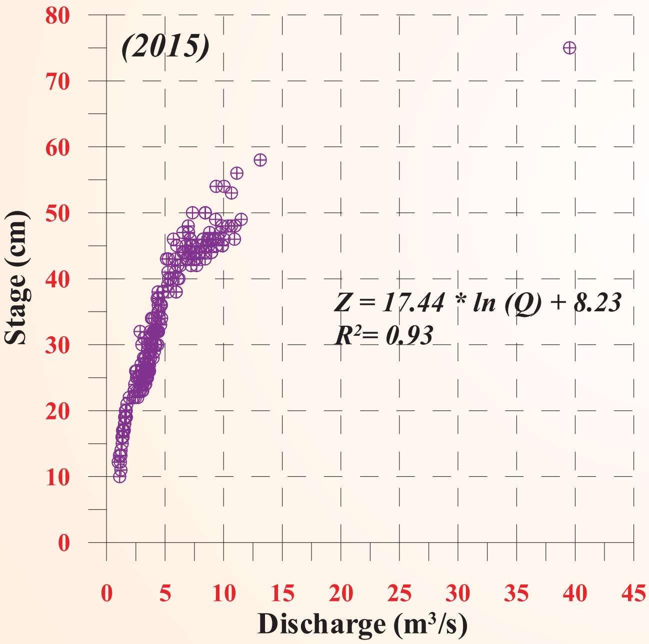

Fig. 58. Rating curve for the Dunagiri Glacier melt-water stream for the ablation season 2015.

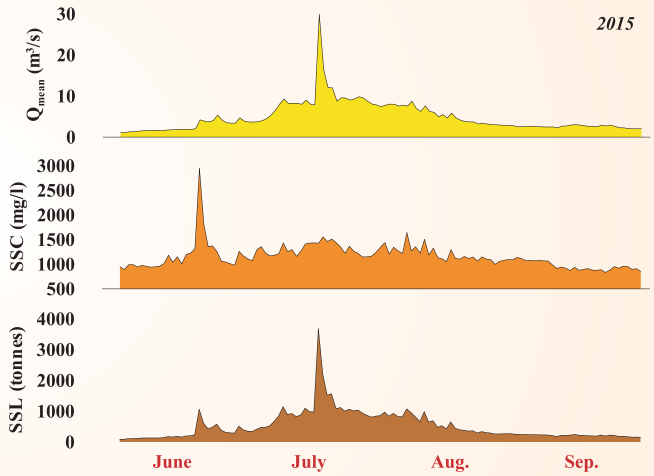

Fig. 59. Distribution of daily discharge, suspended sediment concentration and load near the Dunagiri Glacier termini.

SERB sponsored DST Project

Facies mapping of Gangotri glacier using AWiFS data: A Super Resolution Approach

(Aparna Shukla and M.K. Arora)

The subject of glacier facies/component mapping is very interesting and pertinent to glaciological studies for various reasons like hydrological modeling, glacier related hazard studies, as an indicator of glacier health, identification of the glacier terminus, understanding the snowline dynamics, mass balance studies etc. The main focus of the proposed study is two fold: (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 and, (ii) to apply the developed technique over an extended area including tributary glaciers of Gangotri glacier to facilitate monitoring of frontal changes. Figure 60 shows the location map of the study area.

With regard to meeting the first objective of the proposal related to sub-pixel mapping of the facies

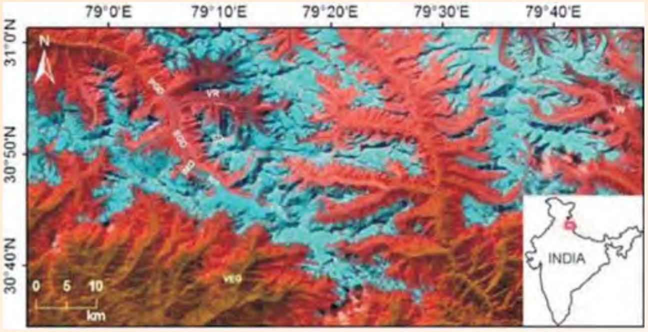

Fig. 60: Location map showing Gangotri and neighboring glaciers under study.

present on Gangotri and adjacent glaciers, six AWIFS scenes on board Resource Sat-1 (acquisition dates: November 22, 2005; October 05, 2006; November 07, 2008; November 30, 2010; November 30, 2011; November 23, 2014) and one LISS IV scene on board Resource Sat-2 (dated November 02 , 2014) of the study area had been acquired along with the SOI toposheets. ASTER GDEM version 2 (30 m) of the study area was also obtained for the present work. The selection of these satellite imageries was made depending on their availability, minimal snow and cloud cover. As a preliminary step, all the toposheets covering the parts of our study area were georeferenced. These georeferenced topographic maps were then mosaicked and the high resolution LISS IV imagery (5.8 m) was registered to this mosaic. Subsequently, the LISS IV and AWiFS (56 m) images were co-registered with each other using second order polynomial transformation at RMSE varying between 0.0003-0.0019 using 20-25 ground control points (GCPs) for each image. AWIFS Image dated October 05, 2006 and LISS IV image were then rectified for the radiometric effects and converted to the physical units (reflectance) from DN values (Mishra et al., 2012).

Various glacial facies have been reported in literature (Shukla and Yousuf, 2016; Alifu et al., 2015; Shukla et al., 2010; Hall, 2008; Winther, 1993) and for their identification in our study area, spectral profile analysis (i.e. close spaced analysis of the facies spectra) was conducted. Facies in this study have been categorized as snow/ice facies and other facies. Spectral profiling was done separately for these two categories of facies on both AWIFS raw and reflectance images dated October 05, 2006, along and across the central line of few representative glaciers (including Gangotri glacier) well-distributed over the scene for the proper identification of various facies present on these glaciers and to ascertain which ancillary layers can further be used as input in the process of sub-pixel classification.

Owing to the high radiometric resolution of AWIFS sensor, we identified five different snow/ice facies present on these glaciers namely dry snow, firn, wet snow, ice, ice-mixed debris (IMD) as shown in figure 61. The reflectance ranges for these facies were defined on the basis of literature of field-based snow-ice spectra and their sensitivity at different spectral bands (Bhardwaj et al., 2015; Dozier and Painter, 2004; Gupta et al., 2004; Philip and Ravindran, 1998; Hall et al., 1992; O' Brian and Munis, 1975). The presence of crevasses and shadows remarkably decrease the reflectance of the accumulation facies (dry/wet snow or firn) to the level that it gives the spectra of ablation facies (ice or IMD) as illustrated in figure 61e. This accounts for the need of inclusion of ancillary data in order to avoid misclassification.

In the other category, facies like supraglacial debris (SGD), periglacial debris (PGD), valley-rock, vegetation, shadow and water had been identified in the study area. As evident from figure 62, there is a high degree of spectral overlap between SGD, PGD and valley rock, therefore segregation of these classes using multispectral data only is difficult. Besides some of the water profiles resemble with SGD/PGD/valley rock while few match with those of shadow. However, spectral signatures obtained from deep and clean water bodies are distinct. Therefore, for better characterization of glacier facies, ancillary layers like slope, aspect, NDSI, snow grain size indices, brightness temperature were used (Alifu et al., 2015; Paul et al., 2013, 2004; Shukla et al., 2010a; Racoviteanu and Williams, 2012; Keshri et al., 2009; Dozier, 1989). In principle, we are attempting to categorize all the glacier facies based on these additional attributes like elevation, slope, NDSI, grain size, illumination, brightness temperature etc. since change in these parameters can be reasonably related to the change in the facies present on the surface of a glacier (Negi et al., 2008; Gupta et al., 2005; Kulkarni et al., 2002; Dozier, 1989, Hall et al., 1988).

In order to find the most suitable sub-pixel classifier, training areas for all these observed facies were selected and sub-pixel classification was run using various algorithms like Artificial Neural Networks (ANNs), Support Vector Machines (SVMs) and Spectral Angle Mapper (SAM). The visual interpretation of the classified maps revealed that SVM is able to produce better results as compared to ANN and SAM. Hence, SVM would be preferably used for carrying out the sub-pixel classification. However, the quantitative estimation/accuracy assessment needs to be done for the appropriate selection of the sub-pixel classifier.

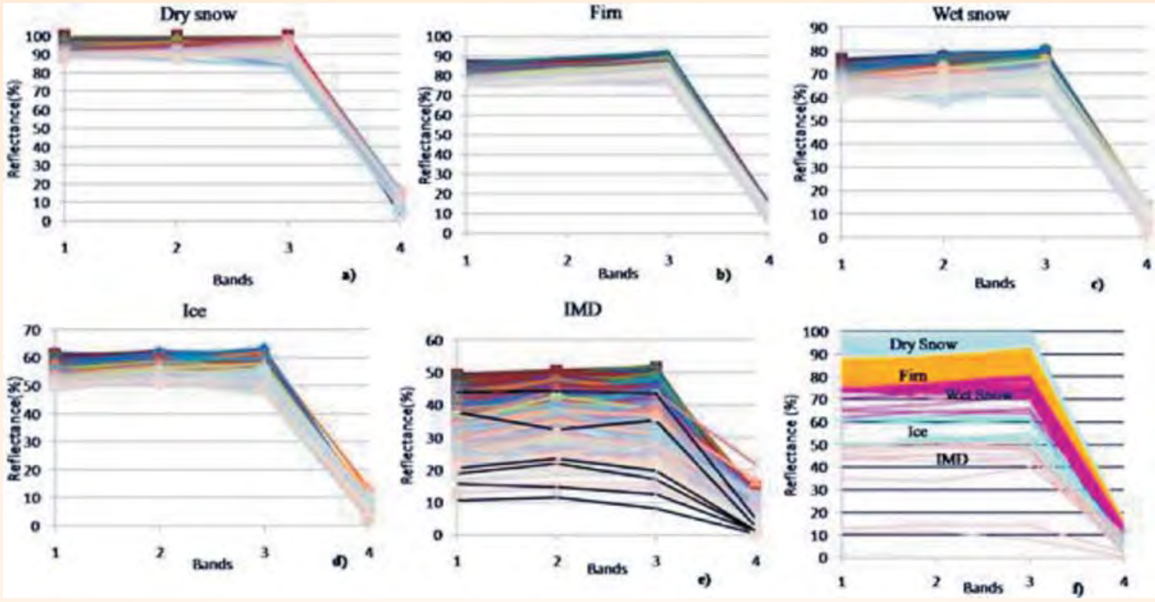

Fig. 61: a-f) Spectral profiles of various snow/ice facies identified in the study region. Note: The black profiles in figure 62e represent the spectra of accumulation facies which resemble the spectra of ablation facies due to presence of crevasses and shadows.

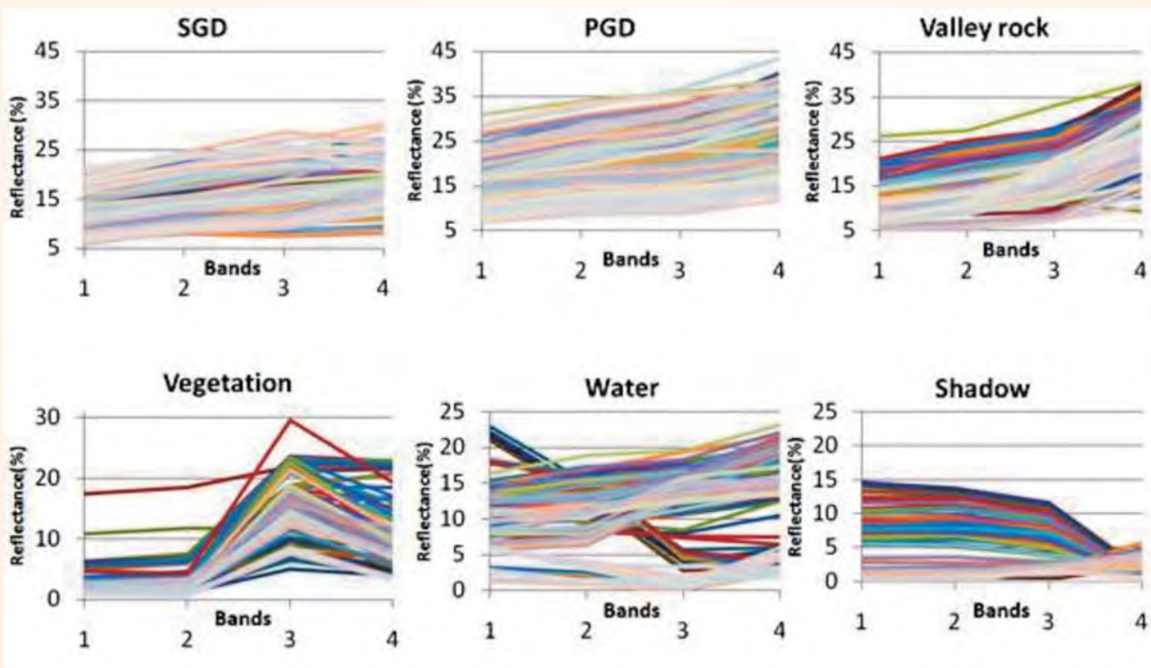

Fig. 62: Mean spectral reflectance (%) of other facies identified in the study region.

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DST-SERC Fast Track Project

Mineralization and petrogenesis of mantle sequence and cumulates of the Manipur Ophiolite Complex, Indo-Myanmar Orogenic Belt, NE India

(A. Krishnakanta Singh)

Coexistence of tholeiitic MORB (Type-I) and OIB (Type-II) mafic volcanics have been reported from the Manipur Ophiolite Complex (MOC) of the Indo-Myanmar Orogenic Belt (IMOB), NE India. The Type-I have comparatively lower TiO_2 concentrations (0.6-1.6 wt. %), show almost flat REE patterns with depleted LREEs [$(La/Sm)_N$ = 0.62-1.03]. However, few samples in the MORB group show enrichment in LREE [$(La/Sm)_N$ = 2.83-2.95] which is the typical composition of P-MORB. On the otherhand, Type-II are characterized by high concentration of TiO_2 (1.7 to 3.5 wt. %) with highly enriched LREE pattern as compared to their HREE [$(La/Sm)_N$ = 2.27-3.44, $(Sm/Yb)_N$ = 2.56-3.29)] implying more than two magma sources involving from depleted MORB mantle to significantly enriched OIB source. Petrogenetic modeling suggests that 20% partial melting of depleted mantle within spinel stability facies zone (shallow depth) is responsible for generation of MORB tholeiites, and 5-10% partial melting of enriched mantle or plume material at garnet facies stability zone (deeper depth) is responsible for production of alkaline OIB-type.

Geochemical signatures of variably enriched MORB and P-MORB samples further suggest possible scenario of mixing of depleted N-MORB and enriched OIB melt**.** It is therefore likely that mafic volcanics of the MOC were derived from chemically heterogeneous mantle sources erupted at the sea floor spreading zone as MORB generated by partial melting of depleted upper mantle, and as OIB generated by partial melting of enriched mantle or a plume source, at the proximity of the spreading axis. Due to prolonged subduction of the Indian plate beneath the Myanmar plate and afterward collisional activity, they might have later accreted along the Indo-Myanmar Orogenic belt as upthrust ocean crust. Thus, it is envisaged that mafic crustal part of the NMO might have formed at mid oceanic spreading tectonic setting as one mechanism and within plate seamount volcanism above a plume source stationed at the proximity of the spreading axis as another mechanism before the initiation of later phase supra-subduction tectonic process. Such nature of coexistence of mafic volcanics formed at different tectonic settings was also reported in many Tethyan ophiolites. There was a phase of major rift-drift activity during the Jurassic-early Cretaceous that provoked the separation of the Indo-Myanmar-Andaman (IMA) block and Sikuleh microcontinents from the Australian margin. This event was followed by the greater Indian continent drifted away from the Australian continent during late Cretaceous. Occurrence of a rifting activity at the eastern margin of the Indian plate and separation of the Indian continent from the Australian continent prior to Latest Santonian/Earliest Campanian was also proposed by earlier workers.

The tholeiitic MORB lavas with low TiO_2 concentration of the MOC, so might be generated by partial melting of depleted upper mantle at shallow depth during late Cretaceous period at the spreading axis when Indian plate was separating away from the Australian plate. At the same time, P-MORB might have formed as the depleted melt and was continuously enriched by OIB (Type-II) component that came from a deeper source/plume source. The Type-II might have erupted as within plate sea mount near the spreading axis. A 2-D model illustrating the possible tectonic setting for the evolution of MORB and OIB mafic

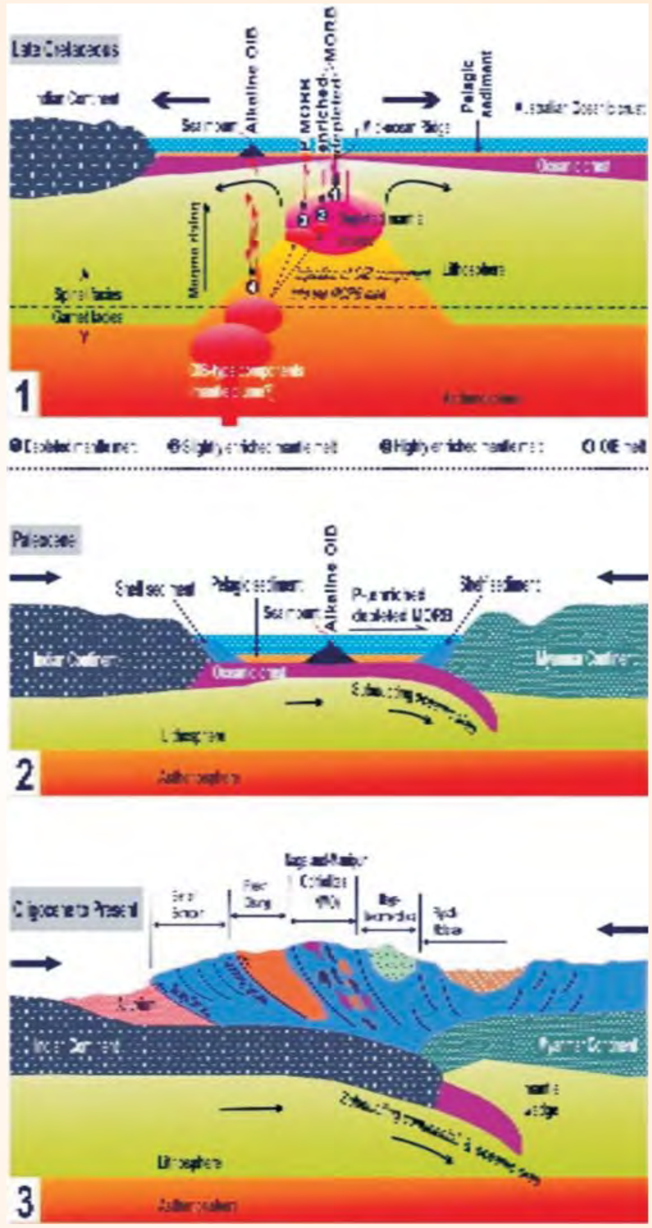

Fig. 63: Models illustrating the tectono-magmatic evolution of the mafic volcanics of the Manipur Ophiolite Complex (MOC), IMOB, North East India. (1) A 2-D model showing the possible sub-surface mantle diapir that generate MORB and OIB mafic lavas at the eastern margin of the Indian plate during late Cretaceous while separating away from the Australian plate. (2) Cartoon showing oceanic consumption during subduction process of Indian plate beneath Myanmar plate. (3) Schematic tectonic framework of the MOC since Oligocene to Present.

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volcanics of the MOC is shown in figure 63a-c. Low degree partial melting of upper mantle and formation of new ocean basin at the spreading ridge during cretaceous period was also supported by geochemistry of MORB-type mafic extrusive, intrusive and residual peridotite from the MOC. According to Ti-based classification of basalts from the NMO, Sengupta et al. (1989) also inferred possible scenarios of its origin from two different tectonic settings i.e. spreading ridge and plume environment. During Paleocene, the IMA block and Indian continent had oblique convergence as the IMA block was continuously rotating clockwise because of the transform faults developed in the Indian Ocean. Later, the northeast end of the Indian continent collided with the northwest end of the IMA during Mio-Pliocene. Due to this collisional process, the NMO was obducted onto the Indian basement and preserved along the IMOB.

DST-SERB Project

Geodynamic evolution of the mylonitic zone across the Lesser Himalayan Belt of the Eastern Himalayan Syntaxis in Arunachal Himalaya, Northeast India

(R.K. Bikramaditya Singh)

Fieldwork has been carried out in March-April 2016 in Lohit and Dibang valleys of Arunachal Pradesh. The Lesser Himalayan Granites (LHG) collected from these region are comprised of quartz, k-feldspar, plagioclase, muscovite and biotite with accessory minerals like zircon and apatite. Geochemical and petrological studies suggest that the LHG have been derived from sedimentary source. This is evident from their high molar $Al_2O_3/CaO+Na_2O+K_2O$ ratio values, which range from 1.00 to 1.72 with normative corundum values in the range of 0.37-6.39, suggesting the peraluminous nature of these rocks. Further, the chemical composition of biotite shows the FeO^t/MgO ratio which ranges from 3.21 to 5.11, and siderophyllite in composition which are typically close to the peraluminous S-type suite. The microstructural features of quartz and feldspar in the LHG indicate that the rocks underwent an early stage of deep level ductile deformation superimposed by shallow level brittle deformation during a later stage of deformation.

SERB Sponsored Project

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

(Vikas)

The project aims to document the exhumation history of the Karakoram Fault (KF) Zone. 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) (Fig. 64). These rock units represent the margin of south Asian Plate and lie to the north of the Shyok Suture Zone (SSZ). Lithologically, the SSZ is composed of peridotite, gabbro, volcanics, conglomerate, shale, diorite and granodiorite rocks. To the south of the SSZ lies the Ladakh Batholith, dominated by medium grained granite-granodiorite undeformed rocks, and having randomly oriented plagioclase, hornblende and minor amount of biotite minerals. To the south the Ladakh Batholith is juxtaposed with a thrust contact with well bedded sedimentary sequence of Indus formation of Indus Tsangpo-Suture Zone (ITSZ) (Fig. 65a). On can also observe the darker mafic enclaves within the light coloured granitic rocks of Ladakh Batholith (Fig. 65b).

Karakaoram Fault (KF) Zone

A narrow zone ~1-5 km of ductile deformed intensely mylonitized granitic-gneiss, slates, phyllites is observed in the north of SSZ representing the Karakoram Fault (KF) zone (Fig. 64). The ductilely deformed rocks of KF zone are observed along the strike in Tangtse-Muglib region, Durbuk-Shyok region and Nubra-valley region in the study area. The fault bifurcates into two strands near Agham: Tangtse strand and Muglib strand (Fig. 64). While moving from Changla to Pangong Tso road transect, near the Tangtse Monestary ~500 m on Tangtse-Chilam road (location TM 1, Fig. 64), the mylonitised rocks are characterised by steep vertical foliations (Fig. 65c) and nearly horizontal stretching lineations (Fig. 65d), with right-lateral shear criteria. These mylonites represents the same direction and sense of motion as the KF zone. No prevailing feature for the major tilting of the mylonites after their formation exists in the field as in the south of mylonites undeformed massive Tanstse granites are exposed. Therefore, these mylonites are interpreted as constituting the KSZ corresponding to the exhumed deep part of the KF zone. The horizontal stretching lineations are in general, plunging towards NW from 11° to maximum 39° on vertical foliation planes within the KSZ. Oriented samples for micro-structural studies are collected during the field. Thin sections along XZ and YZ sections have been prepared for microstructural studies. Intrafolial folds within nearly vertical foliations, assymetric boudins in the shear zone are indicative of dextral right lateral KF (Fig. 65e,f). Similar sets of horizontal lineations on vertical foliation planes are obserevd near Muglib and Shyok village. Near Agham and Rongdo village, a crushed zone the

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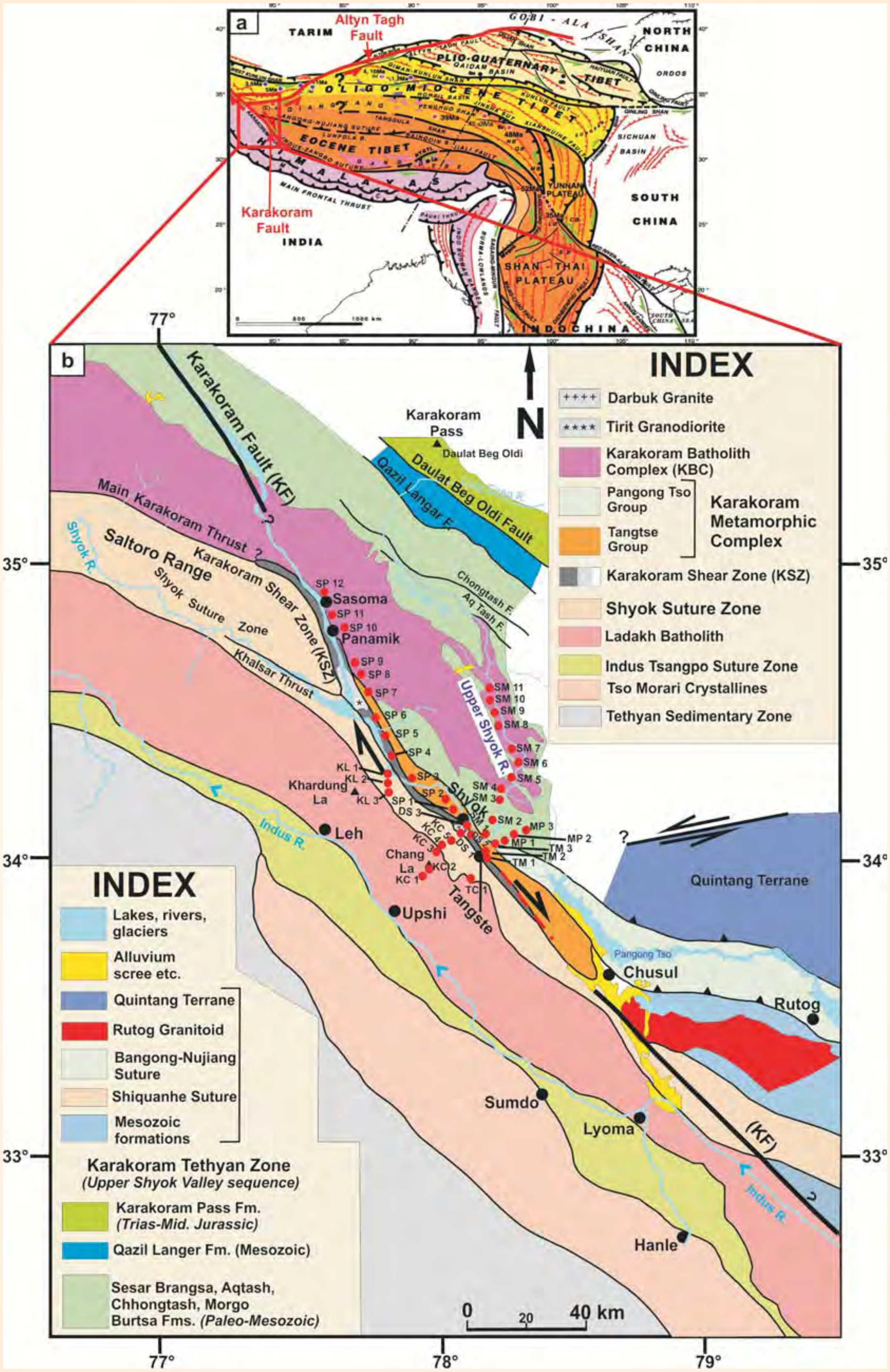

Fig. 64: (a) Location of study area in context of Himalayan-Tibeten orogenic belt, (b) Geological Map (after, Jain and Singh, 2009) with sample locations (red dots) for Fission Track Thermochronological studies.

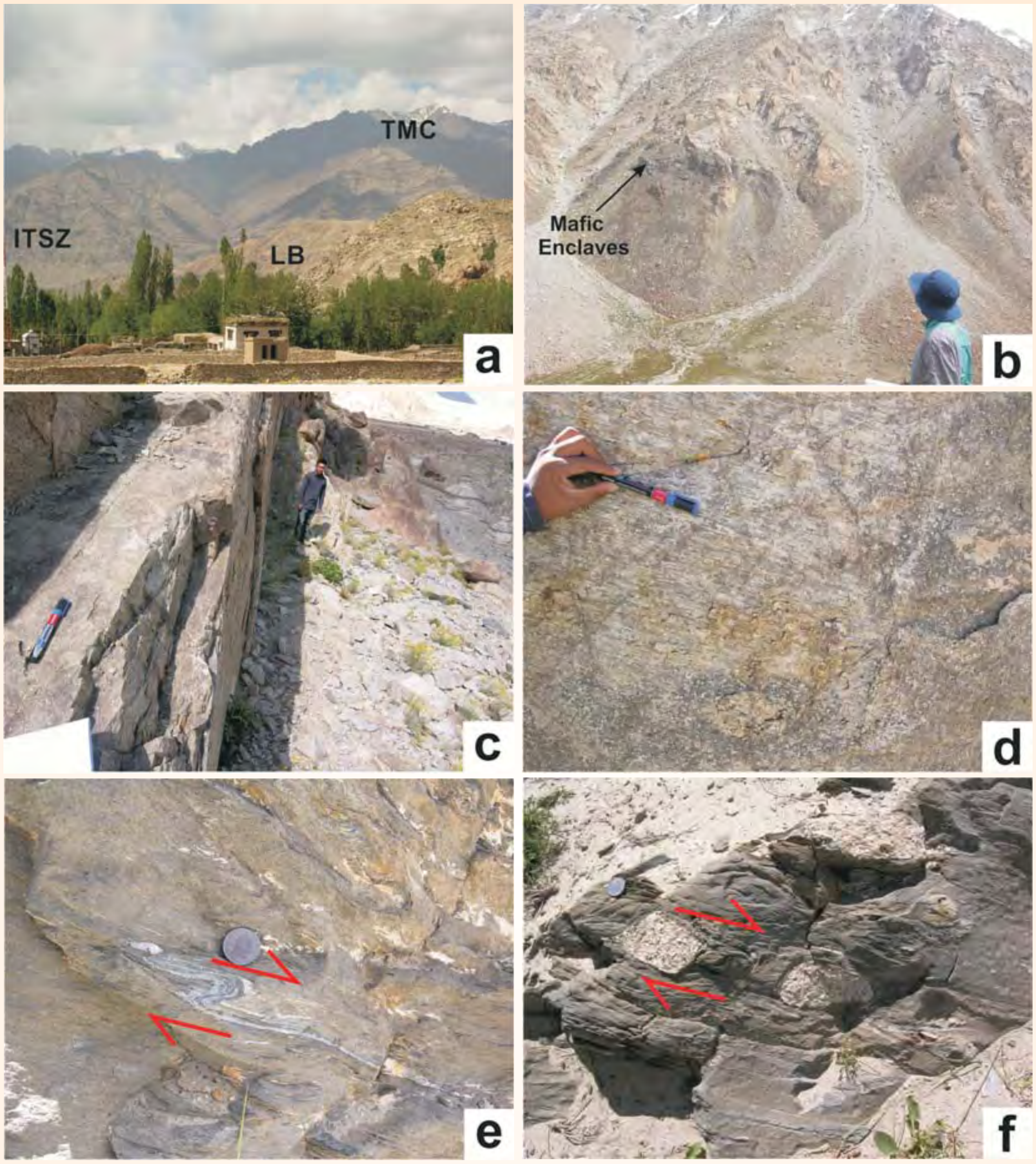

Fig. 65: (a) Exposure of massive underformed granitic rocks of Ladakh Batholith (LB), well bedded Indus formation of ITSZ and Tso-Morari Crystallines are shown. LB are overlain by ITSZ along thrust contact near Upshi. Photograph is taken from Sakti village viewing towards south. (b) Dark coloured Mafic enclaves of SSZ are intruded within the light coloured LB rocks near Tsoltak; (c) Mylonites showing the vertical foliations; (d) nearly horizontal lineations are observed in KF zone; (e) intrafolial fold with nearly vertical axial plane showing dextral sense of motion; (f) asymmetric boudins representing the dextral slip within KF zone.

phyllites and slates have been observed as a representive of the shearing along KF. These features extends along strike in the Nubra valley which confirms the trace of KF.

Metamorphic domains that defines the extent of deformation and metamorphism in this region have been observed in Tangtse-Muglib region and Pangong Region and are termed as Tangtse Group (TG) and Pangong Tso Group (PTG). TG lies in between the two strands of the KF zone. Instense shear heating and partial melting due to activation of KF have generated a completely migmitised zone between Tangtse and Muglib. The rocks comprised of granitic gneiss, amphibolite intruded by large leucocratic dykes. Leucocratic dykes parallel to the foliation plane as well as cross cutting the main foliation have been observed in this region. PTG is exposed in the north of Muglib strand while along the Muglib-Lukung-Phobrang road transect. The rocks consists of amphibolite, slate and alternate bands of marble and schist.

During this year, field work to collect structural data and samples for apatite and zircon fission track thermochronological studies has been carried out in the transects of Changla-Tangtse-Pangon Tso, Darbuk-Shyok, and Shyok-Panamik-Sasoma (Fig. 64). A total of around 80 samples are collected. In the first phase, analysis of 64 samples from Changla-Durbuk-Shyok, Tangtse-Muglib and Shyok-Murgo (upper Shyok) sections have been taken-up for Fission Track dating studies (Fig. 64). Crushing and washing of samples, Magnetic Barrier Separation, Heavy Liquid Separation, and picking of good quality grains of apatite and zircon have been completed. However, fission track dating study is under progress.

Project
Palaeobiology of the Birmania Basin, Rajasthan and its correlation with the Krol-Tal belt of Lesser Himalaya

(Rajita Shukla)

Birmania Basin, a small oval-shaped basin, roughly trending north-south, located in the centre of the Thar Desert, near Jaisalmer, western Rajasthan is the study area for the ongoing project. Considered to be an isolated remnant of the Marwar Basin, it is underlain by the Malani Igneous rocks (780-680 Ma) and unconformably overlain by the Lathi Formation (Jurassic). It comprises of ~900 m thick sequence of siliciclastic, carbonate and phosphorites facies. The sedimentary rocks of Birmania Basin are broadly grouped into two formations, the lower Randha Formation made up of medium to coarse siliciclastic rocks, and the upper Birmania Formation. The contact between the two is not visible owing to large sand covered tracts. Birmania Formation is calcareous in the lower part with light to dark grey, resinous bands, lenses and large nodules of chert occurring deeply embedded within the calcareous rocks. The upper part of Birmania Formation is calcareous with siliceous content. Dark, bands of phosphorite occur along with calcareous sandstone and shale.

Carbon isotopic studies carried out in this basin (Maheshwari et al., 2007) revealed the pattern to be similar to the well-established, global Precambrian-Cambrian isotopic curves. Hence, an Ediacaran-Early Cambrian age was assigned to this basin which had been considered unfossiliferous. The recent discovery of *Wengania exquisita* from the phosphate beds of Birmania Formation shows the fossiliferous nature of the basin, and indicates an Ediacaran age for the formation. During the present study an assemblage of cyanobacterial and algal filamentous forms has been recorded from the cherts of the lower part of Birmania Formation. In the wake of these records, the age of Birmania Basin is being reassessed.

Petrographic and geochemical analysis of cherts, carbonates, phosphorites and siliciclastics from the Randha and Birmania formations and Krol Group is also being carried out. This will aid in definite identification of the rocks, understanding the depositional environment and comparing the two basins for biostratigraphic correlation.

Young Scientist DST sponsored Project
Biostratigraphy and depositional history of the upper Cambrian - lower Ordovician succession of Pin section in the Spiti Basin, Tethys Himalaya

(Shivani Pandey)

Samples were collected from Ordovician to Devonian succession of Pin Valley. Of which, the samples from the Ordovician section were analyzed to study different microfossils assemblage. The Ordovician sedimentary succession is typical of carbonate platform facies. The microscopic studies reveal abundant accumulation of calcareous algae along with, bryozoans and other unidentified microfauna. Among these the widely spread forms are the green calcareous algae and bryozoans. The algal assemblages were consist mainly of the order Dasycladales that were most numerous in the Ordovician-Silurian successions. Calcareous algae are relatively common biotic constituent in marine carbonate units and played an important role in rock-building, and are the important constituents of the reef complexes in Ordovician period. These benthic marine chlorophyte groups, indicates shallower part of the infra-littoral stage, and constitute as useful parameter to define the depositional environment of the sequence. Their relative abundance was probably controlled by substrate and rates of deposition. Calcareous algal remains are widespread in various facies in Ordovician carbonate complexes and provide useful information about the paleoenvironments, which can complement interpretations based on other biota and depositional textures. The most frequent dasycladacean algal recognized in the carbonate facies is *Vermiporella* and *Dasyporella*; these forms are usually accompanied by *Moniliporella*. The various genera of bryozoans identified are as *Calloporella, Cyphotrypa, Dekayai,*

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Eridotrypa, Insignia, Trematopora, etc. The earlier bryozoans fauna reported from Tethys Himalaya indicates the age of Late Ordovician, but the recent studies show that they go even up to Late Silurian.

Young Scientist DST sponsored Project

Geological significance of early Miocene nonmarine fossils from NW Himalaya vis-à-vis their record from eastern Kutch, India

(Ansuya Bhandari)

15 days detail field work has been carried out in Kutch region. The field studies showed that there are only two ossiferous horizons located in the field, Pasuda and Tapar localities from where collection was made and many section where we have collected faunal remains were named as Tapar 1, 2, 3 localities. The fauna recovered from the area (Fig. 66) comprises diversified mammals like *hipparians,* proboscideans, tragulids, suids, and large mammalian bones.

Miocene mammals from the Himalayan and Indian Shield region

In India the pre-Siwalik Miocene mammals are known through latest ongoing phase of paleontological investigations in Dharmsala and coevals in NW Outer Himalaya, from Ladakh Molasse Group in Trans-Himalaya, and Kutch in western India. Through persistent efforts an isolated rodent premolar recovered after maceration of >1000 kg of bulk sample from dark grey facies of Dharmsala Group and referred to as *Hodsahibia*. Though the molar shows insufficient crown details, but has distinctive dimensions leading to its assignment to *Hodsahibia*. Besides rodent records from Bugti localities in Pakistan, studies on fossil rodents from neighbouring localities of older Subathu, coeval Murree, and younger Siwalik beds and from other key horizons and localities provide an appropriate background to our present study. This rodent find from Dharmsala Group is said to mark small but significant paleontological beginning though has fallen short of expectations regarding biostratigraphy aspects because of lack of crown morphology.

Miocene Mammals from Indian Shield are dominantly the terrestrial fossils that have been recently added through extensive field works from Pasuda and Tapar in central Kutch. Eight terrestrial mammal taxa were described from Khari Nadi Formation in Gujarat, India. This treasure of Miocene mammals with some early Miocene elements include African exotics which provide biogeographic insights, especially with regard to the opening of terrestrial routes between Africa and Eurasia via Arabian landmass. *Deinotherium* is significant in the context of palaeobiogeography as its early Miocene record from Dharamsala as well as from Kutch assemblage that indicate the connection of African and Indian land masses. Records of *Hipparion*

Fig. 66: Field photographs showing fossil localities in Kutch.

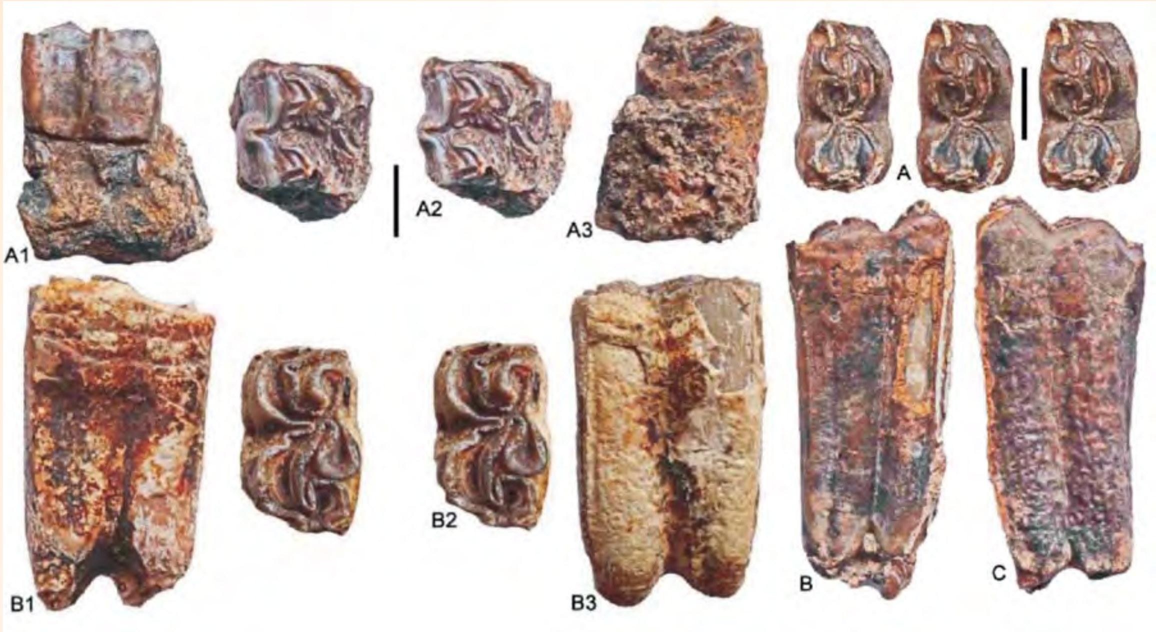

Fig. 67: Equid teeth (A1-A3; B1-B3), and Equid right lower tooth (A-C) from Kutch.

isolated teeth along with *Kachchhchoerus* and *Tetraconodon* from near Tapar in Kutch marks the presence of late Miocene sediments in the region. Equids *Hipparion* (*sensu lato*) indicate the probable presence of open country in the region (Fig. 67).

Miocene Bioevents from Indian Outer Himalaya and Eastern Kutch

Through intense paleontological studies in India, Miocene bioevents in mammalian record from Kangra Valley (Dharmsala Group) and Mohand (Siwalik Group) in Outer Western Himalaya and from Pasuda (Khari Nadi Formation) in eastern Kutch have come to our knowledge. These Miocene bioevents are rather coeval or follow the epoch characterising climatic event named as MMCO - an intriguing geological analogue to the present day global warming. Record of unambiguous fossil remains of *Deinotherium,* an African native in early Miocene levels of Dharmsala in Kangra Valley (Western Himalaya) and in eastern Kutch marks a bioevent of paleogeographical significance; plausible causal abiotic trigger associated with this radiation is the lowering of eustatic sealevel. Similarly, the immigration of *Parapodemus,* an evolutionary progeny of *Progonomys* (of Siwalik origin) from Mediterranean region marks the 9.2 Ma bioevent datum in consequence of destruction and growth of conducive habitat for murids of Indian origin in contiguous Mediterranean and Indian Subcontinent regions respectively. These elaborations of bioevents from nonmarine fossil assemblages of the subcontinent bring to fore subtle aspects that remain unfathomed otherwise.

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62. Thakur, V.C & Jayangondaperumal, R.: Seismo-tectonic variation between Central and Northwest Himalaya: implication for major to giant earthquakes hazard. Journal of Asian Earth Sciences (Under revision).

63. Tiwari, S.K., Bartarya, S.K., Rai, S.K., Gupta, A.K. & Asthana, A.K.L. : Isotopic and Geochemical studies of ground water from Ramganga and Middle Ganga plain: Implication to pollution and metal contamination. Environmental Earth Science (Under review).

64. Tiwari, S.K., Rai, S.K., Bartarya, S.K., Gupta, A.K. & Negi, Manju : 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. Geothermics (Under revision).

65. Tiwari, S.K., Sundriyal, Sipika, Kumar, Amit, Gupta, A.K. & Yadav, Jairam: Evolution of hydro-geochemical processes and solute sources study of Dokriani (Bamak) Glacier meltwater, Uttarakhand Himalaya, India. Quaternary International (Communicated).

66. Yadav, D.K., Hazarika, D. & Kumar, N. : Seismicity and stress inversion study in the Kangra-Chamba region of North-west Himalaya. Natural Hazards (In Press).

67. Yadava, A.K., Bräuning, A., Singh, J., Yadav, R.R. : Boreal spring precipitation variability in the cold arid western Himalaya during the last millennium, regional linkages, and socio-economic implications. Quaternary Science Reviews (Communicated).

Technical Reports

1. Bhakuni, S.S. 2015: A Report on Geological and Bioengineering Investigation of Sukhatal area of Nainital, Uttarakhand, India, submitted to Irrigation Department, Uttarakhand.

2. Singh, Nilendu & Singh, Joyeeta 2016: The report of participation in the workshop "Ecosystem carbon/water cycling research in the changing climate", 23-25 April, NIES, Tsukuba, Japan, Asia Flux Newsletter, March 2016, Issue No. 39.

3. Bartarya, S.K & Gupta, V. 2015: Geological Survey Report on the creeping of slopes in the Kailakhan MIL Area, Nainital. Submitted to MES, Ranikhet, 21p.

4. Rawat, G. & Bartarya, S.K. 2015: Report on AMT studies on Chumathang geothermal field as part of Indo-Norway project on utilization of geothermal energy, submitted to DST Govt. of India and NGI, Norway 12p.

5. Gupta, V. along with Members the Expert Team drawn from various organisations. 2015: Report titled “Landslide Assessment and Technical support to Nepal”, submitted to the National Disaster Management Authority (NDMA), New Delhi.

6. Gupta V., along with Members of the Joint Expert Committee drawn from various organisations.

2015: Report on collateral damages on the selected rim area villages due to the filling and drawdown of the Tehri Reservoir, submitted to the Govt of Uttarakhand.

Special Publications of the Institute

1. Bhakuni, S.S., Sen, K., Thakur, S.S., Rawat, G., Mukherjee, P.K. & Tiwari, Meera 2015: Excursion Guide: Rishikesh-Joshimuth-Malari transact. Special publication No.4 (30th HKT). Wadia Institute of Himalayan Geology, Dehradun, 48p.
2. Bhambri, R., Mehta, M., Dobhal, D.P. & Gupta, A.K. 2015: Glacier lake inventory of Uttarakhand. Special Publication, Wadia Institute of Himalayan Geology, Dehradun, 78p.
3. Jayangondaperumal, R., Thakur, V.C. & Tiwari, Meera 2015: Excursion Guide: Himalayan Frontal Folds-Thrust Belts. Special Publication No. 3 (30th HKT). Wadia Institute of Himalayan Geology, Dehradun, 13p.
4. 30th Himalayan-Karakoram-Tibet Workshop, Dehradun, India, October 6-8, 2015, Abstract Volume. Wadia Institute of Himalayan Geology, Dehradun, 324p.

RESEARCH PUBLICATIONS

SEMINAR/SYMPOSIA/WORKSHOP ORGANISED

30th Himalaya-Karakoram-Tibet Workshop (HKT) (October 5-12, 2015)

The Wadia Institute of Himalayan Geology had the privilege of organizing the 30th Himalaya-Karakoram-Tibet Workshop at its premises in Dehra Dun during October 6-8, 2015, which was earlier organised across the globe in many developed countries. The aim of the workshop was to cover the state of-the-art work carried out so far on various themes; identify the existing gaps, debate and discuss those gaps, and ultimately at the end of the workshop come out with commensurate action plan for future studies. The technical proceedings of the three days conference was inaugurated on October 6, 2015 by Hon'ble Governor of Uttarakhand, Shri Krishna Kant Paul. The workshop was attended by leading and young researchers from all over the world. A total number of 264 participants including 46 foreign participants presented their research work in the conference. It includes leading workers from some of the globally recognised Universities like Stanford University, USA; University of Potsdam, Germany; University of Queensland, Australia; New Mexico State University, USA; Nagoya University, Japan; University Joseph Fourier, Grenoble, France; University of Torino, Italy; University of Chicago, USA; University of Bern, Switzerland; Kyoto University, Japan; and participants from IITs, reputed Universities and Research Organisations across India.

The Chief Guest, Hon'ble Governor of Uttarakhand, Shri Krishna Kant Paul during the inaugural function of the 30th HKT which started with 'National Anthem' and 'Saraswati Vandana'. Hon'ble Governor is addressing the participants and other guests of the Workshop

Prof. Anil K. Gupta, Director WIHG, was the Chairman of the organising committee and Dr Rajesh Sharma was the convener of the workshop. The 30th HKT workshop in total had 9 Thematic Session and had very fruitful discussions on the latest developments related to (i) evolution of Himalaya-Karakoram-Tibet, (ii) fluid-rock interaction, (iii) climate change, (iv) tectonics, (v) earthquake precursor studies, (v) geophysical studies of orogenic belts, (vi) biotic and sedimentary records, and (vii) on natural resources, natural hazards and their societal implications. The workshop also showed special interest on the recent disaster of April 25, 2015, the *'The Nepal Earthquake'* by holding a special session exclusively on it. In total, around 18 Keynote Speakers have presented their papers along with 65 other oral presentations, and with around 185 poster presentations during the three days Workshop. The technical sessions came to an end with the valedictory function on October 8, 2015, Hon'ble Union Minister of State for Science & Technology & Ministry of Earth Sciences, Shri Y.S. Chowdary was the Chief Guest on the occasion.

SEMINAR/SYMPOSIA/WORKSHOP ORGANISED

The Chief Guest, Hon'ble Union Minister of State for Science & Technology & Ministry of Earth Sciences, Shri Y.S. Chowdary along with Shri. Bhagat Singh Koshyari, MP Rajya Sabha, during the valedictory function. The Minister also visited the Institute Museum.

On October 5, 2015, the participants were taken to one day pre-workshop field excursion in the Mohand-Mussoorie section. As a part of the event, a four days post-workshop field excursion tour was also organised during October 9-12, 2015 along the Rishikesh-Joshimath-Malari section. Around 24 foreign delegates and 13 Indian delegates have participated in this post-field workshop.

The Indian and the foreign delegates of the 30th HKT-2015 participating in the post-workshop field excursion along the Rishikesh- Joshimath-Malari section, Uttarakhand.

Indo-Norwegian Project: Kick-off Meeting (April 24-25, 2015)

A kick off meeting of the Indo-Norwegian Project at National Geotechnical Facility (NGF), Dehra Dun was organised during April 24-25, 2015, and was coordinated by Dr Vikram Gupta. Dr. R.K. Bhasin and Dr. Frode Sanderson from Norwegian Geotechnical Institute, Oslo (Norway); Dr. S.K. Mittal from Central Scientific Instrumentation Organisation (CSIO), Chandigarh; Prof. Y.P. Sundriyal from H.N.B. Garhwal University, Srinagar, Uttarakhand; Dr. Bhoop Singh from Department of Science & Technology (DST), New Delhi; and Dr Rajesh Sharma and Vikram Gupta from Wadia Institute of Himalayan Geology, Dehradun along with scientists working in National Geotechnical Facility participated in the meeting. Presentations were made by all the participants in the meeting, and course of action for future research work was planned.

AWARDS AND HONOURS

- Dr. T.N. Jowhar was Sessional President for Earth System Sciences in the 103rd Indian Science Congress held at Mysore University, Mysore from January 3-7, 2016.
- Drs. P.K. Mukherjee, P.P. Khanna and N.K. Saini received the 'Best Paper Award-2015' for their paper *'Rapid determination of trace and ultra-trace level elements in diverse silicate rocks in pressed powder pellet targets by LA-ICP-MS using a Matrix- Independent Protocol'* published in Geostandards and Geoanalytical Research.
- Dr. Naresh Kumar is the Guest Editor of Special Issue of the Quaternary International Journal on *'Himalaya Active Tectonics'*. He is also the regular Associate of the International Centre for Theoretical Physics (ICTP), Italy.
- Dr. Sushil Kumar was nominated the Convener & Session Chair on the theme *'Understanding of Active Tectonics in the Asian Region and Large Earthquake Generation'* in the International workshop AOGS-2015 held in Singapore during August 2-7, 2015.

VISITS ABROAD

- Dr. Nilendu visited Tsukuba, Japan to participate and present his work in a workshop on the *'Ecosystem Carbon/Water Cycling Research in the Changing Climate'* during April 23-25, 2015.
- Dr. Bikramaditya Singh visited National Taiwan University, Taipei, Taiwan as a Postdoctoral Fellow for six months from May 6 to November 5, 2015.
- Dr. Vikram Gupta visited Nepal during June 3-7, 2015 as a member of the Expert team of National Disaster Mitigation Authority (NDMA), New Delhi to assess landslide scenario and to discuss the technical support to Nepal after the Nepal Earthquake.
- Dr. Aparna Shukla visited Milan, Italy to participate and present her work in the 'International *Geoscience and Remote Sensing Symposium, (IGARSS-2015)'* during July 26-31, 2015.
- Dr. Suman Lata Rawat visited Nagoya, Japan to participate and present her work in the *XIX INQUA Congress* on *'Quaternary perspective on climate change, natural hazards and civilization'* during July 25 to August 2, 2015.
- Dr. Sushil Kumar visited Singapore to participate and present his work in the International 'AOGS-2015' Workshop during August 2-7, 2015.
- Dr. Archna Bohra visited Lanzhou University, China to participate and present her work in the *'13th International Paleolimnology Symposium (IPS-2015*)' during August 4-7, 2015.
- Dr. Santosh K Rai visited Germany for training on *'Neptune Plus (LA-MC-ICPMS)'* at Thermo Fisher, Bremen during October 19-30, 2015.
- Dr. A.K. Singh visited National Taiwan University (NTU), Taiwan to deliver an invited lecture, and to visit lab during October 24 to November 8, 2015.
- Sh. Prakasam M. visited Trieste, Italy to participate and present his work in International Workshop on *'Decadal Climate Variability and Predictability: Challenge and Opportunity'*, held during November 16-24, 2015.
- Dr. Akshaya Verma visited ICIMOD, Kathmandu, Nepal to attend the 2nd Regional Training on *'Glacio-Hydrological Modelling using the SPHY Model'* organised by ICIMOD, Nepal and Future Water, Netherlands during December 14-18, 2015.

Ph.D. THESES

Name of Student	Supervisor	Title of the Theses	University	Awarded/ Submitted
Leena Kamra	Dr. V.M. Choubey Prof. R.C. Ramola	Studies of radon and allied Parameters as earthquake precursors in Garhwal Himalaya	H.N.B. Garhwal University, Srinagar	Awarded
Mayank Joshi	Dr. V.C. Thakur Dr. Y.P. Sundriyal	Climate-tectonic interaction in the morphogenic evolution of Ravi river basin in Chamba region, Western Himachal Pradesh, NW Himalaya	H.N.B. Garhwal University, Srinagar	Awarded
Koushick Sen	Dr. B.K. Mukherjee	Formation and Tectonic evolution of Zildat Ophiolitic Melange, Indus Suture Zone, NW Himalaya, India	University of Petroleum and Energy Studies, Dehradun	Awarded
Sameer Kumar Tiwari	Dr. S.K. Bartarya Dr. S.K. Rai	Isotopic and Geochemical Studies of Geothermal Springs of North West Himalayas, India: Implication for Source and Degassing of Metaphoric CO_2	University of Petroleum and Energy Studies, Dehradun	Awarded
Bhanu Pratap	Dr. D.P. Dobhal Dr. V.C. Tewari	Mass balance of Dokriani Glacier, Central Himalaya: A model in response to climate fluctuation and debris cover	University of Petroleum and Energy Studies, Dehradun	Awarded
Kapil Kesarwani	Dr. D.P. Dobhal Dr. Alok Durgapal	Energy Balance and Mass Fluctuation of Himalayan Glacier: A case study of Chorabari Glacier, Garhwal Himalaya, India	Kumaun University, Nainital	Submitted
Smita Gupta	Dr. Kishor Kumar Prof. R.S. Rana	Paleontological and geochemical study of Subathu succession of NW sub-Himalaya with reference to PETM and India-Asia collision	H.N.B. Garhwal University, Srinagar	Submitted
Mala Bhatt	Dr. S.K Bartarya Dr. N.P Naithani	Hydrogeological studies around Tehri dam, Garhwal Himalaya, Uttarakhand with special reference to impact of Tehri dam on the Geo-environment of the Area	H.N.B. Garhwal University, Srinagar	Submitted

PARTICIPATIONS IN SEMINARS/SYMPOSIA/ WORKSHOPS/ MEETINGS/ TRAINING COURSES

National Conference on *'Palaeogene of the Indian Sub-Continent'* at Lucknow during April 23-24, 2015.

Participant: Kapesa Lokho

PAMC Meeting at NGRI Hyderabad during May 5-7, 2015 for ongoing project presentation.

Participant: R. Jayangondaperumal

SERB-DST meeting at VFSTR University, Vadlamudi, Guntur District, Andhra Pradesh during June 29-30. 2015 for ongoing project presentation.

Participant: Archana Bohra

Scientific Exchange Workshop on *'Vulnerability, Risks and Hazards & Adaptation in the Indian Himalayan Region'* at New Delhi during July 2-3, 2015.

Participant: D.P. Dobhal

'XII-International Symposium on Antarctic Earth Sciences (ISAES2015)' at National Centre for Antarctic and Ocean Research (NCAOR) Goa during July 13-17, 2015.

Participant: Kapil Kesarwani

Workshop on *'Management of Glacier Lake Outburst'* organized by Central Water Commission at New Delhi on July 28, 2015.

Participant: Rakesh Bhambri

Workshop on *'Regional Multi-stakeholder Himalayan Sustainable Development Forum (HSDF)'* at Hotel Pacific, Dehradun on August 4, 2015.

Participant: D.P. Dobhal

Workshop on *'Indian Himalayan Climate Adaptation Programme (IHCAP) Phase-II Planning'* at New Delhi during August 10-12, 2015.

Participant: D.P. Dobhal

Workshop on *'First Himalayan Conclave-2015'* at Delhi University, Delhi during September 9-10, 2015.

Participant: D.P. Dobhal

Workshop on *'Earthquake Resistance Construction Technology'* at Uttarakhand Academy of Administration, Nainital during September 28-30, 2015.

Participant: Dilip K. Yadav

'PAC Meeting' at MoES, New Delhi during September 29-30, 2015 for ongoing project presentation.

Participant: R. Jayangondaperumal

30th Himalaya Karakoram Tibet workshop at Wadia Institute of Himalayan Geology, Dehradun during October 6-8, 2015.

Participants: Scientists and Research Scholars of the Institute

International Conference on *'Global environmental change in the Himalayas: Controversies, Impacts, and Futures'* at India Habitat Centre, New Delhi during November 6-8, 2015.

Participant: Rakesh Bhambri

International Workshop on *'Changes in Water Resource and Adaption Options in the Himalayan Basins'* at NIH, Roorkee during November 16-17, 2015.

Participant: D.P. Dobhal

'XXIII International Grassland Conference (IGC)' at New Delhi during November 20-24, 2015.

Participant: Nilendu Singh

Conference on *'Environmental Pollution'* at Kashipur on November 29, 2015.

Participant: P.S. Negi

Brain storming session on *'36th IGC: A Unique Opportunity for Advancement in Geosciences'* at GSI, Northern Region, Lucknow during December 3-4, 2015.

Participant: D.P. Dobhal

'*India International Science Festival (IISF-2015)*' at IIT Delhi during December 4-8, 2015.

Participants: Rajesh Sharma, S.K. Parcha, Ajay Paul, M. Prakasam and Chhavi Pandey

National Conference on *'Palaeogene of the Indian Sub-Continent'* at Lucknow during April 23-24, 2015.

Participant: Kapesa Lokho

PAMC Meeting at NGRI Hyderabad during May 5-7, 2015 for ongoing project presentation.

Participant: R. Jayangondaperumal

SERB-DST meeting at VFSTR University, Vadlamudi, Guntur District, Andhra Pradesh during June 29-30. 2015 for ongoing project presentation.

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Scientific Exchange Workshop on *'Vulnerability, Risks and Hazards & Adaptation in the Indian Himalayan Region'* at New Delhi during July 2-3, 2015.

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'XXIII International Grassland Conference (IGC)' at New Delhi during November 20-24, 2015.

Participant: Nilendu Singh

Conference on *'Environmental Pollution'* at Kashipur on November 29, 2015.

LECTURES BY INSTITUTE SCIENTISTS

Name of Scientist	Venue	Date	Topic
Vikram Gupta	NGF, Dehradun	24.04.2015	Surabhi Landslide - revisited
Sushil Kumar	INSA, New Delhi	25.04.2015	Nepal Earthquake and Earthquake risk in Uttarakhand
Vikram Gupta	Civil Service Institute, Dehra Dun	29.04.2015	Towards establishing rainfall threshold for the Uttarakhand Himalaya
Santosh K. Rai	Govt. Inter College, Jayapur, Varanasi	30.04.2015	Ganga River at Prime Minister's adopted village Jayapur
R. Jayangonda-perumal	Kumaun University, Nainital	02.05.2015	Active faults of Garhwal and Kumaun Himalaya
P.S. Negi	Welhem School, Dehradun	16.05.2015	Himalayan Ecosystem
Vikram Gupta	NGF, Dehradun	18.06.2015	(i) Landslide and various Geotechnical issues in the Himalaya (ii) Geotechnical issues for landslide mitigation in the Himalaya
S.S. Thakur	Kumaun University, Nainital	18-26.06.2015	Delivered series of lectures as guest faculty on metamorphic course for M.Sc. students
Vikram Gupta	Hotel Carnegie, New Delhi	03.07.2015	General hazard scenario in the Indian Himalaya
Aparna Shukla	SASE, Chandigarh	06.07.2015	i) Digital image information extraction techniques for snow cover mapping using Remote Sensing ii) Mapping of debris-covered glaciers using satellite image processing techniques
Reet Kamal Tiwari	SASE, Chandigarh	07.07.2015	Glacier surface ice velocity estimation and glacier dynamics
Santosh K. Rai	LBS National Academy of Administration, Mussoorie	06.08.2015	Mainstreaming climate change in Development
P.K. Mukherjee	Archaeological Survey of India, Dehradun	19.08.2015	Investigation of sub-surface structure Mineralogical & Textural control on weathering of building stones
Rakesh Bhambri	Guru Nanak Khalsa College, Karnal	23.08.2015	Application of geo-spatial technology in Glaciers studies

D.P. Dobhal	LBS National Academy of Administration, Mussoorie	24.08.2015	Climate change, Glaciers and Glacier Lakes in the Himalaya: An overview
S.S. Thakur	Kumaun University, Nainital	26-28.08.2015	Delivered lectures on Mineralogy to M.Sc. students
P.S. Negi	Kashipur, Uttarakhand	27.08.2015	Eco-friendly Industries in Himalaya
D.P. Dobhal	FRI, Dehradun	09.10.2015	Climate Change and State of Himalayan Glaciers: Issues,Challenges and Facts
Sushil Kumar	COER, Roorkee	04.11.2015	Earthquake Hazard and Risk in the NW Himalaya, India
Sushil Kumar	Secretariat, Dehradun	01.12.2015	Earthquake precursor related information for the state of Uttarakhand
G. Philip	IIRS, Dehradun	02.12.2015	Geospatial techniques for active tectonic studies
Vikram Gupta	India Habitat Centre, New Delhi	02.12.2015	Landslide Hazard scenarios in the hilly township of Mussoorie and Nainital, Uttarakhand Himalaya
Santosh K Rai	WIHG, Dehradun	04.12.2015	Mass spectrometry (MC-ICPMS): Instrumentation and exploring possibilities in Geosciences
Pradeep Srivastava	Amrita University, Kollam, Kerala	12.12.2015	Landslides: A perspective from Himalaya
Naresh Kumar	University of Allahabad, Allahabad	24.12.2015	Crustal velocity structure and seismo-tectonic of Kinnaur region of NW Himalaya: new constraints based on micro-earthquake activity
Pradeep Srivastava	INSPRE camp at HNB Garhwal University, Srinagar	25.12.2015	Continental Drift, plate tectonics and build-up of Himalaya
Rajesh Sharma	103rd Indian Science Congress, Mysore	06.01.2016	Trapped Basinal Fluids and Implications in Himalayan Sedimentary Sequences
S.K. Bartarya	ICFRE, FRI, Dehradun	01.02.2016	Geological Aspects of Disaster Management in Himalaya
D.P. Dobhal	ICFRE, FRI, Dehradun	09.02.2016	Climate change impact on glaciers - Observation and Facts
Pradeep Srivastava	BSIP, Lucknow	24.02.2016	A centennial scale climate record from Garhwal Himalaya

Vikram Gupta	HNB Garhwal University, Srinagar	27.02.2016	Landslide hazards in the Mandakini valley, Garhwal Himalaya
G. Philip	IIRS, Dehradun	08.03.2016	Geospatial techniques in the study of active faults
Vikram Gupta	University of Petroleum of Energy Studies, Dehradun	12.03.2016	Series of lectures on the "Various Geo-technical issues and Engineering Geology"
R. Jayangonda-perumal	NGRI, Hyderabad	28.03.2016	Active fault mapping and its characterization along the Himalayan Frontal Thrust of India: Insight to the patterns of strain release along a Continental Convergent Plate Boundary
Sushil Kumar	Tibetan Homes School Happy Valley, Mussoorie	31.03.2016	Disasters and its management strategies in Uttarakhand

MEMBERSHIP

Sharma, Rajesh : Member, Scientific Committee for the 'VI Asian Current Research on Fluid Inclusions', IIT-Bombay, Mumbai

Mukherjee, P.K. : Member, Technical Committee: National Geochronology Centre at IUGS, New Delhi

Kumar, Sushil : Member, Seismological Society of America (SSA), California
Member, Japan Geoscience Union Tokyo, Japan
Member, Indian Society of Earthquake Technology, IITR, Roorkee
Member, American Geophysical Union, California

Dobhal, D.P. : Member, Expert Committee on the theme: *'Glaciology, Climate Change and Societal issues'* for the 36th International Geological Congress (IGC-2020) in India
Member, Programme Advisory Committee (PAC), Earth and Atmospheric Sciences under SERB, DST, New Delhi

Gupta, Vikram : Member, National Green Tribunal (NGT) to look after the construction activities in Shimla, Himachal Pradesh

Shukla, Aparna : Member, Executive Council of Indian Society of Remote Sensing-Dehradun Chapter (ISRS-DC) for the term 2016-2018

Prakasam, M. : Member, American Geophysical Union, California

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section during this year brought out the publications of

- 'Himalayan Geology' volumes 36(2) and 37(1)
- 'Annual Report' of the Institute for the year 2014-15 in Hindi and English
- Hindi magazine 'Ashmika' volume 21
- Newsletters 'Bhugarbh Vani' volumes 5 (Nos. 1-4) and 'Drishtikon' volume 4
- Books: entitled (i) 'Glacier Lake Inventory of Uttarakhand' (authored by Rakesh Bhambri et al.), and (ii) 'Siwalik Mammalian faunas of the foothills with references to biochronology, linkages and migration' (authored by A.C. Nanda)
- Abstract volume of the 30th Himalaya-Karakoram-Tibet workshop
- Field Excursion Guides: (i) 'Himalayan Frontal Folds-Thrusts Belts', and (ii) 'Rishikesh-Joshimath-Malari Transect (Garhwal Himalaya)'

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

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. The 'Himalayan Geology' is indexed in Thomson Reutors (US), SCOPUS (Elsevier, Netherlands) and in Indian Citation Index (ICI) New Delhi. 10 new members got registered under the Life Time Subscriber Scheme (LTSS) Membership for Himalayan Geology journal bring the total registered number to 451.

LIBRARY

The Library of Wadia Institute of Himalayan Geology is an exceptional Library of its kind, consisting of finest collection of books, monographs, journals, e-books and others on the mountain building process, geological and geophysical phenomenon with special reference to the Himalaya. The collection and services offered makes it one of the best library in the country in the field of Earth Sciences. The library has always been as a best information access support to scientists and researchers in their endeavour to highly specialized activities. Specialists and professionals from all across the country also visit the library to utilize the specialized and rare collections available and other services provided by this library.

The Library subscribed to 84 foreign and 44 Indian journals. During the period of this report a total number of 89 reference books are purchased and 13 books are

Panoramic view of the Institute Library

received as gratis. In addition to this, a total number of 23 Hindi books were purchased. The Library has also purchased the back files collection of *Journal of Petrology* from 1966 to 1996, and also purchased the back files collection of the *Special Publications of Geological Society of London,* Nos. 301(2008) to 400 (2014).

The WIHG library has more than 6000 carefully selected e-books from different publishers and learned societies on the thrust areas of the Institute. During 2014-15 the existing collections were updated and some new e-books collections are purchased, which include 850 e-books of Springer's Earth and Environmental Science collection published during the year 2015; 51 titles from Wiley's Earth and Environmental Science subject collection; 66 titles of books published during 2013-2014 from Earth and Planetary Science e-books including series titles, and archive of AGU publications consisting of 16 titles.

The Library has the small hub of computers for accessing the e-books and e-journals and Internet surfing and the other e-resources available, either subscribed by WIHG Library or available through the National Knowledge Resource Consortium (NKRC). We have online access to many of the publisher who contribute to more than four hundred journals' titles, other than subscribed by the Institute. The library also serves as central facility for the photocopying work of the Institute.

S.P. NAUTIYAL MUSEUM

The Museum of the Wadia Institute named after Prof. S. P. Nautiyal, remains the main center of attraction for national and international visitors. During this year more than 2,000 people visited the Museum from the different part of India, and from other countries like USA, Norway, Italy, Canada, France, United Kingdom, Australia, Germany, Japan, Switzerland, Austria, and Russia. The visitors include the students in large numbers from different schools, universities, colleges and other institutions. In addition, army and ITBP cadets, the general public and tourists also visited the museum. A number of students also visit the museum for their respective school projects on Earthquake and geology related topics. A model of extinct species of Giraffe prepared from waste material is kept for display in the WIHG lawn. The model not only provides interesting and important information regarding the extinct species of the Giraffe but also sends out message of saving the environment. The exhibit became centre of attraction for general public and for dignitaries who visited the Institute, and have appreciated it a lot.

Open Days were observed during 'National Technology Day', 'Foundation Day', 'Founder's Day; and 'National Science Day' wherein the Museum is kept open for visitors. Wide coverage for Open Days to public participation is given through print media, as a result of which a large number of people from the general public visited the museum on these occasions. Brochures containing important information regarding the Institute activities are provided free of cost to the visitors.

Partial view of the Institute Museum

TECHNICAL SERVICES

Analytical Services

The number of samples analysed by various instruments like, XRF, ICP-MS, SEM-EDX, XRD, OSL, Stable Isotope Mass Spectrometer and EPMA is given in table below.

Instrument	Samples analysed		
	WIHG Users	Outside Users	Total
XRF	629	898	1527
ICP-MS	645	603	1248
SEM-EDX	393	563	956
XRD	632	188	820
OSL	74	18	92
LA-MC-ICPMS (Zircon geochronology)	293	0	293
Stable Isotope Mass Spectrometer	1314	640	1954
EPMA	53	23	76#
Paleomagnetic Lab:			
AFD & Spinner Magnetometer	630	-	650
Magnetic Susceptibility Meter	630	-	630
Impulse Magnetizer	188	-	108
Anhystric Remanent Magnetizer	630	-	650
Kappa bridge (KLY-3S)	630	630	296

#In EPMA, Thin Sections were analysed which includes analysis of various minerals and taking large number of point analysis from different parts of the individual mineral grains.

Photography Section

During the year around 5,800 digital images were clicked to cover the various functions, including Foundation Day, Founders Day, National Science Day, National Technology Day, New Year's Day, Seminars/Symposia (e.g., HKT-2015), cultural programme, and superannuation function of the Institute staff etc. Apart from this around 700 snaps were clicked for rock and fossil specimens. The colour printing of around 300 digital images was arranged from the market. No new cameras/lenses or any other photographic materials were purchased 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 and Research Scholars of the Institute including the sponsored projects. During the reporting year, the section has provided 32 geological/structural/ geomorphological maps/seismicity diagrams for the scientists and research scholars of the Institute, along with the tracing of fourteen topographic sheets/aerial photo maps, as well as two geological columns have been prepared. The section has also provided seminar ID badges, 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 this year, the laboratory provided 1,047 thin and polished sections to various users for carrying out microscopic, fluid inclusion and EPMA studies. The laboratory also processed crushing/grinding of 1,449 rock samples for carrying out major, trace and REE analysis by ICPMS, XRF and XRD methods.

CELEBRATIONS

Technology Day

The Technology Day was celebrated in the Institute on May 11, 2015. On this occasion Retd. Vice Admiral Raman Puri, PVSM, AVSM, VSM delivered the 'Technology Day Lecture' on the topic *'Technology in Make in India - The Defence Sector'*.

Retd. Vice Admiral Raman Puri delivering the 'Technology Day' lecture

Foundation Day

The 47th Foundation Day was celebrated in the Institute on June 29, 2015. Professor V.K. Jain, Vice Chancellor, Doon University was the Chief Guest and he delivered the 'Foundation Day Lecture' on the topic, *'Climate Change: An Overview'*. The occasion was also marked by distribution of awards by 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. The 'Best Paper Award' was given to Drs. P.K. Mukherjee, P.P. Khanna and N.K. Saini for their paper *'Rapid determination of trace and ultra-trace level elements in diverse silicate rocks in pressed powder pellet targets by LA-ICP-MS using a Matrix-Independent Protocol'* published in Geostandards and Geoanalytical Research.

Prof. M.P. Singh who was Guest-of-honour on the occasion gave away the first award constituted in the honour of late Prof. R.C. Misra named as *'Prof. R.C. Misra Gold Medal in Geosciences'*. An award given annually to the young scientists below the age of 35 years. Dr. Gaurav Srivastava from BSIP, Lucknow was the first recipient of this award, and had received the award from Prof. M.P. Singh.

The 'Best Workers Awards' for the Institute employees were also given by Prof. V.K. Jain, Prof. M.P. Singh and the Director to Sh. Ravindra Singh, Sh. Tajendra Ahuja, Sh. Rambir Kaushik, Sh. B.S. Rana, Sh. Navneet Kumar, Sh. Rakesh Kumar, Sh. S.K. Thapliyal, Sh. Rajendra Prakash, Sh. Tirthraj Ram, Km Shalini Negi, Sh. Rahul Sharma, Sh. Kulvant Singh Manral, Sh. Girish Chandra Singh, Sh. Santu Das, Sh. Hari Singh Chauhan, Sh. Preetam Singh, Sh. R.S.Negi, Sh. M.S. Rawat, Sh. Deepak Tiwari, Sh. Rajesh Yadav, Sh. Sohan Singh, Sh. Shyam Singh, Sh. Vijay Singh, Smt Kamla Devi, Sh. S.K. Gupta, Sh. Chet Ram, Sh. Pritam Singh Powar, Sh. Ramesh Chandra Rana, Sh. Dinesh Singh, and Sh. Hari Kishan.

Prof. V.K. Jain giving the Best Paper Award of the Institute to Drs. P.P. Khanna and N.K. Saini

Dr. Gaurav Srivastava receiving the 'Prof. R.C. Misra Gold Medal in Geoscience'

CELEBRATIONS

Independence Day

The Institute celebrated Independence Day on August 15, 2015. Flag hoisting was followed by a formal address by Prof A.K. Gupta, Director of the Institute. As a mark of Independence Day celebrations various programmes were organized such as tree plantation, drawing competition and games for the Institute employees and their children. Prizes were distributed to the winners of various events.

Children participating in sports events on the eve of Independence Day celebrations

Dr. A.P.J. Abdul Kalam Birth Anniversary

Dr. A.P.J. Abdul Kalam 84th Birth Anniversary celebration was organised in the Institute on October 15, 2015. On this occasion Prof Mahavir Prasad, Vice Chancellor Uttarakhand Sanskrit University, Haridwar delivered a lecture covering the *'General aspects of life with special reference to Dr. A.P.J. Abdul Kalam'*. Institute scientists and research scholars have also shared their feelings about Dr. Kalam. A quiz (on Dr. Kalam) was also organized on this occasion.

Prof. Mahavir Prasad delivering a lecture on 84th Birth Anniversary of Dr. A.P.J. Abdul Kalam

Founder's Day

The Institute celebrated October 23rd 2015 as 'Founders Day' in the honour of Birth Anniversary of Prof. D.N. Wadia. In remembrance of the day, a 'Founder's Day Lecture' was organized on January 27, 2016. The lecture was delivered by Prof. Krishan Lal, President, the Association of Academies & Societies of Science in Asia (AASSA) and Former Director NPL, New Delhi on the topic '*Crystals: From Natures Womb To Most Advance Application'*.

Prof. Krishan Lal delivering the 'Foundation Day Lecture'

Republic Day

The Institute celebrated Republic Day on January 26, 2016. Prof. Anil K Gupta, Director hoisted the National Flag. As a mark of Republic Day celebrations various sports and cultural activities were organized in the Institute for the Institute employees and their children. Prizes were distributed to the winners of various events.

Prof. Anil K. Gupta, Director is seen distributing the prizes to the winners of the sports event

National Science Day

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

Dr. Rajendra Dobhal, Director General, Uttarakhand Science & Technology, Uttarakhand was the Chief Guest on the National Science Day, and he delivered the invited 'National Science Day Lecture' on *'Science, Our Common Strength'*. 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.

Chief Guest Dr. Rajendra Dobhal distributing prizes to the winners of the various events on 'National Science Day'

The Institute also observed 'Open Day' on February 29, 2016. On this day all the laboratories were kept open to students and public. A large number of school and college students, and other public from Dehradun regions visited the Laboratories of the Institute. 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.

Institute Other Activities

- Institute has participated and displayed its exhibits in the *'India International Science Festival Mega Science Exhibition'* held at IIT-Delhi, New Delhi from December 4-8, 2015.
- Institute within its premises has arranged to organize a *'Free Heart Check-up Camp'* by Fortis-Escorts Hospital, Dehradun on July 17, 2015, and a *'Free Eye Test Camp'* by Drishti Eye Clinic, Dehradun on August 19, 2015 for its employees.
- Around 150 employees and research scholars of the Institute participated in *'Swacchata Abhiyan'* on October 2, 2015 in Dehradun, and cleaned the roads & drains and collected garbage from more than 15 points on the GMS road.
- Institute has participated and displayed its exhibits in the *'103rd Indian Science Congress (Pride of India Expo)'* held in Mysore University from January 3-7, 2016.
- Institute has participated and displayed its exhibits in the 12th Uttarakhand state Science & Technology Exhibition during February 10-12, 2016.
- Institute has participated and displayed its exhibits in the Basant Utsav held at Rajbhavan Uttarakhand, Dehradun on March 5-6, 2016.

'Free Heart Check-up Camp' by Fortis-Escorts Hospital, Dehradun for the employees in the Institute premise

CELEBRATIONS

DISTINGUISHED VISITORS TO THE INSTITUTE

- Dr. Krishan Kant Paul, Hon'ble Governor of Uttarakhand, Uttarakhand
- Shri Y. S. Chowdary, Hon'ble Minister of State for Ministry of Science & Technology and Ministry of Earth Sciences
- Vice Admiral (Rtd.) Raman Puri
- Professor Krishan Lal, President, the Association of Academies and Societies of Science in Asia (AASSA) and Former Director NPL, New Delhi
- Prof. David Rowley from the University of Chicago, USA
- Prof. Julia de Sigoyer from the University Grenoble, France
- Prof. Patrick O'Brien from the University of Potsdam, Germany
- Prof. Simon Klemperer from the Stanford University, USA
- Prof. Tina Niemi from the University of Missouri, USA
- Prof. Jonathan Aitcheson from the University of Queensland, Australia
- Prof. Rodolfo Carosi from the University of Torino, Italy
- Prof. Harutaka Sakai from the Kyoto University, Japan
- Prof. Jean-Luc Epard from the University of Laussane, Switzerland

STATUS OF IMPLEMENTATION OF HINDI

In order to promote Hindi language in office work and everyday life, Hindi Pakhwara was celebrated in the Institute during September 14-28, 2015. Inaugural lecture of the Pakhwara was delivered by Dr. Rajendra Dobhal, DG, UCOST, Dehradun. In his lecture he stressed the need of 'Science outreach through Hindi language'. Various other programmes like essay writing and debate for school children, as well as self-written poems & recitation and essay writing competitions for Institute employees were also organised during Pakhwara. The bi-weekly program also had specialized lectures in Hindi by Institute employees like, Dr. S.K. Rai, Dr. Sameer Tiwari, Shri Raj Kishor and Shri Harish Chandra. The Chief Guest for the valedictory session of the programme i.e., on September 28, 2015 was Dr. Savita, Director, FRI and V.C., FRI deemed University. She delivered a talk on 'Use of Hindi language'. Dr. V.K.S. Dave, former Prof of IIT Roorkee, who was Guest-of-honour for the function delivered a lecture in which he stressed the need of 'Correct use of Hindi language'. Prizes were distributed to winners of different competitions among school children and Institute employees.

Chief Guest Dr Rajendra Dobhal is being welcomed by Prof. Anil K. Gupta, Director during the inaugural of Hindi Pakhwara

Dr. Savita delivering the Hindi lecture

Prof. V.K.S. Dave delivering the Hindi lecture

During the year under report, efforts for progressive use of Hindi was continued. The scientists and staff of the Institute were time and again apprised with the various orders and constitutional provisions of official Language. Act to increase awareness for progressive use of Hindi in day-to-day work, various incentive schemes for encouraging progressive use of Hindi were implemented. General orders, circulars and notices were issued in Hindi as well as in English. Orders/decisions regarding use of Hindi received from the Government of India from time to time were circulated to all the concerned officers in the Institute for compliance. The Annual Report of the Institute for the year 2014-15 was also published in Hindi. The Hindi Magazine 'Ashmika' volume 21 was released on June 29, 2015, the '47th Foundation Day' of the Institute. For the promotion of Hindi among the Institute staff a good collection of Hindi books are also procured in the Institute Library. During the reporting period a total number of 23 books were added to the Hindi books collection. The total collection crossed 3000 books consisting of poetry, drama, literature, short stories and novels by eminent authors on wide range of subjects.

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 four Senior Scientists/Officers for redressal of employee's grievances. No request regarding grievance of any of the employee was received during the year by the Grievance 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 2015-16.

6. Status of Vigilance Cases

No vigilance case was either pending or was contemplated against any of the employee of the Institute during the year 2015-16.

7. Information on the RTI cases

Two applications for seeking information and one appeal under the Right to Information Act, 2005 were carried forward from the previous year 2014-15.

The details of information on the RTI cases during the year 2015-16 are as under:

Details	Opening balance as on 01.04.2015	Received during the year 2015-2016	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	02	21*	Nil	Nil	19
First appeals	Nil	Nil	Nil	Nil	Nil

*Four applications under the Right to Information Act, 2005 were carried forward to the next financial year 2016-17.

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 2015-2016

Plan	:	Rs. 2,950.00 lakhs
Non-Plan	:	Rs. 50.00 lakhs
Total	:	Rs. 3,000.00 lakhs

STAFF OF THE INSTITUTE AS ON 01.04.2016

Scientific Staff

1.	Prof. Anil Kumar Gupta	Director
2.	Dr. Rohtash Kumar	Scientist 'G' (Retired on 31.07.15)
3.	Dr. P.P. Khanna	Scientist 'G' (Retired on 31.07.15)
4.	Dr. (Mrs.) Meera Tiwari	Scientist 'G'
5.	Dr. N.K. Saini	Scientist 'G' (Retired on 31.07.15)
6.	Dr. Rafikul Islam	Scientist 'G' (Retired on 30.04.15)
7.	Dr. S.K. Ghosh	Scientist 'G' (Retired on 30.06.15)
8.	Dr. Kishor Kumar	Scientist 'G'
9.	Dr. Rajesh Sharma	Scientist 'G'
10.	Dr. G. Philip	Scientist 'G'
11.	Dr. B.N. Tiwari	Scientist 'G'
12.	Dr. D. Rameshwar Rao	Scientist 'G'
13.	Dr. P.K. Mukharjee	Scientist 'G'
14.	Dr. Keser Singh	Scientist 'G' (Retired on 30.06.15)
15.	Dr. S.K. Bartarya	Scientist 'F'
16.	Dr. T.N. Jowhar	Scientist 'F' (Retired on 30.11.15)
17.	Dr. S.K. Parcha	Scientist 'F'
18.	Dr. H.K. Sachan	Scientist 'F'
19.	Dr. Sushil Kumar	Scientist 'F'
20.	Dr. A.K. Mahajan	Scientist 'E' (On Lien)
21.	Dr. D.P. Dobhal	Scientist 'E' (On Deputation)
22.	Dr. Vikram Gupta	Scientist 'E'
23.	Dr. Suresh N.	Scientist 'E'
24.	Dr. Pradeep Srivastava	Scientist 'E'
25.	Shri V. Sriram	Scientist 'E'
26.	Dr. Ajay Paul	Scientist 'E'
27.	Dr. S.S. Bhakuni	Scientist 'D'
28.	Dr. P.S. Negi	Scientist 'D'
29.	Dr. A.K.L. Asthana	Scientist 'D'
30.	Dr. R. Jayangondaperumal	Scientist 'D'
31.	Dr. A.K. Singh	Scientist 'D'
32.	Dr. (Mrs.) Kapesa Lokho	Scientist 'D'
33.	Dr. Khaying Shing Luirei	Scientist 'D'
34.	Dr. Gautam Rawat	Scientist 'D'
35.	Dr. R.K. Sehgal	Scientist 'D'
36.	Dr. Jayendra Singh	Scientist 'D'
37.	Dr. B.K. Mukherjee	Scientist 'D'
38.	Dr. Santosh Kumar Rai	Scientist 'D' (Lien vacancy)
39.	Dr. Rajesh S.	Scientist 'C'
40.	Dr. Naresh Kumar	Scientist 'C'
41	Dr.(Mrs) Swapnamita Ch.	Scientist 'C'
42.	Dr. Devajit Hazarika	Scientist 'C'
43.	Dr. Narendra K. Meena	Scientist 'C'
44.	Dr. Dilip Kumar Yadav	Scientist 'C'
45.	Dr. Param K.R. Gautam	Scientist 'C'
46.	Dr. Kaushik Sen	Scientist 'C'
47.	Dr. Satyajeet S. Thakur	Scientist 'C'
48.	Dr. Manish Mehta	Scientist 'C'
49.	Dr. (Ms.) Aparna Shukla	Scientist 'C'
50.	Dr Sudipta Sarkar	Scientist 'B'
51.	Sh. M. Prakasam	Scientist 'B'
52.	Dr. Vikas	Scientist 'B'
53.	Sh. Som Dutt	Scientist 'B'
54.	Sh. Anil Kumar	Scientist 'B'
55.	Sh. Saurabh Singhal	Scientist 'B'
56.	Dr. Narendra Kumar	Scientist 'B'
57.	Sh. Vinit Kumar	Scientist 'B'
58.	Dr. Aditya Kharya	Scientist 'B'
59.	Dr. Paramjeet Singh	Scientist 'B'
60.	Dr.(Ms) Suman Lata Rawat	Scientist 'B'
61.	Dr. Indu Shekhar	Scientist 'B'
62.	Dr. (Mrs) Chhavi P. Pandey	Scientist 'B'
63.	Dr. Parveen Kumar	Scientist 'B'

Technical Staff

1.	Shri Saeed Ahmad	Sr. Librarian
2.	Shri B.B. Sharma	Sr. Tech. Officer(Ret.on 30.06.15)
3.	Shri M.M.S. Rawat	Sr. Technical Officer
4.	Shri Sanjeev K. Dabral	Sr. Technical Officer
5.	Shri Chandra Shekhar	Sr. Technical Officer
6.	Shri Samay Singh	Sr. Technical Officer
7.	Shri S.C. Kothiyal	Sr. Tech. Officer(Ret.on 31.01.16)
8.	Shri H.C. Pandey	Technical Officer
9.	Shri Ravindra Singh	Technical Officer
10.	Shri Rakesh Kumar	Technical Officer
11.	Shri N.K. Juyal	Technical Officer
12.	Shri C.B. Sharma	Assistant Engineer
13.	Shri T.K. Ahuja	Jr. Technical Officer
14.	Shri S.S. Bhandari	Librarian
15.	Shri Rambir Kaushik	Asstt. Pub. & Doc. Officer
16.	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
17.	Shri Bharat Singh Rana	Librarian
18.	Dr. Jitendra Bhatt	Sr. Tech. Assistant
19.	Shri Pankaj Chauhan	Sr. Tech. Assistant (On Deputation)
20.	Shri Lokeshwar Vashistha	Sr. Lab. Technician
21.	Dr. S.K. Chabak	Sr. Lab. Technician
22.	Shri R.M. Sharma	Sr. Lab. Technician
23.	Shri C.P. Dabral	Sr. Lab. Technician
24.	Shri S.K. Thapliyal	Sr. Lab. Assistant
25.	Shri Shiv Pd. Bahuguna	Sr. Lab. Assistant
26.	Shri Sashidhar Pd. Balodi	Sr. Lab. Assistant
27.	Shri Rajendra Prakash	Sr. Lab. Assistant
28.	Shri A.K. Gupta	Sr. Lab. Assistant
29.	Shri Tirath Raj	Sr. Lab. Assistant
30.	Shri Balram Singh	Sr. Elect-cum-Pump Optr.
31.	Shri Nand Ram	Elect-cum-Pump.Optr.
32.	Smt. Sarita	Tech. Assistant
33.	Sh. Rakesh Kumar	Tech. Assistant
34.	Km. Sakshi Maurya	Tech. Assistant

35. Km. Disha Vishnoi	Tech. Assistant
36. Shri Abhimanyu Yadav	Tech. Assistant (Lien vacancy)
37. Shri Prateek Negi	Artist-cum-Modeller
38. Shri Rahul Lodh	Lab Assistant
39. Shri Nain Das	Lab. Assistant
40. Shri Navneet Kumar	Draftsman
41. Shri B.B. Saran	Draftsman
42. Shri Tarun Jain	Draftsman
43. Shri Pankaj Semwal	Draftsman
44. Shri Shekhranandan	Section Cutter (Ret. on 31.05.15)
45. Shri Santu Das	Section Cutter
46. Shri Puneet Kumar	Section Cutter
47. Shri Ram Kishor	Field-cum-Lab Attendant
48. Shri Ansuya Prasad	Field-cum-Lab Attendant
49. Shri Madhu Sudan	Field-cum-Lab Attendant
50. Shri Hari Singh Chauhan	Field-cum-Lab Attendant
51. Shri Ravi Lal	Field-cum-Lab Attendant
52. Shri Preetam Singh	Field-cum-Lab Attendant
53. Mrs. Rama Pant	Field Attendant
54. Shri R.S. Negi	Field Attendant
55. Shri Ramesh Chandra	Field Attendant
56. Shri Khusi Ram	Field Attendant
57. Shri Tikam Singh	Field Attendant
58. Shri Bharosa Nand	Field Attendant
59. Shri B.B. Panthri	Field Attendant
60. Shri M.S. Rawat	Field Attendant
61. Shri Sanjeev Kumar	Field-cum-Lab Attendant
62. Shri Deepak Tiwari	Field-cum-Lab Attendant
63. Shri Ajay K. Upadhaya	Field-cum-Lab Attendant
64. Km. Sangeeta Bora	Field-cum-Lab Attendant
65. Sh. Deepak Kumar	Field-cum-Lab Attendant
66. Km. Anjali	Field-cum-Lab Attendant

Administrative Staff

1. Shri Dinesh Chandra	Registrar (Retired on 30.09.2015)
2. Shri Pankaj Kumar	Registrar (Joined on 01.10.2015)
3. Shri Harish Chandra	Fin. & Accounts Officer
4. Shri A.S. Negi	Administrative Officer
5. Mrs. Manju Pant	Asstt. Fin. & Accounts Officer
6. Shri Manas Kumar Biswas	Store & Purchase Officer
7. Shri Hukam Singh	Office Superintendent
8. Mrs. Sharda Sehgal	Assistant (Retired on 31.12.2015)
9. Mrs. Shamlata Kaushik	Assistant (Hindi)
10. Smt. Rajvinder K. Nagpal	Stenographer
11. Shri M.C. Sharma	Assistant
12. Shri S.K. Chhettri	Assistant
13. Shri Vinod Singh Rawat	Assistant
14. Shri Rahul Sharma	Assistant
15. Km. Shalini Negi	Stenographer
16. Km. Richa Kukreja	Stenographer
17. Shri S.K. Srivastava	Upper Division Clerk
18. Mrs. Prabha Kharbanda	Upper Division Clerk
19. Shri R.C. Arya	Upper Division Clerk
20. Mrs. Kalpana Chandel	Upper Division Clerk
21. Mrs. Anita Chaudhary	Upper Division Clerk
22. Shri Shiv Singh Negi	Upper Division Clerk
23. Mrs. Neelam Chabak	Upper Division Clerk
24. Mrs. Seema Juyal	Upper Division Clerk
25. Mrs. Suman Nanda	Upper Division Clerk
26. Shri Kulwant S. Manral	Upper Division Clerk
27. Sh. Vijai Ram Bhatt	Lower Division Clerk
28. Shri Rajeev Yadav	Lower Division Clerk
29. Shri Girish Chandra Singh	Lower Division Clerk
30. Shri Deepak Jakhmola	Lower Division Clerk
31. Km. Rachna	Lower Division Clerk
32. Shri Dinesh Kumar Singh	Lower Division Clerk

Ancilary Staff

1. Shri Sohan Singh	Driver
2. Shri Shyam Singh	Driver
3. Shri Chait Ram	Bearer (Died on 17.09.2015)
4. Mrs. Kamla Devi	Bearer
5. Mrs. Deveshawari Rawat	Bearer
6. Shri S.K. Gupta	Bearer
7. Mrs. Omwati	Bearer
8. Shri Jeevan Lal	Bearer
9. Shri Surendra Singh	Bearer
10. Shri Preetam	Bearer
11. Shri Ramesh Chand Rana	M.T.S.
12. Shri Pankaj Kumar	M.T.S.
13. Shri Ashish Rana	M.T.S.
14. Shri Harish Kumar Verma	M.T.S.
15. Shri Dinesh Pd. Saklani	Guest House Attendant
16. Shri Sunil Kumar	Guest House Attendant
17. Shri Mahendra Singh	Chowkidar
18. Shri Rohlu Ram	Chowkidar
19. Shri H.S. Manral	Chowkidar
20. Shri G.D. Sharma	Chowkidar
21. Shri Satya Narayan	Mali
22. Shri Ramesh	Safaiwala
23. Shri Hari Kishan	Safaiwala

Contractual Staff

1. Shri Neeraj Bhatt	Lower Division Clerk
2. Shri Dhanveer Singh	Lower Division Clerk
3. Smt. Megha Sharma	Lower Division Clerk
4. Shri Rezaw U. Choudhury	Driver
5. Shri Rajesh Yadav	Driver
6. Shri Bhupendra Kumar	Driver
7. Shri Manmohan	Driver
8. Shri Vijay Singh	Driver
9. Shri Rudhra Chetri	Bearer
10. Shri Laxman S. Bhandari	Chowkidar
11. Shri Pradeep Kumar	Chowkidar
12. Shri Kalidas	Chowkidar
13. Ummed Singh	Chowkidar
14. Shri Sang Bang Kach	Chowkidar

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

Governing Body
(during 2015-16)

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-403 004	Member
9.	Shri J.B. Mohapatra	Joint Secretary and Financial Adviser Department of Science and Technology Technology Bhawan, New Mehrauli Road New Delhi-110 016	Member
10.	Prof. Anil K. Gupta	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 2015-16)

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, Nest to Katriya Hotel, Somajiguda Hyderabad-500082	Member
6.	Dr. V.M. Tiwari	Scientist National Geophysical Research Institute Uppal Road, Hyderabad-500007	Member
7.	Dr. J.R. Kayal	73-B, Thakur Pukur Road Kolkata-700063	Member
8.	Prof. M.K. Panigrahi	Department of Geology & Geophysics Indian Institute of Technology-Kharagpur Kharagpur-721302	Member
9.	Prof. S. Tripathy	Deputy Director & Head School of Earth Ocean and Climate Sciences Indian Institute of Technology-Bhubaneswar A-2702, Toshali Bhavan, Satya Nagar Bhubaneswar-751007	Member
10.	Prof. R.P. Tiwari	Dean School of Engineering & Technology Mizoram University Aizawl-796009	Member

Sl.	Name	Address	Status
11.	Prof. Sunil K. Singh	Geosciences Division Physical Research Laboratory Navrangpura, Ahmedabad-380009	Member
12	Dr. Snehmani	Joint Director Snow and Avalanche Study Establishment Him Parisar, Sector - 37A Chandigarh-160036	Member
13.	Prof. Anil K. Gupta	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 2015-16)

Sl.	Name	Address	Status
1.	Prof. M.P. Singh	124, Chandganj Extension (Opp. CN-7, Sector-B), Aliganj Lucknow-226024 (UP)	Chairman
2.	Prof. Anil K. Gupta	Director Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road 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 33, General Mahadeo Singh Road Dehradun - 248001	Member
5.	Shri Harish Chandra	Finance & Accounts Officer Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road Dehradun - 248001	Member Secretary

Building Committee
(during 2015-16)

Sl.	Name	Address	Status
1.	Prof. Anil K. Gupta	Director Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road 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.	Dr. Rajesh Sharma	Scientist 'G' Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road Dehradun - 248001	Member
4.	Representative of ONGC	Tel Bhawan Oil & Natural Gas Corporation Dehradun - 248001	Member
5.	Representative of Survey of India	Surveyor General's Office Survey of India, Hathibarkala, Dehradun - 248001	Member
6.	Shri Pankaj Kumar	Registrar Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road Dehradun - 248001	Member
7.	Shri C.B. Sharma	Assistant Engineer Wadia Institute of Himalayan Geology 33, General Mahadeo Singh Road Dehradun - 248001	Member Secretary

STATEMENT OF ACCOUNTS

PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

61-PNB Enclave, Shimla Road
Dehradun - 248 001
Ph: +91-9997941014, 8650141717
E-mail: capranayseth@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, 2016 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.

Pranay Seth & Associates · 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, 2016;
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 PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

Pranay Seth & Associates Dehradun Chartered Accountants

CA PRANAY SETH
FCA, DISA (ICAI)

FRN: 013929C
M.NO: 407943

Date: 29th Sept, 2016
Place: Dehradun

Annexure 1 to the Consolidated Financial Statements Audit Report

The following observations were noted during the course of audit for the Financial Year 2015-16. The same have been discussed with the management and comments / explanations of the management thereon have also been obtained.

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 in conformity with the generally accepted accounting policies 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 for 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.	The Institute is receiving Grant-in-Aid from Govt. of India on the basis of projection of expenditure submitted by the Institute. However, sufficient funds as against the projected amount are not being received. Hence the accounts are being maintained on cash basis for the actual transaction during the year. Interest on investment out of the fund for GPF/Pension etc. is taken on accrual basis.
2.	The Institute has not booked the current liability for the retirement benefit of the employees as per Accounting Standard 15 "Employees Benefits" as issued by the Institute of Chartered Accountants of India.	Since the accounts are being maintained on actual requirement and on cash basis, the liability on account of retirement benefits is being not been provided.
3.	The internal control regarding Fixed Assets needs to be strengthened. The following observations are made: a) The Fixed Asset Register is not maintained by the Institute. b) The additions to fixed assets are not numbered properly. The Physical verification of the Fixed Asset for the Financial Year 2015-16 has not been undertaken.	Noted for compliance. The physical verification of Fixed Assets of the Institute upto 31st March, 2016 is under progress and the report alongwith the action taken on the observation of audit will be produced in the next audit.
4.	The Institute is adopting the policy of charging depreciation on Fixed Assets on the basis of written down value method as per the rates specified in the Income Tax Act, 1961, however, the following observations are made: a) Full year depreciation is charged instead of six months, on assets purchased for the half year ending 31st March, 2016. As per the management the same policy had been adopted in the previous financial years also. The books are depreciated @ 15% p.a. instead of 60% p.a. on W.D.V basis as applicable to Research Institutes.	Observation of auditor has been noted for compliance.
5.	The Institute has not bifurcated the advances given to the Staff & Parties and also from the Projects where no movement of fund is being done. The Party Debtors amounting to Rs. 1,29,288/- and Staff Debtors amounting to Rs 22,832/- are outstanding since long. The advance which could not be realized in due course should be written off with the approval of the competent authority. Rs 11,634.00 has been shown as credit balance in Party debtors and Rs. 32,729/- in Staff Debtor outstanding since long, which should be taken to receipts after following nodal procedure. An advance of Rs. 17,570 given to	In the Institute has made its best efforts to settle the outstanding advances lying against debtors. Most of the outstanding advances against staff have been adjusted. However, some of the advances outstanding against the party debtors for a number of years could not be settled. Procedure for settlement of these outstanding is under active consideration.

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	M/s Airport Handling Services also need to be adjusted.	
6.	It has been noticed that funds for organizing the Training Workshop Prog- (Ladakh...-) for Rs. 2,19,905.00, Annual Convention (IGU 2009) for Rs. 41,275.00, WIHG-IGU Workshop 2013 for Rs. 3,32,048.00 and HKT-2015 Workshop for Rs. 16,854.00 has been utilized from the Institute grant and therefore the same has been shown as current liability in the Institute Account. It is suggested that the borrowed amount may be recovered urgently.	To organize training, workshop, other short term programme etc., for which funds are provided by other granting agencies, are received occasionally in advance. Otherwise, the funds are received after completion of the activities for successful organization of the proposed activities the required funds are spent from the Institute grant on refundable basis. Request to all the agencies on whose behalf the workshop / training programme were organized will be requested again for release of a excess expenditure made by the Institute.
7.	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.	Institute has already started the process for E-Tendering for procurement of materials and the process will be made functional very soon.
8.	During the course of audit it was observed that there are entries outstanding in the Bank Reconciliation Statement as on 31.03.2016 which should either be taken back or the revalidated cheque be issued to the concerned.	As suggested by the audit the outstanding entries in the Bank Reconciliation Statement will be rectified.
9.	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 do not have 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 the Institute it is suggested that a software which is more user friendly to all the staff working in the Account Section and that to customized as per the need of the Institute be developed and training to the staff be given. The Management of the Institute need to take urgent action.	It was felt necessary by the Institute to maintain the accounts in most popular and available software in use. One part of it i.e. Pay Roll Management is being maintained in a software specially designed and customized as per the need of the Institute. The said software is working perfectly and as suggested by the audit the Financial Accounting of the Institute will also be converted into a more user friendly software. Necessary action has already been started in this direction.
10.	The contribution towards Medical scheme for Pensioners is accounted for in Pension Fund Account whereas the payment of actual expenditure is met from the Institute account. It is recommended that the expenses should be met from the specific fund.	This belongs to a policy matter, which will be taken up in the next meeting of the Governing Body. Outcome of the same will be shown in the next Audit.
11.	An amount of Rs.3,00,000/- was received from M/s Progressive Machine Tools in NGF Project and has been shown as current liability. The amount is required to be booked in proper head of accounts.	The observation of audit has been noted for compliance during the Current Financial Year.
12.	An amount of Rs. 45,00,000/- has been borrowed from the Glaciology Project to the Pension Fund account as temporary loan. Till date the said amount has not been returned, therefore, it is suggested that urgent action for refund be initiated.	The amount has already been refunded during the Current Financial Year.
13.	During the course of Audit it was observed that Rs. 1,427.00 towards Service Tax payable in Consultancy activity has not been deposited to the Govt. account.	The Service Tax is being deposited to the Govt. account in the Current Financial Year.
14.	An amount of Rs. 83,519.00 towards Leave Salary and Pension Contribution in respect of Dr. R.J. Perumal was received by the Institute which should	The Leave Salary Pension Contribution has since been transferred to respected fund during the Current Financial Year.

Pranay Seth & Associates
Dehradun
Chartered Accountants

	have been transferred to the Pension Fund Account instead of booking under Sundry Creditors. The necessary action for transfer of funds required to be taken.	
15.	During the Financial Year 2015-16 an amount of Rs. 3,55,043.00 towards Service Tax for the period 01.07.2008 – 31.07.2015 was received from Union Bank of India, Wadia Branch and was paid to the Govt. Account. Considering the period of Service Tax the tax authority may submit the demand for delay in depositing the said amount. The Management may take note of this.	This was a long pending issue with the bank authorities and after deliberated discussion and several reminders to the bank authorities due Service Tax for the period 01.07.2008 to 31.07.2015 was received and accordingly deposited to Govt. account. In case any demand on this account is raised by the concerned department the same will be paid by the user.
16.	Section 195(6) of the Income tax Act 1961 prescribes certificate in Form No. 15CA & 15CB as a declaration of remitter as information to be furnished for payments, chargeable to tax to a non resident not being a company or to a foreign company. It has been observed that several payments in foreign currency were made by the Institute. However, the Institute has not submitted the applicable form 15CA or 15CB with respect to those transactions. Default in submission above mentioned forms may also lead to penalty under the Income Tax Law under section 195(6).	The observation of the audit has been noted for future compliance.
17.	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	Efforts for recovery/sanction of the outstanding amount from the agencies have been made. However, further action will be taken in the matter for final settlement.
18.	The management has adopted Consolidation of Financial Statements of accounts for the first time and therefore previous year figures along with the current year have been regrouped/rearranged where ever it was necessary w.e.f Financial Year 2014-2015.	Consolidation of the Annual Statement of Accounts has since been done and revised accordingly.
	We are thankful to the management and the staff for the co-operation extended to us during the course of audit. **For Pranay Seth & Associates** **Chartered Accountants** **CA Pranay Seth** **[F.C.A., DISA (ICAI)]** **FRN : 013929C** **M. No. : 407943** **Date :** 29th Sept, 2016 **Place :** Dehradun.	**(Harish Chandra)** **Fin. & Accounts Officer** **(Pankaj Kumar)** **Registrar** 29.09.16 **(Prof. Anil K. Gupta)** **Director**

STATEMENT OF ACCOUNTS

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

CONSOLIDATED BALANCE SHEET
(AS AT 31ST MARCH 2016)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	868,945,053	871,123,215
Reserves and Surplus	2	-	-
Earmaked/ Endowment Fund	3	2,415,919	1,305,537
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	6,473,879	7,904,981
TOTAL		**877,834,851**	**880,333,733**
ASSETS			
Fixed Assets	8	430,622,962	407,423,746
Investments from Earmaked/ Endowment Funds	9	43,314	39,930
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	447,168,575	472,870,057
TOTAL		**877,834,851**	**880,333,733**
Significant Accounting Policies	37		
Contingent Liabilities and Notes on Accounts	38		

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

FOR PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

CA PRANAY SETH
(F.C.A, DISA (ICAI))

Pranay Seth & Associates Chartered Accountants Dehradun

(HARISH CHANDRA)	**(PANKAJ KUMAR)**	**(PROF. ANIL K. GUPTA)**
Finance & Accounts Officer	Registrar	Director

29.09.16

Date : 29th Sept, 2016
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

CONSOLIDATED INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31ST MARCH 2016

(Amt in Rs…)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12	-	-
	Grants/ Subsidies	13	267,777,046	274,324,820
	Fees/Subscription	14	10,000	19,000
	Income from Investments	15	903,834	953,779
	Income from Royalty, Publication etc.	16	51,969	45,950
	Interest earned	17	32,005,220	33,808,879
	Other Income	18	5,638,108	6,095,998
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**306,386,177**	**315,248,426**
B	**EXPENDITURE**			
	Establishment Expenses	20	225,912,901	201,707,647
	Other Research & Administrative Expenses	21	50,071,841	56,690,147
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	8,591,579	9,465,469
	Depreciation Account	8	71,493,925	68,682,202
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	(119,398)	37,052
	Loss / (Profit) on sale of Assets	A-19	(35,501)	(369)
	TOTAL (B)		**355,915,347**	**336,582,148**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		(49,529,170)	(21,333,722)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	BALANCE BEING SURPLUS /(DEFICIT) CARRIED TO CORPUS FUND		**(49,529,170)**	**(21,333,722)**

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

FOR PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

CA PRANAY SETH
(F.C.A, DISA (ICAI))

(HARISH CHANDRA)
Finance & Accounts Officer

(PANKAJ KUMAR)
Registrar

(PROF. ANIL K. GUPTA)
Director

Date : 29th Sept, 2016
Place: Dehradun

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

CONSOLIDATED RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2016)

(Amt in Rs…)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	152,983,668	133,488,332
Grants - in - Aids	26	344,652,028	362,941,431
Grants - in - Aids/Other Receipts (Ear Marked)	27	764,000	906,195
Loan & Advances	28	181,615,351	185,575,015
Loan & Advances (Ear Marked)	31	36,500	40,000
Fees/Subscription	14	10,000	19,000
Income from Investments	15	903,834	953,779
Income from Royalty, Publication etc.	16	51,969	45,950
Interest earned	17	17,539,929	14,543,721
Other Income	18	5,638,108	6,095,998
Investment (L/C Margin Money)	34	158,724,485	96,442,110
		862,919,872	**801,051,531**
PAYMENTS			
Establishment Expenses	20	225,912,901	201,707,647
Other Administrative Expenses	21	50,071,841	56,690,147
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	3,826	6,624
Loans & Advances	29	170,817,538	217,842,506
Loans & Advances (Ear Marked)	32	36,500	43,041
Investment (L/C Margin Money)	35	102,719,383	74,430,241
Fixed Assets	36	94,657,640	96,415,645
Ear Marked Fund Expenses	33	692,002	634,453
Grant - in - Aid (Ear Marked)/Others Refunded	30	362,990	297,559
Closing Balance	25	217,645,252	152,983,668

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

FOR PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

Pranay Seth & Associates, Chartered Accountants, Dehradun

CA PRANAY SETH
(F.C.A, DISA (ICAI))

29.09.16

(HARISH CHANDRA)
Finance & Accounts Officer

(PANKAJ KUMAR)
Registrar

(PROF. ANIL K. GUPTA)
Director

Date : 29th Sept, 2016
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF CONSOLIDATED ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2016

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.

Pranay Seth & Associates • Chartered Accountants • Dehradun

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

5. MISCELLANEOUS EXPENDITURE

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

6. ACCOUNTING FOR SALES & SERVICES

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

7. GOVERNMENT GRANTS / SUBSIDIES

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

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

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

(Harish Chandra)	**(Pankaj Kumar)**	**(Prof. Anil K. Gupta)** 09.09.16
Finance & Accounts Officer	**Registrar**	**Director**

Date : 29th Sept, 2016
Place: Dehradun

Pranay Seth & Associates · Chartered Accountants · Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF CONSOLODATED ACCOUNTS FOR THE YEAR ENDED 31[ST] MARCH, 2016

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 -
)	Disputed demands in respect of		
	i)	Income –tax	58,36,245
	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

Pranay Seth & Associates Chartered Accountants Dehradun

STATEMENT OF ACCOUNTS

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. 2015 -16 is as follows:

Remuneration to auditors		
i)	As Auditors	29,070/-
	Taxation matters	- Nil -
	For Management Services	- Nil -
	For Certification	5,700/-
ii)	Others	- Nil -

8. Separate Financial Statements have also 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, 2016, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2016.

(Harish Chandra)
Finance & Accounts Officer

(Pankaj Kumar)
Registrar

(Prof. Anil K. Gupta)
Director

09.09.16

Date : 29th Sept, 2016
Place: Dehradun

Pranay Seth & Associates
Chartered Accountants
Dehradun

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