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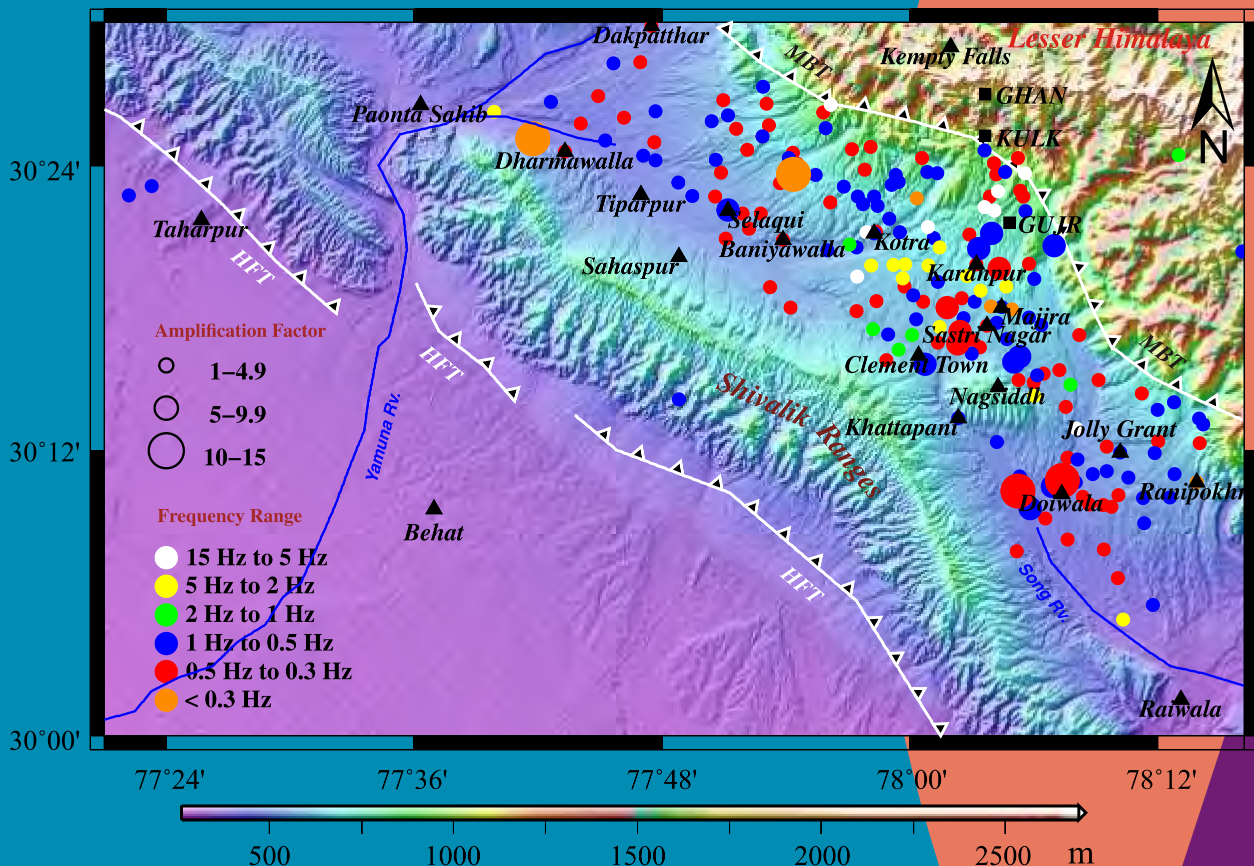

Spot Resonant Frequencies and Amplification Factors
of the top soil from the Doon valley

WADIA INSTITUTE OF HIMALAYAN GEOLOGY
DEHRADUN
(An autonomous Institute of Dept. of Science & Technology, Govt. of India)

Cover photo: Spot resonant frequencies and amplification factors of top soil in the Doon valley obtained from seismic ambient noise measurements.

(Courtesy: Rajesh S.)

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CONTENTS

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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

FOREWORD FROM THE DIRECTOR

The Institute has acclaimed reputation as internationally known center of excellence for research aimed to unravel the orogeny of the world's youngest and loftiest mountain system. Over the years it is engaged in the geological mapping, structure & tectonic, petrology & geochemistry, geochronology, sedimentology, geomorphology, paleontology, glaciology, hydrology and geophysical studies for manifold applications in understanding geodynamic processes, impact on climate, natural resources, evolution of life, and assessment and mitigation of natural hazards. The environmental change in general, and climatic change in particular in the Himalayan region, are likely to impact significantly upon resources such as water, soils, transforming present-day landscapes and their ecological characteristics. An impact due to earthquakes and landslides greatly influence progress of the socio-economic developmental activities, and is of concern to people occupying the unstable hill slope areas under the pressure of increasing population. Effect of natural as well as anthropogenic chemical toxicity and deficiencies because of geological and climatic factors are compounded by socio-economic conditions. Considering these, the research activities of the Institute are planned accordingly, and major thrust has also been given to societal aspects of geoscientific research activities, which include natural disasters and their management, environmental studies pertaining to sustainable development activity and natural resources.

The research activities of the Institute are grouped into thrust area themes that are implemented through long-term and short-term projects, and they are supplemented by sponsored research projects focusing on various themes within the ambit of the Institute mandate. An overview of the on-going research activities shows that the year witnessed all around progress and has yielded interesting and useful results. An executive summary of the significant contributions in each mission mode project is highlighted below along with other activities of the Institute.

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

- The Focal Mechanism Solutions (FMSs) study in the Tethys Himalaya suggested that majority of the FMSs are of normal faulting nature indicating extensional stress regime, and that the N-S strike of the nodal planes in these FMSs can be correlated with the active Kaurik-Chango Fault.
- The Institute has made LA-MC-ICP-MS laboratory fully functional. The results showed that the igneous zircons from the footwall of the MCT of the inner Lesser Himalaya yield magmatic crystallization age of 1901±11 Ma, with internal precision for individual measurements well within 1%.
- An integrated geochemical and U-Pb geo-chronological analysis of the migmatites and associated two-mica granite intrusions within the Ladakh Arc suggest that, the event of migmatization was prior to Indo-Eurasian continental accretion at ~55-50 Ma, and that the two mica granite magmatism to be around 35-40 Ma.
- The Early Cretaceous plagiogranites reported from the Nagaland-Manipur Ophiolites (NMO) were dated to be ~117 Ma, and studies indicate that the NMO are broadly coeval and comparable with Neo-Tethyan ophiolites elsewhere in the Indus-Yarlung-Tsangpo Suture.
- The morphotectonic study of Kulsi basin located on the northern flank of the Shillong Plateau show river migration in the past, due to an interplay of climate and tectonics.
- The occurrence of albitite from the Shyok Suture Zone, Nubra valley of Trans Himalaya, Ladakh is reported for the first time. The significance of this discovery in the Himalayan terrain may be related to possible uranium - REE mineralization, which may open new vistas for their exploration.
- Representative isochors together with the mineral phase PT range in the metapelites of the Pindari valley of the Kumaun Himalaya attribute Type-II H_2O-CO_2 fluid inclusions to be metamorphic fluids, whereas, the Type-I carbonic inclusions and the Type-II aqueous-carbonic inclusions are of retrogressive nature.
- The distribution and abundance of fluid inclusions in the mineralized vein calcite, especially the coeval

gangue calcite in Chamri and Amtiyargad in Tons river valley, points out that the ore forming fluid is of mixed H_2O-CO_2 fluid composition, and that the fluid unmixing may be linked to the suphide deposition.

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

- The chronology of paleoflood deposits of Himalaya established by OSL and ^{14}C AMS dating techniques, indicate: (i) The Alaknanda-Mandakini Rivers experienced large floods during the wet and warm Medieval Climate Anomaly; (ii) the Indus River experienced at least 14 large floods during the Holocene climatic optimum and the magnetic susceptibility of flood sediments indicates that 10 out of 14 floods originated in the catchments draining the Ladakh Batholith; and (iii) the Brahmaputra River experienced a megaflood between 8 and 6 ka.
- The multi-proxy paleoclimatic dataset generated from ~8 m high river cliff exposed on the right bank of the Ganga River valley at Ramnagar indicate two relatively wet (~59-46 ka) and warm (~39-26 ka) climatic phases, intervened with a drier period (~46-39 ka). The relatively wet and dry phases in the Ganga Plain reported are concomitant with higher and lower insolation, respectively.
- The reconstruction of the paleoclimatic variability in India between 46,000 and 35,000 years BP using speleothem sample MWS-2 from the Mawmluh cave, Meghalaya, NE India has suggested weak Indian summer monsoon during the Henrich events, Younger Dryas and Last Glacial Maxima and strong monsoon conditions during the Early Holocene, Bolling-Alleroid and Dansgaard-Oescherg events.
- The studies of fluvial terrace of Satluj valley showed that eight levels of terraces were identifiable in the Lesser- and inner Sub-Himalaya, while in the outer Sub-Himalaya only the younger four levels were documented with the older events absent, and that the sediment is vertically stacked into an alluvial fan.
- Hydro chemical and isotopic studies carried out in the ground waters along the entire Ramganga Basin and parts of middle Ganga Plain showed levels of arsenic above the drinking water criterion of 10 ppb and has been attributed to both geogenic and anthropogenic sources.
- Off-shore age-depth model of the Arabian Sea sediments from the Laxmi Basin based on foraminifera, nanofossils and magnetic stratigraphy suggest an average sedimentation rate of 7 cm/ka from the late early Pleistocene to the Present.

TAT-3: Earthquake Precursors Studies and Geo Hazard Evaluation

- Seismotectonic model studies following the moderate earthquake (Mw 5.7) of February 06, 2017 that occurred in the Garhwal Himalayan region of Uttarakhand state showed that, the hypocenter is at the down dip edge of the Main Himalayan Thrust plane at about 17±3 km and coincides further with the ramp part of the flat ramp flat geometry of the plane in the region.
- Crustal thickness and Poisson's ratios are estimated using 10 Broad Band Seismic stations along a profile of Satluj valley, NW Himalaya, which reveal gradual thickening of crust from ~46 km beneath Sub-Himalaya to ~50 km beneath Higher Himalaya and to ~62 km in the Tethyan Himalaya. The Poisson's ratio also shows significant variation from south to north along the profile and is higher in the Tethyan Himalaya.
- The spatial variation in cooling ages, exhumation rates and seismicity of Kumaun-Garhwal region indicates that the Kumaun region, as a single block, has undergone a rapid exhumation rate of ~4 m/Ma and Garhwal region with the rate of ~1.5 m/Ma, a result of tectonic activity along the Main Central Thrust/Munsiari Thrust.
- Two resistivity and IP profiles were carried out in Doon valley sub-Himalaya, Dehradun to identify the conceivable groundwater zones, and the studies identified two inimitable paleo-channels with potential zone of shallow groundwater pockets below it. The profile data is also useful for seismic hazard studies related to liquefaction due to occurrence of strong nearby earthquake.
- Paleoseismological investigation through trench excavation survey across the Bharli Active Fault in the northwestern Doon Valley in the Sub-Himalaya revealed earthquake induced deformation features of the Trans-Yamuna Active Fault system, and it is observed to be a potential zone for future earthquakes in the seismically active and highly populous mountainous belt of NW Himalaya.
- The use of channel steepness index (k_{sn}) as a proxy for the detachment-limited model to estimate the differential uplift across the fold-thrust belt in the Dikrong river valley, NE Himalaya, showed higher k_{sn} values (86-214) across the nose of the Simna Parvat Anticline. It is suggested that this anticline is propagating towards ENE direction, resulting in the gradual shifting of the Dikrong River towards east and abandonment of paleochannels.

TAT-4: Biodiversity - Environment Linkage

- A variety of agnostid taxa, *Diplagnostus* has been reported from the Cambrian succession of the Zanskar basin, and is significant because, it marks the boundary between the Middle and Late Cambrian. The agnostid fauna reported from Kashmir and Zanskar regions occurs more or less at the same stratigraphic levels as in Australia, China, Kazakhstan, Sweden and North America.
- The $\delta^{13}C$ and $\delta^{18}O$ values from both pedogenic nodules and gastropod shells of Nadah section overlap and clearly indicate the dominance of C4 vegetation and existence of warm and dry condition during a small window of 12,000 years at ~1.8 Ma ago, and that it seems regional tectonic, sedimentation and climate change played a major role in the vegetation changes observed between ~2.7 to 0.6 Ma.
- The Chert Member of Lower Tal Formation exposed in Mussoorie and Garhwal synclines showed large sized tubular structures which are identified as *Megathrix longus,* they are also reported from the basal Cambrian of lower Yurtus and lower Yanjiahe formations, and appear to be restricted to the Meishucunian Stage.
- The presence of bryozoans and calcified green algae in the Thango and Takche formations of the Spiti Himalaya indicates shallow marine to near shore environmental conditions. Also, the genus *Tremaptopora* which is reported from the Spiti Basin is reported from the Ordovician successions of Russia and France.
- It is observed that the Gondwanan taxa from Tadkeshwar lignite mine, western India might represent remnants of ghost lineages shared with Madagascar and might have reached India during the late Cretaceous time or alternatively they might have come from North Africa and passed along the southern margin of the Neotethys to reach India.

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

- The net annual balance of the Chorabari glacier for the year 2015-16 was calculated to be negative, amounting to around $-4.37x10^{-6}m^3$, and the Equilibrium Line Altitude (ELA) was estimated and found at an elevation of ~5075 m a.s.l., while the Accumulation Area Ratio (AAR) is estimated to be ~0.43.
- Kedar Tal is a periglacial lake located on the Kedar Glacier which is located >2 km behind the snout of the glacier and observed to have less moraine material on its path downstream upto Gangotri, yet this lake show potential symptoms for a future hazard.
- Landslide mapping in the Bhagirathi valley showed that in the upper reaches of the valley, rock fall and rock avalanches are the prominent features whereas, in the lower reaches, particularly around Bhatwari and Uttarkashi debris flows and debris slides are common. The study showed huge amount of river sediments deposition in the area with an average aggradation of about 0.5 m/year, thereby posing serious threat to the slope stability on either banks of river.
- The Institute has carried out field and analytical studies of the buried course of River Saraswati and found signature of existence of this river until ~1.7 kilo years before present.
- The study of twenty geothermal springs from the NW Himalaya show that they have the potential to degas ~2.9×107 mol CO_2 per year in the atmosphere, and further their reservoir temperatures (42 to 107°C) indicate their application in space heating and to generate electricity in certain cases.
- Groundwater prospect map has been prepared for the Soan basin of Una district, H.P. by overlaying various thematic maps, and five potential zones of groundwater were identified on the basis of their discharge conditions as low, very low, moderate, high and very high, respectively.

Academic Pursuits

The Institute under the on-going research programs pursued during the year, has published 66 research papers both in national and international journals, and around 81 papers are in press/accepted/communicated. More than 85% of the papers have been published in SCI journals with the annual impact factor of around 104. During the current year the average impact factor per paper is around 1.8. Further six Ph.D. theses have been awarded and eight submitted for the award of Ph.D. Degree. The Institute other than Ph.D's has further trained 135 post-graduate students from various Universities/Institutions, 22 B.Tech graduates, and guided 18 M.Tech/M.Sc project dissertations. Also, during the year, one of the Institute scientist, Dr. R.J.G. Perumal has received Prof. S.S. Merh award conferred by Geological Society of India for his contribution in Quaternary Geology.

To disseminate and share new emerging trends of research in geosciences, the Institute organized *1st National Geo-Research Scholars Meet* in the Institute during June 1-4, 2016. In addition, a Curtain Raiser event to the 2nd India International Science Festival was organized on November 28-29, 2016 in its premises.

The Institute regularly brings out the Himalayan Geology publications and during this year, volumes 37(2) and 38(1) were brought out along with Newsletters 'Bhugarbh Vani' volume 6 (in four parts) and 'Drishtikon' volume 5.

Other Highlights

Dr. Harsh Vardhan, the Hon'ble Minister of Science & Technology and Earth Sciences visited the Institute and delivered a lecture. The Institute apart from the regular celebrations of Foundation Day, Technology Day, National Science Day, Republic Day and Independence Day has also celebrated the International Yoga Day on June 21, 2016. Institute has also observed the National Productivity Week during February 12-18, 2017. Under Public awareness programme, Indian Medical Association, Dehradun has organized *'No Tobacco Campaign'* programme in the Institute on June 27, 2016.

The Institute also organized the Prof. R.C. Misra Memorial Lecture delivered by Prof. S.K. Shah; Prof. M.R. Sahni Memorial Lecture delivered by Prof. Jere Lipps; and Prof. W.D. West Memorial Lecture delivered by Prof. Talat Ahmad.

Hindi pakhwara was celebrated in the Institute during September 14-28, 2016, during which various competitions like poetry, essay and debate were organized. In keeping with the annual program for the implementation of the official language policy of the Union of India, various steps were taken to promote use of Hindi in routine work as well as in scientific research. The scientists and staff of the Institute were time and again apprised with the various orders and constitutional provisions of official Language. General orders, circulars and notices were issued in Hindi as well as in English. Various incentive schemes for encouraging progressive use of Hindi were also implemented. The Annual Report of the Institute for the year 2015-16 was published in bilingual form (Hindi and English), along with volume 22 of the in-house Hindi magazine Ashmika.

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*)

Transverse thrust faulting across leading tectonic edge of Nahan salient, NW Himalaya

The Main Boundary Fault (MBF) marks the leading tectonic edge of the Nahan salient, northwest outer Himalaya. Near southern terminal of the N-S trending linear transverse zone between the Kangra recess and Nahan salient, a lobe-shaped physiographic front, named as *Nalagarh lobe,* has developed across north-western limb of salient. The lobe has formed across the surface trace of the MBF or Nalagarh Thrust that separates the hanging wall Lower Tertiary Dharmsala rocks from the footwall Upper Tertiary Siwalik rocks and overlying Late Pleistocene Quaternaries. In front of the *lobe*, thrust-fault splays (Splay-1 and Splay-2) have developed within the Quaternary fan deposit. Structural elements developed across the front of *Nalagarh lobe* are analysed with reference to the evolution of lobe. It is revealed that the lobe is bounded by transverse thrust faults along its north-western and south-eastern margins. Marking the northern margin of the intermontane piggy-back basin of Pinjaur dun, the MBF is interpreted to be an out-of-sequence thrust. The study suggests that the lateral ramp on the Main Himalayan Thrust (MHT) does not exist beneath the apex and beneath the south-eastern limb of the salient in the Sub-Himalayan region. With this background information, an attempt has been make to reply the question that why the lobe has developed near south of NW end point of salient with respect to the structural architecture of salient? At base of hanging wall block of the MBF, the thrust-parallel folds are the fault propagation folds, suggesting NE-SW compression, whereas transverse folds indicate NW-SE oriented compression. The MBF has made a vertical 15 m high fresh-looking rejuvenated bedrock fault scarp, which forms the hanging wall topographic front of the MBF. The locations of channel-fill deposits at the top of fan surface are interpreted to be the areas of surface ruptures, along which the channel-fills were deposited on gullies formed along ground rupture areas as a result of surface deformation during past seismic activities.

In front of the *Nalagarh lobe*, the Sirsa nadi shows a knick point (as seen in map-view pattern) from where the northwest flowing Sirsa takes a turn towards WNW direction to meet the major Satluj River. The point of deflection or knick point of Sirsa nadi course at Daddi Harnam coincides with the trace of transverse fault. It is inferred that the deflection of river might be controlled by active nature of the *Nalagarh lobe* particularly along transverse fault. The Sirsa nadi back thrust terminates at its knick point. An elongated Pinjaur intermontane valley of around 6 km wide has developed between the Nalagarh Thrust/MBF and Sirsa nadi fault. The Sirsa nadi meanders more while reaching near the lobe, which implies active nature of lobe. Streams (namely Dukhanda Khad, and its connecting Khali nadi and Jasu ki Khad drainages) are parallel to the south-eastern margin of lobe. The parallelism of drainages indicates the presence of lineament along this margin. The maximum height of lobe is 700 m, and general height of flood plain of Sirsa nadi is 330 m. Along north-western margin of lobe there is at least 1.8 km long NE-SW trending straight ridge with its maximum height of 700 m above msl. Its relief is 320 m from the adjacent plain and 371 m from the present Chikni Khad river course, which has been shifted towards northwest direction across north-western margin of *Nalagarh lobe.* After crossing front of lobe the Chikni Khad river again occupies its original course to meet the Sirsa nadi near Jagat Khana. It implies tectonic forcing of stream across north-western margin along which a straight fault ridge has developed. It suggests that there might be the existence of a fault parallel to the linear ridge. Along hinge line of northwest terminal of Chandigarh anticline, the Kanahan nadi flows. The transverse lineament traverses across the north-western terminal of the Chandigarh anticline formed in outermost Siwalik hills. Another implication of the existence of this transverse fault lineament is that this has truncated the north-westward growing of Chandigarh anticline, and the hinge line of fold has been curved along this active lineament. It seems that the salient acted as asperity for releasing seismic energy during major 1905 Kangra earthquake towards Dehradun recess. In Nalagarh region the transverse folds in the hanging wall of the MBF suggest their development caused by displacement out of tectonic transportation plane along north-western limb of salient. The *Nalagarh lobe* falls between two restraining bends. This architecture of restraining zone has induced compression that formed transverse thrust faults along which the *Nalagarh lobe* has been uplifted. Undulated ground surface of Nalagarh town is situated above an imbricate zone of such surfaced thrust splay faults including blind faults, along with much of the recent tectonic activity is distributed beneath the town. The slip along the buried detachment is accommodated by these uplifted fold propagation folds. This displacement also occurs along the MBF and strike-slip faults associated with right-lateral displacement along oblique ramp. A schematic diagram showing splays and transverse thrust faults bounding the *Nalagarh lobe* is illustrated in figure 1.

Magnetotelluric Investigation

Magnetotelluric data collection in the frontal part of the Nahan salient, Himachal Himalaya, was completed at 9 stations as shown in figure 2. The transfer functions were rotated to N45W and rotated transfer functions

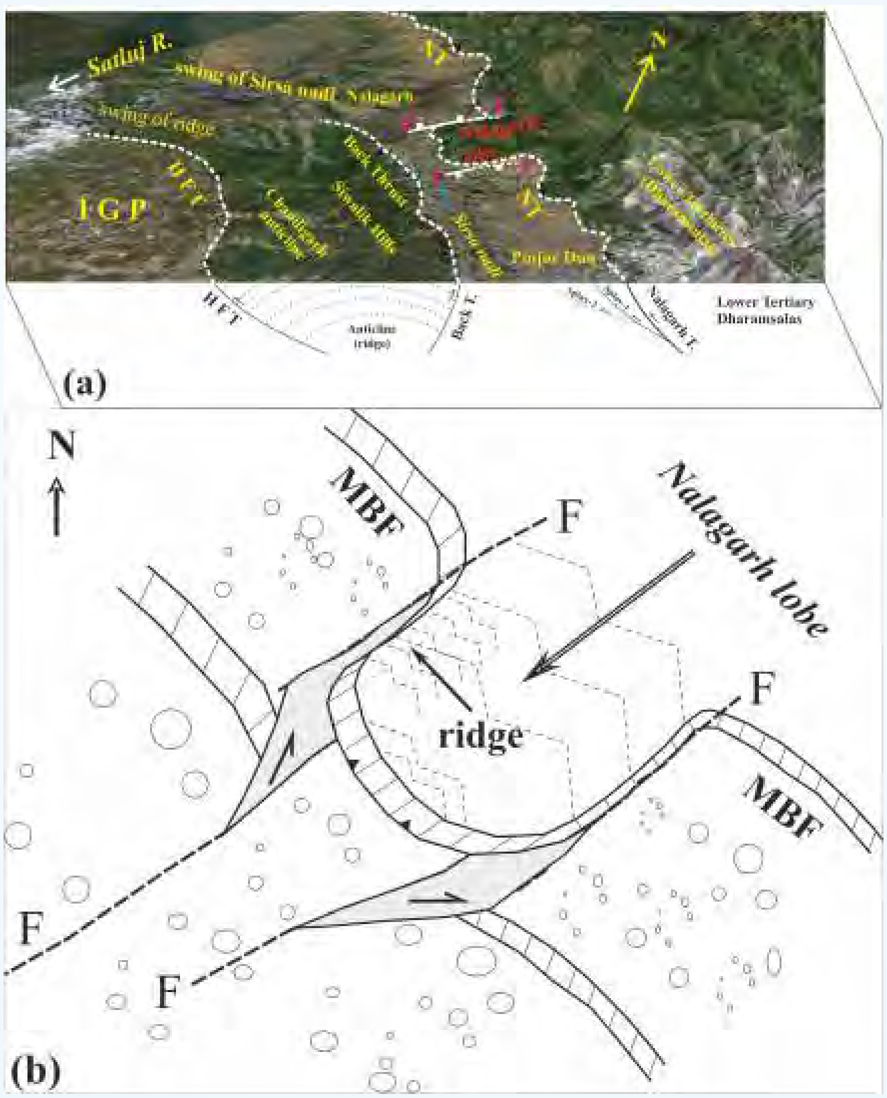

Fig. 1: Google Earth image showing geological features around *Nalagarh lobe* and schematic diagram depicting proposed model of evolution of *Nalagarh lobe* and associated splays. (a) Google Earth image showing *Nalagarh lobe* bounded by transverse thrust faults, south-westward swing of hinge line of Chandigarh anticline (forming anticlinal ridge), Sirsa nadi course, back thrust and truncation of Siwalik hills along wide course of the Satluj River. It seems that the anticline dies out north-west ward as a result of transverse thrust faulting along the north-western margin of lobe. Splay-1, -2, and -3 have been shown in front of the MBF. Intermontane piggy-back Pinjaur dun is bounded by the back thrust and MBF. (b) Schematic diagram showing proposed tectonic evolution of *Nalagarh lobe*, which has been uplifted between two oppositely dipping transverse thrust faults. A straight ridge (1.8 km long) has developed along one of the transverse thrust faults. MBF = Main Boundary Fault, HFT = Himalayan Frontal Thrust, IGP = Indo-Gangetic Plains.

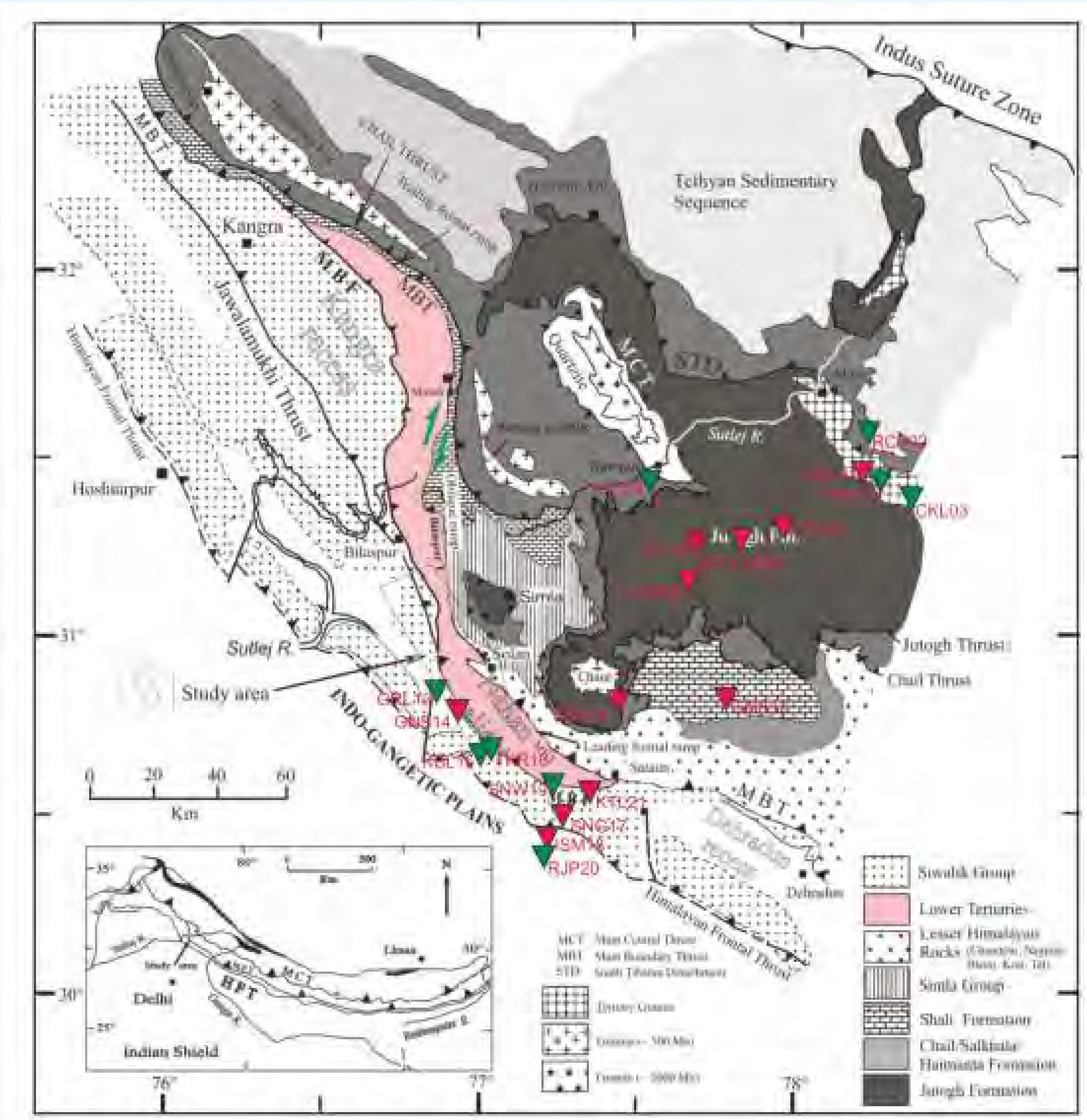

Fig. 2: Locations of MT stations along the Sutlej River valley profile.

were modelled for subsurface resistivity variations. Before rotation, the transfer functions were smoothened using D+ optimization method. These smooth curves were used in TM mode and Joint inversion, using different smoothing parameters and various error floors. From all the observations of inversions, it is observed that the crystalline rocks of the Jutogh Formation have variable thickness, which increases continuously toward north. Different thrust zones are well identified and surface features are well correlated with the known geology of the region along the profile.

Figure 3 depicts the comparison of model and observed TM response. The misfit differences between the model and TM response will be minimized while we decompose MT curves and model.

Further, utilizing particle swarm optimization, an 'R' code has been developed to estimate the distortion parameter of the MT tensor assuming GB model. Initially, the code estimates frequency wise distortion parameters and have the capability of calculations of different parameters (e.g., different skew parameters and phase tensor analysis). Since 'R' is an open source software, the algorithm implemented does not require any commercial module. Further the code is having scope of extensibility of implementing multi-frequency approach of decomposition of the MT transfer function.

Quantification of sub-surface stress regime in Kinnaur Himalaya

Focal mechanism solutions (FMSs) of recent minor magnitude earthquake events and published data of past

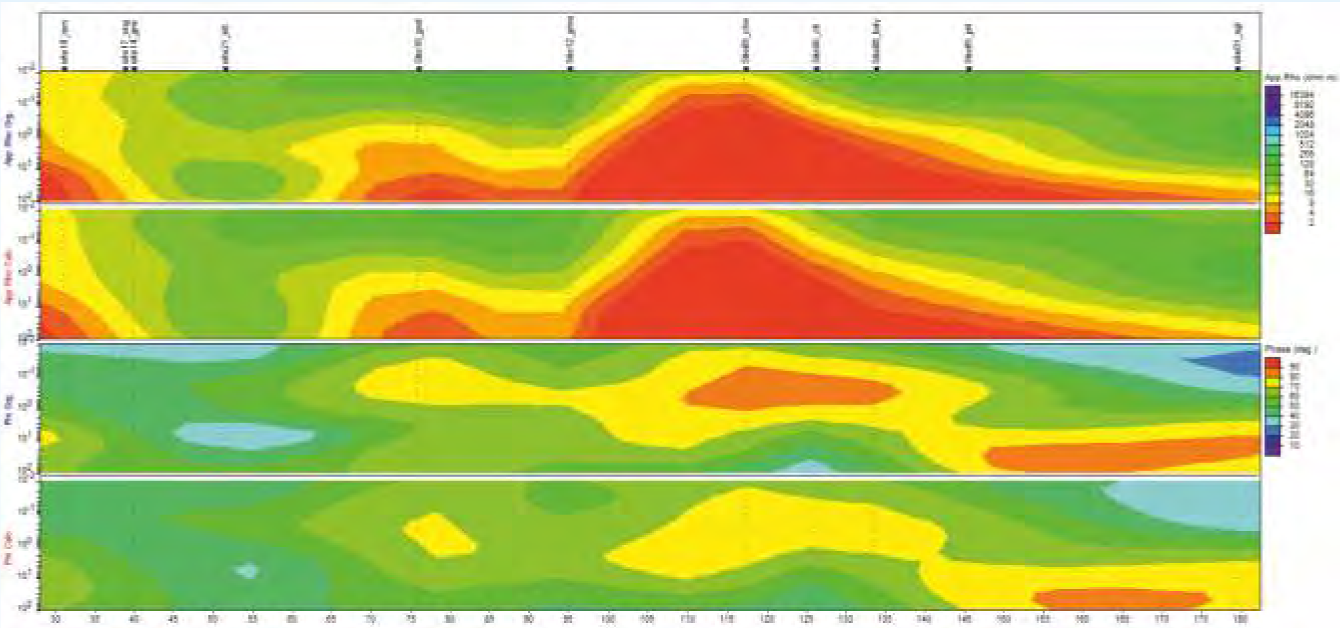

Fig. 3: Comparison of Model and observed response.

moderate magnitude earthquakes are used to assess the stress pattern of eastern sector of the NW Himalaya. We estimated FMSs of seven local earthquakes and also used six FMSs of previous studies (Molnar and Chen, 1983; USGS CMT solution and Harvard CMT solution). The earthquakes for which the FMSs are obtained using P-wave first motion polarity method are of magnitude ranging from 2.8 to 4.0. These events are well located with root mean square error in origin time less than 0.3 s, and epicentre and depth error within ±3 km. These events are selected based on good azimuthal coverage and recorded by at least 12 BBS stations. The FMSs are used for analysis of stress tensor inversion to obtain sub-surface stress pattern in the Tethys Himalaya. The map view of these FMSs is presented in the form of beach balls at the epicentres of earthquake events (Fig. 4). In the beach ball presentation, the shaded area indicates the compressional quadrant and the unshaded area is the dilatational quadrant. Black dots within dilatational quadrant represents P-axes and white dots in the compressional quadrant are T-axes. Majority of these FMSs is of normal faulting nature indicating extensional stress regime. Normal faulting solutions are obtained for the events 1, 2, 3, 4, 7, 9, 11 and 13, which are located close to the transverse Kaurik-Chango Fault (KCF) system and Leopargil horst. The N-S strike of the nodal planes in these FMSs can be correlated with the active KCF. The dip-angle of the inferred fault plane lies between 35º and 83º towards west.

The event 5 has also caused normal faulting along

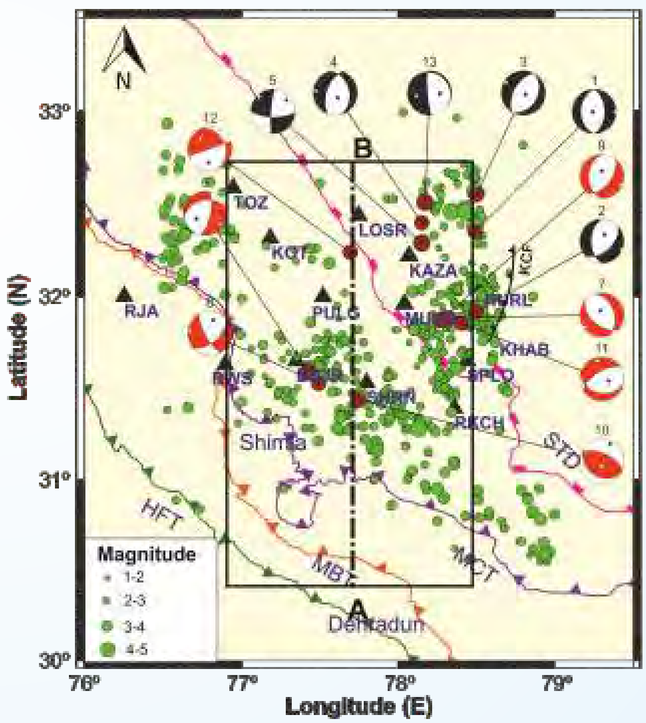

Fig 4: Tectonic map of the study region showing distribution of micro earthquake epicentres (green circles). The black triangles are locations of BBS stations and epicentres of events of the focal mechanism solutions (FMSs) are shown with brown-filled circles. Beach balls of FMSs are represented with usual notation. The major tectonic features are the Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), South Tibetan Detachment System (STDS) and KCF (Kaurik-Chango Fault).

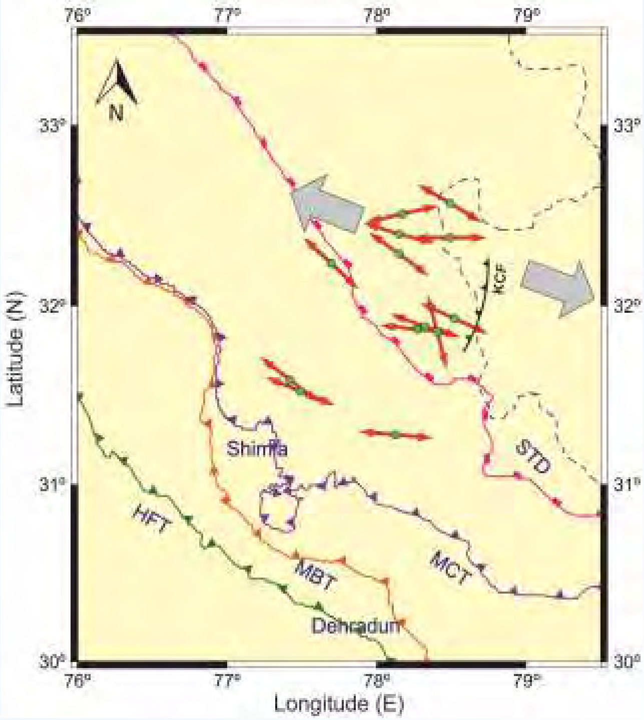

Fig. 5: Orientations of T-axes for 13 FMSs, used in this study, are shown by red divergent arrows at their respective epicentres. The average trend orientation of T-axis, represented by the larger grey arrows, is in WNW-ESE.

with strike-slip component. T-axes orientations obtained from the FMSs are plotted on the tectonic map in figure 5. These T-axes are aligned E-W with NW-SE favoured orientations. The resultant of all solutions is represented by large grey arrows, which portray WNW-ESE extension regime correlating with the prevailing tectonics of the region. However, to its south the thrust dominant tectonics exists favouring the Himalayan tectonics. This extensional stress in the Kinnaur Himalaya is responsible for the cluster of seismicity along the KCF and surrounding region. The FMS for the event 10 (Fig. 4) shows thrust mechanism that can be related to the Chaura thrust near the Wangtu Gneissic Complex (Jain et al. 2000).

Crustal structure study in the Satluj River valley

In continuation of the previous report, the shear wave velocity models at 18 broadband seismological stations of the Satluj River valley (Fig. 6a) have been refined applying the Neighbourhood Algorithm (NA) of Sambridge (Geophys. J. Int., 1999, 138, 727-746). Application of this inversion algorithm largely removes the limitation of considering fixed Poisson's ratio (~0.25) in the least square modelling technique of Ammon et al. (J. Geophys. Res., 1999, 95, 15303-15318) reported earlier. To obtain high resolution image of the crust along the profile, Common Conversion Point (CCP) migration method has also been applied to the computed receiver functions. The CCP image is shown in figure 6b. The depth of Moho and the MHT obtained by NA Inversion at each station is superimposed over the CCP image. The red dots indicate depth of Moho and yellow dots indicate depth of the MHT. The ray piercing points for the stations located over the Indo-Gangetic plain and the Sub-Himalaya (blue rectangle area in Fig. 6b) are calculated using the shear wave velocity model obtained by NA method considering the effect of the top sedimentary layer. The standard IASP91 model (Kennett & Engdahl, 1991) with Moho at 70 km depth is used for rest of the stations. Both of these methods clearly reveal gentle-dipping nature of the MHT between the Sub and Higher Himalaya (depth range of MHT is ~16-27 km), while a ramp structure is identified in the Tethys Himalaya (depth of MHT is ~38 km). The Moho gently dips to the north; the depth increases from ~44 km below the HFT to ~62 km below the Tethys Himalaya.

Seismotectonics of eastern Ladakh-Karakoram zone

The seismotectonics of the eastern Ladakh-Karakoram zone has been studied by analysing the local earthquake data (M ~1.4-4.3) recorded by a broadband seismological network consisting of 14 stations. These stations were operated during 2009-2012. The seismological stations recorded a total of 317 local earthquakes that occurred in and around the NW Himalaya, out of which 148 of the best located earthquakes in the study region encompass Tso-Morari Crystalline Complex, Ladakh batholith and Karakoram Fault Zone (Fig. 7a). The selection of these 148 earthquakes is done based on minimum errors in estimation of hypocentral parameters and high signal to noise ratio and their distribution is shown in figure 4. Source mechanism study of total of 13 selected earthquakes is made through waveform inversion of three-component broadband records. Depth distribution of the earthquakes and focal mechanism solutions (FMSs) of local earthquakes obtained by waveform inversion (Fig. 7b) reveal kinematics of the major fault zones present in the eastern Ladakh. A most pronounced cluster of seismicity is observed in the Karakoram Fault (KF) zone down to a depth of ~65 km. The FMSs reveal transpressive environment with an inferred strike-slip fault plane parallel to the KF. This study reveals that the KF penetrates down to the lower crust and is a manifestation of active underthrusting of Indian lower crust beneath Tibet. Two clusters of microseismicity are

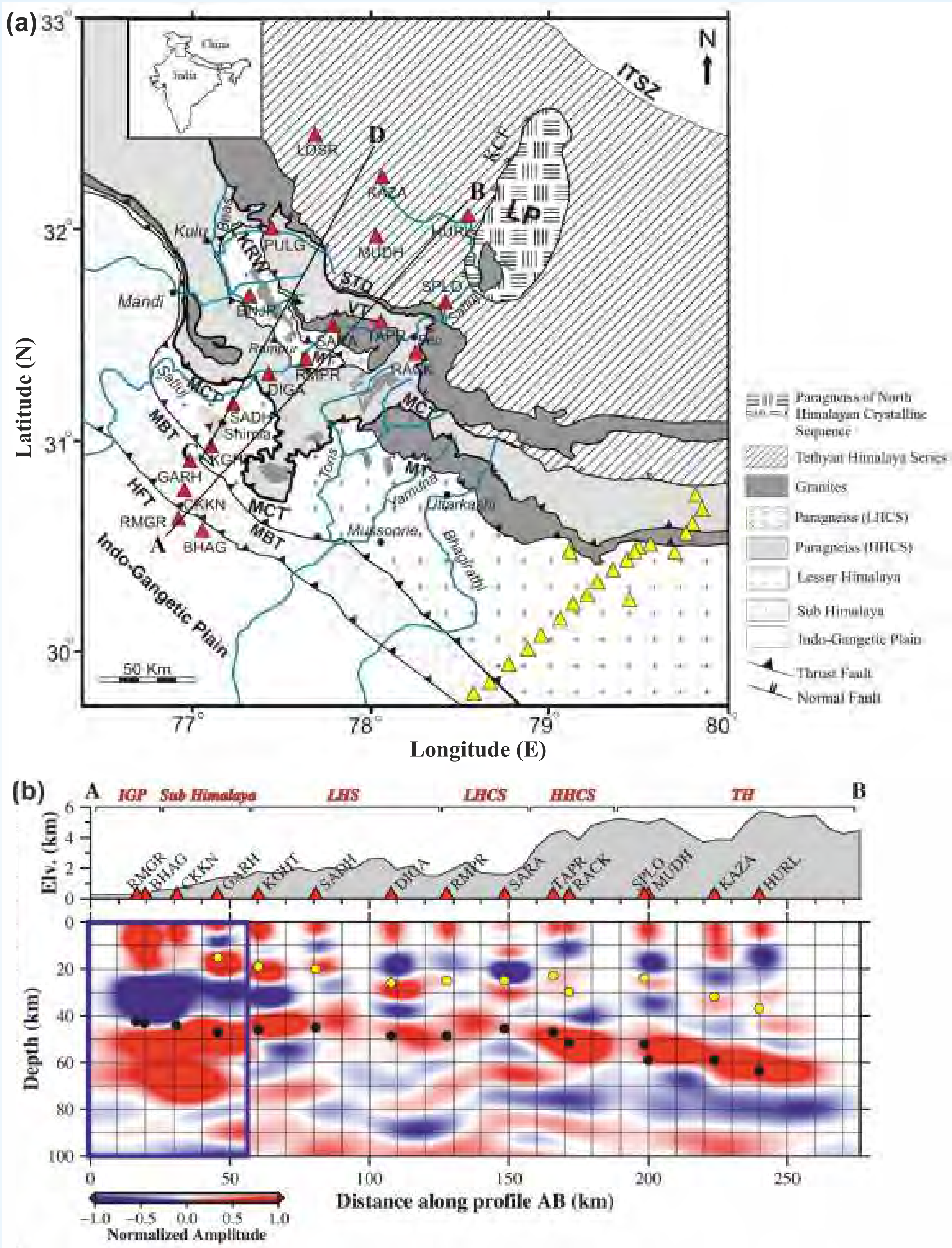

Fig. 6: (a) Simplified geological map of the northwest Himalaya showing major tectonic features (modified from Vannay et al., 2001, Geol. Mag., 138, 253–276). HFT= Himalayan Frontal Thrust, MBT= Main Boundary Thrust, MT= Munsiari Thrust, MCT= Main Central Thrust, VT= Vaikrita Thrust, STD= South Tibetan Detachment, LKRW= Larji-Kulu-Rampur Window, LP= Leopargil Horst, ITSZ= Indus Tsangpo Suture Zone and KCF= Kaurik-Chango Fault. The Common Conversion Point (CCP) depth migrated RF image along the A-B profile shown in (b). The consistent positive polarity shown by red signals of CCP image as well as projected Moho depths estimated by NA inversion (black dots) show a good agreement. The MHT obtained by NA method is shown by yellow dots.

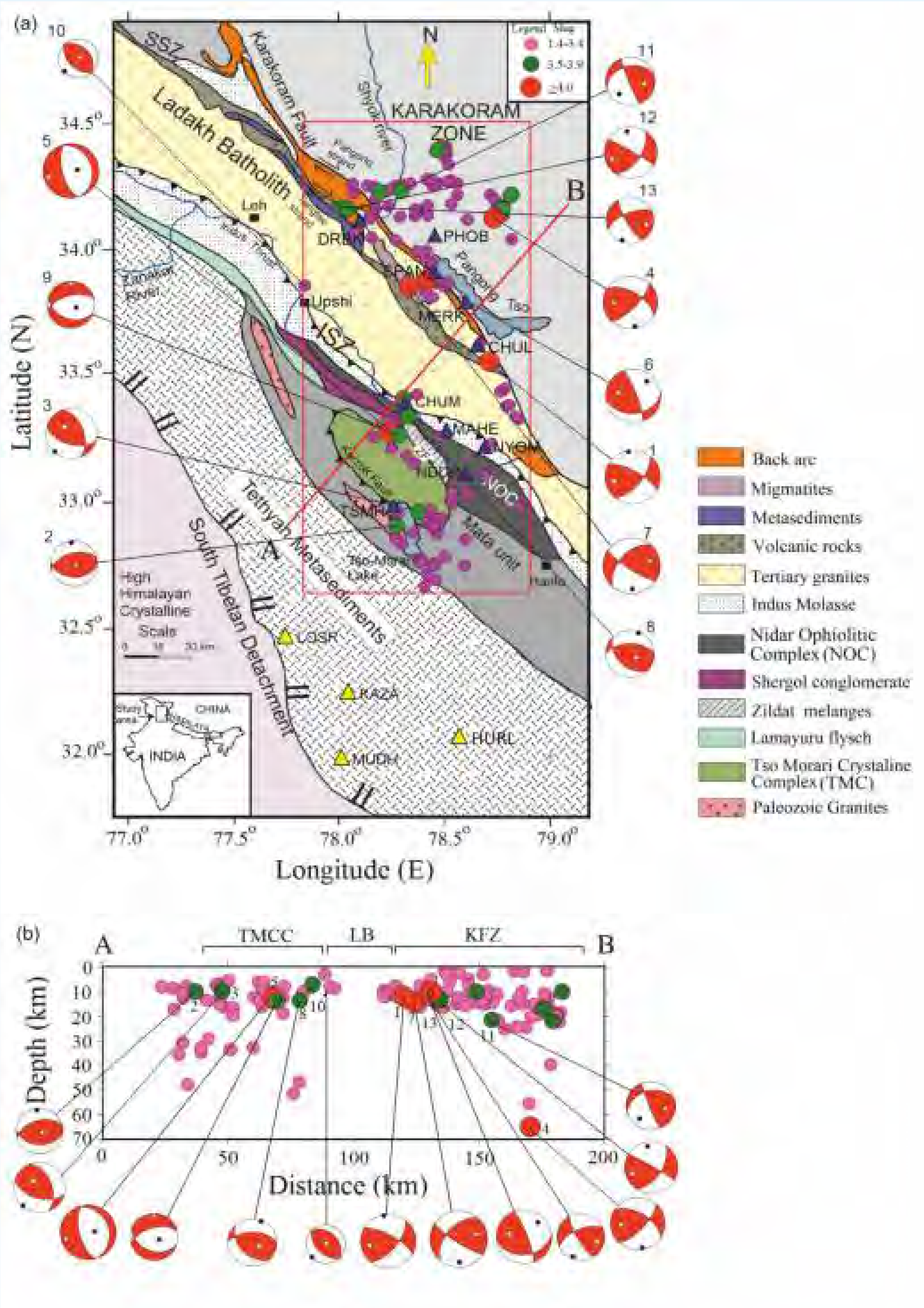

Fig. 7: (a) Simplified Geological map of northwest part of the Himalaya extending from Tethys-Himalaya, Indus Suture Zone (ISZ) and Karakoram zone (modified after Mahéo et al., 2004, Geol. 203, 273–303; Epart and Steck, 2008, Tectonophysics, 451, 242-264). The Zildat fault is marked as ZF. The red rectangle shows the study area. The blue and yellow triangles represent seismological stations of Ladakh and Kinnaur network. The distribution of earthquakes is shown by filled circles. The study region is shown by a rectangular box in the inset map of India and adjoining regions at the bottom left corner. The depth distribution of the earthquakes projected in AB section orthogonal to the NW-SE tectonic features, is shown in (b) where significant tectonic units like Tso-Morari Crystaline Complex (TMC), Ladakh Batholith (LB) and Karakoram-Fault-Zone (KFZ) are marked.

observed at a depth range of 5-20 km at the northwestern and southeastern fringes of the Tso Morari gneissic dome, which can be correlated to the activities along the Zildat fault and Karzok fault, respectively. The FMSs obtained for representative earthquakes show thrust fault solutions for the Karzok fault, and normal fault solutions for the Zildat fault, which acts as a detachment facilitating the exhumation of the Tso Morari dome. On the other hand, the Tso Morari dome is under thrusting the Karzok ophiolite at its southern margin along the Karzok fault due to gravity collapse.

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 (retd. on 30.5.2016))

Geodetically measured positional anomalies are also affected by the shallow sub-surface movement of the fluids in the alluvium pore spaces, especially in the Doon valley. This particular aspect has been investigated with the objective to understand at what predominant frequencies these fluid activities are predominant in the Doon valley. The site fundamental characteristics studied in terms of resonant frequencies and amplification factors in an alluvial region also involves the influence of pore space fluid action. The soft soil site characteristics in the Doon valley has been studied as a test case by utilizing the available seismic ambient noise data along with three broad band seismic data at the topographic transition zone near the MBT and at its northern topographic transition zone. This has helped to quantify the Seismic Vulnerability Index, effective dynamical shear strain and the expected ground deformation in the Doon valley soft soil through H/V site characteristics using seismic ambient noise data. Results show that, in the Doon valley and its terraces, the soft soil formed under fluvial environ is relatively thick (10 to < 535 m) and show a distinct single peak mean amplification factor >2 and mean resonant frequency of 1.1 Hz. The studies showed that the spot resonant frequencies increases from 1 Hz to more than 6 Hz from the HFT region to the MBT, while the amplification factor decreases from 15 to 1 as shown in figure 8.

Investigations carried out on the Dynamical shear strain distribution with depth at eight boreholes in the valley indicate that ~20 m is the liquefaction potential depth, where the pore pressure induced peak shear strain exceeds the threshold shear strain of 0.01 % during the passage of seismic waves. Isolated locations in the valley like Dharmawala (H1) is hazardously vulnerable to liquefaction, while moderate levels of liquefaction is possible at Doiwalla, Selaqui, Sastrinagar and Ranipokhri wherein all site parameters are very high. However, near the MBT the liquefaction possibility of soft soil is less, but would experience ground deformation of more than 50 cm.

Further studies were also carried out following the Mw 7.8 Gorkha (Nepal) earthquake of April 25, 2015, wherein the positional anomalies of CGPS stations were analysed. The objective was to investigate the near and far field static offsets in the GPS measurements. The near field stations like KKN4 and CHLM shows predominant static offsets of 1.8 and 1.4 m, respectively in their NS components and shown in figure 9. The stations near these also show subsidence of half a meter to around a meter. However far stations (>600 km) like at Munsiari (MUNS) and Dehradun (LES2) do not show any significant co-seismic offsets as observed in their three component kinematic displacements with respect to the station of IISc at Bengaluru. Inter comparison of kinematic displacements at MUNS and LES2 stations show concurrent displacements in N-S and E-W components as shown in figure 10. However, vertical component variation of MUNS is quite erratic followed by the arrival of surface Rayleigh wave displacements in the aftermath of the Mw 7.8 Gorkha event. A few pre-processing scripts were developed to do the data editing before inputting it to GAMIT/GLOBK. Combined pre-processing of the 2015 and 2016 data is under progress. Field stations at Shambuwala and Biharigarh were visited and maintained for their continuous running during the year.

The computation of Gravitational potential energy has been made by considering the crust-lithospheric part based on a two layer model and solved the integral equation of GPE. Earlier based on SRTM topographic data the topographic effect of GPE were calculated, which shows high GPE in the Higher Himalayan region. The lithospheric part of GPE by considering the EGM2008 model having a lithospheric thickness of 100 km shows the distribution is divided in accordance with the tectonic plate boundaries. The region from the south of foreland depression shows the flexural fore-bulge of the continental Indian lithosphere. This suggest that, the amplitude of the fore-bulge in the Indian plate is having a bearing on the downward bending of the Indian plate, and hence the load that Himalayan Mountains exerted over the plate. The lithospheric GPE distributed as a single unit divided by GPE lows from the north of

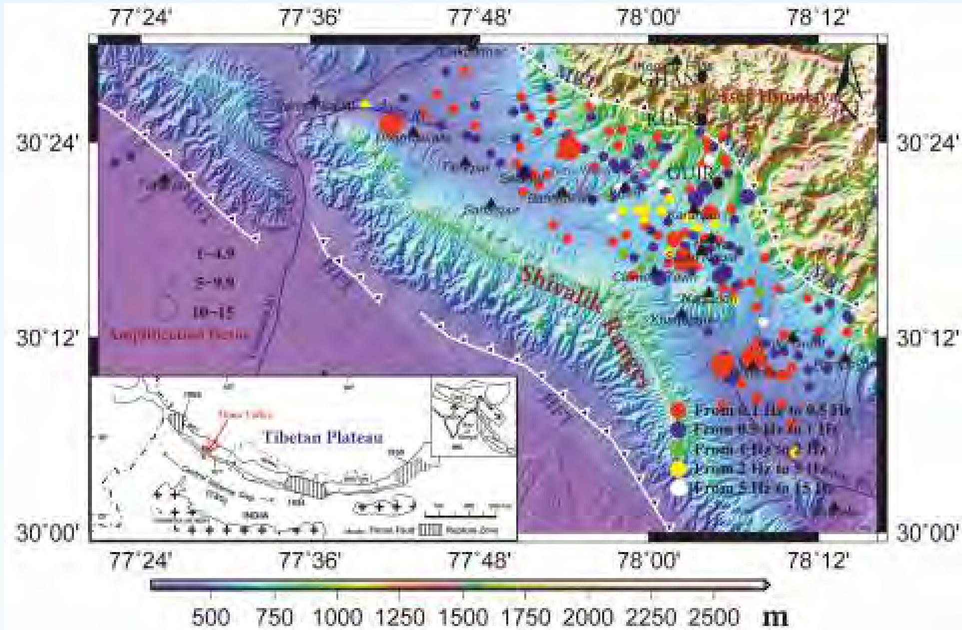

Fig. 8: Spot resonant frequencies and amplification factors of top soil in the Doon valley obtained from seismic ambient noise measurements.

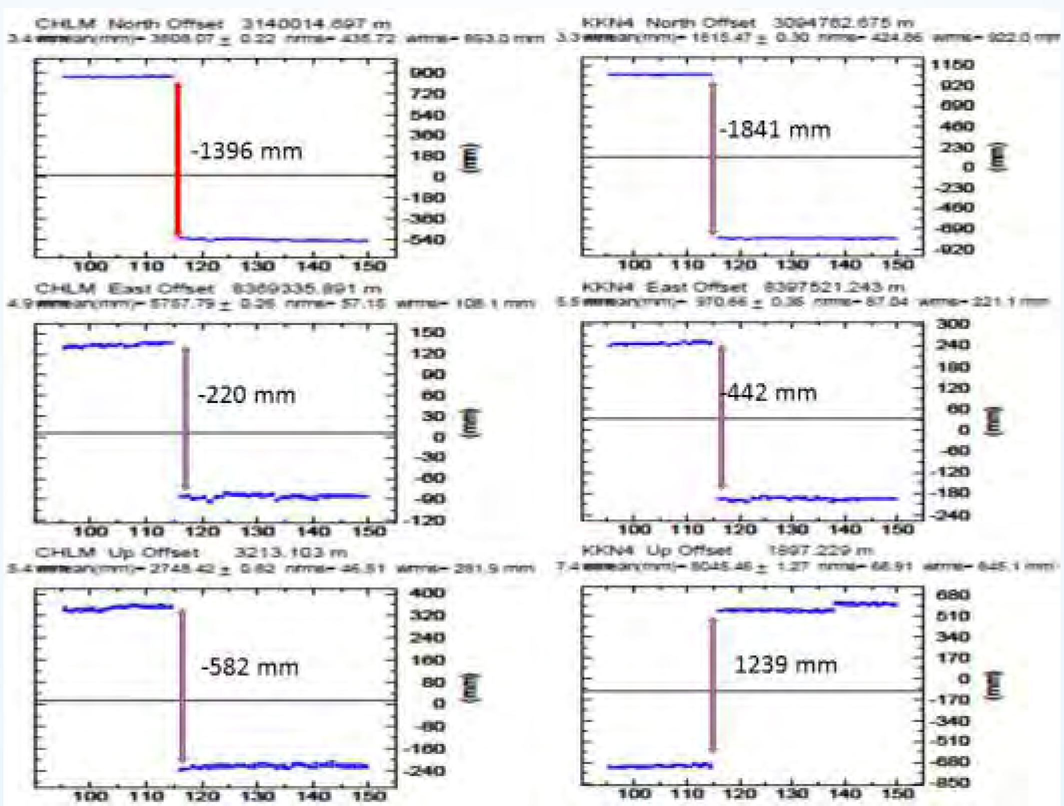

Fig. 9: Near field co-seismic static offsets of 1.8 and 1.4 m are observed respectively in the N-S and E-W components at near stations (distance <100 km from the epicenter) KKN4 and CHLM followed by the Mw 7.8 Gorkha (Nepal) earthquake on 25th April 2015. However, the vertical components show subsidence and uplift respectively at the CHLM and KKN4 stations.

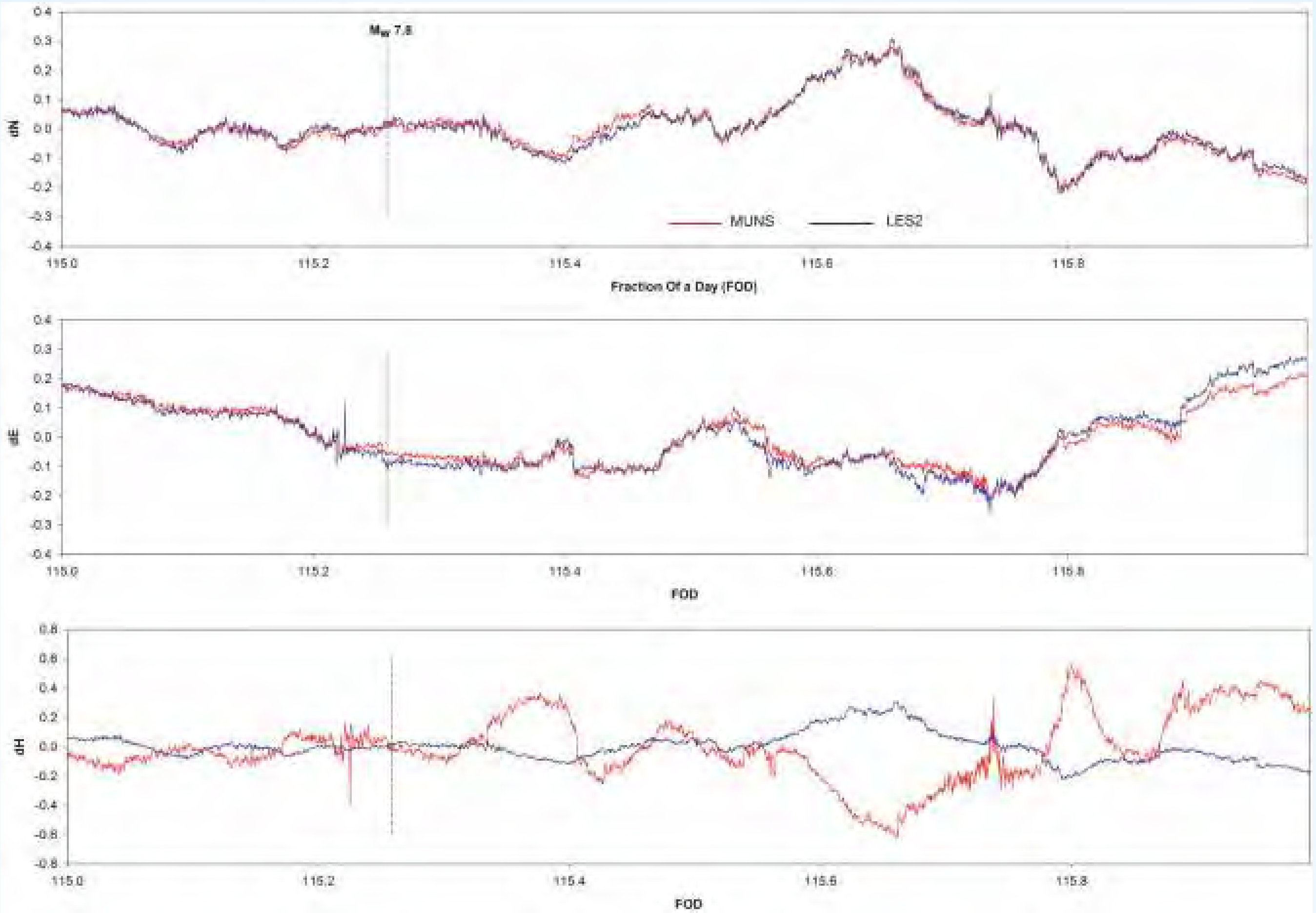

Fig. 10: Concurrent variations in the kinematic offsets of far field (distance > 600 km from the epicenter) stations at Munsiari (MUNS) and Dehradun (LES2) followed by the Mw 7.8 Gorkha (Nepal) earthquake on 25th April 2015. No static co-seismic offsets are observed at the far field stations.

foreland depression to the MCT zone, while from the north of MCT zone towards the ITSZ the lithospheric GPE is relatively high extending from the Garhwal and Nepal Himalaya towards the NE Himalaya.

TAT-1.3

Tectonics of the Shillong Plateau, northeastern India

(Swapnamita C. Vaideswaran)

The Kulsi basin located on the northern flank of the Shillong Plateau was taken up for morphotectonic study. The Chandubi Lake is an interesting depression located in a paleochannel of the Kulsi River, where in-situ buried/submerged and partially submerged tree trunks are found. This basin shows river migration in the past due to an interplay of climate and tectonics. In order to understand the tectonic response of the basin in relation to the overall tectonics of the plateau, GIS based study of geomorphic indices were calculated for the basin. Morphometric parameters such as longitudinal profile analysis, stream length gradient index, valley floor width to valley height ratio, and steepness index indicate that the basin experiences tectonic disturbances originating from the south of the plateau, but also shows indication of activity corresponding to the Guwahati/Rani Faults. Radiocarbon dates have been obtained from tree-trunk samples collected from the Chandubi Lake. The dates 160±50 AD, 970 ± 50 AD and 1190 ± 80 AD coincides with enhanced Indian Summer Monsoons during the Common Era and the Medieval Warm Period showing inundation episodes during the Late Holocene implying coupling of this eastern Indian plateau with global climate phenomenon. These dates also show the presence of the lake before the 1897 earthquake as believed locally. The last date, 1520±30 AD, records the last inundation episode in the area, which falls within the Little Ice Age. We are now able to relate this date with the 1548 AD earthquake located on the Dauki Fault (Morino et al., 2011). This earthquake finally shifted the Kulsi River eastward to the present day course with uplift on the southern front of the plateau. Thereafter the lake has been shrinking in size and no major inundation has been recorded.

Further, field work has been carried out in the eastern most segment of the plateau towards the Mikir Hills. This region shows extensive old alluvium terraces where tea gardens are plenty. In the Ransali area, at least four levels of terraces have been mapped. Samples have been collected from the area and are under analyses for obtaining dates for further study. Very few terraces are preserved in the Shillong Plateau, especially the Garo Hills regions due to a play of climate in terrace formation and denudation. However, a few terraces along the Ganol River and Rongram River were explored and samples collected for OSL dating which is under progress. Mostly flood plain deposits and T1 was seen developed. However, at certain places north of the presumed Chokpot scarp some terraces were seen to develop. In several terraces, surfaces lithic tools were found in abundance. Typology of the tools has been studies which give the relative age as Paleolithic Period. OSL age obtained from one sample collected from Misimagre gives the age as 11000±1.6 years and can be estimated for lithic cultures to have flourished during that period.

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)

An integrated geochemical and U-Pb geochronological analysis was carried out on the migmatites and associated two-mica granite intrusions within the Ladakh Arc. One sample of mesosome from this migmatite gives a crystallization age of 66.9±1.5 Ma and a younger population of zircons giving an age of 62.1±1.3 Ma. This sample also bears a younger cluster of zircons (n=7) giving a concordant age of 50.0±2.9 Ma. The other sample of one leucosome contains a cluster of zircons that gives a crystallization age of 55.3±1.5 Ma. Limited Hf isotopic analysis of the leucosome shows positive $\varepsilon_{Hf(t)}$ values ranging from 7 to 15, comparable to that of the LMA. High and positive $\varepsilon_{Hf(t)}$ values and absence of any Palaeozoic xenocrystic zircons help us infer that the Indian continental crust was not involved in the partial melting and leucosome generation processes. Therefore, this event of migmatization predates Indo-Eurasian collision. Geochemical signatures and presence of muscovite suggest crustal origin for the two-mica granite. Zircons from this granite give an age spectra of 38.1±1.1 Ma. This two-mica granite also contains xenocrysts of Palaeozoic ages. By integrating our studies with earlier works, we infer that this migmatization of the LMA indicates its collision with the Indian plate, prior to Indo-Eurasian continental accretion at ~55-50 Ma. The two-mica granite contains xenocrystic material from both the LMA and the Indian continental crust, and indicates S-type granite magmatism related to India-Eurasia continental collision at 35-40 Ma.

TAT-1.5

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

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

Field work was carried out in the summer of 2014 in the Shergol, Tangtse valley and collected samples of blueschists and metapelites. The blueschists occur seldom along the Yarlung-Tsangpo Suture zone, i.e. the suture marking the India-Asia collision. These blueschists are mostly interpreted as related to paleo-accretionary prisms formed in response to the subduction of the Neo-Tethyan Ocean below the Asian plate. They are crucial for constraining the evolution of the India-Asia convergence zone during the closure of the Neo-Tethyan Ocean. In the Western Himalaya, the best occurrence of blueschists is in the Sapi-Shergol Ophiolitic Mélange in Ladakh. This unit is dominated by volcanoclastic sequences rich in mafic material with subordinate inter bedding of metasediments, characterized by very fresh lawsonite blueschist-facies assemblages. The blueschist rocks from Shergol Ophiolitic Mélange record metamorphic peak conditions at ~19 kbar, 470°C. Fluid inclusions of several types are trapped in quartz and garnet, most of them being two-phase at room temperature. Basing on microtextures and fluid composition, three types of fluid inclusions have been recognized: Type-I are primary two-phase carbonic-aqueous fluid inclusions (V_{CO2}-L_{H2O}); Type-II are two-phase aqueous fluid inclusions (L_{H2O} - V_{H2O}) as either primary (Type-IIa) or secondary (Type-IIb); and Type-III are re-equilibrated fluid inclusions. In the Type-I, primary carbonic-aqueous inclusions, H_2O is strongly predominant with respect to CO_2; the homogenization temperature of CO_2 range from -7 to -2°C. The clathrate melting temperature of such inclusions varies between +7.1 to +8.6°C. Type-II, two-phase aqueous fluid inclusions show a wide range of salinity from 7.8-14 wt. % $NaCl_{eq}$ (Type-IIa) to 1.65-6.37 wt. % $NaCl_{eq}$ (Type-IIb) with accuracy of around ±0.4b wt. % $NaCl_{eq}$.

Type-I and Type-IIa primary fluid inclusions are hosted in peak minerals (garnet and quartz included in garnet), therefore they were likely to be entrapped at or near to peak P-T conditions. The dominantly aqueous fluid of both Type-I and Type-IIa inclusions was most likely produced through metamorphic devolatilization reactions occurring in the subducting slab. Despite their primary nature, the isochores of Type-I and Type-IIa inclusions do not intersect the peak metamorphic conditions of the blueschists mineral assemblage, suggesting that these inclusions stretched or re-equilibrated during nearly isothermal decompression from 19 kbar to 3 kbar or less, at T=290°C. The conclusion is further supported by their large variability in shapes and sizes which range from irregular inclusions ('C'/arc shaped, hook shape and satellite type). This decompression stage was followed by nearly isobaric cooling, testified by the occurrence of dendritic networks of decrepitated and 'imploded' fluid inclusions.

The medium grade metapelites of Pangong-Tso area in the trans-Himalayan region underwent sillimanite-grade metamorphism initiated during the Cretaceous, associated with the collision of the Kohistan arc and the Indian plate with Asia. The petrological and fluid inclusion studies were carried out to understand the metamorphic P–T conditions and fluid history of these rocks. The calculated phase equilibria in the Na_2O-CaO-K_2O-FeO-MgO-MnO-Al_2O_3-SiO_2-H_2O-TiO_2 (NCKFMMnASHT) system suggest P-T conditions of 8 kbar and 650°C for the peak metamorphic event. Primary fluid inclusions occur in staurolite and garnet, whereas quartz carries mostly secondary fluid inclusions. The trapped fluids in primary inclusions show initial melting temperatures in the range of -56.9 to -56.6°C, suggesting nearly pure CO_2 composition. The secondary fluids are of mixed carbonic-aqueous nature. The re-equilibrated inclusions show annular morphology as well as necking phenomena. The CO_2 isochors for the primary inclusions indicate pressures of 6.1-6.7 kbar, suggesting that the CO_2-rich fluids were trapped during post-peak exhumation of the rocks, or that syn-metamorphic carbonic fluids underwent density reversal during isothermal decompression. The secondary CO_2-H_2O fluids must have been trapped during the late exhumation stage, as their isochores define further lower pressures of 4.8 kbar. The morphology of re-equilibrated fluid inclusions and the rapid decrease in pressure are consistent with a near-isothermal decompression trajectory following the peak metamorphism. The carbonic fluids were probably derived locally from decarbonation reactions of the associated carbonate rocks during metamorphism or from a deep-seated reservoir through Karakorum fault.

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)

New detrital zircon U-Pb data for the Higher Himalayan Crystallines (HHC) and part of adjacent Tethyan sediments (Martoli and Ralam Formation) further north of HHC across STD were generated (Figs. 11A to E). Thereby, giving a comprehensive picture of detrital zircon population from the Inner Lesser Himalaya, through MCT zone (Munshiari Fm) and HHC to the base of Tethyan sediments across STD. HHC consists of three main formations viz, from south to north (i) Joshimath, (ii) Suraithota or Pandukeswar, and (iii) Bhapkund. Following are the salient observations:

- The three sub-units (Formations) of HHC group show interesting zircon population patterns. Whereas, the Neoproterozoic zircons (770-890 Ma) predominates in HHC, a notable Paleozoic (475-550 Ma) phase zircon population is observed in Joshimath and Bhapkund. This paleozoic component is absent in the Suraithota Fm of the middle HHC. This is a new observation not reported earlier.
- The ortho-gneisses from MCT zone (or Munshiari Fm) reveal a unimodal distribution of zircon population of Paleoproterozoic age with a very narrow age range of 1894 to 1994 Ma suggesting a very short duration of extensive arc magmatic phase. However, the Berinag quartzites show much wider population, but 'no' zircon younger than 1700 Ma are present in the inner-Lesser Himalaya.
- Tethyan sediments (one sample each from Martoli and Ralam conglomerate) show detrital zircon populations much similar to that of HHC with the difference that, the Paleozoic zircons predominates with a notable population of Neoproterozoic zircons. The youngest zircon in Martoli is about 600 Ma old while that of Ralam conglomerate is about 425 Ma. This also suggest a northward younging of the sequence.
- Across STD, Ralam conglomerate shows much younger zircon ages between 468 and 528 Ma.

The above observations suggests that the inner-Lesser Himalayan rocks are the oldest group (Paleoproterozoic) and the Tethyan sediments are

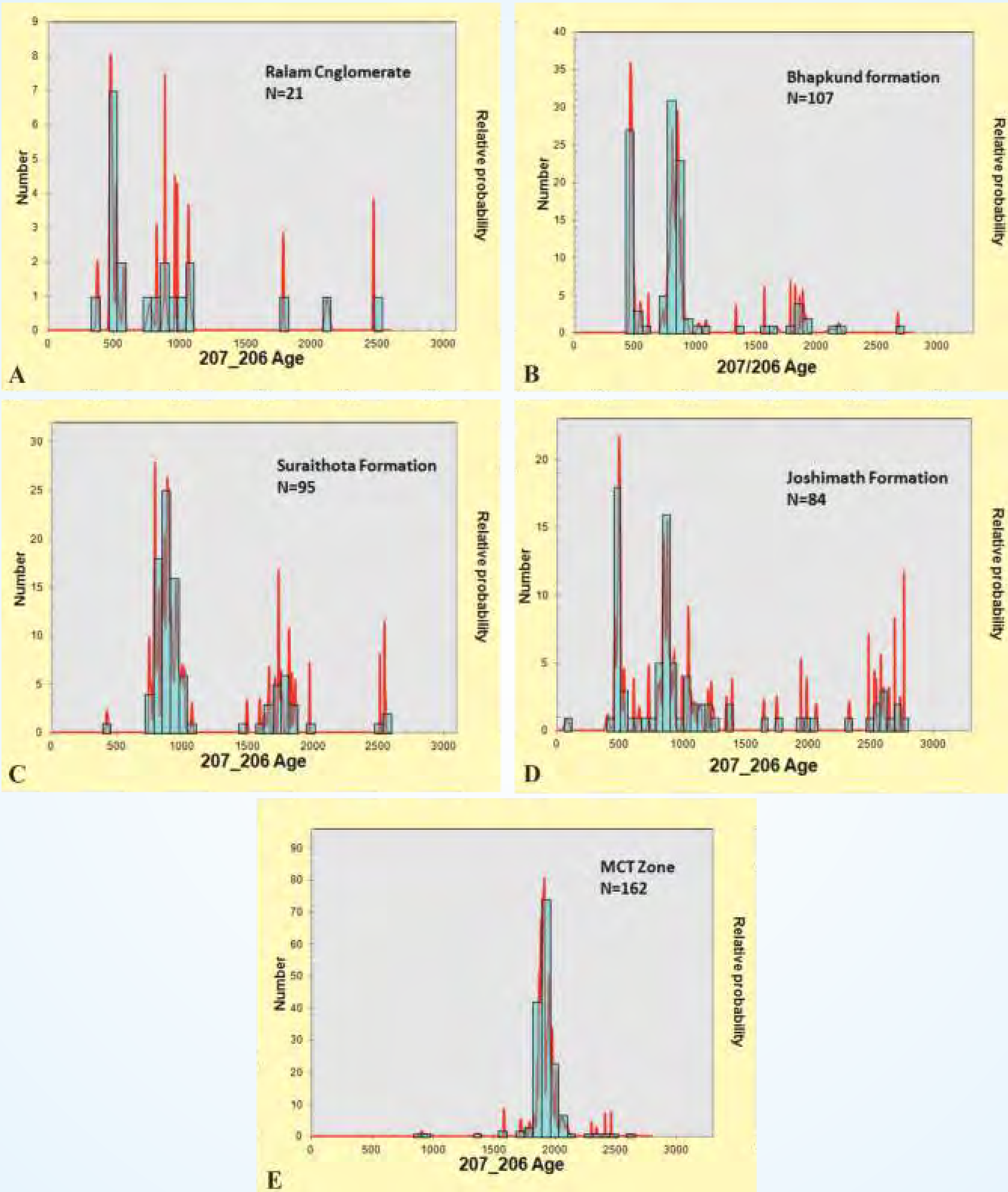

Fig. 11: Histogram of $^{207}Pb/^{206}Pb$ Zircon Age (in Ma): (A) Ralam Conglomerate, (B) Bhapkund Fm., (C) Suraithota Fm., (D) Joshimath Fm., and (E) MCT Zone (Munshiari, Baijnath and Berinag Group).

youngest of all <550 Ma). The intervening HHC rocks are intermediate in age and are probably deposited prior to Paleozoic (>500 Ma) but much later than Neoproterozoic (<750 Ma). Going by the youngest zircon reasoning, the maximum age limit of HHC may be assigned at 750 Ma. Whereas, the source for Paleoproterozoic igneous zircons is considered to be derived from an arc setup in Columbian Super Continent set-up, the source for the Neoproterozoic zircons remains unclear. This would require more extensive provenance investigation using tools like Hf and Os-Re isotopic systematics.

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 lower Palaeozoic two-mica granite body known as the Jaspa granite has undergone garnet grade metamorphism. The granite body encloses mafic enclaves as well as xenoliths of country rocks which belongs to Tethyan Himalayan Sequence. The common mineral assemblage observed in mafic enclaves and xenoliths (country rock) is muscovite-biotite-plagioclase-quartz±K-feldspar±garnet with accessory epidote, titanite, apatite and opaque. Titanite occurs either as solitary grain scattered in the matrix or occurs as inclusions in biotite. Tourmaline has developed in the country rocks. The garnet exhibits high grossular to spessartine content. EPMA analyses show chemically homogeneous plagioclase. The preliminary *P-T* pseudo-section modelling of the garnet bearing xenolith suggests peak metamorphic *P-T* condition in range of 4.5-7.5 kbar and 450-500°C.

In Alaknanda valley, NW Himalaya, monazite and allanite have been observed as an accessory minerals. Both phases are rich in REEs. Yttrium content occurs in considerable amount. Monazite occurs as amoeboid shaped grains of up to ~200 micron length in the matrix of the MCTZ samples. Allanite occurs as anhedral equant to elongated grains of ~20-25 micron length in the matrix and also as inclusions in garnet porphyroblasts. A zircon inclusion of ~180 micron length occurring in the rim of garnet, contains inclusions of xenotime and pyrite inside it. Accessory allanite has yttrium content of <3.52 wt % Y_2O_3. It shows increasing X_{Mg} and Al_2O_3 content with increasing grade of metamorphism. The occurrence of monazite (0.44-1.58 wt % Y_2O_3) is restricted to lower grade rocks at the lower structural levels of the MCTZ which indicates that the mineral became unstable relative to allanite at higher temperatures.

The fluid inclusion studies have also been carried out in the (i) Quartz mineral inclusions present within Garnet (QzG), (ii) Garnet porphyroblasts (GrP), and (iii) Matrix Quartz (MQz) occurring in the metapelites across the Loharkhet-Phurkiya section along the Pindari valley of the Kumaun Himalaya. The studies showed that they are four types of fluid inclusions found in the studied minerals, which are classified as Type-I carbonic inclusions, Type-II aqueous-carbonic fluid inclusions, Type-III bi-phase aqueous fluid inclusions, and the Type-IV multiphase aqueous carbonic inclusions filled with an aqueous fluid, a carbonic bubble and a salt daughter crystal. Representative isochors of the carbonic and aqueous-carbonic inclusions in QzG, GrP and MQz together with the mineral phase PT range, attribute H_2O-CO_2 fluid in Type-II inclusions in Gr and QzG to be metamorphic fluids, whereas, the Type-I carbonic inclusions and the Type-II aqueous-carbonic inclusions of MQz are C-O-H fluids, and are of retrogressive nature. Further, the pressures deduced from the representative isochors for the aqueous-carbonic (Type-II) inclusion in QzG and GrP upto staurolite grade metamorphism is ~6.7 and 6.9 kbar at 550°C, and is ~5.5 and 6 kbar at 500°C, respectively. Similarly, the pressure deduced from CO_2-H_2O isochors are ~7.2 kbar at 550°C or ~8.8 kbar at 650°C for the kyanite grade metamorphism *(Him Geol., 2017, v. 30(1), pp. 56-67).*

NE Himalaya and adjoining area

Outcrop-scale structures and magnetic fabric anisotropy of the Bomdila Gneiss (BG) that intruded the Lesser Himalayan Crystallines (LHC) of the Arunachal Lesser Himalaya are studied to understand the BG deformation history and tectonic evolution. Detailed analysis of structures reveals that the LHC have undergone three phases of deformation, D1, D2 and D3. The S2 foliation developed during the second phase of deformation (D2) is the most penetrative planar fabric in the studied rock, which shows a general ENE-WSW strike with moderate NW dip. Mesoscopic evidence of a later phase of deformation (D3) in the BG is lacking. Evidence of D3 deformation in the form of F3 folds is only observed in the adjacent metasedimentary rocks of the LHC. The magnetic foliations recorded from anisotropy of magnetic susceptibility (AMS) analysis of the BG are mostly striking NW-SE with a moderate dip towards the NE or SW, and magnetic lineation is mostly sub-horizontal and dominantly plunging towards the

SE. Our study shows that the magnetic fabric of the BG does not correspond to any visible outcrop-scale mesoscale foliation. However, the magnetic foliation of the BG is parallel to the axial plane of the F3 folds of the adjacent metasedimentary rocks of the LHC. Integration of AMS and outcrop-scale structural analysis helps us envisage the superposed deformation history of the BG. Our study emphasizes the importance of AMS to detect late-stage or feeble deformation events that leave no visible outcrop-scale imprint and are difficult to discern through conventional geological means.

New U-Pb zircon ages and whole-rock chemistry of plagiogranites were reported from the Nagaland-Manipur Ophiolites (NMO) exposed in the Indo-Myanmar Orogenic Belt (IMOB), NE India, which represents the southeastern extension of the Indus-Yarlung-Tsangpo Suture of Neo-Tethyan origin. The plagiogranites (SiO_2=57-76 wt %) are characterized by high sodium (Na_2O=5.9-7.2 wt %) and low potassium (K_2O= <0.6 wt %), coupled with low Rb (2-10 ppm), low Rb/Sr (<0.1) and molar A/CNK <1. Geochemically the rocks represent to be of oceanic plagiogranites with trondhjemitic compositions and metaluminous affinities. Their rare earth element (REE) patterns exhibit depletion in LREE (La_N/Sm_N=0.50-1.13) relative to HREE (Sm_N/Yb_N=0.59-0.88), with low ΣREE and incompatible trace element contents that indicate derivation from a depleted mantle source. High ratios of Large Ion Lithophile Elements (LILE) to High Field Strength Elements (HFSE) with pronounced Nb, Ta and Ti depletions likewise suggest the presence of the subduction component in the source region. Zircon U-Pb geochronology yielded mean $^{206}Pb/^{238}U$ ages between 116.4±2.2 and 118.8±1.2 Ma that record crustal formation in the Early Cretaceous. Collectively the data indicate that the NMO are broadly coeval and geochemically comparable with Neo-Tethyan ophiolites elsewhere in the Indus-Yarlung-Tsangpo Suture.

The NMO of Northeast India forms a part of the Tethyan ophiolites and comprises a suite of tectonite peridotites and cumulate mafic-ultramafic sequence with mafic extrusive-intrusive rocks, felsic intrusive and oceanic pelagic sediments along with minor podiform chromitites. However, sheeted dykes, which are considered as a significant component of ophiolites are absent in the NMO. The tectonite peridotites are distinguished from the cumulate pyroxenites by the presence of pyroxene lineation, deformed bands and strained extinction in olivine, kink twin lamellae in pyroxene. Both the tectonite peridotites and cumulate pyroxenites contain aluminous spinel with Cr number (Cr/(Cr+Al)) in the range of 0.14 to 0.29 and 0.27 to 0.48, respectively. Mg number ($Mg/(Mg+Fe^{2+})$) in Cr-spinel is higher in tectonite peridotites (~0.71-0.76) than cumulate pyroxenites (~0.44-0.53). Chondrite-normalized rare earth elements (REE) patterns of cumulate pyroxenites exhibit depleted LREE (La_N/Sm_N=0.380-0.759), flat HREE (Sm_N/Yb_N=0.622-0.756). However, the tectonite peridotites show gradual decrease in HREE (Sm_N/Yb_N=0.285-0.460) and slight enriched LREE (La_N/Sm_N=0.721-2.201). The cumulate pyroxenites show higher PPGE concentrations (ΣPGE=86-164 ppb) and strong enriched PGE patterns as compared to the tectonite peridotites (ΣPGE=35-113 ppb). The estimated equilibration temperature ranges from 890 to 931°C for cumulate pyroxenites and 971 to 1156°C for tectonite peridotites. The olivine-spinel equilibrium along with Cr-spinel chemistry and PGE data suggests that the tectonite peridotites represent the residual mantle left after limited extraction of basaltic melts by low-degree partial melting (<15%). Conversely, the presence of high magnesian orthopyroxene and clinopyroxene in the cumulate pyroxenites in conjunction with their geothermometry suggests that they were formed at high pressure and temperature by 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 devoid of plagioclase suggesting their derivation in the mantle beyond the stability limit of plagioclase in a mid-oceanic ridge tectonic setting. To conclude it can be said that the ultramafic sequence of the NMO was initially generated at a mid-oceanic ridge tectonic setting close to the eastern boundary of the Indian passive margin and then thrust over the continental margin of the Indian Plate towards the west during its collisional and subduction process with/beneath the Myanmar Plate.

The study also reports the first documented occurrence of platinum group minerals (PGM) and silicate inclusions in the podiform chromitites of the NMO complex, IMOB of NE India. The studied chromitites were divided into three groups, high-Cr (Cr#=0.72-0.80), intermediate-Cr (Cr#=0.66-0.68), and low-Cr and/or high Al chromitite (Cr#=0.46-0.47). The bulk PGE content is low and varies in the range of 57-162 ppb. The chondrite normalized PGE patterns show that the studied chromitites are enriched in IPGE (Os, Ir, Ru) over PPGE (Rh, Pt, Pd), which in general is consistent with podiform chromitites hosted in a mantle sequence of ophiolites. All the PGE patterns are characterized by a consistent positive anomaly in Ru and some samples display a slight positive anomaly in Pt, compared with Rh and Pd. Most of the PGM occur in fresh chromite crystals consisting of single or polyphase grains composed of different PGM associated with Ni and Cu sulphides and silicates. The primary PGM paragenesis consists of minerals of the laurite (RuS_2) - erlichmanite (OsS_2) series with minor osmium, iridium, and ruthenium. An unidentified Ir-Ni sulfide mineral, probably kashinite, was also observed. Based on their assemblage, it can be argued that, the PGM discovered in the Naga-Manipur chromitites are magmatic in origin and formed at relatively high sulfur fugacity, as testified by the presence of Os-rich laurite, erlichmanite, and kashinite. However, the relatively low PGE content of the investigated chromitites suggests that sulfur saturation was not achieved in the parental magma during the early stage of their crystallization. The presence of heazlewoodite in chromite fractures and in the altered matrix reflects its secondary origin, suggesting that it formed progressively during the serpentinization process. The presence of both Cr-rich and Al-rich chromitite suggest that the Naga-Manipur chromitite formed from separate intrusions of magmas derived from different depleted mantle sources (e.g., MORB versus boninitic) during evolution of the oceanic lithosphere from the MOR (Al-rich chromitite) towards a supra subduction zone (SSZ). Abundant hydrous silicates inclusions were found exclusively in the Cr-rich chromitites, whereas the Al-rich chromitites contain only clinopyroxene, confirming the proposed geodynamic evolution.

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

The phosphate minerals of Mg-Al-Ca-Fe are important because of their stability properties, economic relevance and potential as index minerals. Earlier, the fluid inclusion study has been carried out on the blue colour lazulite mineral reported from quartz veins in the fractured Beringag quartzite, near MCT in northeast Kumaun Himalaya. The EPMA analyses of MCT lazulite has been carried out, which show minor variation in Mg, and a distinct predominance of Mg over Fe. The P_2O_5 content of lazulite varies from 45.51 to 47.76 wt. % with an average of 46.68 wt. %. The Al_2O_3 content of studied lazulite varies from 30.84 to 32.57 wt. % with an average of 32.03 wt. %, while it's FeO content ranges from 2.39 to 3.17 wt. %, suggesting intermediate solid solution strong towards lazulite end member rather than scorzalite. The plot of Fe/(Fe+Mg+Al) vs Mg/(Mg+Fe+Al) values are scattered near parallel to the $Fe^{2+}Mg^{-1}$ substitution line indicating an ideal $Fe^{2+}Al_2[(OH)_2(PO_4)_2]$ - $MgAl_2[(OH)_2(PO_4)_2]$ stoichiometry without Fe^{3+}. A relative depletion of phosphorous in system and incipient replacement of Mg by Fe is also attributed. The cationic contents in the structural formula has been calculated indicating that the studied mineral is not an ideal end member. However, the narrow range of Mg/(Mg+Fe) atomic ratio suggest that it is near homogeneous in composition. The present results also characterize a high stability of MCT lazulite. There is possibility that the material from both quartzite and gneisses participated in lazulite formation.

The sulphide mineralization in Chamri and Amtiyargad in Tons river valley occur in rocks of Chakrata Group consisting of dolomitic limestone and slate. The fluid inclusion study is carried out on the mineralized vein calcite, with a particular focus on coeval gangue calcite. Associated quartz gangue has also been observed. Overall the gangue minerals show four types of inclusions: abundant biphase inclusions with aqueous liquid varying from 30 to 70 vol % and a CO_2 liquid phase. Three phase inclusions with a salt daughter crystal and aqueous liquid and gas phases (vol % = 80/90:20/10) are not uncommon. They are found in random distribution and small trails. Monophase dark inclusions are also seen but are not widespread. They coexist with biphase H_2O-CO_2 inclusions in groups, and also occur in trail, though large scale multigrain trails are not seen. Secondary monophase inclusions at time consisting upto 5 vol % vapour bubble represent a late phase of fluid circulation. The groups of fluid inclusions in the island of calcite show predominance of biphase inclusions with uncommon monophase dark inclusions. The trails of such inclusions, present along the cleavage planes, terminate without crosscutting the calcite-quartz grain boundary. The distribution and abundance of fluid inclusions points out that the ore forming fluid was a mixed H_2O-CO_2 fluid in composition. The fluid unmixing may be linked to the suphide deposition.

TAT- 1.9
Tectonic and Exhumation history of Lesser Himalayan and Sub-Himalayan rocks of Himachal Himalaya along a defined transects
(Paramjeet Singh)

Although much of research on the Himalayan exhumation history has been done in the past, but the feedback relationship between tectonic and exhumation history is poorly understood. This information is

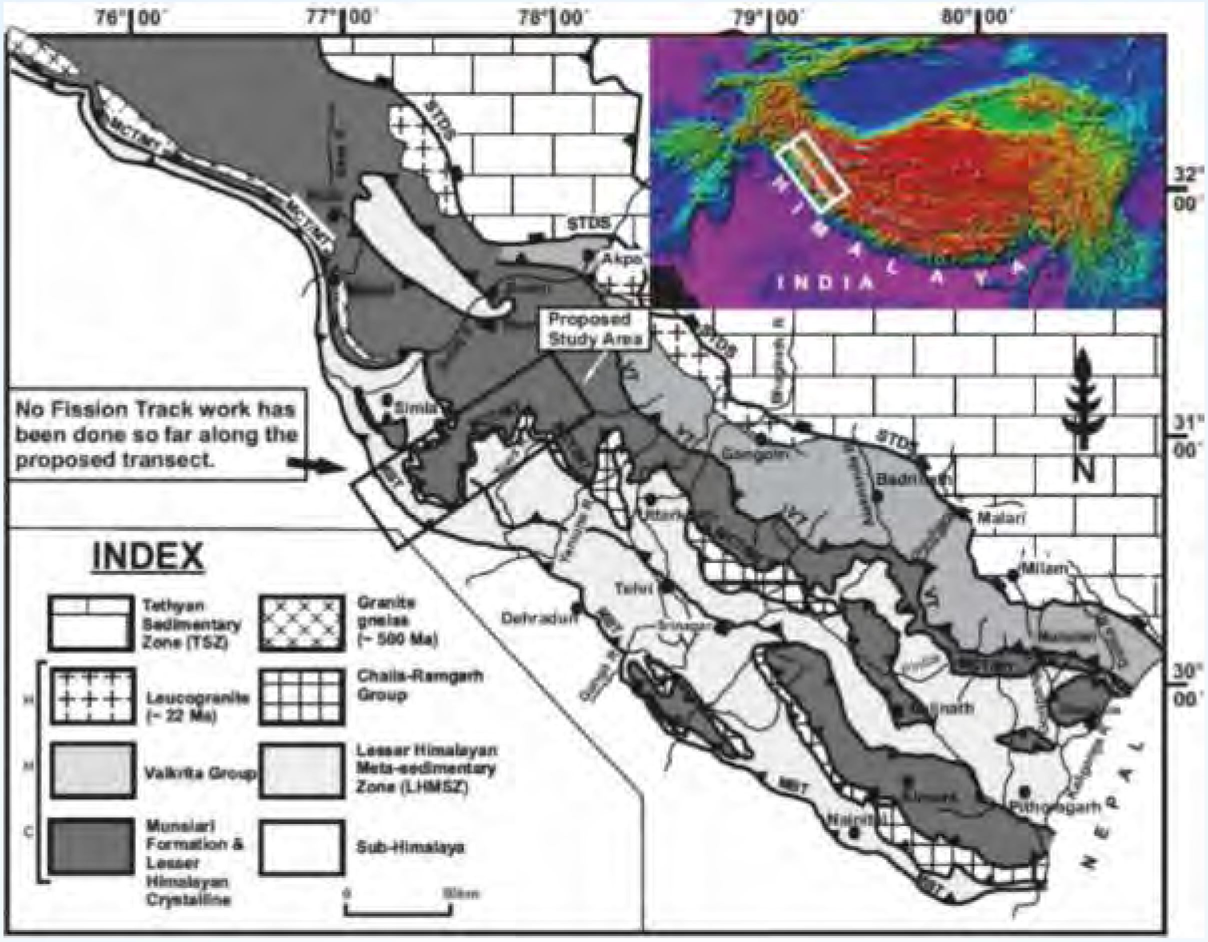

Fig. 12: The Geological map of North-West Himalaya and box showing the proposed study area of the project (after Valdiya, 1980).

obtained from (a) the cooling history of the mountain range (T-t paths) as determined by Fission Track (FT) Thermochronology, (b) the timing and conditions of metamorphism (P-T-t paths) as determined by a combination of geochronological studies (U-Pb zircon geochronology), and (c) sedimentary history and provenance of the HFB. Considering these facts and in order to address (i) the Early Paleoproterozoic magmatic events and emplacement of the Lesser Himalayan Crystalline sheets with its evidences, (ii) post-emplacement kinematics and exhumation history of Chail and Jutogh thrust sheets, (iii) role of major thrusts and Lesser Himalayan duplexes (LHD) in exhumation of LHS/HHC, and (iv) provenance and un-roofing (exhumation) history of Sub-Himalaya, studies of the Geo-Thermochronology along the defined transect (Fig. 12) were carried out.

To constrained the exhumation history of the Himachal Himalaya, the first geological field in the eastern part of Himachal Himalaya along the Kala Amb-Nahan-Sataun-Rohru-Chirgoan-Sangla transect was carried out. A total 70 samples have been collected, of which 35 samples are from Chail, Jutogh and Vaikrita Formations and 35 samples were collected from HFB belts. The geochemistry part of REE, major and trace elements has been completed. U-Pb zircon geochronology work from the Chail, Chur granites, Jutogh and Vaikrita rocks have also been completed. This data set will provide a complete depiction of pre-, syn- and post-collision history of Indian and Eurasia, and emplacement of Chail/Jutogh/Vaikrita thrust sheet of the Himachal Himalaya. The thermochronological work is however under progress.

TAT -1.10
Exhumation History of the Zanskar Himalaya using Fission Track Thermochronology
(Vikas)

The aims of the project includes, (a) to constrain the timing of slip along Chenab normal fault (CNF) zone and to constrain the exhumation history of Zanskar crystallines along CNF, (b) to constrain the exhumation history of the Chamba Nappe, and (c) to test whether channel flow continued after the middle Miocene or some other process drove normal slip along the Chenab normal fault zone and Zanskar Fault zone.

The study area lies along Chamba-Killar, Udaipur-Urgos sections of Himachal Pradesh where rocks of Chamba Nappe and Higher Himalayan Crystallines (HHC) are well exposed (Fig. 13). Chamba Nappe is mainly comprised of meta-sedimentary rocks and lies in contact with the Zanskar Crystallines/Higher Himalayan Crystalline (HHC). The contact between the Chamba Nappe and HHC is a tectonic contact that can be observed near Killar (Fig. 13), along Chamba-Killar road section. Both shortening as well extensional shear fabric have been observed within HHC near Killar region at the contact between Chamba Nappe and HHC (Fig. 14).

Similar shear sense has been observed in the Miyar valley. This suggests CNF fault zone is a similar structure like South Tibetan Detachment System, locally known as Zanskar Shear Zone (ZSZ) that has experienced contraction overprinted by extension. The high grade rocks of HHC have been extruded between CNF and ZSZ. To constrain the timing of activity along CNF, deformed leucogranite samples near Dharwas, Himachal Pradesh, showing the extensional shear sense as well as undeformed leucogranite samples crosscutting the general foliation along with host gneiss have been collected for zircon U-Pb geochronology. Mineral separation of six samples and slide preparation for LA-MCICPMS analysis have been carried out. Backscattered electron (BSE) and cathode-lumine-scence (CL) images were taken using a scanning electron microscope (SEM-Zeiss EVO 40 EP) in Central Laboratory facilities of WIHG, Dehradun, India. Five samples have been collected along a vertical transect across the CNF for Fission Track dating studies to constrain exhumation rates across the CNF.

Twenty one samples have been collected along Chamba-Killar road transect across Chamba Nappe for apatite and zircon Fission Track dating studies to constrain exhumation history of Chamba Nappe. Crushing in jaw crusher and disk mill, Gravity separation, Magnetic Barrier Separation, Heavy Liquid

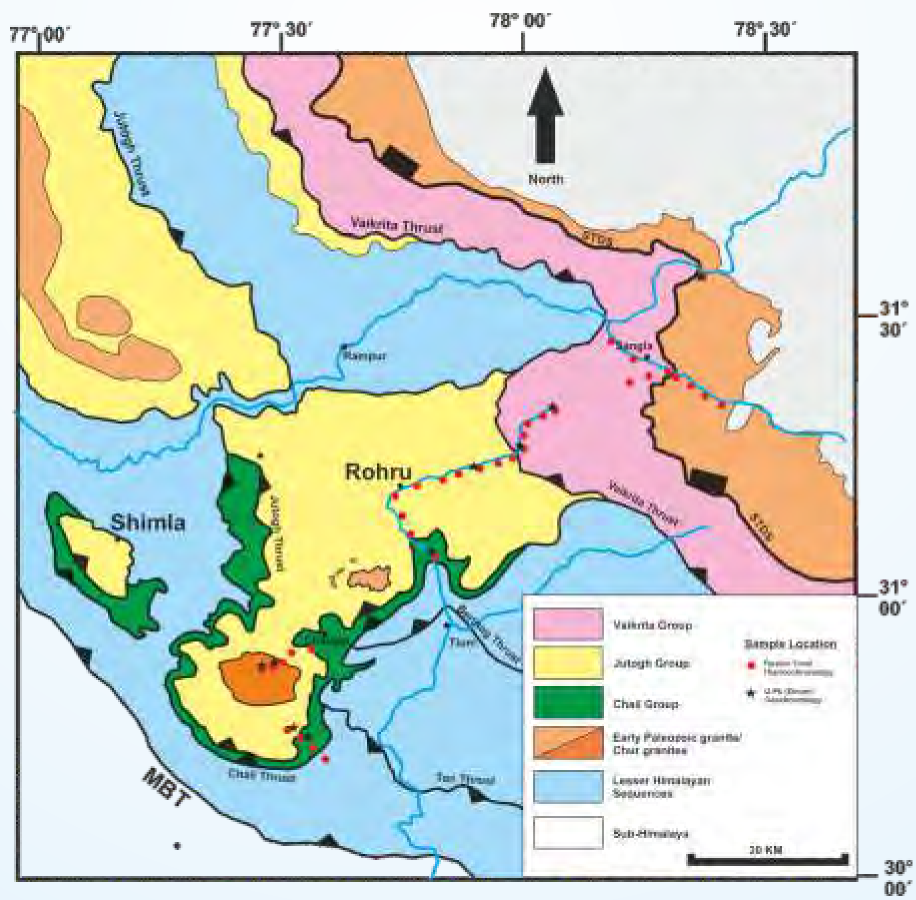

Fig. 13: Geological and Sample Location Map of the Chamba Nappe and HHC.

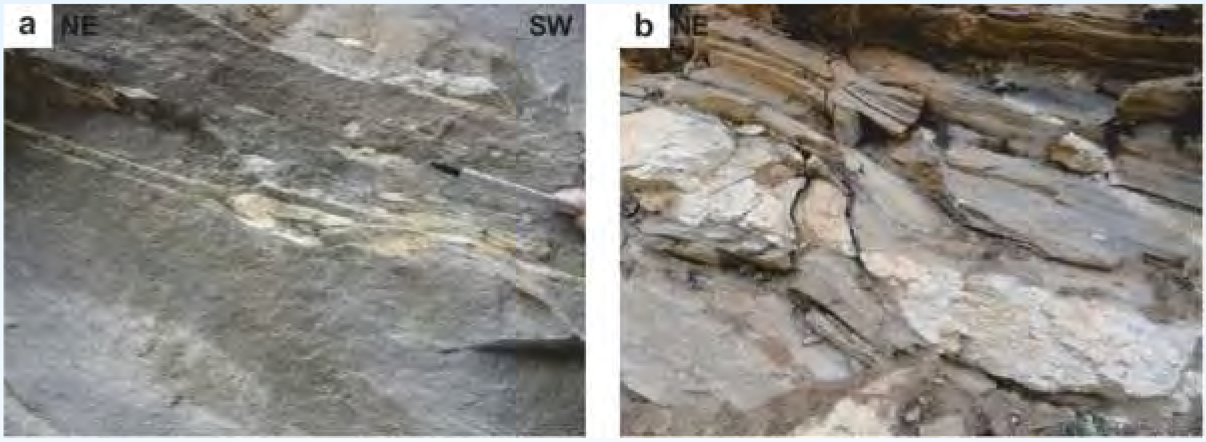

Fig. 14: (a) Intrafolial fold showing shortening shear sense due NE; (b) Extensional shear sense along CNF depicted by leucogranite near Dharwas region.

Separation using Bromoform and Di-iodomethane for all the sample have been completed. All the 21 samples yielded zircon. Picking of good quality zircon grains for all 21 samples have been completed under stereozoom microscope. While 12 samples yielded apatite. Fission Track analytical work is under process. Apart from this, 9 samples (41 slides) have been irradiated with thermal neutrons in FRM II reactor, Germany, for zircon Fission Track thermochrnology from Pathankot-Dalhousie transect to constrain the exhumation history of source region of Siwalik sediments.

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, Anil K. Gupta and Koushik Sen)

The work in this project is focused on (i) understanding landscape evolution of Upper Zanskar River, (ii) development of paleoflood chronologies of Ladakh Himalaya, and (iii) reconstructing the past climate using peat deposits

Landscape evolution of Upper Zanskar River

Zanskar river valley which is a major tributary of the Indus River that originates in the Higher Himalayan crystallines and flows northward. It flows past the South Tibetan Detachment system (STDS), the Tethyan Sedimentary series and after crossing the Zanskar counter thrust traverses through the Indus Molasses and joins Indus at Nimu. The Molasse belt internally is deformed along several north vergent thrusts e.g. Choksti Thrust and Stok Thrust. The headwater region has relatively higher rainfall than the lower reaches. The catchment geomorphology has potential to unravel (i) the responses of tectonic movements that took place along these thrusts, and (ii) response of monsoonal variation in shaping up the landscape.

Geomorphology along the Zanskar shows the development of (i) a level of fill terrace, (ii) large fans superimposed on fill terrace, (iii) Lake sequence developed in the inter fan areas, and (iv) 1-2 levels of strath terraces. Morphostratigraphically the strath terraces are the oldest and the lake sequences are the youngest. 35 samples were collected for Optically Stimulated Luminescence (OSL) dating, 15 samples were processed and the ages suggest that the fill terraces developed before the Last Glacial Maxima (LGM).

Paleoflood Deposits

Awareness towards the extreme floods and its terrain response is detrimental to the developing economy and society's preparedness to this natural hazard. During last year we studied 10 sections showing records of past floods along the Zanskar, the Indus and the Shyok. In the Upper Zanskar, around Padum three sequences preserve records of 20 large floods dating to Early-Mid Holocene. A section also bears record of 30 floods that are pre-LGM. Likewise in the lower Zanskar region near Chilling and Nimu, two sections showed occurrence of 14 flood events dating early-Mid Holocene. Similar observations were made in Upper Indus, near Hymia where 8 floods occurred around Early-Mid Holocene. The field observations, sedimentological and chronology data thus indicates increased flooding during the Early- and Mid- Holocene Climatic Optimums. The studied sequences also show presence of Hearths at several levels and that indicates that flood plains were actively used by migrant population and that the human migration into Ladakh might have initiated around Early Holocene.

Peat Deposit

Ladakh is known for presence of large lakes and high altitude wetlands. The stratigraphy of these wetlands offer good opportunity to reconstruct past climate. We studied and sampled peat sequence located at (i) Ringdom Gompa in Upper Zanskar, (ii) Gya village section, and (iii) Sarthi village section near Upshi. The work on the early sampled sequence along the Mandakini River near Kedarnath is completed, and significant progress had been made on Gya village section. Kedarnath section shows climatic variations for the past ~7500 yrs where proxy records of magnetic susceptibility, pollen and mineral chemistry showed prominent warm and humid phases between 6-5 ka BP, Medieval Climatic Anomaly and Little Ice Age. Gya section comprises wet and dry intervals during the past 2200 yrs.

TAT-2.2

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

(N. Suresh and Rohtash Kumar (retd. July 2015))

Fluvial terraces are important geomorphic features that can provide records of sediment accretion and incision history, and are the most common landforms used to infer climate change and tectonic impacts on landscapes. The distribution of fluvial terraces in the Satluj River valley in the Lesser- and Sub-Himalayan region was studied to understand the genesis of terrace developments related to climate variation and tectonic impacts. Four to eight levels (T1 to T8) of the staircase of terraces are identified between Luhri and Ropar. Google image, toposheets and SRTM image were used for the identification, mapping and profile constructions. In the Lesser Himalaya, all the 8 levels of terraces were identified, however, within the Sub-Himalayan region, a marked variation in terrace distribution is observed. In the inner Sub-Himalaya, six levels of terraces were well developed, whereas in the outer Sub-Himalaya only the younger four terraces were developed. The development of older terraces in the outer Sub-Himalaya are absent and the time equivalent sediments are vertically stacked into an alluvial fan, which cut across the Himalayan Frontal Thrust (HFT). The facies analysis on the terraces and the fan sequences shows dominance of gravel and sand facies with typical fluvial architectures. The oldest deposit, which deposited as the topmost terrace sequence in the Lesser Himalaya, comprises a thick sequence of sandy facies. These sandy facies are dominated by medium- to very coarse-grained texture, massive but locally faint trough cross-stratified and parallel laminated, resting over Lesser Himalayan bed rock. The bulk composition of the sand is dominated by quartz followed by feldspar with minor calcite. The associated clay minerals are illite and chlorite. The similar sandy sequence is traced up to about 100 km downstream, in the vicinity of Himalayan Frontal Thrust. In the outer Sub-Himalaya, the sandy facies are deposited in the form of an alluvial fan and are fine- to medium-grained, multi-storied, and internally consist low angle trough cross-stratifications and parallel lamination. They were laterally traced in a wider area between the two frontal anticlines along HFT and are deformed and uplifted. Extensive aggradation of sandy facies traced for hundreds of kilometres suggests that the sediments were produced by extensive weathering of granite in the Higher Himalayan catchment under relatively stable condition during the late Quaternary period. The subsequent lower terraces in the Lesser Himalaya are, however, dominated by gravel facies, clast to matrix supported, poorly sorted, fining upward and imbricated and consist of quartzite, granite gneiss, volcanic, limestone and/or slate clasts. Similar pattern of terrace sequence is observed in the inner Sub-Himalaya. However, in the outer Sub-Himalaya, the gravel facies are vertically stacked over the sandy sequence, but their distribution shows they are confined to a lesser area within the paleo-exist of the Satluj River in the vicinity of HFT. The chronology of the terraces is established using optical dating. However, most of the samples are contaminated with feldspar even after additional 10 minutes etching and a modified protocol, double SAR OSL dating technique, is applied and is in progress. It can be concluded that the distribution of fluvial river terraces in the Satluj River, from the Lesser Himalaya to Sub-Himalaya, shows variation. In the Lesser- and inner Sub-Himalaya, all the terrace levels were developed, however, in the outer Sub-Himalaya only the younger four levels were documented with the older events are absent and the sediment is vertically stacked into an alluvial fan.

TAT-2.3

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 paleoclimatic reconstruction in the north-western Himalayan region and Ganga Plain, India. The Ladakh Himalayan region has scarcity in paleoclimatic data. To achieve this goal, following work has been done during the reporting year.

The north-western Himalayan lakes are climatically more significant since these lakes are best place to study the variability of the Indian Summer Monsoon (ISM) and westerlies. Multi-proxy paleoclimatic data set for Tso-Moriri lake cores has been developed. Around 3 m of Tso-Moriri lake cores were analysed for organic and inorganic phosphorus (OP and IP) using ICP-MS of the Institute. The generated data reveals interesting results. The data synthesis and handling of already generated geochemical and sedimentological data for ~3 m of Tso-Moriri Lake cores were done. The findings are indicative of alternate strengthening and weakening phases of ISM during the past ~600 years.

The Rewalsar Lake, a lesser Himalayan lake is also important for its location on the pathway of south-west monsoon. The Rewalsar lake cores have been analysed for reconstructing climate, sedimentation history, and pollution etc. from the mid-altitude region of the Himalaya. Geochemical analyses (trace/rare earth elements) were analysed on 2 m of Rewalsar lake core samples using ICP-MS. This will help in dust source identification and lake environmental studies. Magnetic mineralogical analyses were also performed on around 3 m of Rewalsar lake core samples. The data synthesis and handling of already generated geochemical and sedimentological data for the Rewalsar lake cores were done. As during the previous years the higher rate of the sedimentation history and low to moderate heavy metal pollution were reported from the past ~50 yrs sediments of Rewalsar Lake, it has recently been found about the grain size effect on

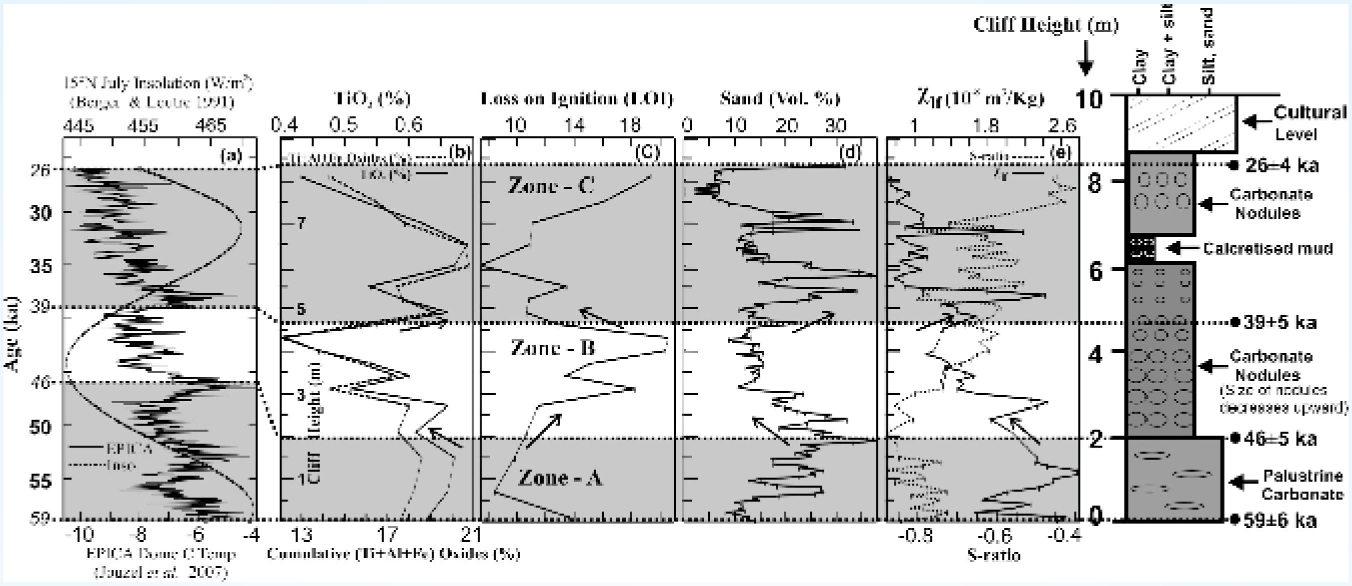

Fig. 15: (a) Temporal variation of 15ºN July insolation (Berger & Loutre, 1991) and EPICA Dome C Temp. (Jouzel et al., 2007) during ~59-26 ka; (b) vertical profiles of TiO_2 and cumulative oxides (Ti+Al+Fe) percent; (c) Loss-on-Ignition (LOI) percent; (d) sand volume percent; and (e) magnetic susceptibility (χlf) plotted against the schematic litho-log representing the Ramnagar river cliff section of around 10 m height including cultural level. Dark circles represent optically stimulated luminescence (OSL) ages (Srivastava & Shukla, 2009; Shukla et al., 2012) at respective cliff heights.

multi-element concentrations closely linked to instrumental record of precipitation.

Around 8 m of Ganga River cliff section at Ramnagar, Varanasi, UP, were studied during the previous years for paleoclimatic reconstruction of the Ganga Plain, India. Fluctuating paleoclimatic condition in the Ganga Plain was reported ~59 ka to ~26 ka using multi-proxy paleoclimatic dataset generated from ~8 m high river cliff exposed on the right bank of the Ganga River valley at Ramnagar. Our data is indicative of two relatively wet and warm climatic phases, intervened with a drier period around 46-39 ka that represents ~2-4.7 m of the cliff section (representing Zone B of the study region). The wet and warm periods prevailed around 59-46 ka and around 39-26 ka which represents ~0-2 m (Zone A) and ~4.7-8 m (Zone C) of the river cliff section, respectively. Carbonate nodules are ubiquitously present in the section and responded well to increased aridity across ~46 ka, transition from Zone A to B and also to intensified monsoon across ~39 ka, the boundary of Zone B and C as recorded by the sharply fluctuating loss-on-ignition (LOI) curve (Fig. 15). The study carried out corroborates earlier findings from the Ganga Plain region whereby the major paleoclimatic shifts occurred with changing hydrological conditions. The multi-proxy data-set is also supported by the global paleoclimatic record. The relatively wet and dry phases in the Ganga Plain reported in this study are concomitant with higher and lower insolation, respectively. Hence, insolation appears to have played a certain role as forcing mechanism leading to the late Quaternary paleoclimatic oscillation during the reporting period in the Ganga Plain region.

TAT-2.4

Climate Variability and Treeline Dynamics in Western Himalaya

(P.S. Negi and Jayendra Singh)

PSN has conducted twenty four days field work to accomplish various objectives related to real time monitoring of black carbon (BC) aerosols and treeline dynamics. With the view to monitor BC aerosols and biomass burning (BB) in high Himalayan region, especially in snowbound and glaciated area, monitoring stations were established at Chirbasa (3600 m a.s.l) and Bhojbasa (3800 m a.s.l in Gangotri Glacier Valley (Fig. 16). As Chirbasa station is close to the treeline ecotone and Bhojbasa is close to the snowline both station represent ecologically sensitive zones in the study area. The BC data recorded from January to October, 2016 at Chirbasa station shows that maximum BC

Fig. 16: BC monitoring station at Chirbasa.

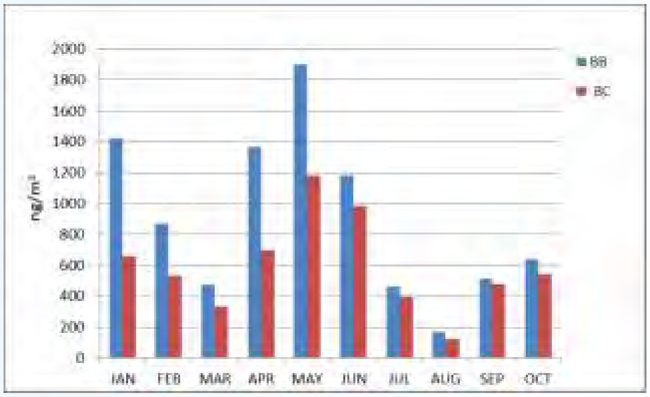

Fig. 17: Monthly variation in BC and BB concentration.

concentration was during the month of May (~1899 ng/m^3 biomass burning with 1180 ng/m^3 black carbon), while minimum concentration, i.e., 168 ng/m^3 biomass burning and 123 ng/m^3 black carbon was during the month of August (Fig. 17).

Field investigation reveals that both natural as well as anthropogenic factors contribute BC aerosols in the Gangotri Valley. The tourist season i.e., April-June shows remarkable increase in BC aerosols concentration due to anthropogenic activities that increase tremendously to cater the transport, food, shelter and other associated everyday need of tourists, pilgrims and other visitors in the area. The visitors of the Gangotri Temple have a direct and indirect bearing on BC aerosols emission to the surrounding area and it can be visualised by the fact that more than 87,736 tourists and pilgrims visited to the Gangotri Temple with in a 14 days after commencing of tourist season on May 09, 2016. Moreover, summer tourist season is also a season for local forest fires that is reported to actively contributed to the biomass burning component of BC aerosols. It is also evident from observed data that occasionally, forest fire incidences independently enhanced the BC concentration during January and February in-spite of being non-tourist season. The second highest BC aerosols concentration reported during September and October which are also winter tourist months and contribute significant aerosols to the surrounding atmosphere. The lowest BC concentration was recorded during the month of August followed by the March and it is observed that due to the absence of tourism activities and forest fire incidences during these months, the BC concentration in the atmosphere remains at lowest level. Moreover, rain wash of the atmospheric pollutants during rainy season and snow precipitation during winter season also considered one of the important reason for low BC and BB concentration during August and March. The occurrence of high concentration BC aerosols during summer season, especially May-June is likely to affect sensitive ecosystem along with its resources, eco-biological processes and their overall dependents including people residing and visiting in downstream areas.

JS has carried field trip in Gangotri and adjoining region and collected 240 tree cores from two conifer (*Pinus wallichiana* and *Cedrus deodara*) and one deciduous (*Betula utilis*) species. The important aspect of the filed work was the collection of samples from oldest (~1300 yrs) deodar tree, the longest record of deodar tree so far from India growing in Gangotri region. In lab, the above tree cores were mounted on wooden mount and prepared tree cores (~150) from the above three species for further microscopic analysis. Each year ring-widths of 100 tree cores of above three tree species were measured with an accuracy of 0.001mm and successfully dated each growth-ring to the level of calendar year of their formation of 90 trees cores. Tree ring-width chronologies of two conifer species (*Pinus wallichiana* and *Cedrus deodara*) were also developed for further climate change studies. Calendar year dating of annual growth rings of *Betula utilis* from Gangotri region is in progress. Besides, annual growth rings of *Aesculus* collected from Din Gad valley (Tela camp) area, Uttarkashi District, Uttarakhand were dated and separated for stable isotope analyses. Moreover, analysis of stable isotope records of two conifer species and one deciduous species collected from Din Gad valley (Tela camp) area, Uttarkashi District, Uttarakhand are in progress.

TAT-2.5

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)

Hydro chemical and isotopic studies were carried out in groundwaters along the entire Ramganga Basin and parts of middle Ganga Plain to examine the quality of shallow groundwater accessed by hand pumps. The aim of the study was to determine the spatial distribution of arsenic (As) in groundwater of the Middle Ganga (Haridwar-Banaras-Saidpur region) and of the Ramganga (Ramnagar-Kannauj) basins. Groundwater samples were collected from a shallow depth because most of the population in the study area use locally drilled hand pumps for obtaining drinking water. A large area encompassing the Rampur, Bareilly, Bilsi, Faridpur, Badaun, Farrukhabad and Varanasi districts were found to have levels of arsenic above the drinking water criterion of 10 ppb. Sampling has indicated that arsenic (As) and nitrate (NO_3) present in groundwater in elevated levels are the chemical constituents of most health concern in the shallow alluvial aquifers of Ramnagar, Bareilly, Badaun and Jaunpur districts of Uttar Pradesh in the middle Ganga Plain. These chemical constituents in groundwater are likely to have been derived from both geogenic and anthropogenic sources. The geochemical characteristics of groundwater may be influenced by factors like changes in climatic conditions, mineral weathering (silicate, carbonate), mixing of polluted surface water at shallow depths, ion exchange and anthropogenic activities. Stable isotopes of oxygen ($\delta^{18}O$), hydrogen (δD) and carbon ($\delta^{13}C_{DIC}$) suggest that the process of carbonate weathering during the post-monsoon season has increased the input of chemical constituents into shallow groundwater. A shift in $\delta^{18}O$ suggests soil-water interaction at shallow depths, which is reflected in elevated metal concentrations. The results indicate that arsenic concentrations in groundwater increase in the dry season and are decreased by recharge during the monsoon season.

As a part of this work, the morphological study was also conducted to understand the tectonic frame work of the river Ramganga. Towards this, it is observed that a thick clay deposit at different sites along Ramganga River has resulted from the blocking of the river particularly along the BBNF which suggests a tectonically induced landslides due to movement along the fault. Later phase of tectonic activity is evident from deformed Quaternary fluvio-lacustrine deposits in the form of folding and fault; the tectonic activity has been bracketed to be older than 27 ka but younger than 24 ka. Sediment analysed from the strath terrace of Chaukhutiya area indicates that the erosion rate by Ramganga River in the country rock of uplift block of the CF is of the order of 2 mm/year. Evidence of tectonic activity is also observed in the footwall of the HFT, where soft sediment deformation structures (SSDS) generic to seismic activity are observed. The SSDS are observed in layers comprising alternation of clay and sand, the diagnostic features being dykes, faults and folding; the shaking event took place between 38 and 30 ka. Morphometric analysis carried out includes Transverse Topography Factor (T), Stream longitudinal profile and Stream Gradient Index (S_L) and Ratio of valley floor width to valley height (V_f). The computed V_f values from the transverse fault zones are characterized by higher values than the other; while S_L is characterized by higher indices in the fault zones. Valleys developed along the South Almora Thrust and BBNF is characterized by stream migration in two direction NE and SW; suggesting BBNF with dip slip components.

TAT-2.6

High resolution Paleoclimate records from the Himalaya and adjoining regions

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

Developed 506 years (AD 1509-2014) long ring-width chronology of Himalayan cedar from Kishtwar, J&K (Fig. 18). Further, *Cedrus deodara* ring-width chronology with Expressed Population Signal (EPS) 0.85 was used to reconstruct 275 years (A.D. 1740-2014) long Standardized Precipitation Index (eight months SPI of May, SPI8-May) for Kishtwar, Jammu and Kashmir, northwest Himalaya (Fig. 19). The reconstruction captured pluvial in 1950s, 1990s and dry in 1970s. The wettest phase of 1990s captured in the reconstruction was followed by a drying since 2000s in Kishtwar region. The reconstructed SPI8-May series also revealed consistency with tree-ring based upper Indus basin discharge record and gridded summer (June-July-August) PDSI data of the northwest Himalaya-Karakoram region (Singh et al. 2016, Quaternary International, DOI: org/10.1016/ j.quaint.2016.09.031).

Ganga plain, Uttar Pradesh

Fourteen days field work from June 5-18, 2016 was carried out in Ganga plain, Uttar Pradesh. Four cores (~40 to 50 m long) were raised (3 from Lilour Lake,

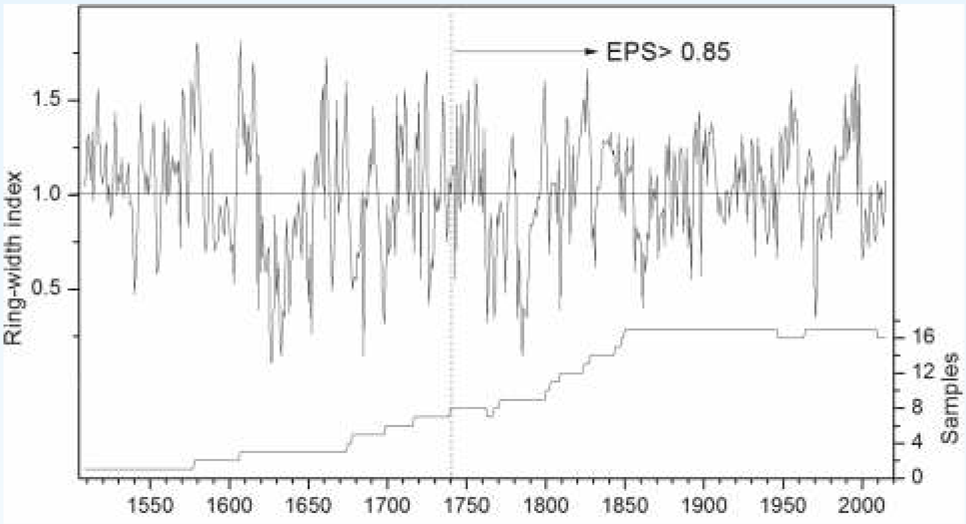

Fig. 18: Ring-width chronology (A.D. 1510-2014) of *Cedrus deodara* from Kishtwar, Jammu and Kashmir. The vertical dotted line at A.D. 1740 denotes the chronology exceeding 0.85 threshold value of Expressed population signal (EPS).

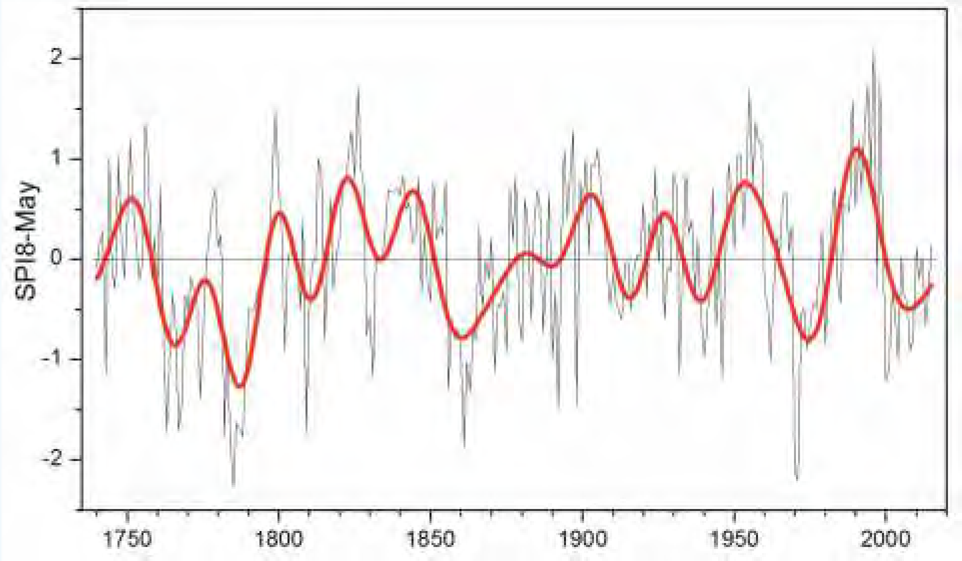

Fig. 19: SPI8-May reconstruction (A.D. 1740-2014) for Kishtwar, northwest Himalaya overlaid with 20-year low pass filtered version (thick smooth line).

Bareilly and 1 from Vikram-Charsora, Badaun). The cores have been sliced at 1-3 cm interval for the multi proxy study to generate high resolution paleo monsoon record of late Quaternary period. A total of 35 samples from four lakes have been sent to Poznan Laboratory, Poland for the AMS ^{14}C dating. Rock magnetic analysis of 65 samples from the Lilour lake core has been done.

Garhwal, Uttarakhand Himalaya

An ~116 cm long organic-rich lake trench from the alpine meadow located at an altitude of ~3,350 m a.s.l., in Chamoli, Garhwal Himalaya is being investigated using multi-proxy analyses (elemental chemistry, grain size, organic carbon (OC) and environmental magnetism) to reconstruct the mid- to late-Holocene climate. The preliminary results indicate decreased magnetic concentrations (χ_{lf}, SIRM and Soft-IRM) and elemental concentrations (Fe, Mg, Si, Ti, and K) between ~4000 and 2000 yr BP suggests reduced influx of minerals. The increased clay percentage and decreased sand percentage during this interval also suggests near stagnant lake level conditions. The increased phosphorous and OC % between ~970 and 730 yr BP suggest high productivity under warm-wet climate. The reduced OC % and phosphorous concentration between ~730 and 560 yr BP suggest a reduction in productivity due to unfavourable climatic condition for growth of plants. The increasing trend of elemental ratios Na/Al, Na/K and Na/Ti and Ca, Na and Mg values suggest drought like condition in the region during this interval. To understand modern climate control on vegetation types in the vicinity of lake, surface samples from catchment has been processed for the palynological investigations.

TAT-2.7

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*)

The reconstruction of Indian summer monsoon variability since MIS-3, using high resolution paleoclimatic records from the Himalayan region, Ganga Plain and Central India is being attempted in this work. To achieve this, following work has been carried out during the reporting year.

One speleothem sample MWS-2 from the Mawmluh cave, Meghalaya, NE India has been analyzed for stable oxygen isotope to reconstruct the palaeoclimatic variability in India between 46,000 and 35,000 yrs BP. This data extends our earlier palaeoclimatic record from 33,800 to 5,500 yrs BP. Our record suggests weak Indian summer monsoon during the Henrich events, Younger Dryas and Last Glacial Maxima and strong monsoon conditions during the Early Holocene, Bolling-Alleroid and Dansgaard-Oescherg events.

A sediment core from the Vikram Charsora Lake, Uttar Pradesh has been raised in June, 2016 and sliced into 629 samples. Out of which, 150 sediment samples have been prepared for the analysis of major and trace elements using XRF technique and grain size characterization using Laser Particle Size Analyser. To establish the chronology, 5 samples for AMS radiocarbon dating and 8 samples for optically stimulated luminescence dating are under process.

Further, to reconstruct the Indian summer monsoon variability in the Central India, 4 speleothem samples have also been collected from Jagdalpur and adjoining regions, Chhattisgarh.

TAT- 2.8

Late Quaternary summer - monsoon variability through multi-proxy data from site U1457, Arabian Sea

(Anil Kumar, Anil K Gupta and Som Dutt)

The project focusses on the reconstruction of past Indian monsoon variability and sediment source at final deposition in the Indus fan. As a part of the study the Arabian Sea sediments from the Laxmi Basin were retrieved in the International Ocean Discovery Program (IODP) Expedition 355 during April-June, 2015 (Fig. 20A). A total of 40.2 m core was received, and samples were analysed for multiple proxies including environmental magnetic parameters, inductively coupled plasma mass spectrometer (ICPMS), clay mineralogy and particle size distribution. Off-shore age-depth model based on foraminifera, nanofossils and magnetic stratigraphy suggest an average sedimentation rate of 7 cm/ka from the late early Pleistocene to the Present. Out of 648 samples of 20 cc volume, 92 samples were sorted and analysed for clay mineralogy.

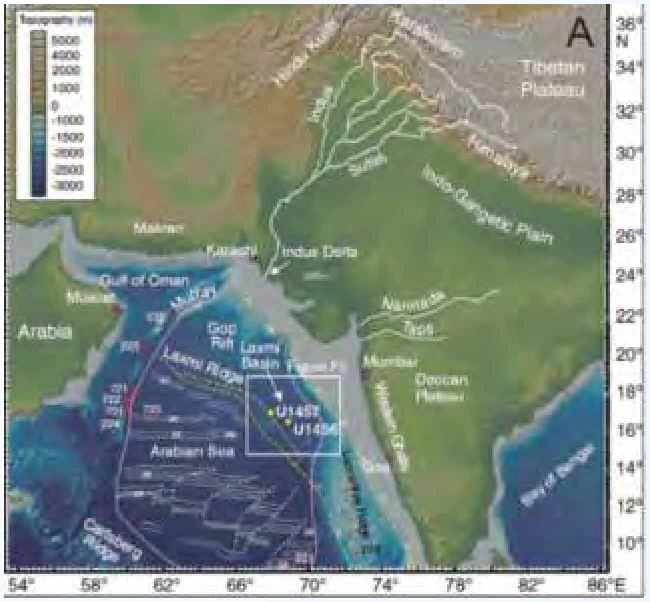

Fig. 20A: Bathymetric map of the Arabian Sea, surrounding landmasses and Indian subcontinent from GeoMap App (Ryan et al. 2009). White lines are major rivers and tributaries, yellow circles are drilling sites during Expedition 355, red stars are earlier scientific drilling sites that have sampled the Indus Fan, pink line shows approximate extent of the fan after Kolla and Coumes (1987), yellow dashed lines are speculated location of the continent/ocean boundary, depending on whether Laxmi Basin is oceanic or continental, the magnetic anomalies are shown using gray lines from Royer et al. (2002).

The analysis for grain size has been done on 63 samples, magnetic parameters on 91 samples and ICPMS analysis on 56 samples. The present status shows large variation in the dataset (Fig. 20B). The magnetic susceptibility, anhysteretic remnant magnetization and coercively (Fig. 20B) suggest grain size dependent magnetic enhancement. There is no scope of in-situ iron mineralization at this shallow depth, therefore, the magnetic enhancement is due to detrital magnetic grains only. Elemental ratios in top 450 cm indicate large variation in climatic conditions and productivity. Sr/Ca and Al/Ti ratios depict increased aridity at 150-100 cm. In contrast to this, there was a wet and warm climatic phase 350-300 cm interval.

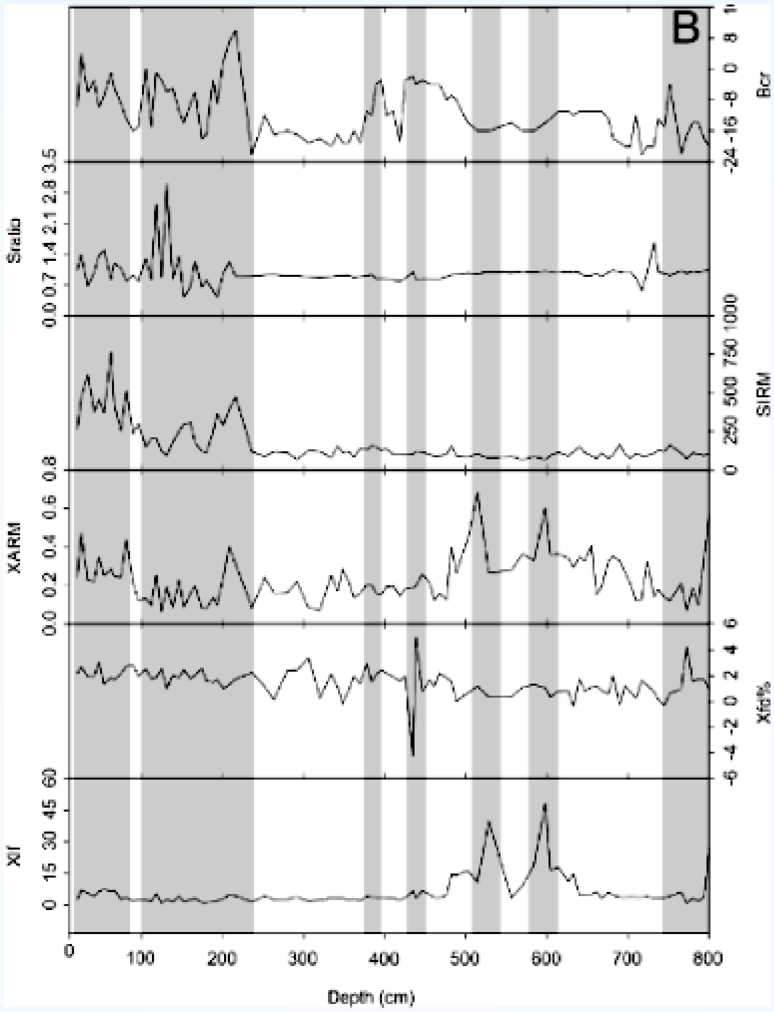

Fig. 20B: Variation in environmental magnetic parameters of Arabian Sea sediment core samples Expedition 355, Site U1457.

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, Devajit Hazarika. P.K.R. Gautam, Narendar Kumar, Chhavi P. Pandey and Parveen Kumar)

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 for 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 obtain these objectives a regional network of seismic stations is being operated in the NW Himalaya 41 Broad Band Seismographs and 5 accelerographs (Fig. 21), along with other Geophysical equipment's were operated in the NW Himalaya. The data is being acquired and analyzed continuously by the networks. The earthquake events for period during April 2016 and March 2017 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 small area as compared to the total area of fault plane. Some of the fault planes show multiple asperities and the focus lie close to the nearby thrust.

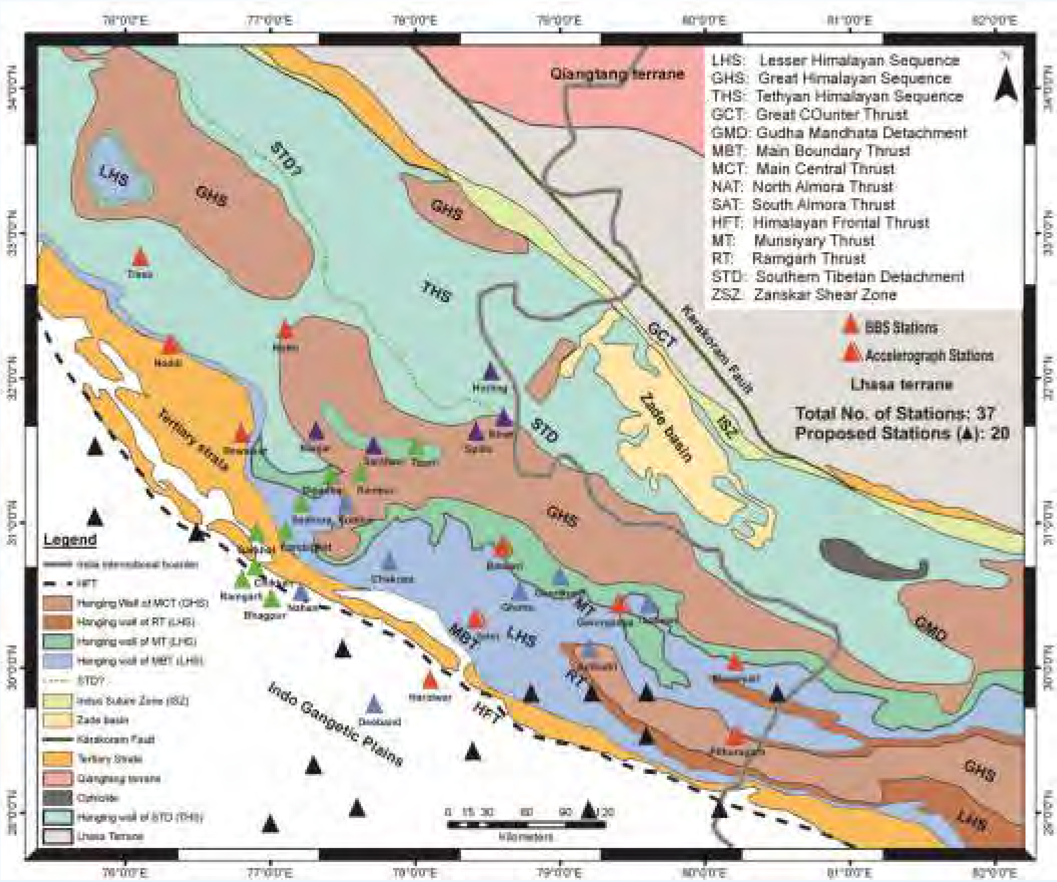

Fig. 21: Broadband seismographs and accelerographs locations are shown with triangles.

Source parameters and moment tensor of Mw 5.7 earthquake of February 06, 2017, Garhwal Himalaya, India

A moderate earthquake (Mw 5.7) occurred in the Garhwal Himalayan region of Uttarakhand state on February 06, 2017 (17H: 03M: 04S UTC). Seismic activity of this region is significant and under debate as this region lies in the central seismic gap zone of 1905 Kangra earthquake (7.8 Mw), Himachal Pradesh and the 1934 Bihar-Nepal earthquake (8.0 Mw), India-Nepal. Further, this earthquake is important and draws attention as it occurred at about 24 km northwest of the epicentral location of the 1999 Chamoli earthquake (6.6 Mw) of Garhwal Himalaya (Fig. 22). This earthquake is very well recorded with an array of 10 Trillium, 240 Broadband Seismometers, with a response flat to velocity from 240 seconds to 35 Hz, and thus provides us with an opportunity to constraint on the elements of seismotectonic model with better accuracy. The earthquake with its epicenter lies at 30.558°N and 79.076°E is positioned on the Munsiari thrust (MT) which is a part of the Main Central Thrust (MCT). The centroid depth calculated utilizing the grid search with a fixed epicenter inversion approach placed the hypocenter at the down dip edge of the Main Himalayan Thrust (MHT) plane at about 17±3 km which coincides further with the ramp part of the flat ramp flat geometry of the plane in the region. The source parameters computed shows a 347°N oriented NW-SE strike direction and dipping 40° towards NE, and a rake of around 151° (Figs. 23 and 24). This clearly signifies an oblique thrust movement along the footwall of MCT resulting from dipping of the MHT along the Mid Crustal Ramp (MCR). The present study signifies the associated seismic hazard in the region with emphasis to current seismotectonic scenario prevailing in the Garhwal Himalaya.

Seismic risk around Chamoli, Garhwal Himalaya

The analysis of upper crustal earthquakes from the dataset of 8 years recorded by a seismic network installed in Garhwal region of Central Seismic Gap (CSG) in Northwest Himalaya has been carried out for Moment Tensor (MT) and Stress Tensor studies. The epicentral locations of the micro-moderate size earthquakes in Garhwal Himalaya is concentrated in a

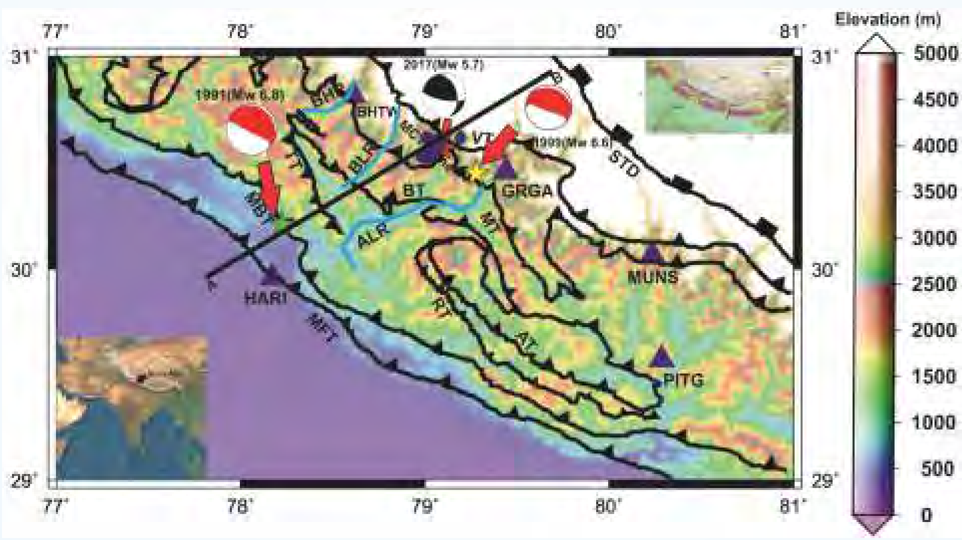

Fig. 22: Topographic map of the Garhwal Himalaya boxed in the inset map of India (below left panel) showing the locations of 12 aftershocks (blue solid circles) reported by WIHG. The central seismic gap (after Avouc, 2007) is shown on the inset on the up right panel. The epicenters of recent Rudraprayag seismic event, 1991 Uttarkashi event and 1999 Chamoli event are plotted as solid red star, solid green star, and solid yellow star respectively. The focal mechanism of the 1991 Uttarkashi earthquake (Mw 6.8) and 1999 Chamoli earthquake (Mw 6.6) is taken from the Global Centroid Moment Tensor (Global CMT) catalog (see Data and Resources), and that of the Rudraprayag earthquake (Mw 5.7) (computed in this study) are plotted as beach balls of red and black colours respectively. The locations of broadband seismological stations, being deployed and operated by WIHG is represented as solid blue triangles and major tectonic boundaries (lines) are presented as MFT (Main Frontal Thrust); MBT (Main Boundary Thrust); MT (Munsiari Thrust); VT (Vaikrita Thrust); MCT (Main Central Thrust); STD (Southern Tibetan Detachment); TT (Tons Thrust); RT (Ramgarh Thrust); BT (Berinag Thrust); and AT (Almora Thrust) (modified after Valdiya, 1980).

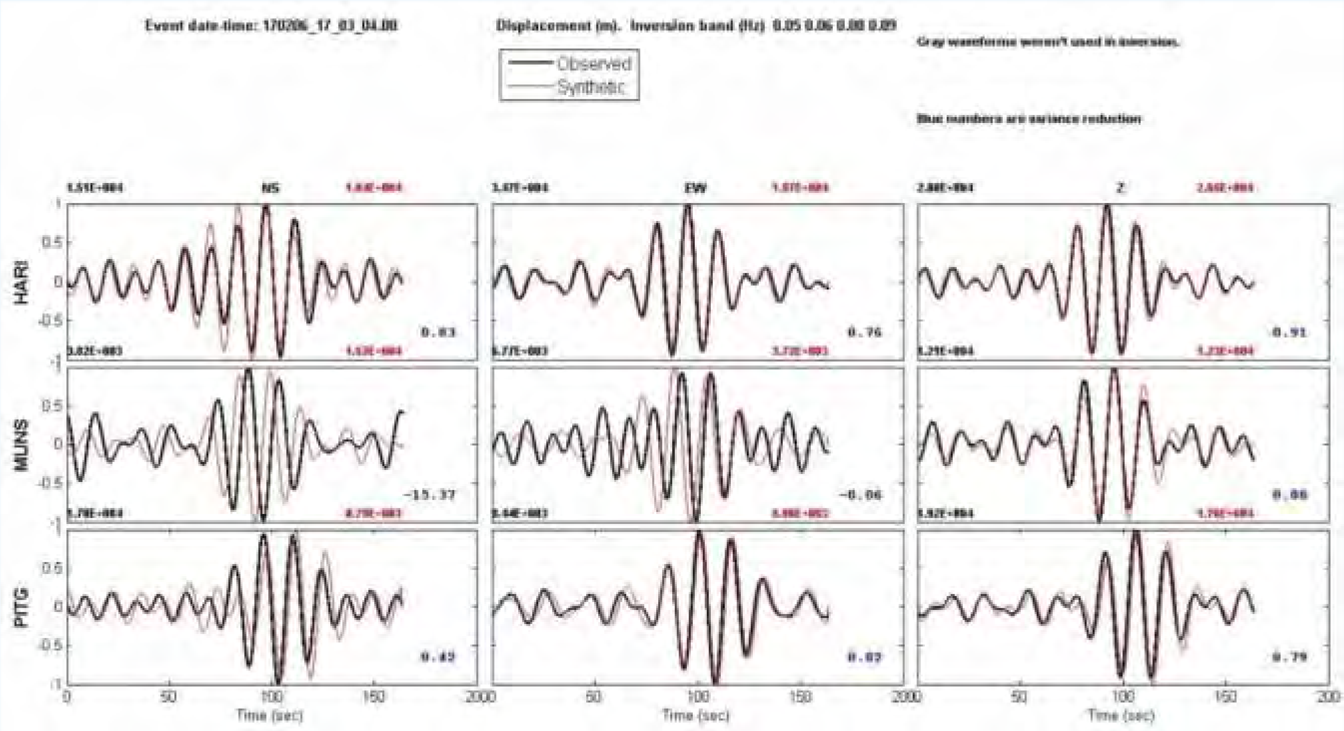

Fig. 23: Figure shows the normalised correlation plot between observed and synthetic wave form data. The observed seismograms were represented by black lines, whereas the synthetic waveform data were represented by red lines. The correlation factor between observed and synthetic data is represented at the upper right corner of each component, inside the box. The seismograms were filtered in the frequency band of 0.05 to 0.09 Hz, and tapered between 0.04 to 0.05 Hz and 0.08 to 0.09 Hz. Stations Haridwar (HARI), Munsiari (MUNS) and Pithoragarh (PITG) were used in inversion.

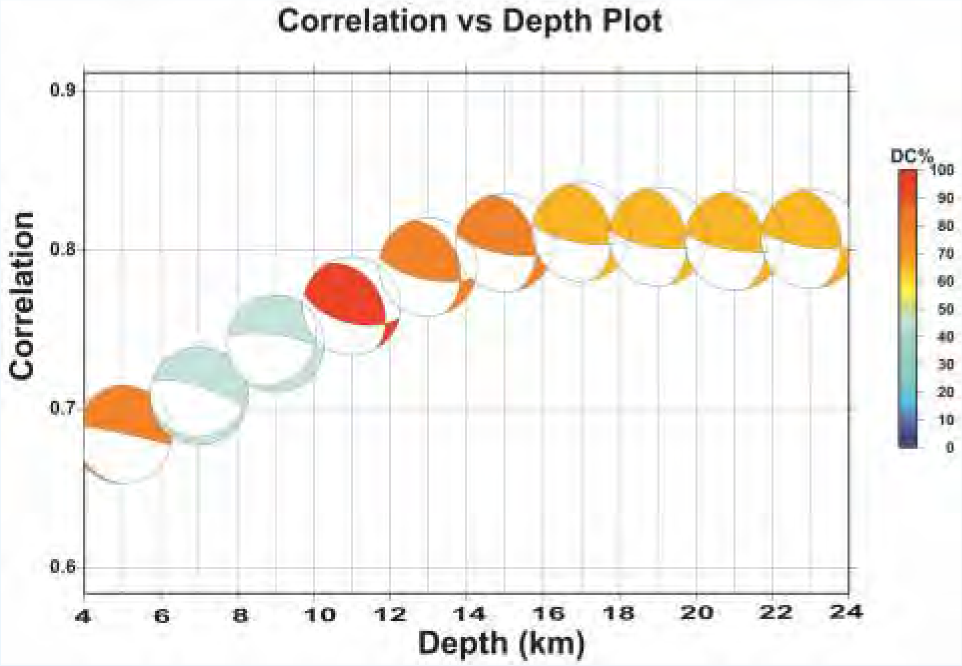

Fig. 24: The figure signifies for the best time and source position with maximum correlation relationship for various source and time position utilizing the grid search method.

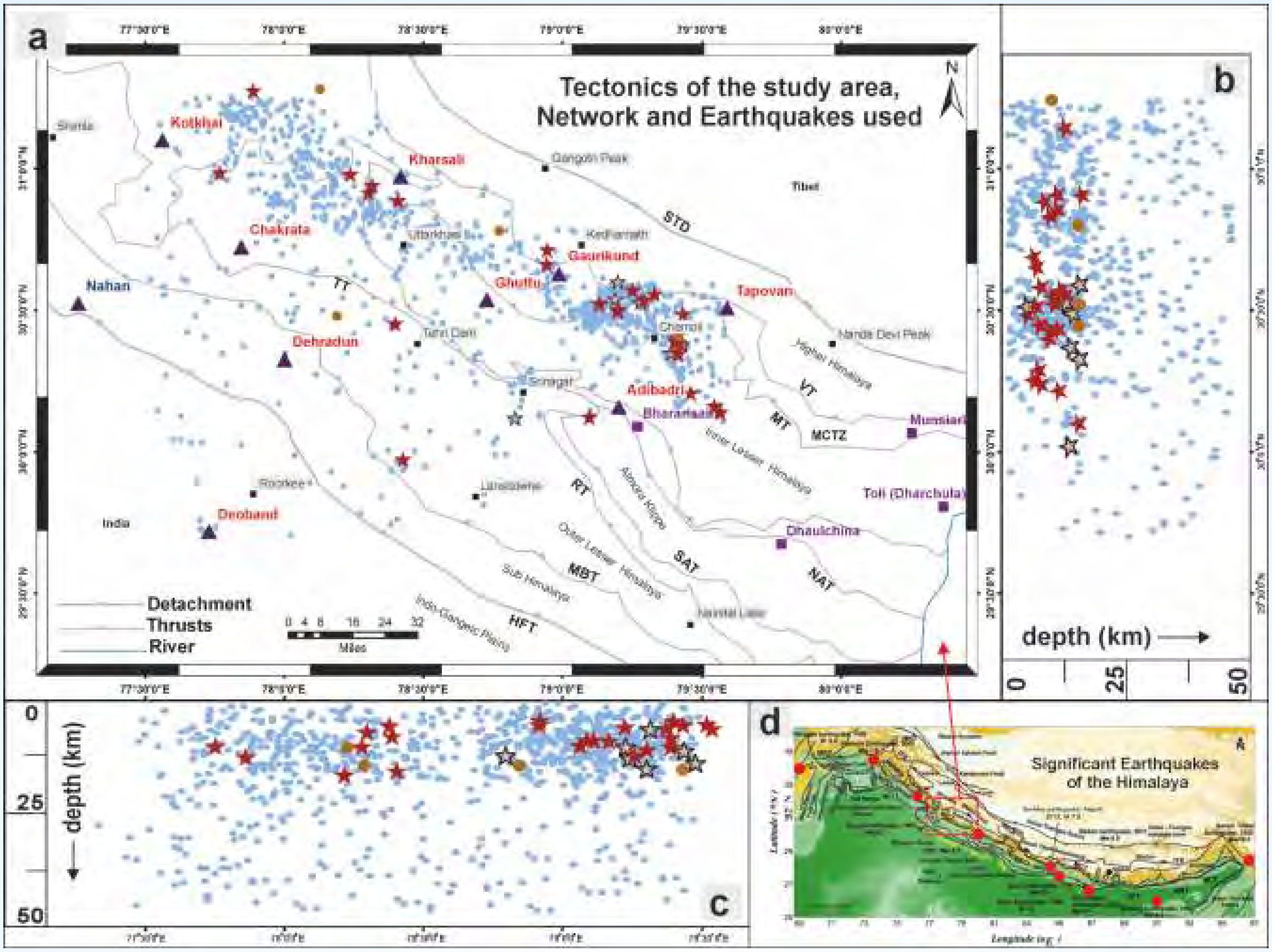

Fig. 25: (a) Location of the study area, network and tectonics. (ref. Valdiya, 1980); ▲ and ■ - seismic stations of Garhwal and Kumaun region, respectively. (b) and (c) are the 3-D distributions of earthquakes within the network. · - Earthquakes of M >2.0, ★ - earthquakes used for MT inversions. (d) Locations of the great and significant earthquakes (·) and the location of CSG in the Himalaya.

narrow zone trending parallel to the MCT zone (Fig. 25). The small-moderate earthquakes (3.0<M<5.0) of the region have been utilized to evaluate the MT solutions using a FORTRAN waveform inversion program i.e., Isolated asperities (ISOLA).

The results of MT inversions show majority of the upper crustal earthquakes are thrust fault mechanisms, with one of the two nodal planes having gentle dip angles (<20°). The P-axis orientation and the P-axis plunge are oriented towards NE direction, hence suggest the influence of a NE shallow dipping seismogenic fault. The centroid depth of these small-moderate earthquakes are closely placed with the locations of the Mid-Crustal Ramp (MCR) structure of the MHT as given by the recent studies of the region.

The MT solutions and few other historical moderate size earthquakes of this region (including 1991 Uttarkhasi and 1999 Chamoli earthquakes) are utilized to estimate the stress field of the Garhwal region. The sigma-1 i.e., the principle stress ($_1$) is oriented towards NE-SW direction of the relative plate motion between India and Eurasia plates. Friction Coefficient (FC) estimated along with the stress inversion suggest that the Chamoli region is critically stressed with the low friction as evident by the low FC values (FC<0.65) in comparison to the whole region (FC>0.8). The low friction around Chamoli (NE Garhwal region) has been correlated with the presence of fluids, trapped around the MCR region. The study reveals that the small-moderate earthquakes of this regions are related to the NE dipping MHT/detachment plane, in particular to the MCR region. The regions in and around Chamoli are seismotectonically active and structurally complex, hence the seismic risk is high in this region.

Crustal structure beneath Tozing broadband seismological station

The average crustal thickness and Poisson's ratio have been estimated beneath Tozing broadband seismological station with the help of teleseismic *P*-wave receiver function (RF) method. About 150 telesesmic earthquakes have been selected for receiver function analysis based on (i) high signal-to-noise ratio (visual inspection), (ii) body wave magnitude ≥5.5, and (iii) epicentral distance 30-90°. Iterative time domain deconvolution technique of Ligorria and Ammon (1999, BSSA, Vol.89, pp-1395-1400) has been applied for computation RFs. Prior to RF computation using deconvolution algorithm, the original waveforms are pre-processed by windowing the data to include no more than 60 s before and 100 s after the *P*-wave arrival, re-sampling the waveform data to 10 SPS, filtering the waveforms using a Butterworth bandpass (filter range 0.01-4.0 Hz), and rotation into ZRT (vertical, radial and transverse) system. During computation of RF, a Gaussian filter is used with Gaussian width 2.0. The RFs with high SNR and more than 80 per cent waveform fit are used for further analysis. Example of RFs are plotted as a function of back azimuth (Fig. 26). The *P* to *S* converted phase (or *Ps* phases) can be observed at around 6.5-7.0 s. To study azimuthal variation of crustal structure, the RFs from different BAZ are plotted and clustered into four group e.g. NE, SW, NW and SE groups. The H-K stacking method of Zho and Kanamori (JGR, 2000, vol.105, pp-2969-2980) has been adopted to selected RFs with clear record of Ps phase and it corresponding crustal multiples for obtaining average crustal thickness and Vp/Vs or Poisson's ratio value. The results from H-*k* show average crustal thickness to be about 56 km and Poisson's ratio ~1.76. The inversion for shear wave velocity model is in progress.

SKS splitting technique used to understand the interiors of the active crustal and upper mantle deformation in the Himalaya

The teleseismic SKS/SKKS phase has been used to compute the anisotropic behavior of the Sikkim region. It measures the strength and orientation of azimuthal anisotropy. The basic principal involved is that when shear wave SKS/SKKS passing into anisotropic medium from the isotropic splits into two orthogonally polarized waves having different speeds. Delay time between the faster and slower pulses is measured from

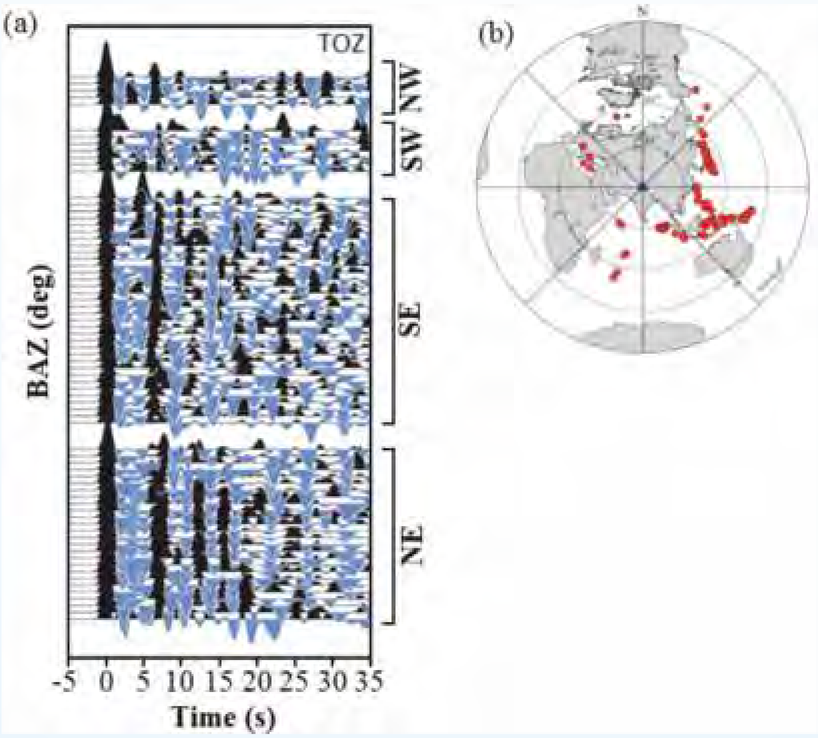

Fig. 26: (a) example of individual radial RFs as a function of back-azimuth for Tozing seismic station, and (b) distribution of teleseismic earthquakes used in this study. The blue triangle in (b) indicates network centre.

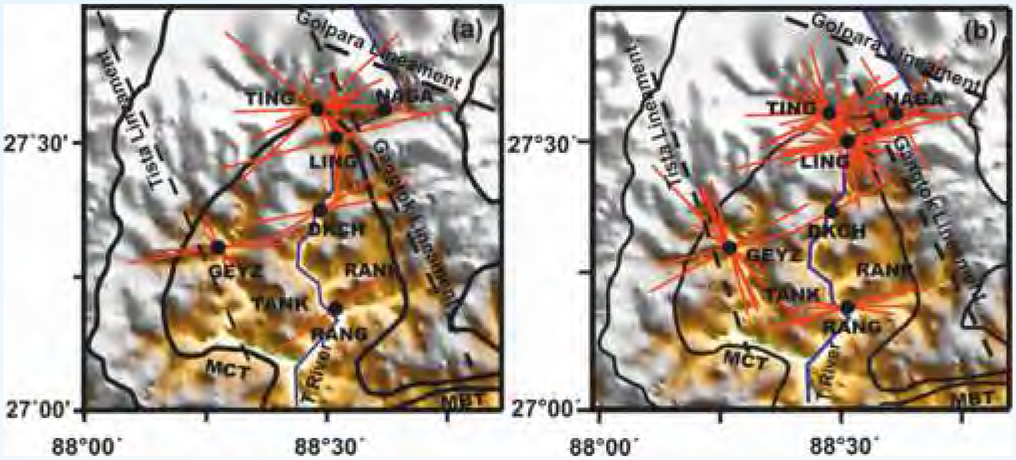

Fig. 27: SKS splitting result for the Sikkim station using the SKS/SKKS phases.

data to infer the orientation and strength of the anisotropy of the earth. A total of 66 splitting measurement were obtained from 8 seismic stations (Fig. 27), and the anisotropy strength i.e. delay time varies from 0.6 to 3.0 sec, and orientation results are scattered.

TAT-3.2

Earthquake precursory studies in the Himalaya through Multiple Geophysical Approach

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

Earthquake source parameter estimation using variable anelastic attenuation

The M_w 7.8 Gorkha Nepal earthquake of April 25, 2015 originated at 15 km depth is the biggest event of the Himalaya region since 1950 which has caused a widespread destruction and casualties of over 8500 in Nepal and also in nearby regions (Bilham, Nature Geosciences, 2015, 8:582-585). The Hindukush region is one of the world's most seismically active areas, where most of the earthquakes occur at 70-300 km intermediate focal depths (Pavlis, Tectonics 2000, 19(1):103-115). The recent Hindukush earthquake of M_w 7.5 occurred on October 26, 2015 is the largest event of the region of last 10 years. Strong motion records are used to estimate the source parameters of recent Gorkha Nepal earthquake (M_w 7.8), its strong aftershocks and seismic events of Hindukush region (Fig. 28). The Gorkha Nepal earthquake and its six aftershocks of magnitude ranging between 5.3 and 7.3 is recorded at Multi-Parametric Geophysical observatory (MPGO), Ghuttu, Garhwal Himalaya (India), which is stationed more than 600 km west from the epicentre of main shock of Gorkha earthquake. The acceleration data of eight earthquakes occurred in the Hindukush region also recorded at this

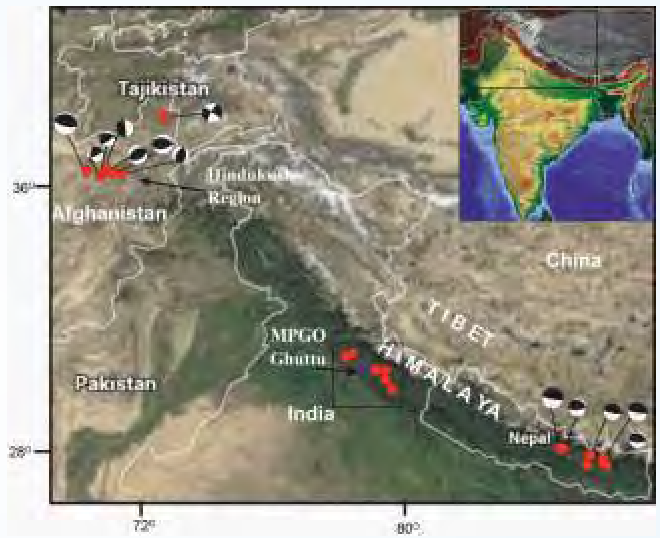

Fig. 28: MPGO station (blue triangle) and epicenters of recent major events of Nepal and Hindukush regions along with big size aftershocks. Epicentres of major events (M_w>7.0) are marked with orange star and other earthquakes with red circle. Focal mechanisms extracted from USGS Harvard CMT solutions of M>5.3 are shown with lower hemisphere beach balls.

observatory, which is located >1000 km east from the epicenter of M_w 7.5 Hindukush earthquake of October 26, 2015. The strong motion data of some local moderate magnitude events close to the recording station are also used for evaluating site effect on the data. The shear wave spectra of acceleration record are corrected for the possible effects of an elastic attenuation at both source and recording site as well as for site amplification. The strong motion data of six local earthquakes is used to estimate the site amplification and the shear wave quality factor (Q_β) at recording site. The corrected spectrum is compared with theoretical spectrum obtained from Brune's circular model for the horizontal components using grid search algorithm. Computation after utilization of different technique for each event is elaborated in figure 29 for the devastating M_w 7.8 Gorkha Nepal earthquake. Computed seismic moment, stress drop and source radius of the earthquakes used in this work range 8.20 x 10^{16} to 5.72 x 10^{20} Nm, 7.1 to 50.6 bars and 3.55 to 36.70 km, respectively. The results obtained after application of proper anelastic attenuation and removal of site effect match with the available values reported by other agencies.

Evaluation of precursory signature for recent M_w 5.8 earthquake of Garhwal Himalaya

In 2017, there was an earthquake of magnitude 5.8 occurred on February 06, 2017 at 17:03:8 UTC time (10:33 PM Indian Standard Time) in district Rudraprayag, Uttrakhand Garhwal Himalaya. This earthquake is nicely recorded by strong motion seismic equipment with Peak Ground Acceleration 55.48 mg on the N-S horizontal component. Three component records of the accelerometer is given in figure 30. ULF

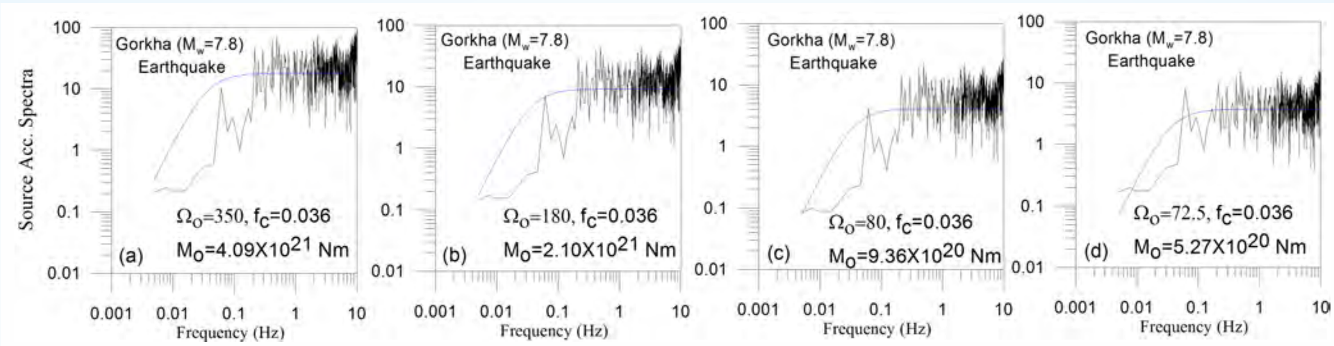

Fig. 29: Comparison of observed and theoretical spectra of NS component of Gorkha (M_w 7.8) earthquake using correction of (a) anelastic attenuation ($Q_\beta(f)$) for source region only, (b) $Q_\beta(f)$ for site region only, (c) both $Q_\beta(f)$ for source and site regions and (d) using both $Q_\beta(f)$ for source and site regions along with the site amplification term. The blue and black colours denote theoretical and observed spectrum, respectively.

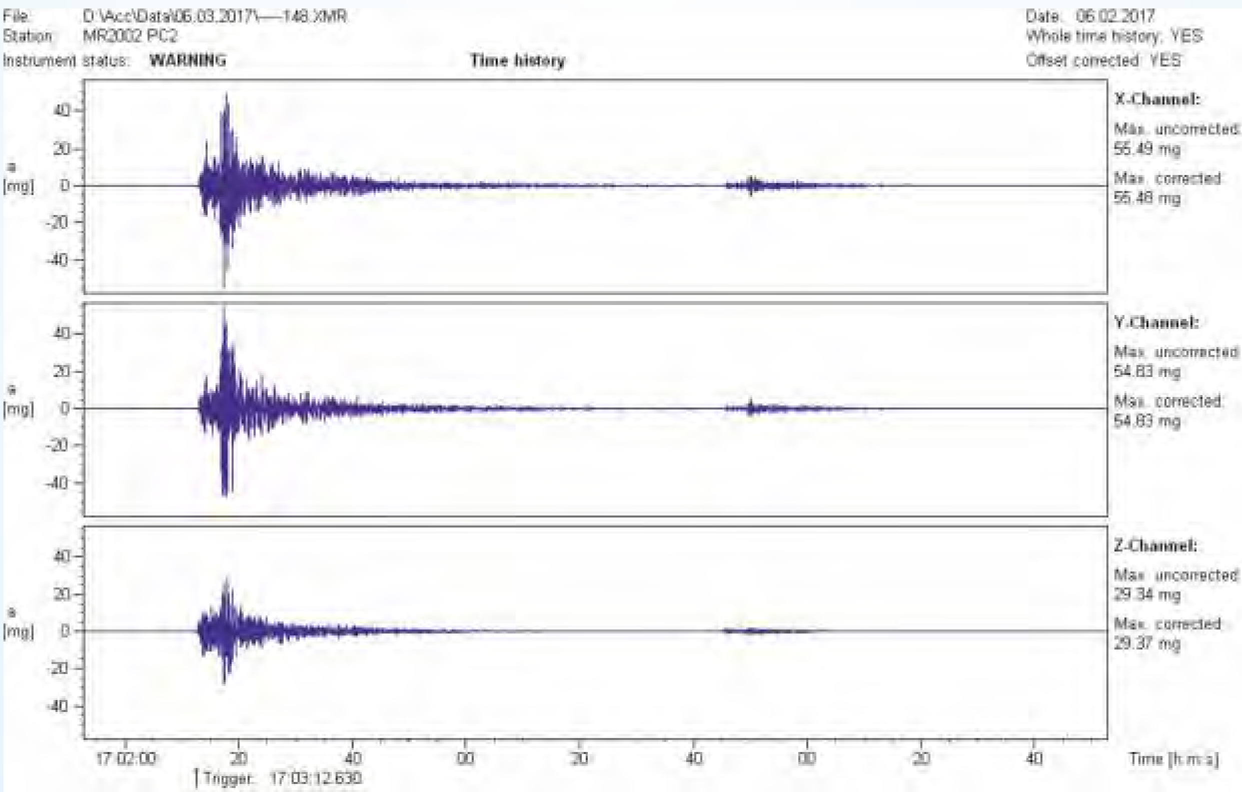

Fig. 30: Strong motion record at MPGO Ghuttu of M_w 5.8 earthquake of February 06, 2017.

time series was looked for any precursory signature related to this nearby earthquake. Temporal evaluation of fractal dimension of ULF time series in the frequency band 0.03 to 0.1 is calculated. To reduce the ionospheric and cultural noise, time series of 19-20 UTC hours equivalent to local midnight from 11:30 PM to 12:30 AM was used for analysis. The time series is detrended and FFT is calculated for number of windows with 50 % overlap. These power spectrum over number of windows is stacked, and stacked spectra is used to estimate fractal dimension. Fractal dimension variability is shown as a figure 31. As observed from figure, from 1 January, 2017 to 28 February, 2017, the fractal dimension is high with less variability. Whereas, before and after the period the fractal dimension is less than 1.5 and having significant variability, indicating different level of complexity in ULF field signifying the presence of seismogenic em signal during the above mentioned period.

Shallow sub-surface structure investigation for seismic hazard studies

Ongoing tectonic activity and under-thrusting of the Indian plate below Himalaya causes continuous tectonic stress development and seismic hazard within the Himalaya and surrounding regions. The geodetic measurements are capable to discriminate areas on the basis of strain distribution which is important for gradually slipping areas of the Himalaya. For the purpose of earthquake precursory study and ongoing deformation pattern in the Himalaya, we are using multi-geophysical approaches, and GPS is one component of them. To achieve the goal of the project and for estimating the strain pattern in the Himalaya, we have installed a network of permanent GPS stations in different part of the Himalaya and data is acquired on near real time at 1 sec and 30 sec sampling interval simultaneously. High sampling rate (near real time) data is useful for earthquake precursory study, while 30 sec sampling data is used for the crustal deformation study. Each part of the

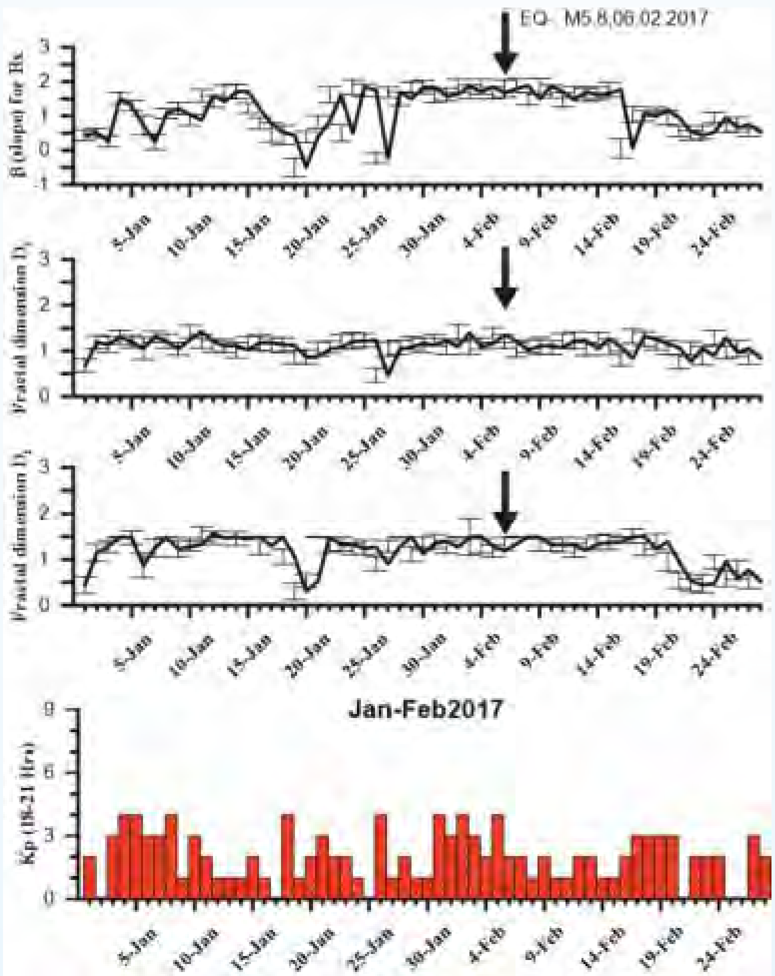

Fig. 31: Fractal dimension variability of ULF band em variations during January 1, 2017 to February 28, 2017.

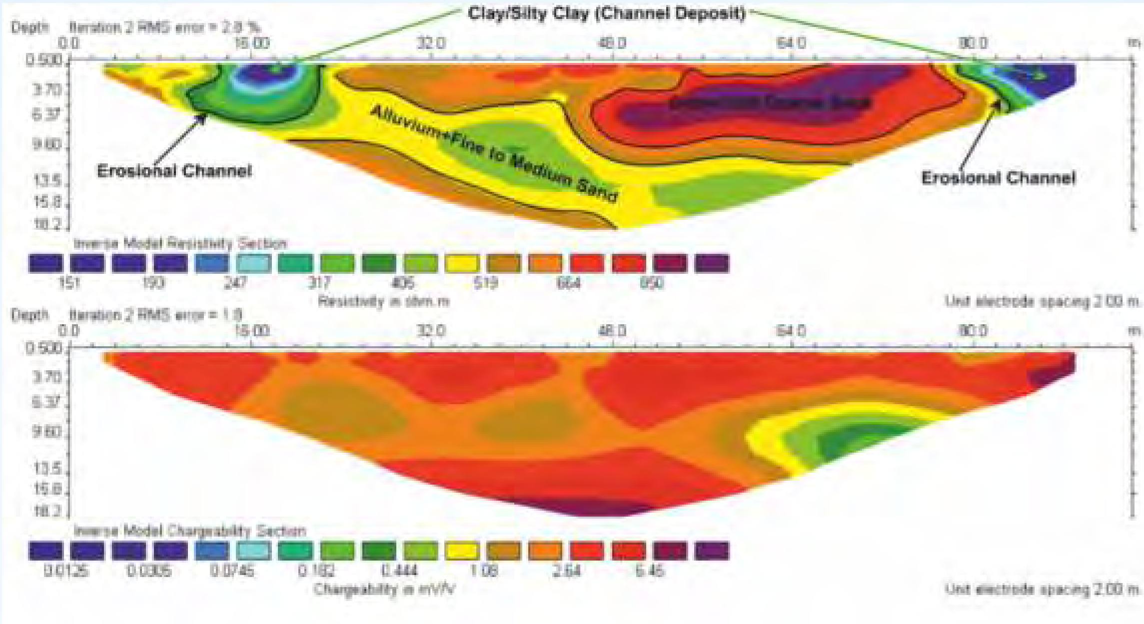

Fig. 32: Inverted 2D section for resistivity and IP-chargeability.

Himalayan region is important for seismic hazard studies, and this requires the understanding of the uppermost shallow structure. Analysed the 2D geo-electrical data collected in Doon valley sub-Himalaya, Dehradun for possible shallow subsurface groundwater aquifer identification, and to obtain the resistivity and IP sections (Fig. 32). Two resistivity and IP profiles were carried out to identify the conceivable groundwater zones in this area. It revealed that there are two inimitable palaeo-channels in these areas. These channels act an erosional passages which was earlier assumed to be a little stream. Beneath this, there is thick gravel and coarse sand stores in the close surface which is arranged at a profundity of 0.5-5 m with a thickness of 10 m. This zone goes about as brilliant potential for shallow groundwater pockets. Besides, inside the surroundings of these rock stores, fine to medium sand is likewise present in the vast majority of the zones which also may likewise goes about as potential groundwater resources at a shallow depth. This data may also be useful for seismic hazard studies related to liquefaction due to occurrence of strong nearby earthquake.

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)

The Trans-Yamuna Active Fault (TYAF), delineated in the northwestern Doon Valley in the Sub-Himalaya, has been investigated with reference to paleoseismicity. The present study mainly focuses on the Bharli Active Fault (BAF), an E-W striking normal fault identified in the easternmost segment of the TYAF. The south side up of the fault has varying dip from 30 to 35N which has obliquely cut across the Main Boundary Thrust in this area. The lithology consists of pre-Tertiary Chandpur Phyllite exposed on either side of the fault, which is highly deformed and sheared with conspicuous folding. A strike-slip component is also confirmed by the presence of two sag ponds in the vicinity of the fault scarp. Use of high resolution satellite data integrated with geophysical surveys and paleoseismological investigation using trench excavation survey across BAF was carried out.

Generation of high resolution DEM (mean vertical error of 0.277) from Cartosat-1 stereo pair, with Ground Control Points (GCPs) collected by Differential Global Navigation Satellite System (DGNSS) survey, could delineate the terrain features. Lateral offset of few streams substantiate strike slip fault motion along BAF. Ground Penetrating Radar (GPR) survey helped in comprehending the subsurface features of the fault. The GPR profiles of the shallow depth survey substantiate deformation within the lithounits that are believed to be due to faulting.

Paleoseismological investigation through trench excavation survey across the BAF revealed earthquake induced deformation features of the TYAF system. Two trenches, which are perpendicular to BAF have been excavated to understand the recent tectonic activity

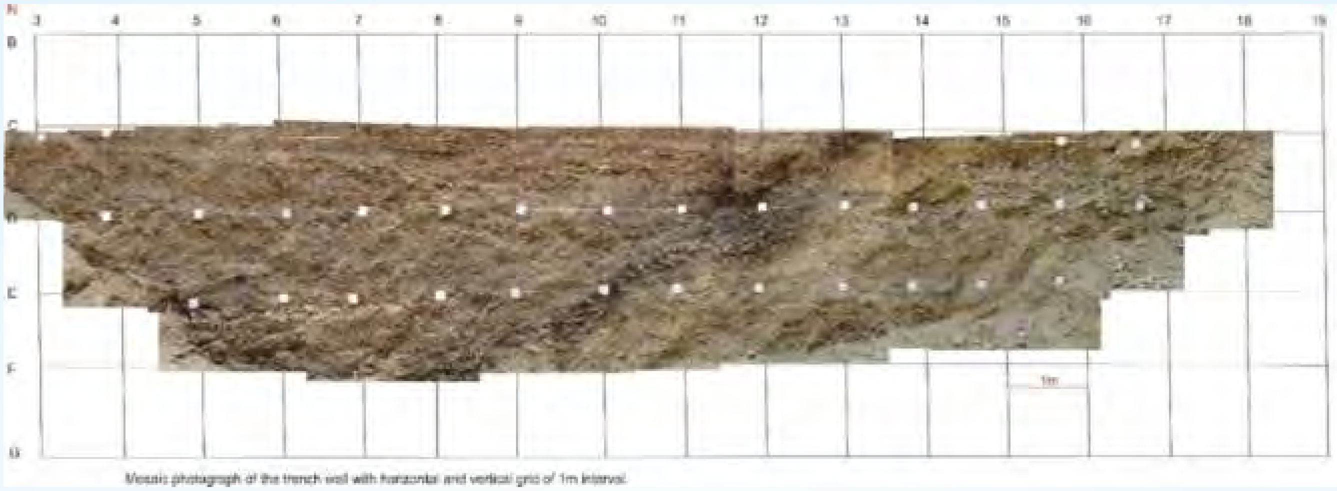

Fig. 33: Mosaic photograph of the trench wall with horizontal and vertical grid of 1m interval.

along BAF. The trench (Fig. 33) across the BAFs scarp show highly sheared and fractured phyllite filled with secondary quartz veins which are offset confirming the fault activity. The depressions created in the northern side of the fault scrap have been subsequently filled-up by fluvial sediments. The trench excavated very close to one of the sag ponds vividly displays soft sediment deformation which is believed to be attributed to recent large magnitude earthquakes. Highly deformed beds along with off-setted quartz veins and soft-sediment deformation features identified in the trenches suggest their genetic link with major paleoseismic activity. Based on the preliminary ^{14}C ages obtained for the carbon samples from the trench suggest probable timing of the faulting events was estimated to have occurred after the deposition of 3000 BC and 900 AD. The TYAF recognized in the Sub-Himalaya to north of the Himalayan Frontal Thrust, demonstrates that the recent strain release is not only concentrated in the Frontal Himalaya but also distributed over a broader area further to its north in the Sub-Himalaya. The study on TYAF reveals its potential for future earthquakes in the seismically active and highly populous mountainous belt of NW Himalaya.

Non-invasive geophysical techniques were employed across the Himalayan Frontal Thrust (HFT) at Singhauli near Kala Amb in the northwestern Frontal Himalaya to understand shallow subsurface geological structures and their nature in relation to active tectonics. The combination of high-resolution Ground Penetrating Radar (GPR) and Induced Polarization Resistivity (IPR) techniques with different acquisition parameters have found to be useful in obtaining high-resolution imaging of structures in the shallow subsurface. Repeated surveys comprising of different arrays across the HFT at Singhauli were carried out using Lippman 4 point light hp earth resistivity meter consisting of 40 electrodes. 2D multiple IPR profiles were acquired with electrode separations varying from 1 to 5 m. The inversion was performed with Res2DInv software to produce two-dimensional sub surface image of the area which was interpreted and analysed in conjunction with published geological information of the area. GPR method was applied with 100 and 200/600 MHz dual frequency antennas. The 2D profiles interpretation reveals correlation between GPR anomaly and fault plane. The study has established a strong correlation existing between fields based geological observation carried out earlier in this area through trench excavation survey, which had established repeated tectonic activities in this region, with the geophysical observations. The study has also highlighted the presence of a prominent liquefaction feature associated with a large magnitude paleo earthquake that occurred in the area. The integrated approach argues for judicious use of the GPR and IPR techniques to delineate subsurface geology across various faults in the Himalayan terrain to geologically comprehend the area which are structurally complex and lithologically dissimilar.

TAT - 3.4

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

(R.J.G. Perumal and Pradeep Srivastava)

A study in Central Nepal discovered a great earthquake in A.D. ~1100 that according to Lavé et al., (2005) produced a coseismic slip of ~17 m, while Kumar et al.

(2010) attributed this earthquake to have produced observed fault slips of ~14 and ~12 m, respectively in the Chalsa and Nameri trenches that lie along northeastern Himalayan front. The status of this event is, however, paradoxical when correlated with the contemporaneous medieval reports. A 6 m terrace offset at Koilabas of Nepal Himalayan front was attributed to the A.D. 1255 earthquake (Mugnier et al., 2011). Substantiating historical records, Sapkota et al. (2013) reported evidence of surface rupture by A.D. 1255 medieval event at Sir Valley in Central Nepal. In retrospect, this earthquake might have been misconceived with the 1100 event at Chalsa and Nameri and with the 1950 event at Harmutty (Kumar et al., 2010). Further, from a recent trench study in northwest Kumaun Himalaya (~29.31°E, 79.20°N), Rajendran et al. (2015) postulated a 'two-event scenario', tactfully correlating the events with the 1255 and 1344 earthquakes (Pant, 2002; Mugnier et al., 2013; Jayangondaperumal et al., 2016). However, Kumar et al. (2006) attributed the surface faulting to the 1505 earthquake (Bilham and Ambraseys, 2005). Thus, putative suggestions of Rajendran et al. (2015) regarding the extension of the 1255 event to west of the discovered surface rupture in trench (Sapkota et al., 2013) and speculations of the 1505 event (Kumar et al., 2006) is a matter of debate. More recently, Bollinger et al. (2016) have also suggested that the 1255 rupture propagated eastward from the Kathmandu valley to Hokse Khola in Nepal.

These complicacies involved in the propagation style of the 1255 rupture provoked us to carry paleoseismic investigations at Panijhora village in West Bengal, northeast India (Fig. 34). We reported the results of a paleoseismic investigation carried across a ~10 m high fault scarp at Panijhora village, West Bengal in northeastern India. Accelerator Mass Spectrometer analyzed ^{14}C radiocarbon age constraints from six detrital charcoal samples ranging between 1688 B.C. and A.D. 1152 are consistent with the great medieval earthquake of A.D. 1255 that is interpreted to have produced a minimum observed fault slip of ~5 m in the trench exposure. Recalibration of radiocarbon ages

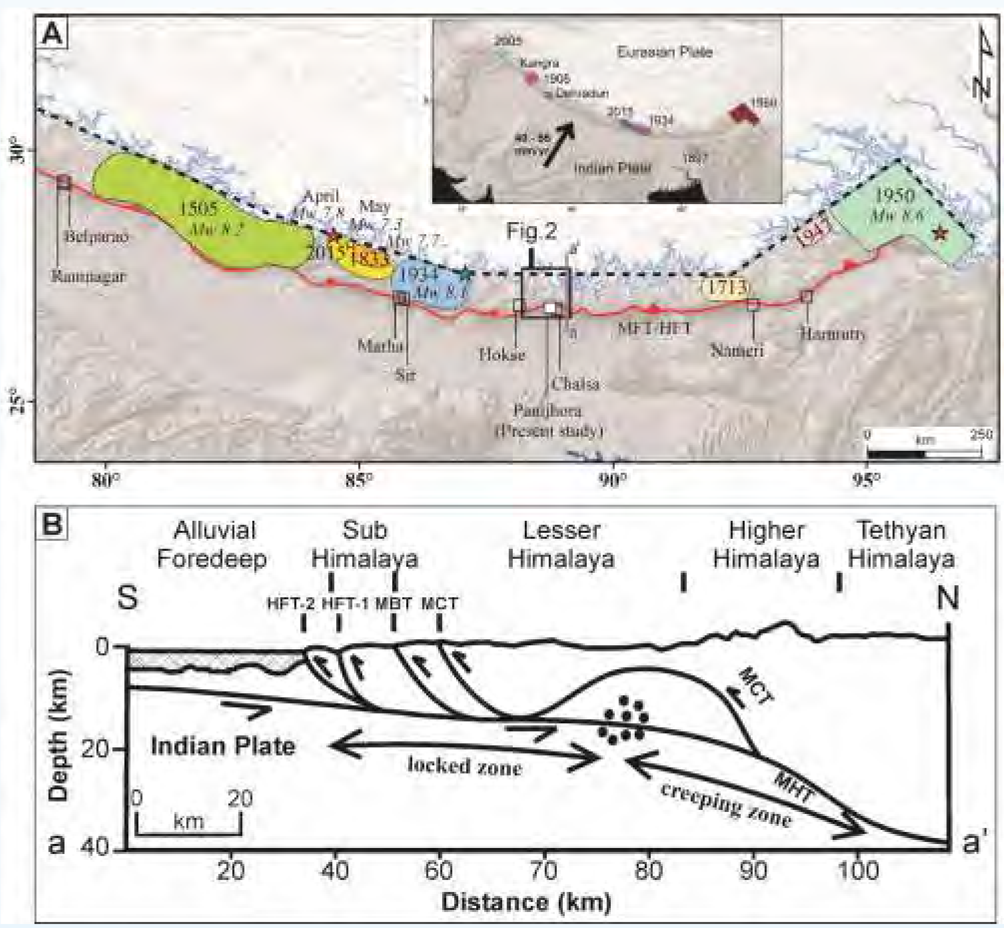

Fig. 34: Map showing study area and motivation of the present study, Hollow Square previously trenched sites by various researchers discussed in the text, and White Square shows location of trenched site in this study.

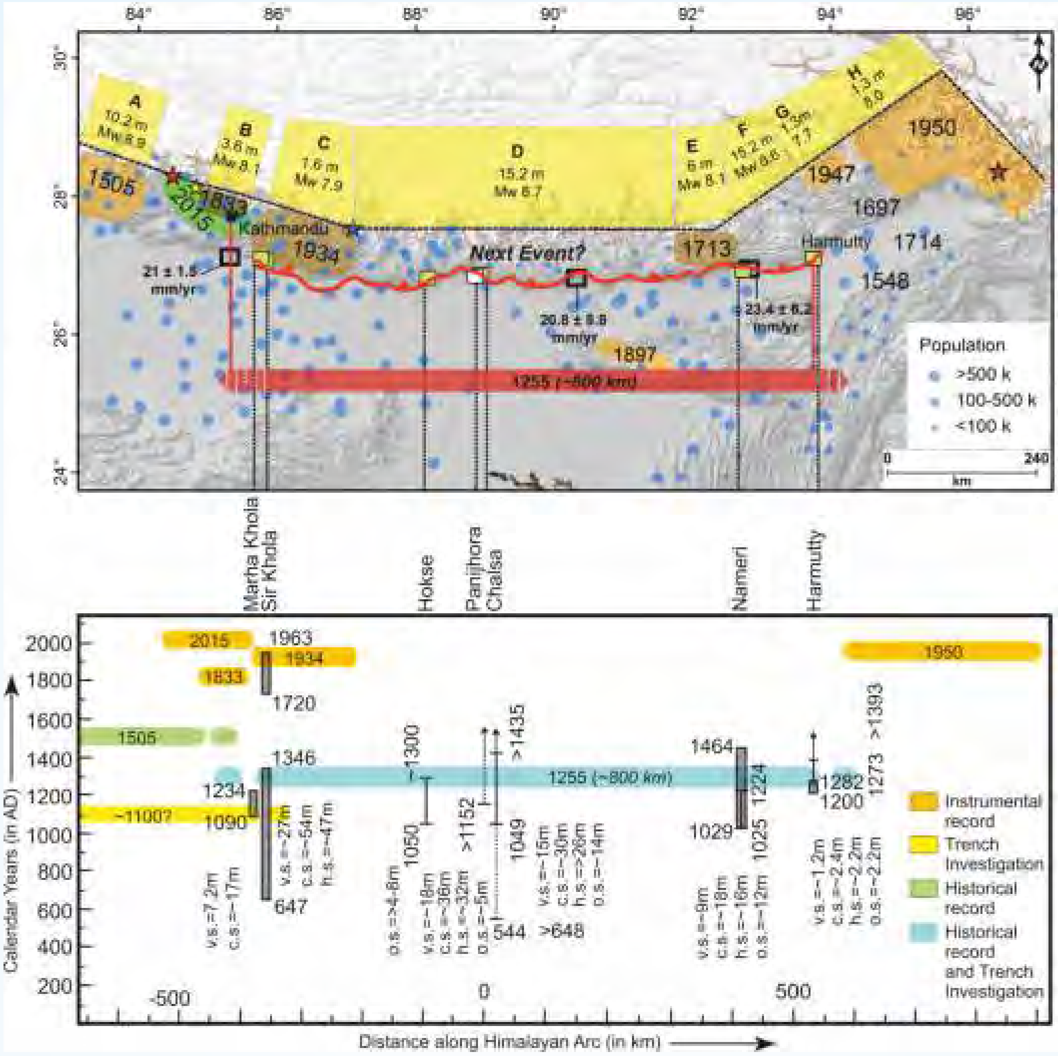

Fig. 35: Discovered A.D. 1255 surface faulting along northeastern Himalayan Frontal thrust. The 1255 event was discovered by Sapkota eal 2013 and Bollinger et al 2014 in the Nepalase Himalaya, upto to Hokse Khola near Western Nepal exit at the border between Nepal and India. In this study, we extended the 1255 rupture in the eastern Himalayan front.

from previous studies at Harmutty, Nameri, and Marha in the eastern Himalaya using Bayesian statistical analyses further substantiates the possibility that the A.D. 1255 earthquake might have ruptured the Himalayan front over a length of ~800 km from ~85.87 to 93.76°E longitudes (Fig. 35).

TAT-3.5
Morphotectonic evolution of the Himalayan frontal belt between Kosi and Kali rivers, Kumaun Himalaya

(Khayingshing Luirei and S.S. Bhakuni)

The shape of the Himalayan frontal part around northeastern corner of the Kumaun sub-Himalaya along Kali River valley is defined by folded hanging wall rocks of the Himalayan Frontal Thrust (HFT). Two parallel faults (Kalaunia and Tanakpur faults) trace along axial zone of the folded HFT. Between these faults the hinge zone of this transverse fold is relatively straight and along these faults the beds abruptly change their attitudes and their widths are tectonically attenuated across two hinges. Regional trend of the mountain front in the NW Himalaya is NW-SE but it locally becomes SW-NE towards north of Tanakpur and NW-SE and N-S at the exit of the Kali River from the mountain front. This variation in trend of mountain front is as a result of presence of a syntaxial structure. The N-S trending Thuli Gad and other stream at 1.2 km east of Thuli Gad flow along the axial zone of this major fold. These tributaries follow the N-S trending brittle axial planar fracture cleavages of fold. The Kalaunia Fault (offsetting the trace of the Bastia Fault) and Tanakpur Fault are also parallel to these tectonic fabrics. At Bastia the Siwalik rocks dip towards north direction while near the confluence of Thuli Gad and Kali River the bed rocks dip towards ENE/E direction. At Senapani the bedrocks comprising of the pre-Siwalik rocks (~Dharmsala/Subathu) of the bedrock dips moderately (37-50°) towards N20W-N15W. The strike of the mountain front here is almost E-W. Further east at Khorpa Tal northwest of Tanakpur, the attitude of the bedrock is moderately dipping (34-35°) towards west-N80W, while the trend of the mountain front becomes NE-SW. At Khorpa Tal the mountain front shows 2-3 m high south dipping gentle fault scarp. The attitude of bedrock along Hathi khor River west of Bastia just at the point of exit into the piedmont zone, dips 57-73° towards N53W-N40W. Along the Tanakpur-Champawat highway just north of Bastia the bedrock dips moderately (44-52°) towards north-NNE, and in this section the trend of the mountain front is almost E-W with slight curvature. The sudden change in slope gradient is observed along this section and is characterized by sheared bedrocks. This is the relict mountain front, where the present active mountain front lies south of Bastia at about 3 km from the former. At Thuli Gad where the Kali River exits into the piedmont zone the attitude of the bedrock becomes steeply dipping (60-70°) towards N80E-S40E. In Thuli Gad section the mountain front becomes NE-SW trending and the Kali River flows parallel to the strike of the bedrock. Before cutting across the Tanakpur Fault, Kali River flows across the bedrocks perpendicularly, where the strike of bedrock is almost N-S and flow direction of the Kali River is towards W; thereby resulting in deep cut V-shaped valley. The bedrock is subjected to brittle deformation as evident from bedding parallel movement having slickensides indicating sense of movement (Fig. 36a,b). The sense of movement on the bedrock is similar with the sense of movement indicated by Goswami (2012; figure 4 therein).

Raiverman (2002) has discussed about existence of localized syntaxial bend north of Tanakpur due to indentation of the Delhi-Moradabad ridge into the sub-Himalaya. Tanakpur area is traversed by right lateral transverse faults trending NNE-SSW. The transverse fault produced pronounced displacement that has placed different lithologies in juxtaposition and the Kalaunia Fault west of Tanakpur has been marked on the basis of dextral movement of the lithounits, and also from number of cliffs and landslides along fault. The area is constituted of various surfaces of coalescing fans and terraces. Fans

Fig. 36: (a,b) Photographs showing the SE dipping bedrock exposed along the Kali River with horizontal slickenside indicating the sense of movement of the Tanakpur Fault.

comprise predominantly of sandstone clasts traversed by the steep gradient streams originating from the Siwalik range. The alluvial fans are characterized by compound and superimposed fans with high relief, which are interpreted to be related to the tectonic activities associated with the thrusting along the HFT. The truncated fan along the HFT has formed a-100-m high escarpment running E-W for about 5 km. At Senapani tectonic induced erosion has exposed 30-m-high escarpment comprising 16 m of the pre-Siwalik rocks (~Dharmsala/Subathu) and the overlying 14 m terrace deposits. The dip of the pre-Siwalik rocks is 45° towards NW direction. Overlying the pre-Siwalik rocks is the base of the terrace with angular unconformity between them. Stream cutting across the 30 m high escarpment has exposed the terrace that is made up mainly of clasts of the Siwalik sandstones and quartzite, which is about 2.7 m thick. This is overlain by almost 2.26 m thick horizons of pebbles and laminated sand. Pebbles (quartzite and sandstones) and laminated sand horizon is characterized upward fining sequence. The top horizon is made up of thick sequence of cobbles and pebbles of about 9 m made up of clasts of quartzite and sandstones. The terrace sediments are tilted by ~30° towards NW direction; the tilted sediments are characterized by hosts of deformation structures. The main deformation structures observed are the closely spaced reverse faults dipping 38° towards NW direction. Maximum displacements have taken mainly along the basal and the uppermost faults; in between the faults of smaller extent are also observed. The movement along basal fault has resulted in placing the laminated sand over the upper pebbly horizon. Faulting along the uppermost fault has moved the underlying pebbly horizon forming the base of the laminated sand by about 65 cm over the laminated sand layer. The maximum displacement along the uppermost fault measures about a meter. In between the basal fault and the uppermost fault the NW dipping laminations have become horizontal to SE dipping that resulted from the movement along successive minor faults. The reverse faults are associated with other deformed structures, such as crumpled lamination at the top of the thrust plane, kink folds, and wavy undulation of laminations, pop-up structure and folding. Faulting in opposite directions has resulted in small scale flower structures. Fault propagation folds are also observed towards the top of the deformed laminated sand. Small-scale parallel reverse faults resembling back thrusting are also observed that dip 7° towards SE direction. The back thrusts are gentler than the main fore fault. The south facing hill slopes exhibit numerous landslides along active channels incising hanging wall of the HFT. There is absence of seismicity in the study area. The major Moradabad Fault crosses near the study area. This transverse fault may have suppressed the seismicity in the Tanakpur area, and the movement along the Moradabad and Kasganj-Tanakpur faults cause the neotectonic activities as observed. The role of transverse fault tectonics in the formation of the curvature cannot be ruled out.

TAT-3.6

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

(Vikram Gupta)

During the reporting period, emphasis was given mainly on the various identified hot-spots in the Satluj. One such hotspot taken for detailed study in the Satluj valley is Urni landslide (31˚31′15"N; 78˚07′34”E) located in the Lesser Himalaya. It is an old chronic landslide, located on the right bank of the Satluj river. In 1990s it was a small rockfalls that has grown into a complex landslide, and is presently posing serious threat to the inhabitants of the area. It is a complex-type landslide with debris slide in the central part, and rockfalls at right and left flanks of the landslide zone. The present dimension of the landslide is 600 x 300 m, and the active scarp of the landslide is located at an elevation of ~2200 m, whereas river Satluj flows at the base at an elevation of about 1775 m.

The spatio-temporal growth of the landslide was studied and analyzed using satellite images (google earth imagery, Cartosat-1, LISS-IV) and field visits. Slope stability analysis and modelling of the entire slope was attempted using finite element analysis - shear strength reduction (FEM - SSR) approach. High resolution digital elevation model (DEM) was prepared from Cartosat-1 data having 2.5 m spatial resolution. Slope geometry was extracted from the DEM and updated with the field checks. Kinematic analysis to understand the future rockfall potential in the area has also been carried out. Also, to understand the impact of this landslides in the downstream region due to landslide lake outburst flooding (LLOF), debris flow run-out analysis was carried out using RAMMS software version 12.0.

It has been observed that the size of the landslide has grown exponentially since 2012. This can very well be correlated with increased rainfall and/or with intensity of rainfall in the area. In 2013, the landslide has partially dammed the river by dumping ~0.076 million m^3 of debris into the river and also damaged ~300 m stretch of the National Highway (NH)-05.

The slope stability analyses revealed shear strain on the slope of the order of 0.01-0.03 with 15-20 cm displacement in the detachment zone. Further, kinematic analysis indicated planar failure condition in the rock mass. Two scenarios were analysed:

- in case of high intensity rainfall which is frequent in the area, debris flow run out model using rapid mass movement simulation has been attempted (RAMMS Software). The model predicated the occurrence of debris flow with a velocity of 20-30 m/s and flow height of 15-20 m (Fig. 37). This will damage a zone of 100 m upstream and downstream of the landslide site.
- in case of further slope failure ~1.1 million m^3 debris may move down and dam the river to a height of ~40 m. Such damming may result into landslide lake outburst flood (LLOF). Therefore immediate slope intervention is required in order to avoid any further disaster due to this landslide.

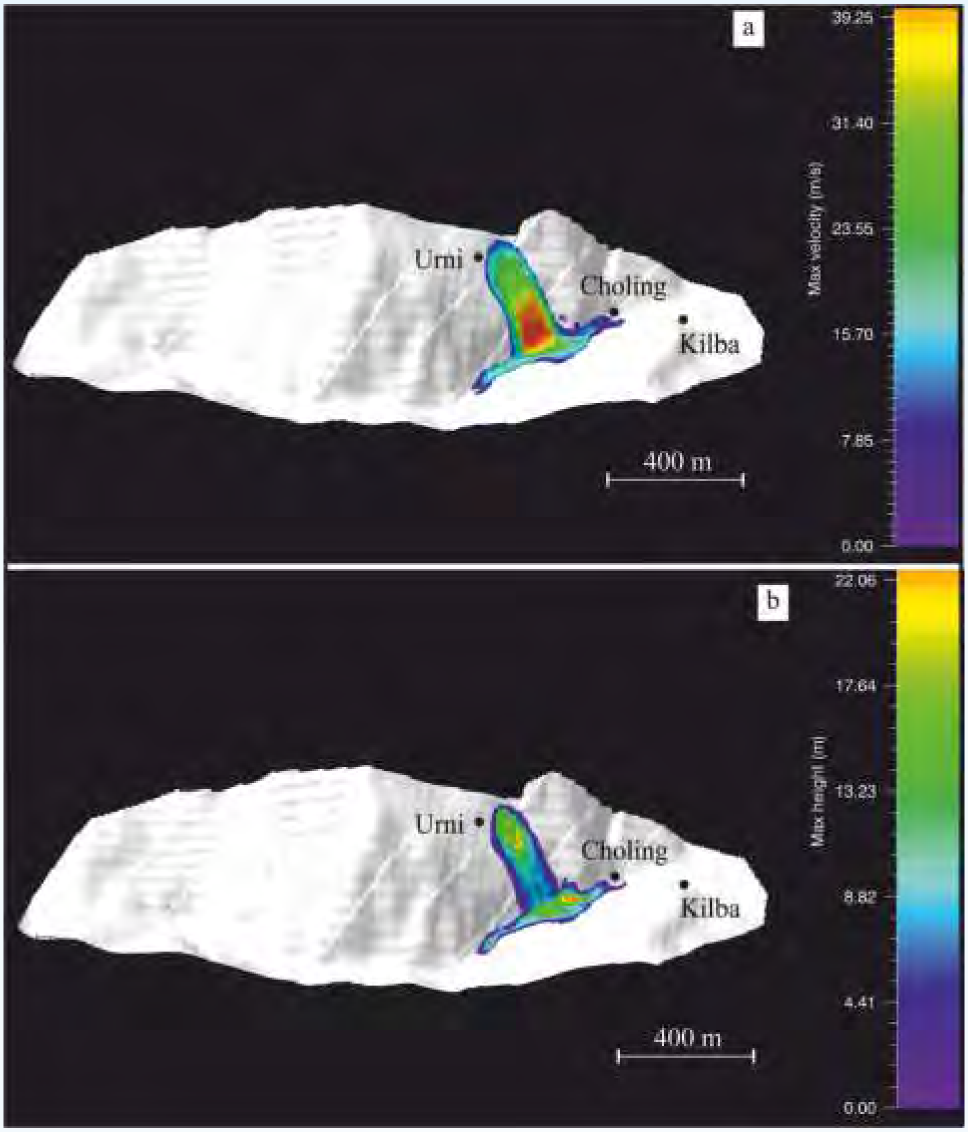

Fig. 37: Debris flow run out model of the Urni landslide using rapid mass movement simulation (RAMMS Software).

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)

The Ediacaran-early Cambrian is a significant time interval of geological history. During this time interval soft-bodied faunas came into existence and disappeared, being replaced by the skeleton-bearing faunas. This was an important evolutionary event during the early Cambrian when biomineralization replaced the soft bodied fauna. This results in a revolution of the biotic structures, generating behavior in the organisms and thus facilitating their competitiveness (Bengtson, 1994).

The Blaini-Infra Krol-Krol-Tal sequence of the Lesser Himalaya represents Ediacaran - early Cambrian time interval. The Infra Krol and lower Krol Formation contain cyanobacteria and very significant large acanthomorphic acritarchs i.e., *Tianzhushania spinosa*, *T. polysiphonia* and other LAA of early Ediacaran age. The Chert Member of the Lower Tal Formation postdate the disappearance of the Ediacaran biota and precedes the arrival of Cambrian fauna. Earlier, small shelly fossils (e.g., Azmi et al., 1981; Azmi, 1983), small acanthomorphic acritarchs, cyanobacteria and sponge spicules (Tiwari, 1999) were reported from Chert Member. It is conventionally correlated with the Nemakit-Daldynian and Tommotian stages in Siberia. In addition to these fossils, several different types of sponge spicules, large sized tubular structures and processes bearing spherical structures were observed recently from Chert Member of Lower Tal Formation exposed in Mussoorie and Garhwal synclines. The tubular structures are identified as *Megathrix longus*. These tubes are characterized by large tube diameter and corrugated incomplete and complete cross walls. The transverse sections, the tubes are more or less circular. Though, Liu et al. (2008) also described large tubular microfossils from the Ediacaran Doushantuo Formation at Weng'an, South China, but the diameter is much greater than *M. longus* and have flat walls. The phylogenetic affinity of Megathrix is uncertain. These are superficially similar to silicified and phosphatized *Oscillatoriopsis* like cyanobacterial filaments, but differs in its large diameter of tube and corrugated cross walls and the intercalation of complete and incomplete cross walls. So *Megathrix longus* is unlikely to be a filamentous cyanobacterium. Yao et al. (2005) regarded *Megathrix longus* as a stem group cnidarian. The tubular microfossil *Megathrix longus* may also have biostratigraphic significance. It has so far been reported from the basal Cambrian of lower Yurtus and lower Yanjiahe formations, and it appears to be restricted to the Meishucunian Stage.

TAT-4.2

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

(S.K. Parcha)

Biostratigraphy and biogeoghraphy of the Tethyan Cambrian sequences of the Zanskar Ladakh Himalaya and of associated regions

Cambrian sediments of Tethyan Himalaya are fossiliferous, comprising trilobites, trace fossils, hylothids, cystoids, archaeocythid and brachiopod, etc. Prolific trilobite fauna were collected from the Cambrian successions. During recent years a variety of agnostid taxa have been reported from the Cambrian succession of the Zanskar basin. Agnostids constitute the most important index fossils for the global correlation of Cambrian succession. The agnostid fauna from Zanskar reveal the presence of *Baltagnostus, Clavagnostus, Peronopsis, Hypagnostus, Diplagnostus, Lejopyge* and *Goniagnostus,* a characteristic taxa of Hsuchuanigian to Changhian stages of the Middle Cambrian. The record of *Diplagnostus* from Zanskar and from north-western part of Kashmir is significant because, it marks the boundary between the Middle and Late Cambrian. In Zanskar, the *Diplagnostus* is associated with *Lejopyge*, which is more significant in order to establish the (Late Middle Cambrian - early Late Cambrian) boundary in the region. The presence of *Lejopyge* sp. is stratigraphically important as it underlies the characteristic early Late Cambrian faunal elements. In Kashmir, the *Diplagnostus* occurs at the top of the *Shahaspis* (=*Bolaspidella*) zone, of early Late Cambrian age. The agnostid fauna reported from Kashmir and Zanskar regions occurs more or less at the same stratigraphic levels as in Australia, China, Kazakhstan, Sweden and North America.

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

Pagetia is the most profusely occurring trilobite at various levels in the Middle Cambrian succession in the Spiti area, in association with it genera *Oryctocephalus*. The cluster of samples contain various species of *Pagetia*, which show different growth stages. These growth stages are classified from meraspid to holaspid. During the meraspid stage radial marking, eye ridge and occipital ring spine are absent in the cephalon, while in the holaspid stage these features are more prominent. In the meraspid stage only two to three axial rings are present in pygidium, and in case of the holdspid stage, six pygidial axial rings are present, the last axial ring cuts the posterior border and the axial spine also develop in this stage. It seems that due to the isopygous nature of *Pagetia*, the growth changes in the morphological features indicate a progressive maturity and stages of ontogenic development. These morphological changes provide an overall variation within the genera, which are further useful for the classification of *Pagetia* into different species. Its importance increases, as it is one of the most widely present genera throughout the Middle Cambrian successions of the Himalayan region, which makes it a useful tool for biostratigraphic correlation, and to understand the depositional environment during that time.

Provenance, tectonics setting and source area weathering of the Lower Cambrian sediments of Parahio section

The present work carried is the first attempt to understand the geochemical signatures of paleoweathering and provenance using major, trace, and rare earth elements (ref. Pandey and Parcha, 2017)). The geochemical analysis of Lower Cambrian siliciclastic rocks of Parahio valley is employed to reveal weathering, provenance and tectonic setting of inferred source areas. The major elemental ratio and correlation with trace elements suggest the presence of clay minerals denoting a warm and humid climatic conditions for Lower Cambrian succession. Chondrite-normalised REE plot of siliciclastic rocks reflect an enriched LREE and depleted HREE pattern similarity to that of the upper continental crust. A good correlation between Ce/Ce* and Eu/Eu* was observed, which suggest that the effect of diagenetic process on the REE concentrations is high. Chemical analyses data of the present siliciclastic rocks have been plotted on three tectonic setting discriminant diagrams (Fig. 38a-c). The discrimination diagram indicates that the majority of samples plot within the active continental margin, while few plot within the passive marginal setting. The samples falling in the ACM reveal that the sediments are delivered from mixed sources and stored on or adjacent to active plate margins and in strike-slip settings, whereas PM indicates that the rocks are derived from stable continental blocks and deposited in several types of basins including rift basins. The major element discriminant function diagram reflects that the samples mostly lie in the quartzose sedimentary provenance, with a few in felsic igneous provenance (Fig. 38d) probably indicating that the sediments to be derived from different crystalline rocks and/or from pre-existing sedimentary rocks. The CIA values reflect a low to moderate degree of chemical weathering, and the average ICV values suggest immature sediments, first-cycle deposits to tectonically active settings. The CIA values were plotted in an A-CN-K ternary diagram (Fig. 38e). In the A-CN-K diagram ($A=Al_2O_3$; $CN=CaO^*+Na_2O$; $K=K_2O$) all the rocks fall above the plagioclase-K-feldspar join line. The A-CN-K plot depicts the clustering of points near the A-K edge, towards the illite composition, which suggests moderate weathering. The ICV values for the Lower Cambrian siliciclastic rocks vary from 8 to 11 (mean=9). On the basis of ICV values it can be interpreted that Lower Cambrian sediments are compositionally immature and deposited in tectonically active settings.

Late Permian succession of Guryul section of Kashmir, India

The storm generated carbonate beds occur not only during a short interval close to the Permian-Triassic boundary but through a major part of the late Permian succession. During our recent study in other area exposed in Mandakpal are of Khrew region, no signs of tsunamites have been detected in time-correlative fine-grained sediments. From the detailed studies of the entire succession and that of the sedimentary structures including the biogenic activities and ichnofossils which were recorded and observed in the Guryul ravine, Zewan and in the Mandakpal and Pokhtoon sections, it is interpreted that the late Permian of Guryul is relatively shallow, neritic and delta-influenced. The so-called tsunamites are shelly-enriched discontinuous carbonate lenses fed downslope through local channels. The distinct facies change from the storm related 'tsunamites' to thinly bedded mud turbidites above, and the sudden deepening may be explained by local and stir rift-related tectonics along the North-Indian Gondwana Margin, which led to episodic seismic induced sediment redeposition in the area of Guryul. Syn-sedimentary tectonic activity with tilting and eventual Horst and Graben structure building along the large NIM is

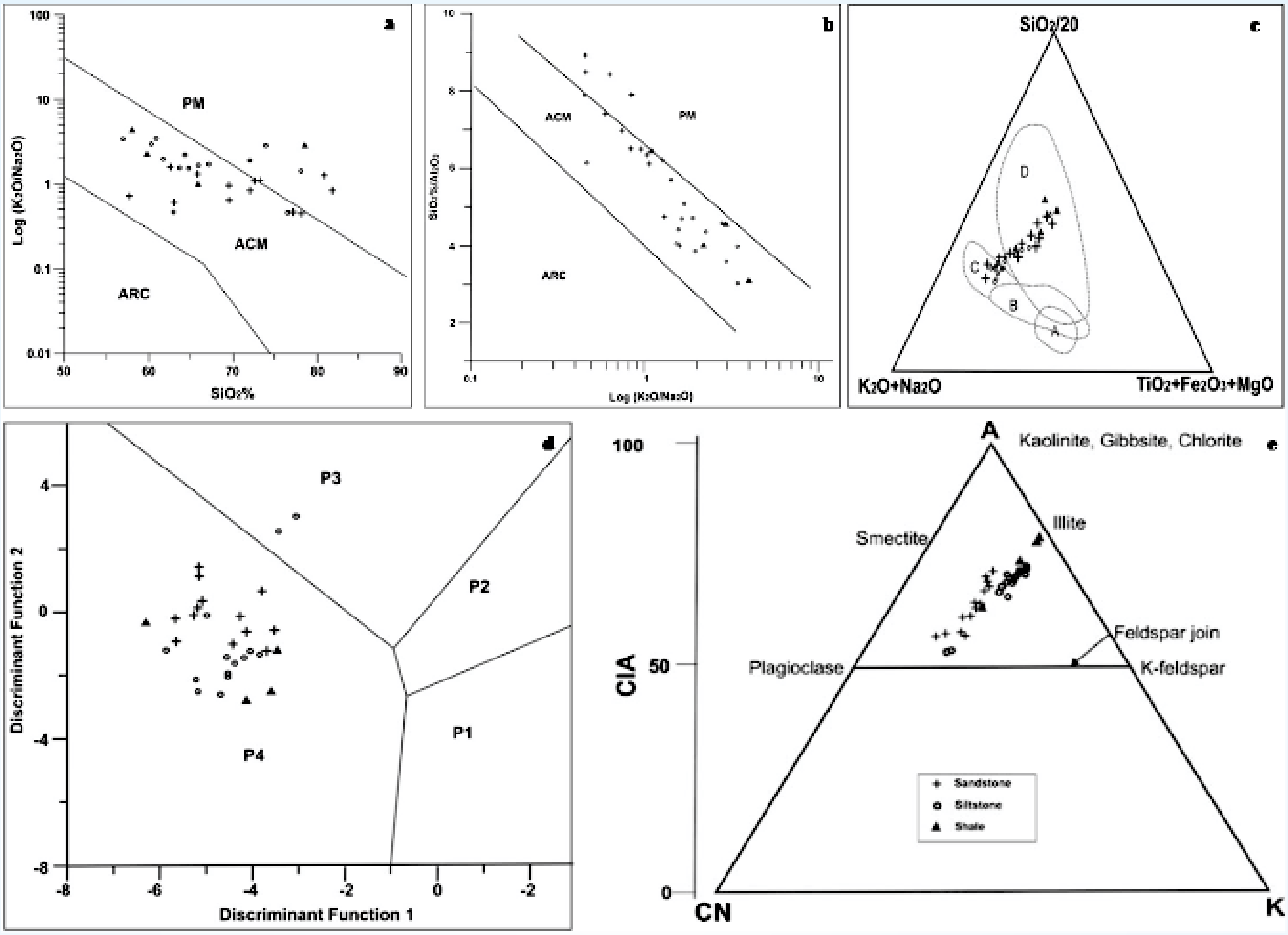

Fig. 38: (a-c) Major element composition on the tectonic setting discrimination diagram by Roser & Korsch (1986) and Kroonenberg (1994). Fields are after PM: Passive margin; ACM: Active continental margin; ARC: Oceanic Island Arc. (d) Discriminant function 1 against discriminant function 2 variation diagram. Fields after Roser and Corsch (1988), Provenance fields: (P1) mafic igneous provenance, (P2) intermediate igneous provenance, (P3) felsic igneous provenance, and (P4) quartzose sedimentary provenance. (e) A-CN-K diagram showing the weathering trend of the siliciclastic rocks (after Nesbitt & Young 1982). A: Al_2O_3; CN: CaO + Na_2O; K: K_2O (molecular composition).

indicated by margin inversion during the P-T boundary interval.

Late Permian Trace Fossil from the Guryul Ravine section of the Kashmir basin

The present study focuses on the Late Permian (Changhsingian) succession, present in the Guryul ravine, Kashmir Basin. The Permian succession of the Guryul Ravine is mainly comprised of mixed siliciclastic-carbonate sediments deposited in a shallow-shelf or ramp setting. The present assemblage of Ichnofossils is the first significant report of trace fossils in the Guryul ravine. The ichnofossils are mainly preserved in medium grain sandstone-mudstone facies. The Ichnofossils are widely distributed throughout the section and mostly belong to arthropods and annelid origin, showing behavioral activity mainly dwelling and feeding and evidence of the dominant presence of deposit feeders. The vertical to slightly inclined biogenic structures are commonly recognized from semi-consolidated substrate which are characteristic features of the near shore/foreshore marine environment with moderate to high energy conditions. No trace fossils could be recognized in the topmost 3 m beds of Zewan D due to their gliding related amalgamated structure.

Characteristic Micro Faunal assemblages from the Thango and Takche formations of the Spiti Himalaya

The Thango and Takche formations of the Spiti Himalaya contain a rich assemblage of microfossils. The present study of the carbonate beds from these

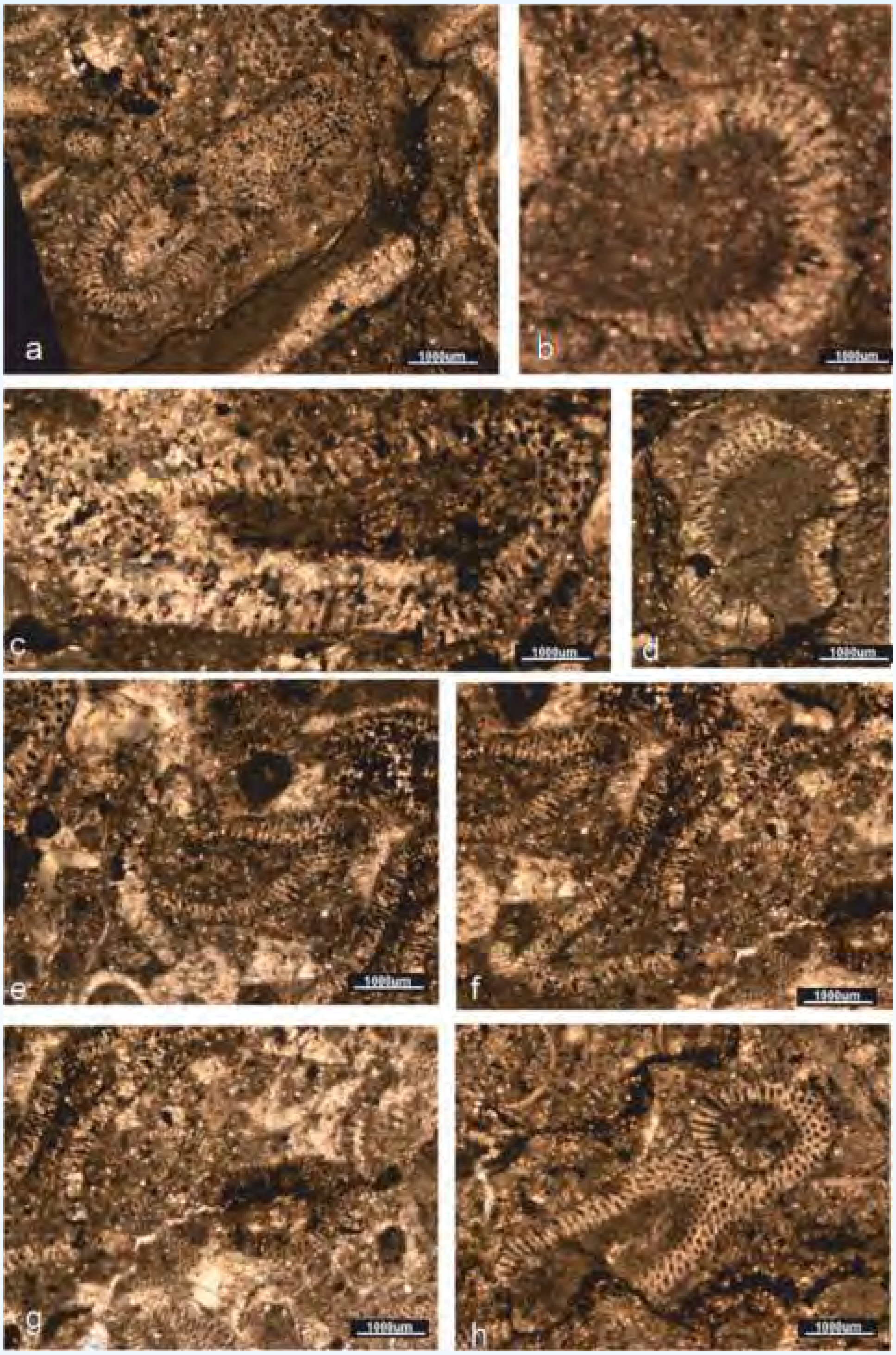

Fig. 39: Calcareous algae from the Thango Formation of Pin valley, Spiti Basin.

formations yielded a variety of marine calcareous algae the Dasyclade (Fig. 39), bryozoans, crinoid stems, broken fragments of cephalopods, lamellibranchs, hyolithids and brachiopods with fragmentary remains of arthropods and trace fossils. The various genera of bryozoan (Fig. 40) identified are as *Calloporella, Stictopora, Trematopora, Sceptropora, Parvohallopora, Amplexopora, Phylloporina, Dekayia, Lichenalia, Graptodictya*. etc. along with them are various forms of calcified algae, trilobites, bivalves, gastropods, brachiopods and ostracods which were found in association in the same thin sections. The

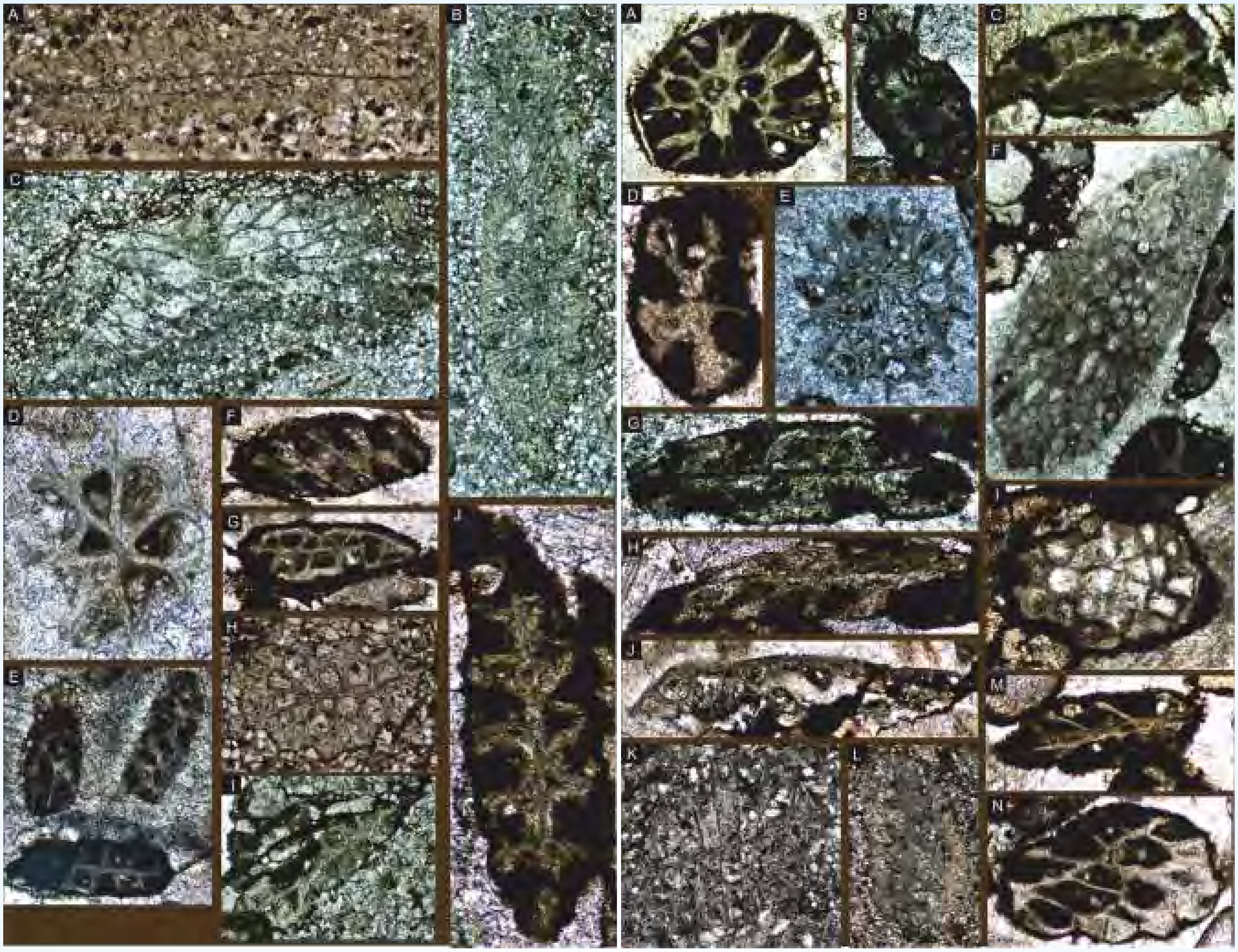

Fig. 40: Bryozoans from the Ordovician succession of Pin valley, Spiti Basin.

presence of bryozoans and calcified green algae in these successions indicates shallow marine to near shore environmental conditions followed by different stages of regression and transgression during this time span.

In the present study palaeogeographical distributions of Ordovician bryozoans fauna of the Spiti Basin is reviewed. Using the inferred ecological habitats of these fossils one can reconstruct the palaeoenvironmental setting of the different stages of Ordovician period. Based on the faunal elements, middle to late Ordovician age can be assigned to Thango Formation and late Ordovician to late Silurian to the Takche Formation. The bryozoan communities identified indicates a correlation with that of southern Russia, France, Norway, Ireland and India. The genus *Tremaptopora* which is reported from the Spiti Basin is also reported from the Ordovician successions of Russia and France. Many of the microfossil reported from our material are new and has not be reported earlier from the Spiti Basin and needs detailed studies. The studied microfaunal assemblage of Spiti Basin shows a cosmopolitan nature and is correlatable to other well-known successions of the world.

TAT-4.3

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

(Kapesa Lokho)

As part of the long term monitoring effort in evaluating the Paleogene and Neogene foraminiferal biostratigraphy and reconstruction of the Assam-Arakan Basin of Indo-Burma range (IBR), field work has been carried out in the region for 15 days. Samples were collected from the Paleogene sedimentary succession. Besides collecting samples for the recovery of microfossils, mega fossils were collected, sedimentary structures (Fig. 41a) and neotectonic

Fig. 41: (a) Ball and pillow sedimentary structures recorded in the Paleogene sediments of the Naga Hills, Indo-Burma range, (b) Neotectonic activity observed in the Naga Hills, Indo-Burma range.

activity in the region (Fig. 41b) were also noted for reconstructing the depositional and tectonics of the basin.

Processing of around 150 samples for recovery of microfossils from the Paleoegene and Neogene sediments was carried. The processing in the lab includes the picking of microfossils, light micro-photography, SEM photography, identification and description of the recovered fossils. Maceration of 50 samples were carried out for the recovery of Miocene calcareous nannofossils. The recovery of the Neogene microfossils from the IBR will reveal on the timing of the closure of the Tethys Sea in the region and thus have an important inferences on the tectonic evolution of the Himalayan and the IBR orogeny as well as the timing of the collision. The results of our findings were presented at the International Conference on 'Emergence and Evolution of the Indian Foreland Basin' held at Panjab University, Chandigarh.

Fossil leaf impressions from the Laisong Formation of the Barail Group (late Eocene-early Oligocene) are described from Mao-Pfutsero road section in Phek District of Nagaland. Most of the collected specimens are poorly preserved, however, two of them belonging to families - Fabaceae and Moraceae are well preserved. The fossils are biogeographically significant and throw light on the possibility of migration of plants between the Indian sub-continent and Burma as a result of collision of the Indian and the Burmese plates. The present fossil assemblage suggests that migration may have been possible between the two landmasses before the suturing. The aforesaid idea gets support from the recently discovered earliest fossil record of *Gluta* L. of the family Anacardiaceae from the early Eocene sediments of India (Shukla *et al.* 2014) and late middle Eocene sediments of Myanmar (Licht *et al.* 2014). However, more fossils from the Paleogene sediments are required from both the landmasses to validate the aforesaid idea.

TAT-4.4

Biotic 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 Indian sections and their

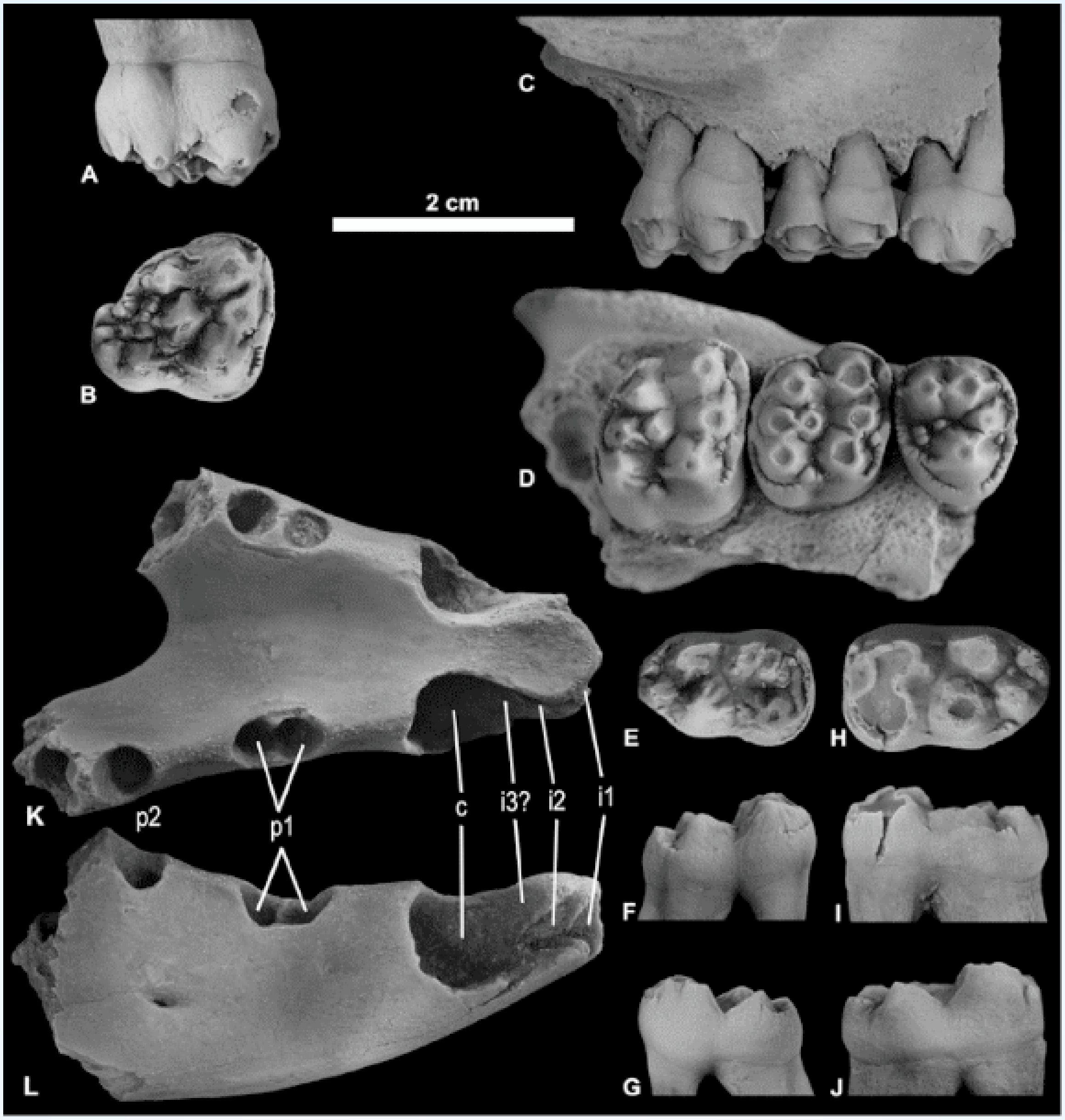

Fig. 42: Cambaytheriidae, *Cambaytherium thewissi*. A-B, WIF/A 4219, right M3 in (A) labial and (B) occlusal views. C-D, WIF/A 4217, right maxilla with P4-M2 in (C) labial and (D) occlusal views. E-G, WIF/A 4222, right m3 in (E) occlusal, (F) labial, and (G) lingual views. H-J, WIF/A 4223, left m3 in (H) occlusal, (I) labial, and (J) lingual views. K-L, GU/RSR/TAD 9002, mandibular symphysis in (K) occlusal and (L) right lateral views.

palaeogeographic implications was continued. A new assemblage of vertebrates was documented from two layers of the early Eocene Cambay Shale Formation in Tadkeshwar lignite mine, western India. It comprises a mammal fauna approximately contemporary and similar to that from the nearby Vastan lignite mine with the co-occurrence of the perissodactyl-like cambaytheriid *Cambaytherium thewissi*, the adapoid primates *Marcgodinotius indicus* and cf. *Asiadapis cambayensis*, rodent *Meldimys*, and the hyaenodontid *Indohyaenodon raoi* (Figs. 42-44). The presence of these taxa in both Vastan and Tadkeshwar mines and at different levels suggests that the deposits between the two major lignite seams represent a single land mammal age. Apart from the aforementioned species there is a new, smaller species of *Cambaytherium* (*C. gracilis*), and a new esthonychid tillodont, *Indoesthonyx suratensis*, gen. et sp. nov. in the fauna (Fig. 45). This fauna also contains the first large early Eocene vertebrates from India, including an

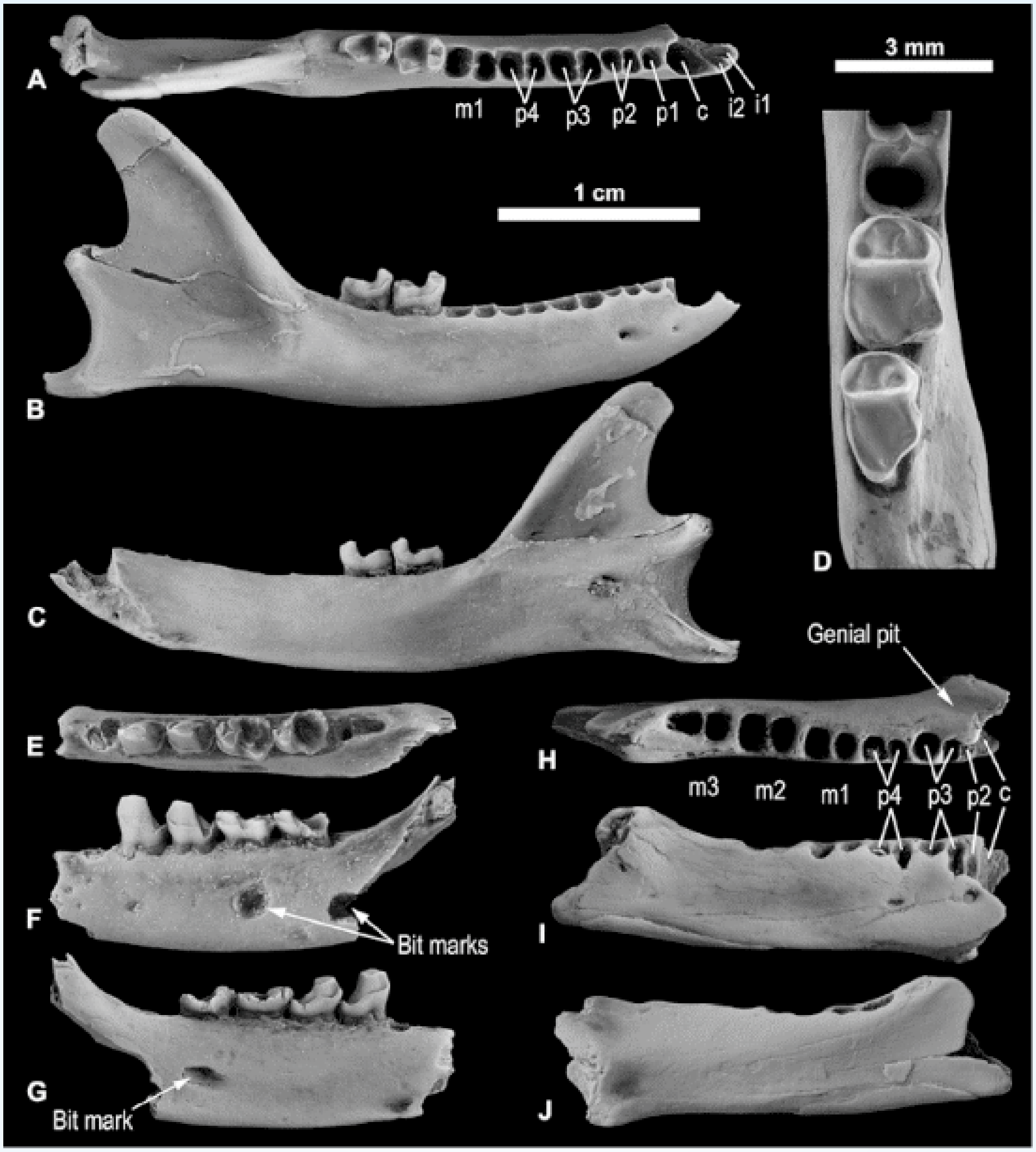

Fig. 43: Primates. *Marcgodinotius indicus*. A-D, WIF/A 2334, right dentary with m2e3 in (A) occlusal, (B) labial, and (C) lingual views, and (D) occlusal close-up. E-G, WIF/A 4231, left dentary with p3-m2 in (E) occlusal, (F) labial, and (G) lingual views. cf. Asiadapis cambayensis. H-J, GU/RSR/TAD 9004, edentulous right dentary in (H) occlusal, (I) labial, and (J) lingual views.

unidentified *Coryphodon*-like pantodont, a dyrosaurid crocodyliform and a new giant madtsoiid snake, *Platyspondylophis tadkeshwarensis*, gen. et sp. nov. Whereas most of the Vastan mammal fauna shows European affinities, among the Tadkeshwar vertebrates several taxa, such as pelomedusoide turtles, dyrosaurid crocodiles, and large madtsoiid snakes exhibit typical Gondwanan affinities, attesting that the early Eocene was a crucial period in the geodynamic history of India during which Laurasian taxa of European affinities co-existed with relict taxa from the Gondwana before the India-Asia collision. Our study suggests that terrestrial early Eocene faunas could have dispersed to or from Europe during episodes of contact between India and different island blocks along the northern margin of the Neotethys, such as the Kohistan-Ladakh island-arc system. Gondwanan taxa might represent remnants of ghost lineages shared with Madagascar, which reached the India during the late Cretaceous; alternatively they might have come from North Africa and passed along

Fig. 44: Rodentia, cf. *Meldimys* sp. AeE, WIF/A 2331, right femur in (A) anterior, (B) posterior, (C) medial, (D) proximal, and (E) distal views. FeJ, WIF/A 2278 right tibia in (F) anterior, (G) posterior, (H) medial, (I) distal, and (J) lateral views. Chiroptera. (K) "Eochiroptera" indet. 1, WIF/A 2330, left humerus in anterior view. (L) "Eochiroptera" indet. 2, WIF/A 2316, left humerus in anterior view.

the southern margin of the Neotethys to reach India (Geoscience Frontiers, 2016).

The oldest primates of modern aspect (euprimates) appear abruptly on the Holarctic continents at the beginning of the Eocene (~56 Ma). When they first appear in the fossil record, they are already divided into two distinct clades, Adapoidea (including extant lemurs, lorises, and bushbabies) and Omomyidae (comprising living tarsiers, monkeys, and apes). Both groups have recently been discovered in the early Eocene Cambay Shale Formation of Vastan lignite mine, where they are known mainly from teeth and jaws. These primates were small enough to fit in the palm of our hand and were living on trees of the ancient rainforests in what is now Gujarat. New, exquisitely preserved limb bones of primates documented from the same early Eocene beds of Vastan belong to distinct clades, Adapoidea (basal Strepsirrhini) and Omomyidae (basal Haplorhini) as determined from their earlier reported dentitions (Figs. 46 and 47). They reveal more primitive postcranial characteristics than have been previously documented for either clade and differences between them are so minor that in many cases we cannot be certain to which group they belong. Nevertheless, the small distinctions observed in some elements foreshadow postcranial traits that distinguish the groups by the middle Eocene, suggesting that the

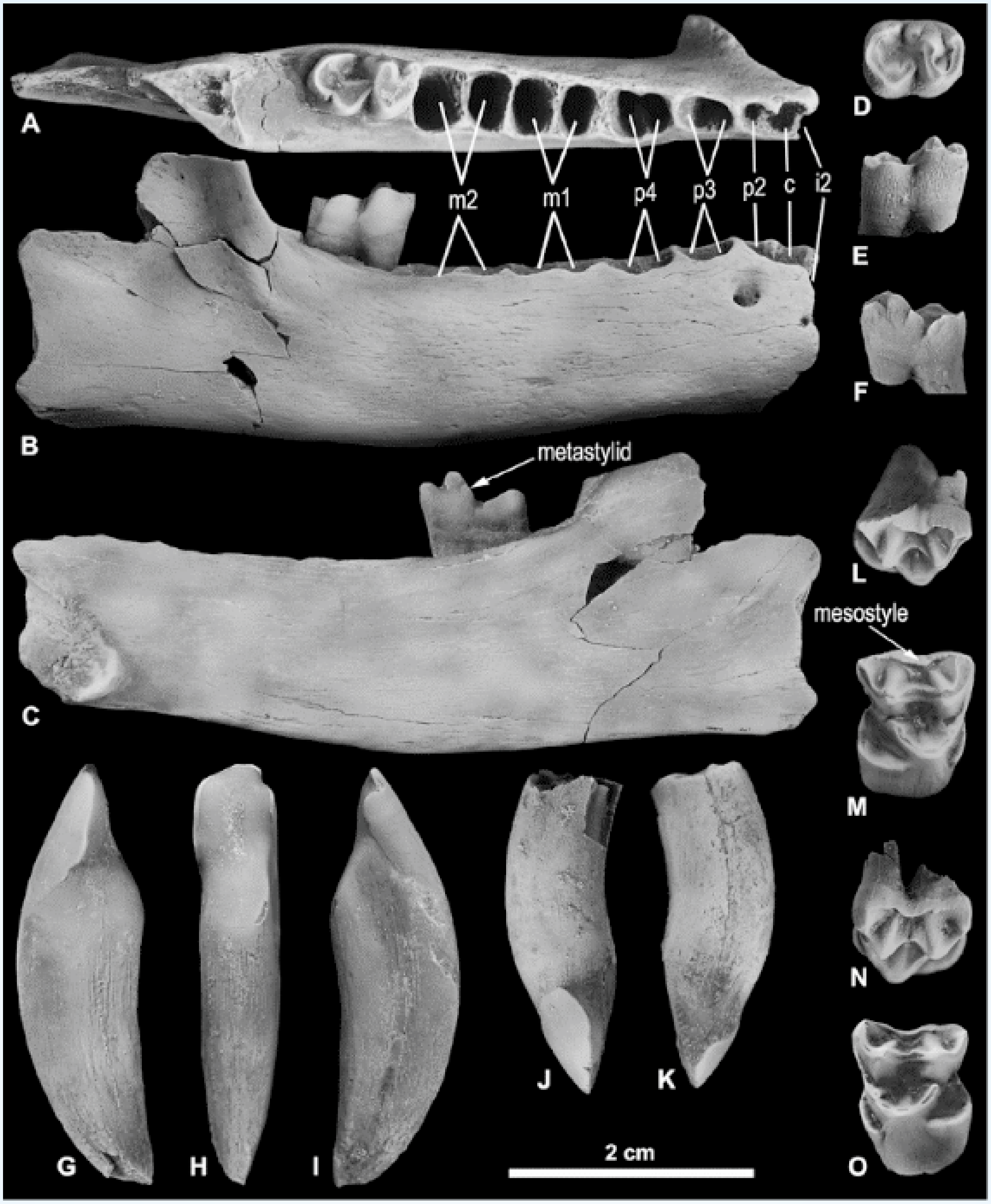

Fig. 45: Tillodontia. *Indoesthonyx suratensis*, gen et sp. nov. A-C, WIF/A 2333, holotype, right dentary with m3 in (A) occlusal, (B) labial, and (C) lingual views. D-F, WIF/A 4225, right m1 in (D) occlusal, (E) labial, and (F) lingual views. cf. *Indoesthonyx suratensis*, G-I, WIF/A 4230, left i2 in (G) distal, (H) lingual, and (I) mesial views. J-K, WIF/A 4229, left I2 in (J) distal and (K) mesial views. LeM, WIF/A 4227, right M1 in (L) labial and (M) occlusal views. N-O, WIF/A 4226, left M2 in (N) labial and (O) occlusal views.

Vastan primates, though slightly younger than the oldest known euprimates, may represent the most primitive known remnants of the divergence between the two great primate clades (*Journal of Human Evolution*, 2016).

Sixteen days field work in the Paleocene-Eocene sections of western India (February 5-20, 2017),

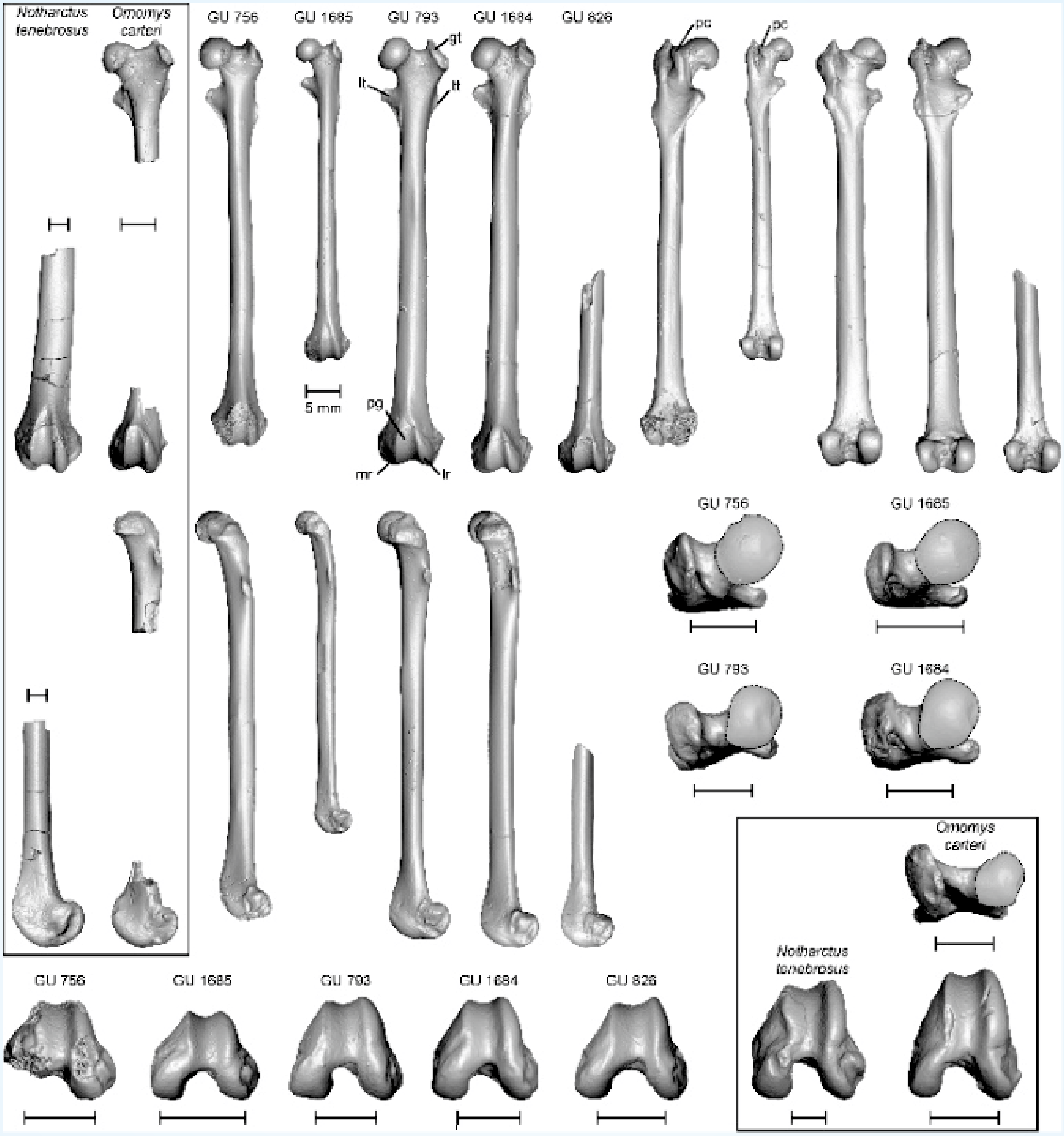

Fig. 46: Selected euprimate femora from Vastan Mine and comparative specimens. Boxes contain femoral specimens from *Notharctus tenebrosus* (AMNH 127167) and *Omomys carteri* (UCM 69060, proximal; UCM 67917, distal). Femora in anterior view (top left), posterior view (top right), lateral view (middle left), proximal view (middle right), and distal view (bottom). All scale bars represent 5 mm.Abbreviations: gt = greater trochanter, lr = lateral patellar rim, lt lesser trochanter, mr =medial patellar rim, pc = paratrochanteric crest, pg = patellar groove, tt = third trochanter.

yielded a few important additional vertebrate fossils. Matrix of bulk samples macerated in the field itself is being sorted under the microscope for recovery of microvertebrates.

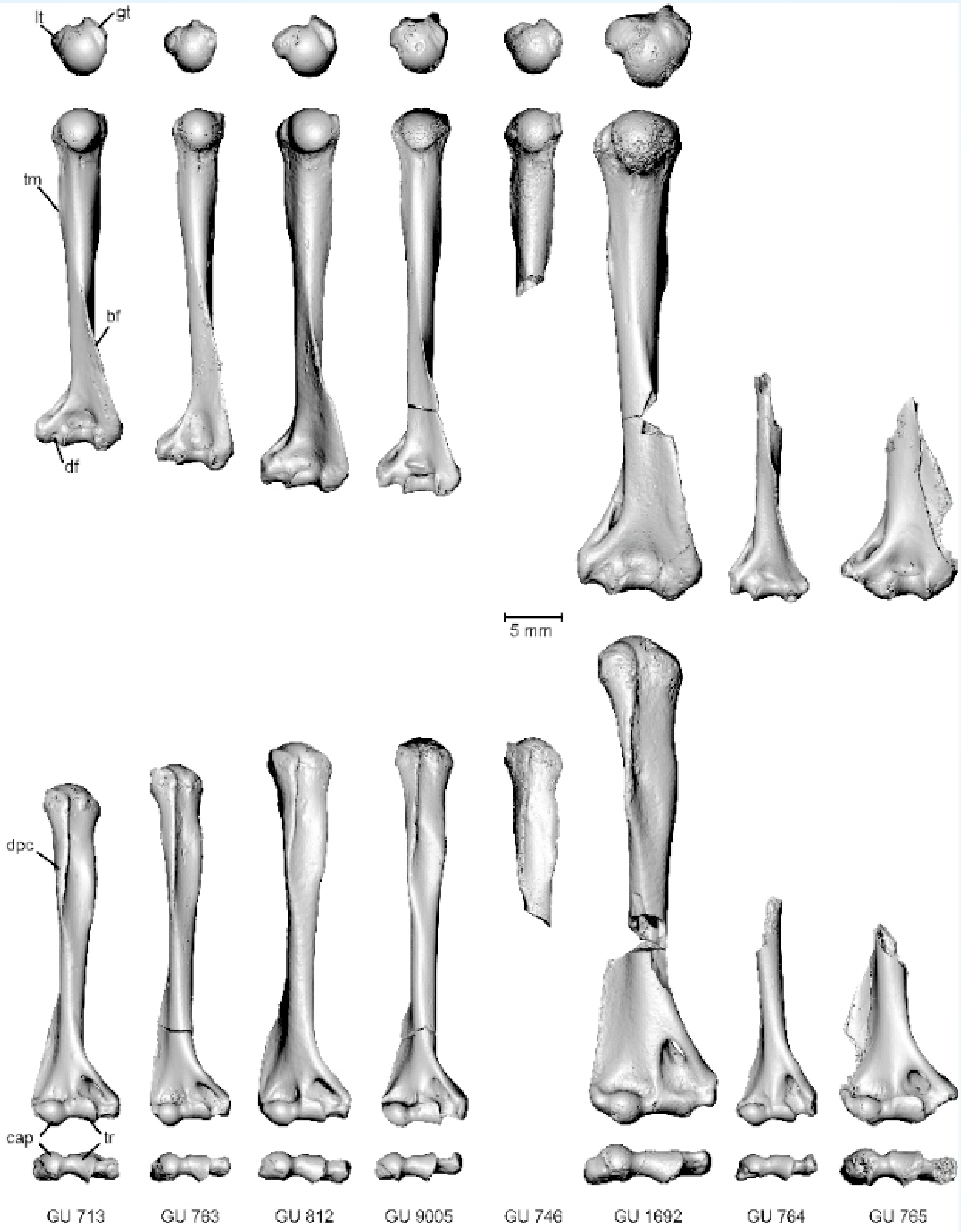

Fig. 47: Primate Humeri from Vastan Mine. Right humeri in proximal view (top), posterior view (second from top), anterior view (second from bottom), and distal view (bottom). Images of GU 812, and GU 9005 are reversed. All scale bars represent 5 mm; all to same scale. Abbreviations: bf=brachialis flange, cap = capitulum, df= dorsoepitrochlear fossa, dpc= deltopectoral crest, gt=greater tubercle, lt= lesser tubercle, tm= teres major tubercle, tr= trochlea.

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 faunas of the Neogene Siwalik Group (NW Himalaya) with an aim to understand the migration history and Himalayan uplift is continued. During the period under report, a detailed study of the faunas of the Himalayan Foreland Basin (HFB) was attempted. It is noticed that HFB is characterized by three principal sedimentary successions, the Subathu Group (Palaeocene-Eocene), the Murree or Dharamsala Group (Oligocene-Miocene), and the Siwalik Group (Miocene-Pleistocene). The basin was linked in the east to the Bay of Bengal through the Bengal Basin and its western part was connected to the Arabian Sea through Rajasthan and Kutch, Gujarat. The Himalayan foothills have long been known for yielding rich mammalian fossil occurrences and significant localities in the Indian Siwaliks include Kalagarh, Ramnagar, Haritalyangar, Chandigarh and Jammu regions (Fig. 48). The Bugti Basin and Zinda Pir area of Sulaiman Ranges of Pakistan were also part of the foreland basin as Lower and Middle Siwalik fossils are known from the Vihowa and Litra formations, respectively. The Marwat Formation of Bhittani and Marwat Ranges, Pakistan have also yielded Pinjor age vertebrate fossils. The Middle and Upper Siwalik age fossils are also known from the Irrawaddy Formation of Myanmar, where older Pegu beds have also yielded scanty Lower Siwalik age fossils. This faunal succession in the Irrawaddy Valley may have geologically and biogeographically belonged to the Himalayan foreland basin in the past. Additional mammalian fossils having an affinity with the Lower and Middle Siwaliks are known from the Khari Nadi Formation of Kutch. The Bokabil Formation of Tripura also yielded scanty Lower Siwalik fossils. A younger Siwalik faunal succession belonging to the Dhok Pathan is known from Piram Island of Gujarat. These areas are also part of the foreland basin. Most recently, a late Miocene suid species was discovered and reported from near Baripada, Odisha. A detailed interpretation of the respective faunal lists of the various successions mentioned above was carried out. The implications of the foreland faunas with correlatives in other parts of the world were studied. It is noticed that the faunas of Lower and Middle Siwaliks of foreland basin have links with Europe, Turkey, Africa and central Asia and a significant outcome of the study is that it throws light on the timing of uplift of the Himalaya. The post-Siwalik faunas of central and Peninsular India and Indo-Gangetic Plains have also yielded remnant Siwalik taxa, including *Stegodon insignis, Elephas hysudricus* and *Potamochoerus theobaldi.* The Kurnool Cave Fauna and Recent Fauna of India have also generic resemblance with the foreland faunas. The results are communicated for publication.

In order to reconstruct the palaeoclimate and palaeovegetation, the Carbon ($\delta^{13}C$) and Oxygen ($\delta^{18}O$) values of pedogenic nodules from Ghaggar River section and a 6 m thick swamp deposit (Nadah section) were studied. The $\delta^{13}C$ and $\delta^{18}O$ values from gastropod shells were also studied from the palaeoswamp. The $\delta^{13}C$ values of Ghaggar river section suggest the dominance of C4 vegetation from ~2.7 to 0.6 Ma. However, there were times when C3/C4 mixed vegetation in the form of wooded grasslands existed. Around 0.6 Ma, pure C3 plants existed on the landscape. On clubbing the $\delta^{13}C$ and $\delta^{18}O$ values from the Ghaggar section, the period between ~2.7 to 2.15 Ma witnessed warm and dry climatic conditions (dominated by C4 grasses). Thereafter, at three occasions i.e. at 2.15, 2 and 1.8 Ma, the warm and humid conditions prevailed (dominated by C3 trees). Again a drier phase exists between 1.79 and 1.1 Ma followed by a humid phase between 0.95 to 0.6 Ma. The $\delta^{13}C$ and $\delta^{18}O$ values from both pedogenic nodules and gastropod shells of Nadah section overlap and clearly indicate a dominance of C4 vegetation and existence of warm and dry condition during a small window of 12,000 years at ~1.8 Ma ago. However, few $\delta^{18}O$ values from gastropod shells indicate existence of cold and dry climatic conditions for some time during this period. It seems regional tectonic, sedimentation and climate changes played a major role in the vegetation changes observed between ~2.7 to 0. 6 Ma. The results are communicated for publication.

An intercontinental correlation of the Siwalik faunas was also attempted. It was noticed that bulk of the Siwalik faunas are non-endemic and it shares several faunal elements with equivalent horizons of Europe and Africa. The degree of similarity of faunas with central Asian localities is good enough during Lower Siwalik period, but during the span of Middle Siwaliks (~10 Ma) the faunal links became scanty, and it is inferred that the Himalaya started acting as a barrier for faunal migration across its width during and after the Middle Siwaliks.

A significant microvertebrate assemblage was recovered from the Lower Siwaliks of Udhampur and Upper Siwaliks of Chandigarh region. Some molluscan fossils were also recovered from the Middle Siwaliks of

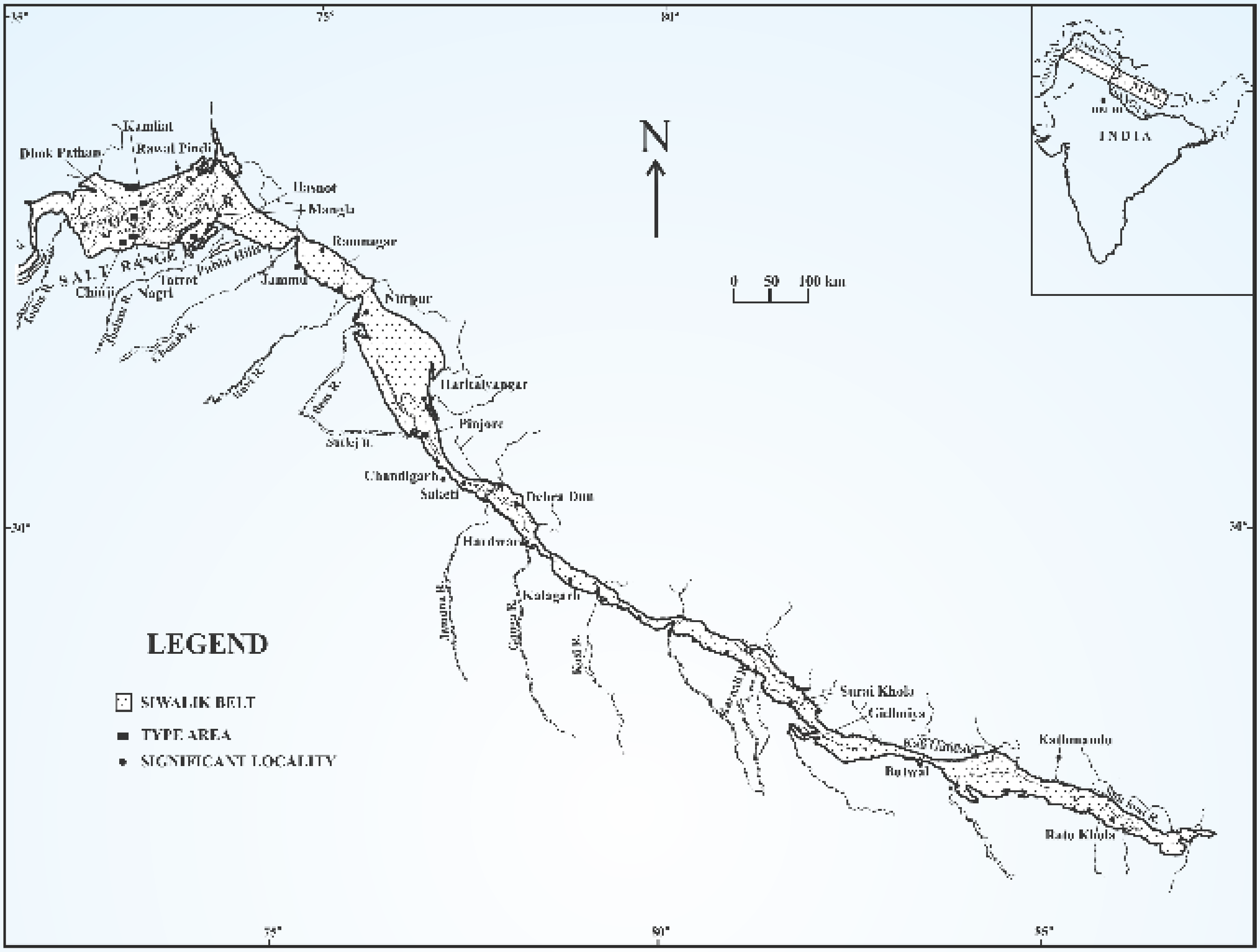

Fig. 48: Siwalik belt of the northwest Himalaya showing significant stratigraphic localities.

Nurpur (H.P.). These fossil assemblages are under study. A very rare Primate fossil was collected from Ramnagar Basin of J&K, and it is under collaborative study.

A collaborative palaeontologic and chronologic work was carried out for the Dhasan river section of Southern Ganga Plain. *Elephas namadicus* was described for the first time from the area (~50 ka). For the reasons that large mammals were part of the ecosystem until at least 50 ka indicates that the ravine development in the region is younger than 50 ka.

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; GEG Group)

Annual net balance of the Chorabari Glacier after the June 2013 disaster has been investigated for the period 2015-2016 in the area. In October 2015, network of 15 ablation stakes were installed along the centre line of the glacier and further 20 stakes were installed in May 2016, over the ablation area of Chorabari glacier. These stakes were measured regularly at 15 days interval to obtain the melting in the entire ablation period. The winter balance was surveyed in the month of June and again in October 2016. The snow depth was measured at different altitudes in the accumulation area by snow pit and probing. Besides, the mass balance AAR and ELA fluctuations trend has also been analysed and computed.

Annual Mass balance of Chorabari glaciers

The net annual balance of the Chorabari glacier for the year 2015-16 was calculated to be negative, amounting to -4.37×10^{-6} m^3. The Equilibrium Line Altitude (ELA) was estimated from the field observation as well as vertical mass balance gradient and found at an elevation of 5075 m a.s.l. The Accumulation Area Ratio (AAR) estimated was 0.43. The detailed mass balance results given in the table 1. The snout retreat of the glacier during the period was not carried out due to the damage of permanent survey point during the Chorabari lake outburst in 2013. The area is still unstable to establish the permanent survey point. However, the present snout located at the altitude of 3875 m a.s.l

Snow line/ELA Fluctuation

ELA is very sensitive to climate and also amount of snow cover during the period. The present ELA is demarcated at the altitude of 5075 m which was at a slightly higher elevation than previous year. The year to year variability of the snow cover is mainly determined by large-scale mapping and by measuring net ablation/accumulation and altitude. Long-term measurement mass balance and snow line/ELA in the Chorabari glacier show significant changes and shifted from 5069-5075 m a.s.l. since last one decade. It has been observed that although there is no abrupt change in the amount of snowfall and glacier melting but significant changes/shifting in snowfall duration. It is observed that during the last few year the maximum snow fall occurred in the month of January onward. In fact, late snowfall doesn't have sufficient time to get metamorphism as it just entered in to warmer temperatures in spring and rapidly melt out. The reduction in net winter snow accumulation may leads to less snow packing and upward shift of the snow line (Fig. 49).

Spatio-temporal variability of near-surface air temperature in the Dokriani Glacier catchment

Air temperature is an important meteorological factor that affects glacier melting and distribution of snowfall and rain in the high altitude regions of the Himalaya. An attempts have been made to study spatio-temporal variability of air temperature in Dokriani Glacier catchment and also quantify 0°C isotherm and temperate sustainability over the glacierized area using dataset of three Automatic Weather Stations (AWSs). The average Near-Surface Temperature Lapse rate (NSTLR) of the studied catchment varied from 4.6 to 7.5°C km^{-1} for all measurement seasons and suggested that the Standard Environmental Lapse Rate (SELR: 6.5°C km^{-1}) is not a promising input for realistic glacio-hydrological modelling. Monsoon (warm and humid period) lowers the temperature lapse rate in this catchment due to presence of moisture in the air and sublimation process that increase the air temperature at higher elevations. The pre-monsoon season recorded steepest lapse rate in association with clear and drier weather conditions. The preliminary results show a strong variability in lapse rate at diurnal as well as sub-diurnal level, with higher in day time and lower in night time. The measured and extrapolated air temperature observed was positive during the monsoon season

Table 1: Annual mass budget, specific balance AAR and ELA: 2015-2016.

Elevation extension	Ablation area km^2	Accumulation area km^2	Net ablation $x10^{-6}m^3$	Net accumulation $x10^{-6}m^3$	Net Balance $x10^{-6}m^3$	Sp. Balance m	AAR	ELA m
3860-6000	3.70	2.64	-5.32	0.95	-4.37	-0.72	0.43	5075

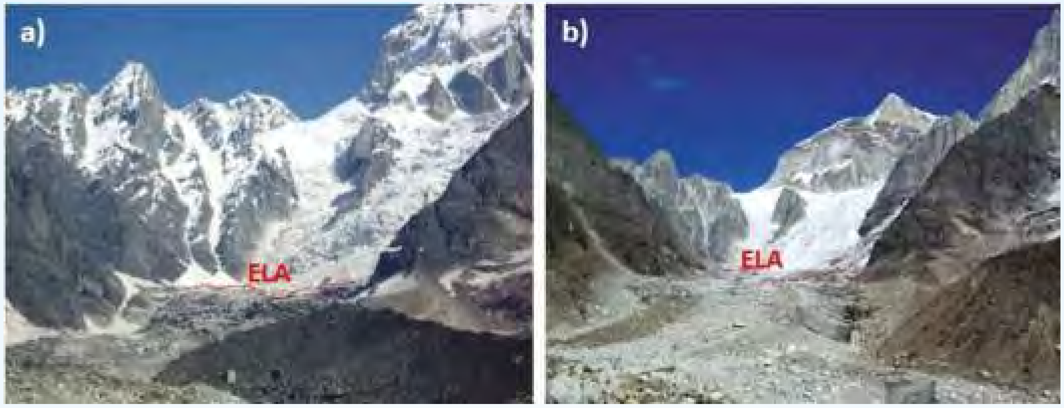

Fig. 49: Ascending Equilibrium Line Altitude (ELA) and snow cover depletion of Himalayan glaciers: An example from Chorabari Glacier, Central Himalaya during (a) 2005 and (b) 2016.

(June, July, August, September) in the ablation zone of the Dokriani Glacier as compared to other seasons (pre-monsoon, post-monsoon, winter). It is also observed that a large variation in 0°C isotherm with altitude ranges between 5000 and 5500 m a.s.l in accumulation area during the study period. The studies are being continued for more detailed and long term data collection of meteorological parameters.

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 glacial lakes in the vicinity of the Gangotri Glacier in the Bhagirathi catchment were identified from Google Earth Digital Globe images and Bing Aerial satellite images during the reporting year, and some lakes as mentioned below were identified:

- Vasuki Tal in the Chaturangi Glacier, a tributary of the Gangotri Glacier from the right bank. This lake is a supraglacial lake located in the medial moraine of IITG of Chaturangi, Suralaya, Seela and I TG of Chaturangi Glaciers. The lake has abundant moraine material around. The glacier is located about 6 km from the Gangotri Glacier main tongue and is about another 3 km from the Gangotri Glacier snout at Gaumukh.
- Neel Tal is a small pro-glacial lake of the Meru Glacier. The melt water of the Meru Glacier meets the melt water of the Gangotri Glacier near Gaumukh. The lake is surrounded by moraine walls and the entire glacier valley is on paleomoraine on a height above a steep slope. This lake though very small is in an ideal condition for an outburst.
- Kedar Tal is a periglacial lake located on the Kedar Glacier. Melt water from this glacier meets the Bhagirathi River near the temple town of Gangotri. Similar situation exists for this region with narrow valleys with moraine clad cliffs and a town brimming with tourists. Though the lake is located >2 km behind the snout of the glacier and has less moraine material on its path downstream upto Gangotri, yet this lake show potential symptoms for a future hazard.

Using ALOS PALSAR 25 m DEM, the catchment of the valley from the snout of the Gangotri Glacier has been generated. Stream orders, flow map, elevation profiles, river gradient map, cross section of the valley beginning from the Kedar Glacier snout has been generated.

Downstream in the lower reaches of the Bhagirathi valley, landslide mapping has been carried out. It has been observed that in the upper reaches of the valley, rock fall and rock avalanches are the prominent features whereas, in the lower reaches, particularly around Bhatwari and Uttarkashi debris flows and debris slides are common. Many of these slides are deep seated. These landslides have well been correlated with the river gradient that is highly variable ranging between 3.6 m per km to 66.6 m per km, and is marked with numerous knick points, and various geomorphic indices. The river gradient around Uttarkashi is very gentle and thus there is deposition of huge amount of river sediments in the area. It has been estimated that there is an average aggradation of about 0.5 m/year in the area around Uttarkashi. This huge volume of material deposited in the area around Uttarkashi town are posing serious threat to the slope stability on either banks of river.

TAT-5.3
Hydrogeology of Himalayan springs
(S.K. Bartarya and S.K. Rai)

ASTER DEM, LANDSAT 8 satellite data and Geological Map of Himalayan Foothills are used to prepare the groundwater prospect map of the Soan basin of Una district, H.P. Geologically, the region consists of the alluvium of Quaternary period and sedimentary rocks of Siwalik Group. Hydrogeologically the basin is divided into hilly upland and valley fills. Alluvial Fans, terraces and piedmont deposits mark the most prominent geomorphic features in the valley, whereas hilly regions are characterized by structural and denudational hills. Various thematic maps including geomorphology, drainage and land use map by visual interpretation of the LANDSAT 8 Satellite data and geological map of Himalayan Foothills were prepared in GIS environment using ARC GIS 10.0. Watershed and Slope map are extracted from ASTER DEM with 30 m resolution.

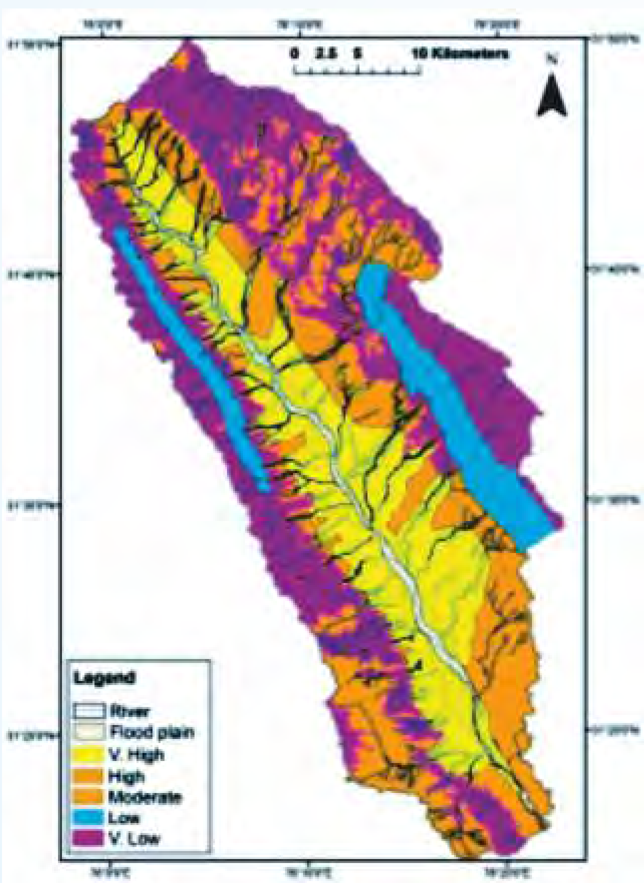

Fig. 50: Prospect map: In accordance with the discharge capacity, the region is divided into the following five potential zones: a) >800 lpm (very high potential), b) 400-800 lpm (high potential), c) 100-400 lpm (moderate potential), d) 50-100 lpm (low potential), and e) >50 lpm (very low potential).

Groundwater prospect map (Fig. 50) has been prepared by overlaying various thematic maps, which is further subdivided into five potential zones on the basis of their discharge conditions. These are regions bearing, very low (<50 LPM), low (50-100 LPM), moderate (100-400 LPM), high (400-800 LPM) and very high (>800 LPM) potential zones of the groundwater. The yield data of the wells also support the groundwater prospect map derived from superimposition of the thematic maps. The high and very high potential zones are located in central synclinal valley along the fluvial terraces, alluvial fans and piedmont deposits whereas low and very low potential zones are in the hilly areas with high slopes and rugged topography due to which the water moves down slope more rapidly resulting into less infiltration and thus, deep groundwater level with low discharge condition prevails.

TAT-5.4
Glacier Surface Changes and Mass Fluctuation of Pensilungpa and Durung-Drung Glaciers, Ladakh, Western Himalaya, India
(Manish Mehta, Aparna Shukla and Vinit Kumar)

Glaciers monitoring in Western Himalaya is a long term project. The study area was revisited this year (during August-September, 2016) and field work was conducted on Durung Drung and Pensilungpa glaciers. Eleven stakes have been installed on the Pensilungpa Glacier to measure the accumulation, ablation and debris thickness, while 4 states were installed on Durung Drung glacier which are used to ascertain the surface melting and debris thickness (Fig. 51A,B). Each stake is fixed at a depth of 10-20 m by a stream drill. Surface temperature is measured before fixing stakes by using an infrared thermometer and the debris thickness was also measured once the ice was exposed. In addition, more than 20 moraine sediment samples for Optically Stimulated Luminescence (OSL) dating were collected to reconstruct the paleo-extent of the glaciers, and to understand the paleo-climatic conditions of the region (Fig. 51C,D). About 70 water samples from the streams emerging from the glaciers, high altitude lakes from Pensi La and moraine dammed lake at the snout of Durung Drung lake were also collected for their corresponding environmental and climatic significance (Fig. 51E,F). In addition, 30 samples have been collected for grain size and SEM analysis from different zones of glaciers (supraglacial, englacial, subglacial) to understand the sediment transport pathways from the source area to glacier snout. Apart from these geomorphological mapping of the area was also carried out.

The result of field data shows that the snout of Pensilungpa glacier between 2015 and 2016 receded ~13.22±5 m (with central part receding ~10.68 m and the right part ~15.76 m). Field observation also reveal that the collapse of an ice cave formed at the right part of the glacier snout which was seen in 2015 but not observed in 2016 could be probable reason behind the enhanced retreat of the right flank. The volume of ice lost at the snout of the Pensilungpa glacier was estimated to be 7.13×10^4 m^3. The remote sensing studies have further shown that, the Drung Drang Glacier between 1977 and 1980 had advanced around +55(±44) m a^{-1}, with an average rate of around +18(±14) m a^{-1}; and Pensilungpa Glacier between 1971 and 1977 had advanced around +27(±1.5) m a^{-1}, with an average rate of around +4.5(±0.23) m a^{-1}. The remote sensing studies also suggested that during the periods between 1966 and 2015, the Drung Drang Glacier had lost ~10 % of the total glacier area, whereas, the Pensilungpa Glacier had lost ~8 % the total glacier area.

On the basis of detailed mapping of glacial moraines, four stages of glacial advancements were identified in Suru and Zanskar basin, between Marine isotope stage 3/4 (MIS 3/4) and Marine isotope stage 1 (MIS 1). The studies suggest that, the older glacial stage-I, glaciation occurred during the cool and wet MIS 3/4. The stage II glaciation began with the onset of LGM (MIS 2), whereas, the stage III and IV glaciation occurred during the mid and late Holocene (MIS 1).

The grain size characteristics of samples from supraglacial debris suggest that the granules along with coarse to very coarse sand (mean size) are dominant in glacial debris. The finer fraction in the supraglacial debris ranges from 2-7 %. However, in subglacial debris it is scattering from 0.5-16 %.

Fig. 51: Photograph showing the field activity. A) Installation of stakes over the glacier surface. B) Measurements of installed stake. C&D) Moraine sediments sampling for OSL dates. E&F) Water sampling from streams emerging from the glaciers, high altitude lakes and moraine dammed lake at the snout of glaciers for their corresponding environmental and climatic significance.

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

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

The continuous observations of different geophysical parameters is performed at MPGO Ghuttu to identify the variable trends and relate these with the earthquake activity of local and regional events. The temporal changes in gravity, magnetic and GPS time series along with occurrence of moderate and higher magnitude earthquakes are reported.

Comparative study of gravity and crustal deformation

Temporal changes in the gravity field originate from mass redistribution as well as from vertical crustal deformations. The Superconducting Gravimeter (SG), a high resolution gravity measurement instrument can monitor changes to sub-micro-gal level. It is useful to extract temporal variations of gravity field that may be caused due to small tectonic motions or mass distribution. During the past three decades, the global positioning system (GPS) has been established as an important tool for the study of plate movements on boundaries and within tectonic plates. Furthermore, temporal variations in crustal deformation have also been reported. Crustal movement/deformation may be influenced by temporal variations in different time domains/range (diurnal, seasonal and annual) due to various meteorological processes like monsoon, snow load, atmospheric pressure and temperature etc. We compared the results obtained through SG and GPS records for a three year period from 2007 to 2010 and found strong seasonal variations in both data sets. A phase difference in the annual cycles of both data sets is also observed.

Gravity variation observed after removal of tidal and atmospheric pressure has well defined annual/seasonal effect (Fig. 52) which is well correlated with ground water variation and rain precipitation. Annual changes in gravity is to the order of 300-350 nms^{-2} with stronger variations mainly during rainy seasons. In the Himalayan region, rainfall occurs mainly in the monsoon season (July to September) and therefore causes seasonal hydrological variations/ cycles. The Newtonian attraction due to accumulation of underground water as the resultant of rainfall or soil moisture below the sensor and vertical displacement are main factors for significant changes in gravity data. Based on tank model evaluation of ground water, we calculated the ratio of gravity residual and the rainfall amount which resulted in the average admittance of rainfall ~0.2 $nms^{-2}\,mm^{-1}$ on gravity. Further, theoretical values of gravity were calculated using a differential equation and utilizing Heaviside step function. By eliminating the underground water effect or the Newtonian effect, the gravity residual is correlated with vertical deformation obtained through GPS. It can be concluded that the variation in the remaining residual gravity may be the cause of vertical displacement.

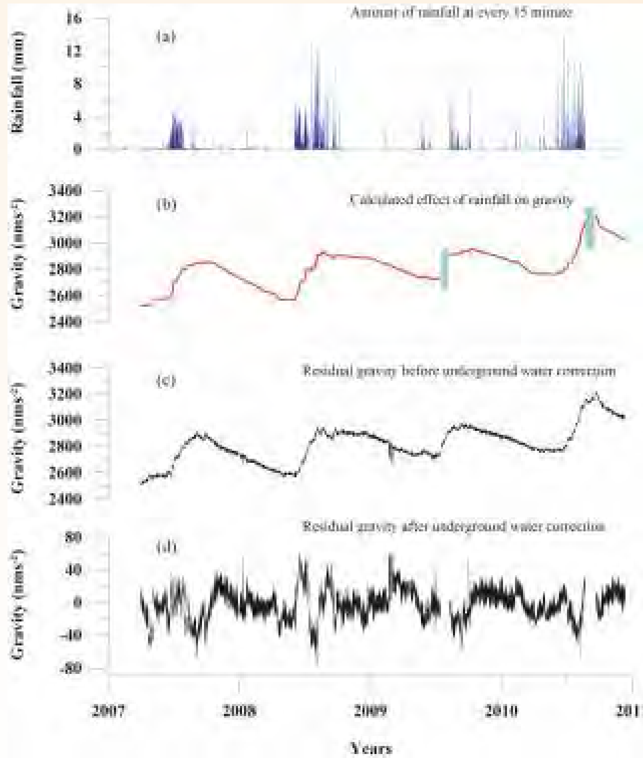

Fig. 52: (a) Amounts of rainfall at every 15 minute, (b) Calculated effect of rainfall on gravity, (c) Residual gravity before underground water correction, and (d) Residual gravity after underground water correction.

Temporal variability in Magnetic field

Three component digital flux gate magnetometer is utilized for calculating tippers. Tippers reflect the relationship between horizontal components of magnetic field to vertical component of magnetic field and are sensitive to lateral conductivity variations.

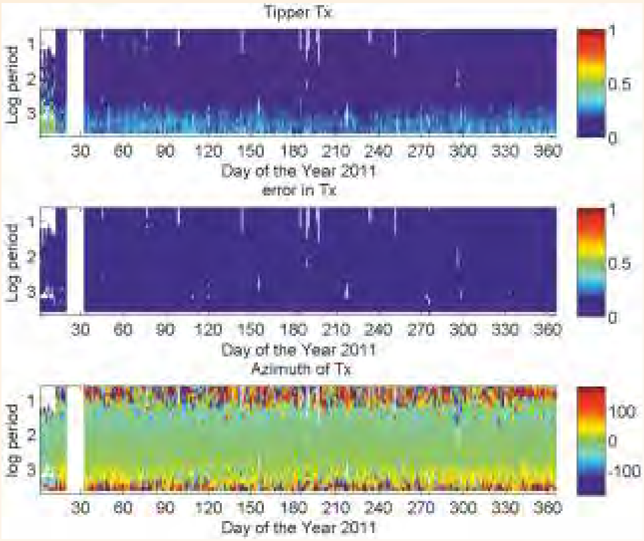

Fig.53: Variability in daily tippers for the data of three components digital flux gate magnetometer.

Using each day data, tippers are calculated on daily basis. Figure 53 depicts the variation in daily tippers. It is observed that there is no significant variation. This data set will be inverted for temporal resistivity variation at Ghuttu.

Further using Higuchi method of fractal dimension calculation, we have calculated fractal dimension for ulf band time variations utilizing 19-20 UTC time data sets. Temporal variability of fractal dimension is shown in figure 54. The arrows denotes the occurrence of local moderate magnitude earthquakes occurred within 150 km radius from the location of MPGO Ghuttu observatory.

TEC variation observed during Mw 7.8 Nepal earthquake

For the earthquake precursory study and to investigate the behaviour of deformation pattern around the MPGO, which was established just south of MCT at Ghuttu, we installed a permanent GPS station (GHUT) there along with multi-geophysical instruments. The data was analysed through GAMIT software with the inclusion of IGS stations in global reference frame. The results are obtained in the terms of time series which provide us rate of horizontal as well as vertical deformation. In the analysis GHUT shows convergence rate ~15 mm/yr. Also, studied co-seismic ionospheric disturbances (CIDs) generated due to the Nepal earthquake of Mw 7.9 through GPS-derived total electron content (TEC). In this case CIDs were identified at almost all used GPS sites (Fig. 53). The disturbances are observed after 21.15 min of earthquake incidence and it was continued for the time period of 22.78 min long with the amplitude variation range -0.530 to 0.517 TECU (Fig. 55).

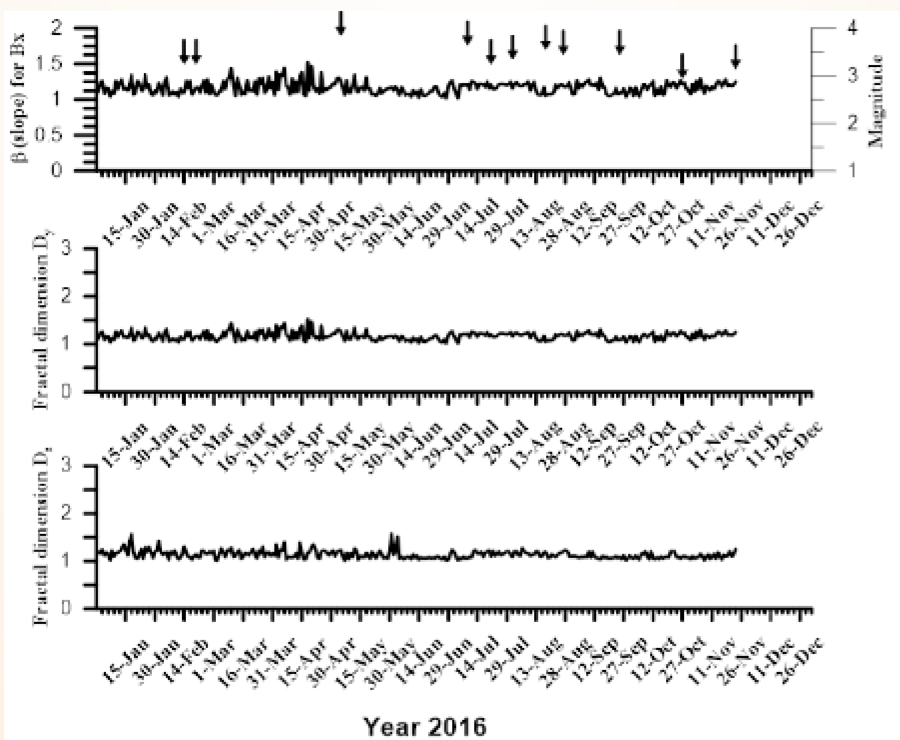

Fig. 54: Temporal variability of fractal dimension for year 2016.

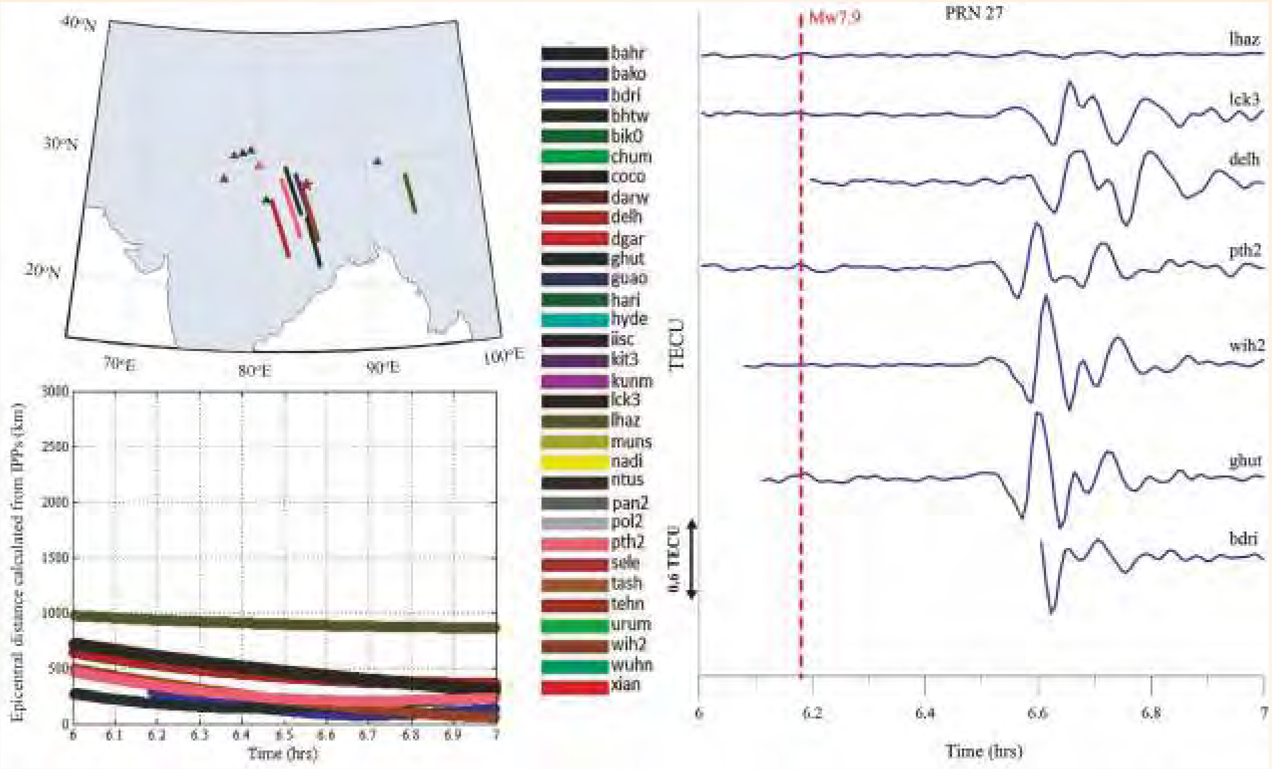

Fig. 55: For locked satellite PRN-27 (a) IPP plots at stations, (b) Epicentral distances of IPPs vs time plots at stations, and (c) Co-seismic ionospheric TEC variation.

MoES Sponsored Project

Present Day Subsurface configuration and Geodynamics of the Kumaon Himalaya: An Integrated Geophysical and Geological Investigation

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

Establishment of Seismological Network & preliminary analysis of seismological data

A seismological network consisting 10 broadband seismograph stations have been established in a nearly linear profile along the Kali river valley, Kumaun Himalaya. The locations of seismological stations are shown in figure 56. The site selection survey and construction of the seismological pit and hut as well as installation of equipment's were completed during May 2016. The seismological stations are equipped with Trillium-240 sensors with TAURUS data logger. The Global Positioning System (GPS) receivers are attached with the data logger for time synchronization. These stations record earthquake data in continuous mode with recording sampling rate 20 samples per second. Most of the stations are established over exposed hard rock. The KHAT and TANK stations are located to the south of the Himalayan Frontal Thrust over the sediments of Indo Gangetic Plane. A special care has been taken for construction of seismological pit for installation of the sensors at these stations. Photographs of two seismological sites are shown in figure 57.

Earthquake data recorded during May-October 2016 were retrieved from field stations. Initially, the teleseismic earthquake data with magnitude ³ 5.5 and epicentral distance range 30 to 90° have been extracted from continuous mode data for crustal structure study using Receiver function (RF) analysis. The information of teleseismic earthquakes are obtained from PDE catalog of US Geological survey (www.neic.usgs.gov). The distribution of recorded data at each of the recording sites are shown in figure 56 (inset). During the 5 months period of May to October, the network recorded 100 teleseismic earthquakes. Although this data-set is not sufficient to carry out crustal structure study, we processed the data for computation of *P*-wave receiver functions using Iterative Deconvolution Method of Liggoria and Ammon (1999; *Bull. seism. Soc. Am.*, 89, 1395–1400). The RFs are plotted with respect to back azimuths (BAZ) to see the BAZ variations. Example of RF computations are shown in figure 58.

SPONSORED PROJECTS

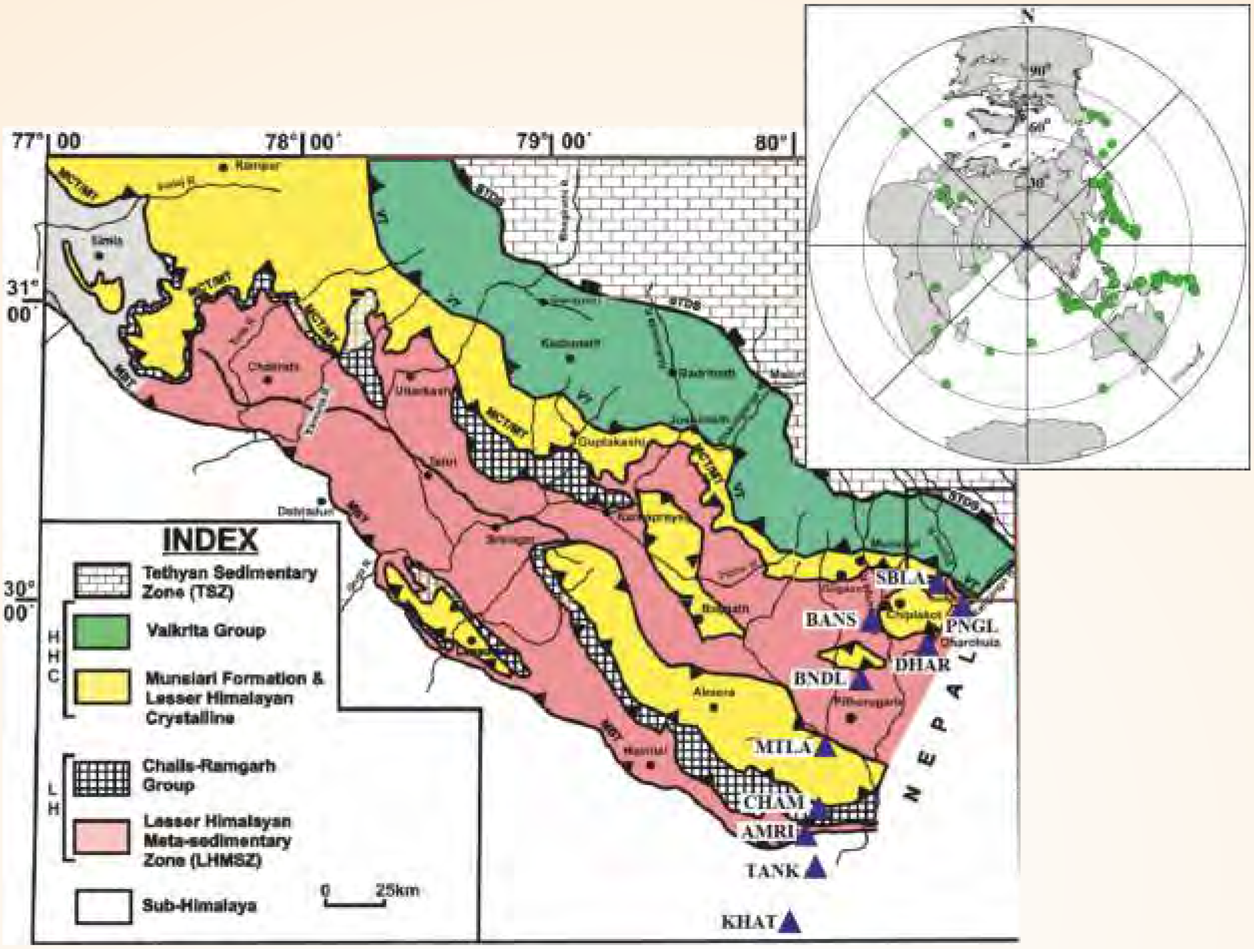

Fig. 56: Geo-tectonic map of northwest Himalaya (Patel et al., 2011, JGSI, 77, 47-72). The campaign mode seismological stations are shown by blue triangle along the Kali river. Distribution of teleseismic earthquakes used for RF analysis is shown in the inset. The blue triangle in the inset shows network center.

Geological Field work and analysis

A geological fieldwork was carried out in the month of May covering the Higher Himalayan part from Berinag Thrust Zone and Chiplakot Crystallines to the hanging wall of the South Tibetan Detachment Zone. Samples were collected for structural, petrographic, geochemical and chronological analysis. AMS (Anisotropy of Magnetic Susceptibility) study is already completed for the Chiplakot Crystallines that shows slight increase in intensity of deformation towards the Munsiari Thrust. Sample preparation for XRF and ICPMS is already done and petrographic slides of representative samples are also made. Samples were also selected for ^{40}Ar-^{39}Ar chronological analysis.

Preliminary analysis of Magnetotelluric (MT) data along the profiles

MT time series collected earlier along this profile is processed using robust statistical procedures using 50 % overlap of sections utilizing welch approach. The time series at each station is divided into subsets with a length that is of order a few over the period (frequency) of interest. Each subset is pre-whitened in a time domain and tapered with a data window. The data sections are overlapped to improve a statistical efficiency. Fourier transforms are then taken and pre-whitening is corrected for. The coherence for a wide frequency band for each time section may be calculated and only the sections which achieve a specified minimum coherence level are used for further processing. The data of interest are these Fourier coefficients of the windowed data from each section at a single period. The standard least square algorithm and the robust one that are relatively insensitive to a moderate amount of bad data are utilised for this transfer function estimation. The robust procedure is based on the Huber regression M-estimation and extended by an automatic "leverage control" based on a

Fig. 57: Photographs during seismological Pit and Hut construction at (a) Matela village and (b) Champawat, Kumaun Himalaya.

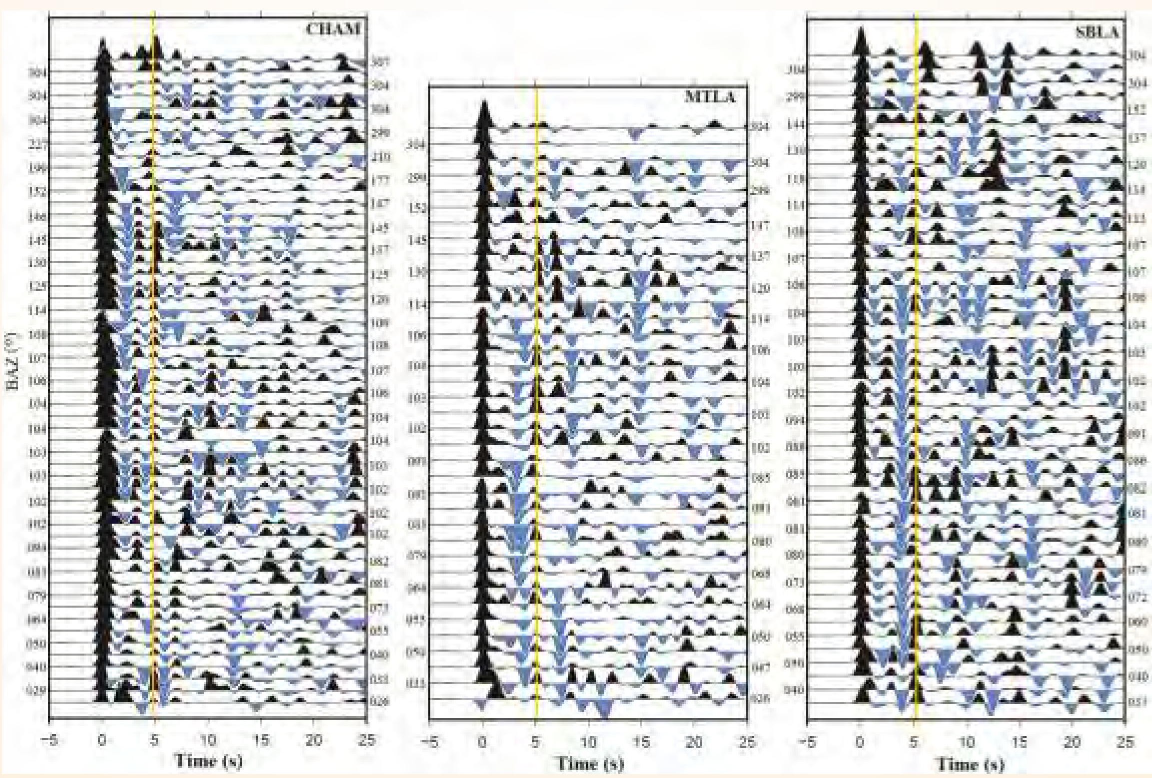

Fig. 58: Example of radial receiver functions estimated using teleseismic data recorded by Champawat (CHAM), Matela (MTLA) and Sobla (SBLA) stations. The RFs are plotted with respect to back azimuth.

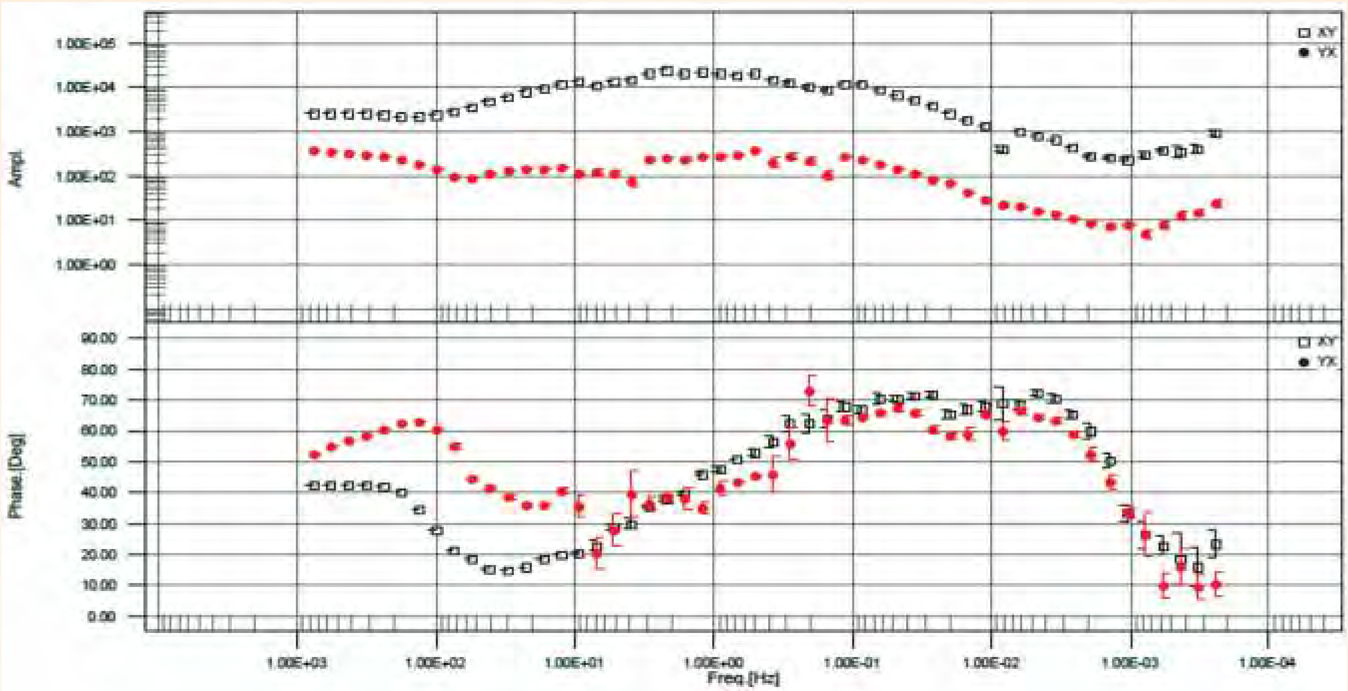

Fig. 59: Example of sounding Curve obtained at Sobla site, Uttarakhand.

'hat' matrix diagonal elements criterion. The sounding curve, thereby obtained shows a complex geoelectrical setup in the study region (Fig. 59). Below is one example of apparent resistivity curve from Sobla which is immediate south of MCT. A prominent low resistive layer between 1 and 100 sec is apparent from the apparent resistivity curve. The variability in phase suggest complex nature of subsurface beneath the site. Dimensionality and decomposition analysis is in progress. However at few places MT data collection is required to reduce the inter-station spacing and to increase the resolution.

DST-SERB sponsored project

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

(Gautam Rawat, Devajit Hazarika and Koushik Sen)

The Tso-Morari Crystalline (TMC) is a significant litho-unit between the north Indian continental margin and the south of the ISZ. The TMC is a gneiss dome that is bounded by the north dipping Zildat fault to the NW and the south dipping Karzok fault to the south. The Zildat fault separates the TMC from the melange and ultramafics of the ISZ, and the Karzok fault demarcates the boundary between TMC and Palaeozoic granites and metasediments of the Indian continent and Tethyan group of rocks. The TMC is an exhumed part of the north Indian continental margin that underwent HP to UHP metamorphism during subduction and collision of the Indian plate. The ISZ consists of Zildat Ophiolitic Melange (ZOM) which is overlain by the Nidar ophiolites. The Nidar ophiolite extends along the ISZ and exhibits a complete cross section from upper mantle to supra ophiolitic sediments (Maheo et al. 2004). The TMC and the ophiolites are well exposed in the Mahe valley as well as in the adjacent Nidar valley of the study area and are separated by ZOM. During fieldwork major intra-formational faults were identified and a cross-section is prepared to fix the locations for MT studies.

Magnetotelluric time series is robustly processed for MT transfer function. Figure 60 below shows the pseudo section of XY and YX polarisation apparent resistivity and phase along the profile. Apparent resistivity variation indicate upper crustal part of Tso Morari Dome is resistive and the extent of high resistivity variation indicate depth limitation of crystalline rock. Dimensionality parameters indicate broadly 2-D variation of regional resistivity structure, however, few period band at few stations suggest 3-D environment of regional resistivity. The MT transfer function is being modelled for resistivity section along the profile.

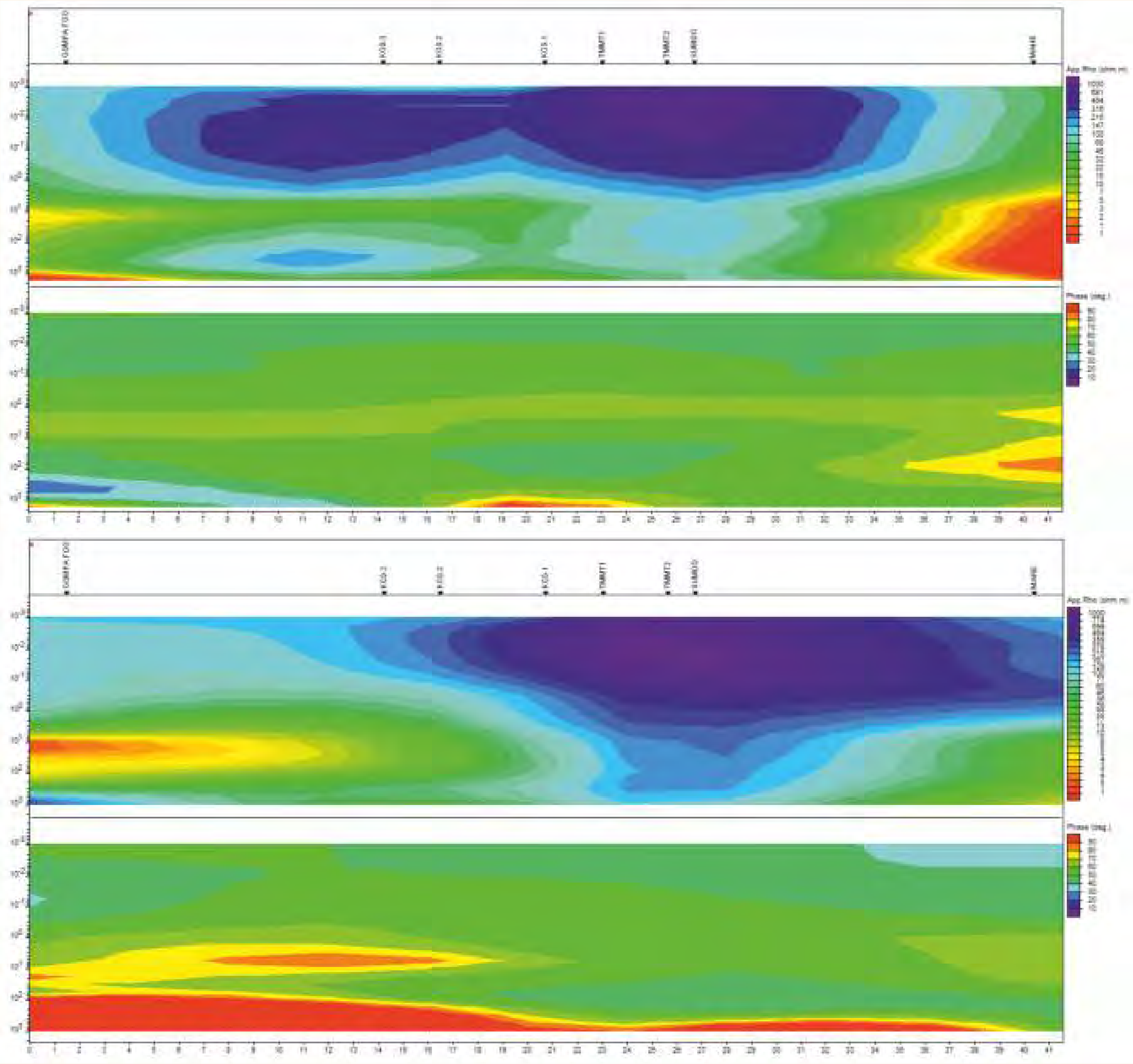

Fig. 60: Pseudo section of observed MT response along the profile.

Seismic anisotropy in the upper crust

Seismic anisotropy of the upper crust beneath the eastern Ladakh-Karakoram zone has been studied by shear wave splitting analysis of S-waves of local earthquakes. The splitting parameters (and t), derived from S-wave of local earthquakes with shallow focal depths, reveal complex nature of anisotropy with NW-SE and NE oriented Fast Polarization Directions (FPD) in the upper ~22 km of the crust. The observed anisotropy in the upper crust is attributed to combined effects of existing tectonic features as well as regional tectonic stress. The maximum delay time of fast and slow waves in the upper crust is ~0.3 s. The FPDs are parallel or sub parallel to the Karakoram fault (KF) and other NW-SE trending tectonic features existing in the region. Dextral shearing of the KF creates shear fabric and preferential alignment of mineral grains along the strike of the fault, resulting in the observed FPDs. A similar observation in the Indus Suture Zone (ISZ) also suggests crustal scale deformation owing to the India-Asia collision.

MoES sponsored project

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

(Ajay Paul)

Data acquisition and seismological investigations have been carried out for the Garhwal-Kumaun region in the Central Seismic Gap (CSG). The region between the great earthquakes of Kangra (M8.4) and the Bihar-Nepal 1934 (M8.2) is a potential zone for the occurrence of future great earthquakes, and is termed as CSG (Fig. 61). The seismicity monitoring of Garhwal Himalaya and adjoining Shimla hills regions in the CSG has been carried out through a dense broadband seismic (BBS) network. The epicentral location of the events show a large number of micro-earthquakes concentrated in a narrow zone, south of Main Central Thrust (Fig. 61a). The strain energy budget analysis has been carried out for the Garhwal-Kumaun region of Central Seismic Gap in Himalaya. The strain energy budget analysis involves three steps of calculations, (i) accumulated strain energy, (ii) the rate of building up of strain energy, and (iii) the rate of release of strain energy. The accumulated strain energy has been taken from the earlier published work, while the GPS study conducted in Garhwal-Kumaun region shows the convergence rate which accounts for the strain energy buildup, and the fault slip amplitudes evaluated for micro-earthquakes in the central seismic gap shows slip amplitudes ranging between 14 to 175 cm and the average slip (calculated for all the micro-earthquakes) is ~2.87 cm per month. The parameters evaluated for strain energy budget were (i) the energy accumulated is ~6 m of strain (1997), (ii) the rate of energy accumulation is ~1.8 cm/year (2014) and (iii) the rate of energy release is ~2.87 cm/year (2015). These numerical values show that the energy accumulation is receding, and hence it can be suggested that the probability of a great earthquake in Garhwal-Kumaun region is decreasing.

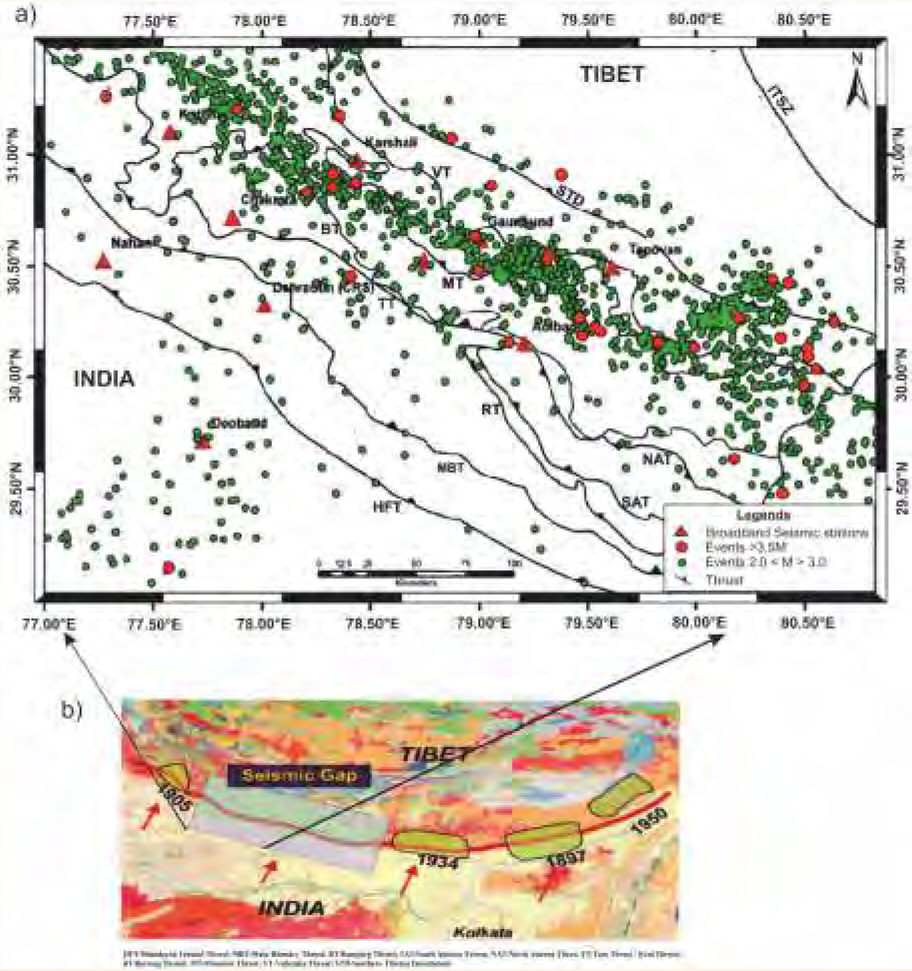

Fig. 61: (a) Tectonic map of the region showing epicentral locations for the events recorded between 2007 and 2016. Concentration of events is observed in a narrow zone south of MCT (Ref: Valdiya 1980), (b) The four great earthquakes in the last 120 yrs and the seismic gap.

The analysis of 352 earthquakes recorded by a seismic network installed in Garhwal region of CSG has been carried out for stress field studies and focal mechanism solutions. The epicentral location map shows that the seismicity in Garhwal Himalaya is concentrated in a narrow zone of 25-35 km trending parallel to Main Central Thrust (MCT). On the basis of the earthquakes of magnitude (2.5£ M_L ³ 4.9), epicentral location, and hypocentral proximity six clusters along the three profiles cutting across the seismicity zones were selected for further analysis. From the Composite Focal Mechanism Solutions (CFMS) of these clusters and dip angles it has been found that the MCT is active in eastern and western parts in comparison to the central part of Garhwal Himalaya. The location of events in the central part and their dip angle (20º) from the CFMS suggests that these earthquakes have their origin from the mid-crustal ramp that lies in the transition zone between the seismically active detachment under the Lesser Himalaya and aseismically slipping detachment under the Higher Himalaya at an angle of 16º. It is inferred from CFMS that compression in the NW-SE direction is the main stress in Garhwal Himalaya and it is nearly orthogonal to the direction of the plate motion.

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 and Suresh Kannaujiya from IIRS, Dehradun)

Monitoring of current seismicity in the gap areas

Two seismic stations at Nainital and Mussoori are established where broadband (Trillium-120) seismometer and strong motion recorder are installed at each station (Fig. 62a,b). Establishment of these stations, located close to the Main Boundary Thrust, are made after the noise survey carried out at different places in the frontal Himalaya. Continuous records of both weak and strong seismic waves are useful to extract local and regional seismicity of the Himalaya and adjoining Indo-Gangetic plains. These stations are very useful for integration of the data of regional seismic networks which will also strengthen azimuthal coverage for the high seismicity of the Himalaya region. The data of recent Mw 5.8 strong earthquake and its aftershock activity has been recorded by these two

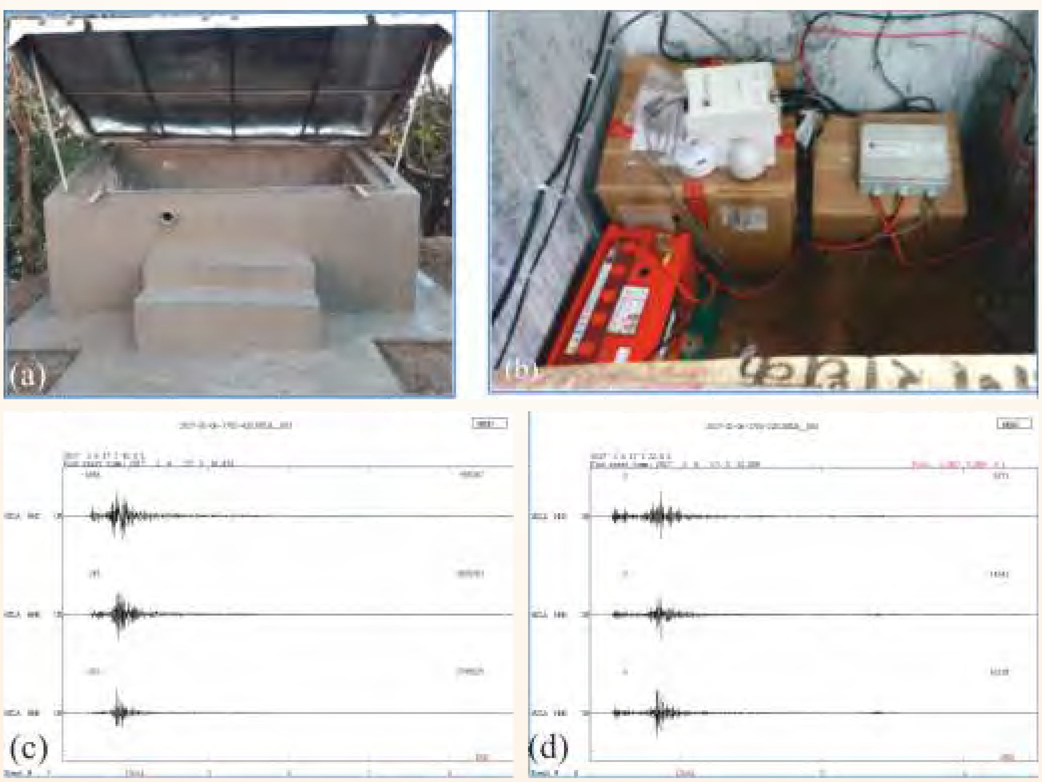

Fig. 62: Recently installed seismic stations and records of Mw 5.8 earthquake. (a) Outside view of seismic pit at Nainital station, (b) Inside view of seismic pit at Mussoorie station, and (c) & (d) are the 3-component strong motion records of Mw 5.8 event of February 6, 2017 recorded at Mussoorie and Nainital stations respectively.

stations (Fig. 62c,d). These events are located immediately after their occurrence by integrating data from other stations. Strong motion data of the main shock and few aftershocks (M >3.0) are well recorded at these stations, located at ~95 km (Mussorie) and ~120 km (Nainital), away from the epicentral zone.

Monitoring of seismic activity of the NW Himalaya is being carried out to understand the strain partitioning and earthquake fault segmentation. Ongoing tectonic collision of India-Eurasia result to strain accumulation in structurally weak zones thereby generating intense seismicity in the Himalayan region. We are in a process to prepare a uniform seismic catalogue using phase data from different agencies and waveform data of WIHG seismic network. Preliminary analysis has been done based on the recent seismic data extracted from International Seismic Catalogue (ISC) besides data from past catalogues (Lyubushin et al., 2010). Relocation of some of these events are also made after including data from WIHG's seismic network. Epicentral distribution of seismicity of the NW Himalaya (M^{3} 3.0) for the period between 2000 and 2016 is shown in figure 63a. Spatial distribution of seismic events are biased due to different sizes of the events. However based on the magnitude of these events seismic energy budget of different zones can be estimated. The energy budget of the NW Himalaya (Fig. 63b) highlight the high seismic belt aligned along NW-SE direction which is also parallel to the main Himalayan arc. Temporal variation of this seismicity is shown in figure 63c. This high seismicity is close to the surface trace of Main Central Thrust. The seismicity is mainly due to the occurrence of thrust and reverse fault dominated mechanisms (Yadav et al., 2017).

Except Hindukush region, the seismicity is mainly shallow focused and can be related with major tectonic features of the region. High seismicity is recorded from the central part throughout Himalayan arc, however, there is segmentation due to zones of high and low seismic intensities (Paul and Sharma, 2011; Arora et al., 2012). The present analysis highlight segmentation of seismicity which indicates that local tectonic features also has some impact. In brief, in the Kangra-Chamba region, the seismicity is high and spread over as compared to other parts of NW Himalaya. It has been observed earlier that the epicentre zone of 1905 Kangra earthquake has high seismicity (Kumar et al., 2009; Lyubushin et al., 2010). It is noticed that after the inclusion of local station data there is much improvement in the earthquake source parameters of ISC data. Therefore, the main goal is to include additional data from local network so as to improve the location, and to identify more events of lower magnitude. Improved and unified catalogue will be helpful to identify the high seismic zones and the gap areas. Evaluation of earthquake source processes and delineation of causative faults provide basic inputs for the assessment, mitigation and reduction of seismic hazards.

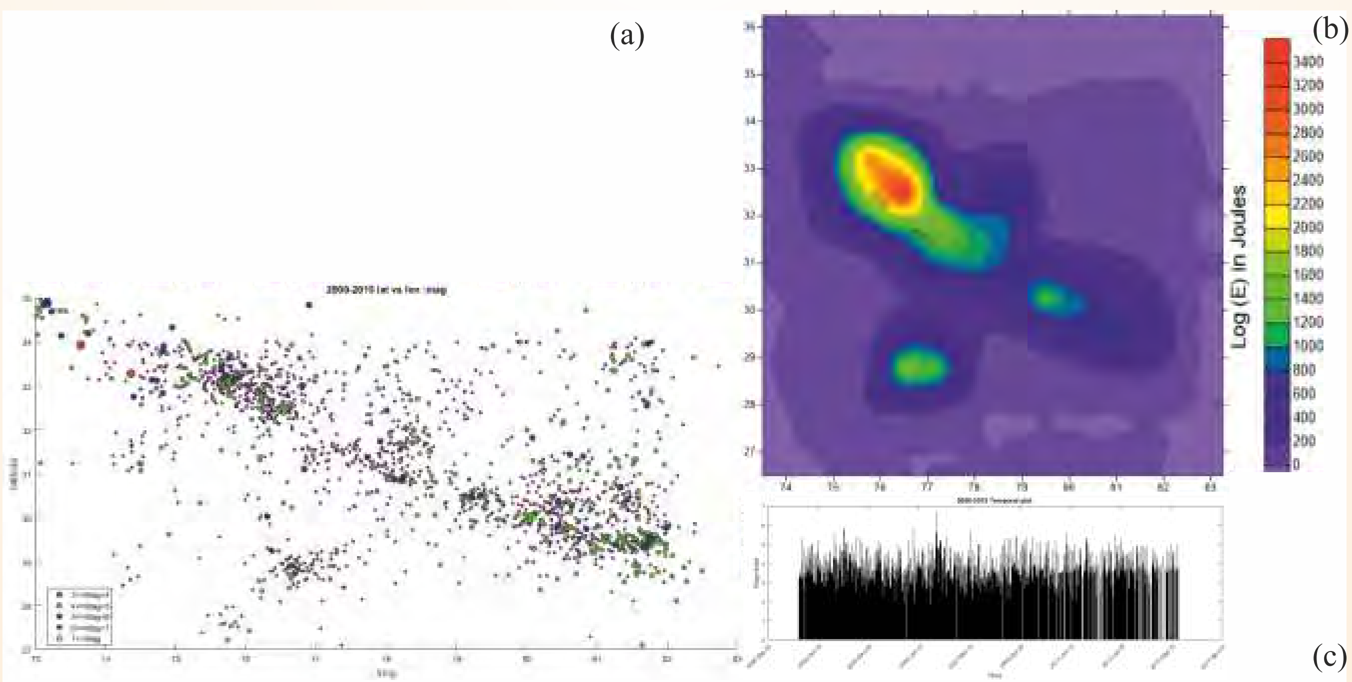

Fig. 63: (a) Epicentre distribution of all earthquake of M ≥3 for the NW Himalaya for a period between 2000 and 2016, (b) Energy budget released by the occurrence of these earthquake, and (c) Temporal variation of the seismicity.

Deformation monitoring, strain modelling and earthquake precursor studies using TEC

Under this project a continuously operating GNSS station was made operational at the north of MBT in Mussoorie, Dehradun at Guru Nanak Fifth Centenary School. One of the objectives is to understand how the atmospheric TEC anomalies can be used to study the earthquake preparation processes. We have analysed extensively the CORS GPS data from WIHG and Nepal network to know whether any significant changes in TEC occurred during co-, pre- and post-seismic ionospheric scenarios caused by 2015 April 25th Mw 7.9 magnitude Gorkha-Nepal earthquake. The spatio-temporal variation of TEC is quite vast from a few to thousands of kilometres with minutes to hours of duration. Considering this we have analysed data not only from those stations close to the earthquake preparation zone; but also farther away at thousands of kilometres and compared their respective TEC values to know its dynamical behaviour during, before and after the Nepal event. The variation of TEC and its residuals at near field or near epicentre stations like that at KKN4 is shown in figure 64a,b followed by the Mw 7.8 Magnitude of 25th April Gorkha-Nepal and the subsequent M_w 7.2 Magnitude of 12th May 2015 earthquakes. The background level of TEC at this near field station is around 65 TECU with residual variation up to 25 TECU. But stations far from the epicentre towards south at Hyderabad (HYDE) as shown in **figure 64c,d** and situated close to the equatorial anomaly zone show a high background TEC of 60 to 90. Thus, as far as the study of earthquake preparation processes due to Himalayan earthquakes are concerned the northernmost stations are relatively better compared to the southernmost. We modelled the observed daily TEC variations at various stations and obtained the residual TEC. The opposite behaviour of TEC residuals at these stations are yet to be ascertained and may be because of reduced ion formation and its migration dynamics.

We also investigated ionospheric TEC anomaly variations associated with a few Great and Moderate Magnitude earthquakes originated from different source regions in Himalaya and its adjoining regions. It has been observed that only three significant events; mainly the M_w 7.8 April 25th 2015 Gorkha-Nepal earthquake, the M_w 7.6 October 8th 2005 Kashmir earthquake and the M_w 8.1 March 28th 2005 Sumatra earthquake produced co-seismic ionospheric disturbances. The co-seismic ionospheric disturbances originated because of Himalayan earthquakes are relatively faster in registering the ionsopheric disturbances compared with other non-Himalayan

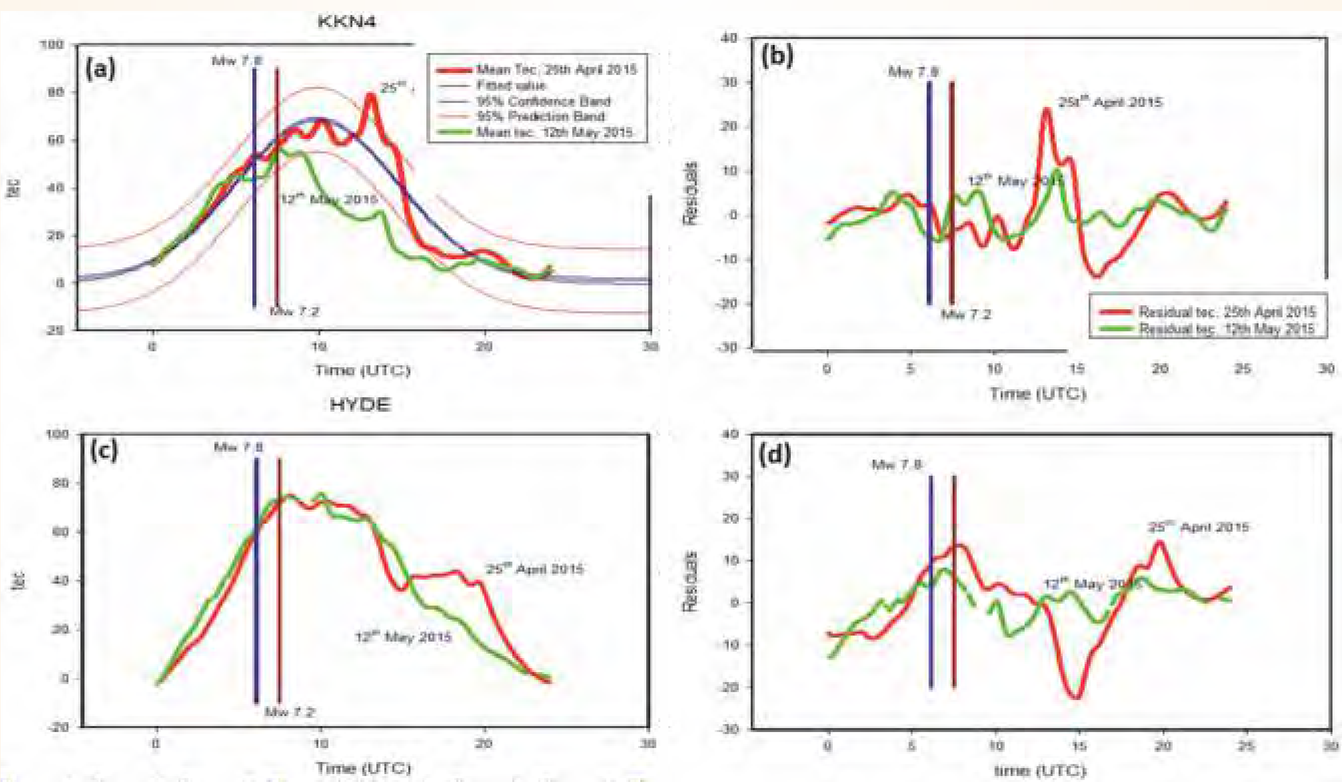

Fig. 64: Observed and residual ionospheric mean TEC variations followed by the Nepal earthquakes: (a) & (b) are for the near field station at KKN4, and (c) & (d) are for the far field station at HYDE.

earthquakes and the reasons thereof are under investigation.

Active fault mapping using high resolution EO data and geophysical investigation

Mapping of active faults and paleoearthquake ruptures of NW Himalaya towards understanding the geology of earthquakes within the geographical limits of Uttarakhand and Himachal Pradesh remained the primary objective of the project. Keeping this in view we have selected some of the active fault systems during the reporting year. Ground Penetrating Radar surveys have been carried out to understand the subsurface features which are correlatable with surface expression of the faults in the field. Although the subsurface features could corroborate the deformation, intense modification for agricultural practice has limited the scope of interpolation of the faults on either sides. 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. Repeated surveys comprising of different arrays across the HFT at Singhauli were carried out using Lippman 4 point light hp earth resistivity meter consisting of 40 electrodes. 2D multiple IPR profiles were acquired with electrode separations varying from 1 to 5 m. The inversion was performed with Res2DInv software to produce two-dimensional sub-surface image of the area which was interpreted and analysed in conjunction with published geological information of the area. The surveys have been carried out across Bhauwala fault and Barwa fault in the main Doon fan, in the Trans Yamuna segment of the Doon Valley and in the Frontal Himalaya. 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.J.G. Perumal 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 work was carried out in 2016-17. During the field work four trenches were excavated at Ultapani, Upper Assam, Diyun and Changa village near Mechi River of Indo-Nepal border (Fig. 65). For these four trenches photo-mosaic logs will be constructed. About 48 charcoal samples were cleaned and upon completion of the logs the suitable samples will be send out for dating. Several sites like Dhanshiri River, Lokhaitora River have been sampled for the estimation of long term uplift history of the respective sites (Figs. 66 and 67). The truncated terraces have been mapped using Real Time Kinematics-Global Positioning System

Fig. 65: Aerial view of the trench site at Changa Village near Mechi River (Indo-Nepal Border) taken by UAV-drone.

Fig. 66: General tectonic map of the area traversed during field work. The square boxes 'a', 'b' and 'c' are the sites where active faults have been marked and terrace sampling has been carried out.

Fig. 67: Field photograph of the truncated abandoned terrace around the Bhairabkunda (square 'c' in fig. 66).

(RTK-GPS) and Total Station (TS). Additionally, 32 OSL sediment samples were collected across the HFT at four regions to infer the long-term vertical uplift rate of the HFT.

MoES Project

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

(R.J.G. Perumal, V.C. Thakur and N. Suresh)

Laboratory based terrace mapping along the major rivers crossing the Surin Mastgarh Anticline (SMA) has been done by using the Cartosat stereo pair imageries, ALOS 30 m and SRTM 30 m. Further field mapping of these terraces followed by the investigation of surface deformation corresponding to mapping of active faults associated with the SMA, has been carried out. Potential trench sites have been identified for the paleoseismic investigations near Line of Control (LOC), Munwar Tawi River (Fig. 68).

In addition, to understand the rock strain or bulk strain 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 fold. The AMS (magnetic fabric) samples were collected from the forelimb, hinge and the back limb of the anticline. Since no escarpments were found in the frontal region of the anticline in the satellite data, the area was closely observed in the field in search of escarpments. Our preliminary field study reveals that the MFT is not emergent unlike other segment along HFT (or MFT) in the east of Beas River.

Fig. 68: Geomorphic map of River Munavar Tawi showing three levels of terraces and alluvial fans. Paleoseismic trench location and ephemeral tributary cut section cleaned are also shown in the figure. MT-1 shows location of strath terrace along forelimb of SMA.

Institute Flag ship project on mapping of Active faults in Uttarakhand Himalaya

Active faults of Garhwal and Kumaun Himalaya (Book and On-line Interactive Active fault data base in progress)

(R. Jayangondapeurmal, V.C. Thakur, Joe Vivek, P.S. Rao and A.K. Gupta)

Crustal collision between Eurasia and the Indian subcontinent has produced a thrust fault system that accommodates a share of the strain associated with convergence. The foremost of these faults is the Himalayan Frontal Thrust (HFT), which has produced numerous, large-magnitude earthquakes along discrete segments of the fault throughout the last two centuries that are constrained through instrumental and historical records. Paleoseismic studies have aimed to establish comparable constraint for pre-instrumental ruptures of the fault. Toward this goal an identification and detailed mapping of active faults of Uttarakhand state was done

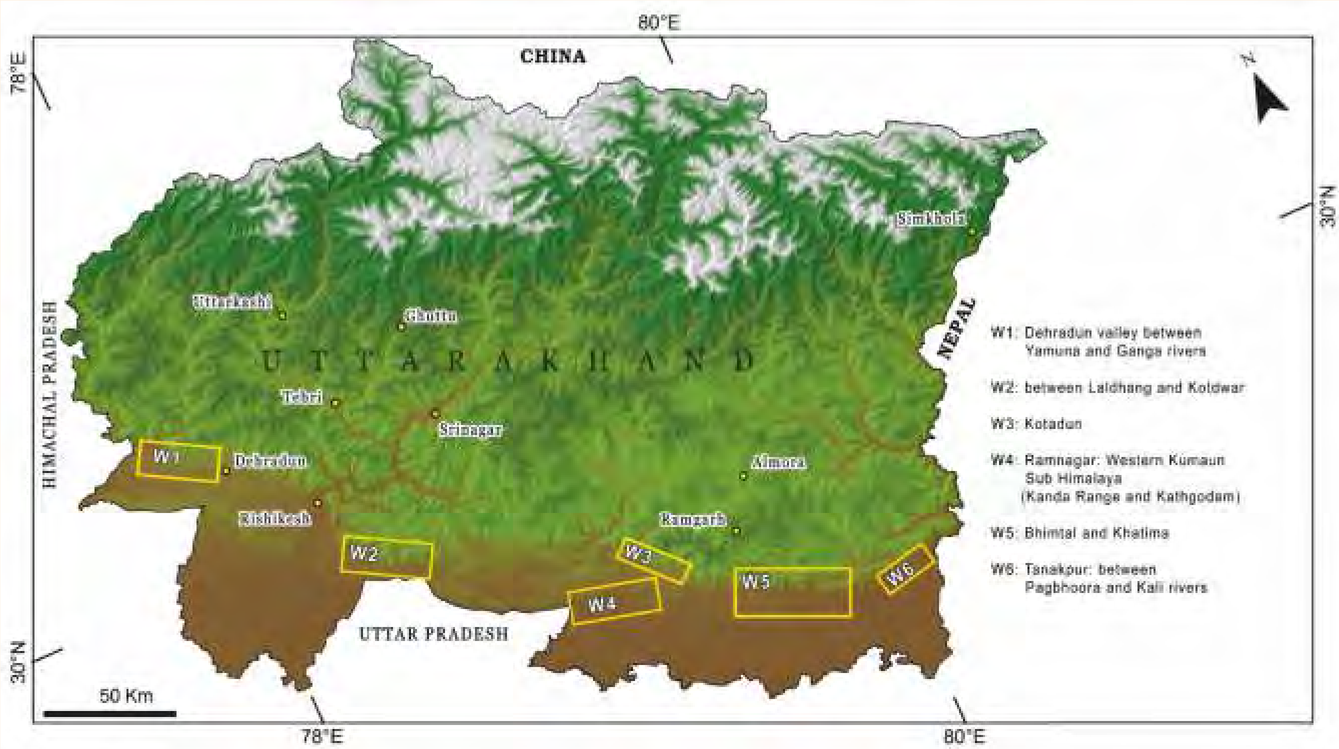

Fig. 69: Index map showing selected locations (Windows 1–6) where the active fault mapping has been undertaken.

(Fig. 69). The identified features and fault scarps are mapped using Socext-GXP and Arc-GIS 10 software and Cartosat-1 stereo-pair and Resource sat LISS IV MSS, combined with ground check along with high-resolution field mapping. The hosting of on-line interactive active fault data base in the WIHG server is in progress, and also the work is accepted for book publication in Springer, the final chapters will be submitted for publication shortly.

DST Project

Centre for Glaciology

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

The Centre is currently monitoring seven glaciers in Uttarakhand region of Central Himalaya and four in Himachal Himalaya namely Gangotri & Dokriani in Bhagirathi River basin, Chorabari in Mandakini River basin; Dunagiri & Bagni in Dhauliganga River basin, Pindari in Pindar River basin, Panchi Nala & Patisou glacier in Bhaga River basin. These glaciers were developed as full-fledged research stations with facilities to capture high resolution data on different aspects of glaciological studies. During this period, extensive field works have been carried out to generate high quality time series data on glacier dynamics, meteorology, micro-meteorology, glacial hydrology, sediment transport, melt-water chemistry, isotopic characteri-zations of precipitation (snow, rain), glacial geomorphology and tree-ring based annual isotopes ($\delta^{13}C$ and $\delta^{18}O$) chronology for paleo-environmental studies. Besides, in-situ measurements, the study on glacier surface changes, snow cover assessment and glacier lake inventory have been documented using vigorous high resolution space based observations and datasets. The summary of the work carried out is as follows:

Western Himalayan water cycle study

To understand the water cycle acceleration in the western Himalaya, annual tree-ring based stable isotope ($\delta^{13}C$ and $\delta^{18}O$) chronology of the last 200 year were analysed. Also, space-based observations of the vegetation dynamics, in-situ meteorological datasets, geochemical, palynological and ecological records were utilized to further strengthen the interpretations. The preliminary results clearly indicate unprecedented water cycle acceleration in the western Himalaya during anthropocene (Fig. 70).

Black carbon measurement at the Dokriani glacier

Black carbon (BC) is formed through the incomplete combustion of fossil fuels and biomass. BC travels

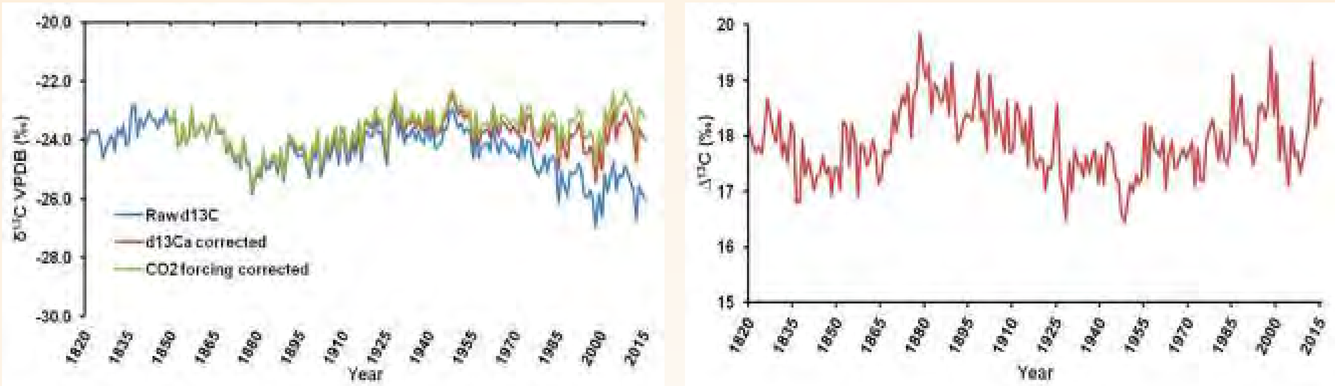

Fig. 70: The $\delta^{13}C$ time series of a species based on raw data (blue line) and corrected for atmospheric inputs of emissions of ^{13}C-depleted ($\delta^{13}Ca$) CO_2 from the combustion of fossil fuel (red line) and increasing atmospheric CO_2 concentration since the industrial revolution (green line), and atmosphere-to-tree ring carbon isotope fractionation ($\Delta^{13}C$) showing significant enhancement (1960s onwards) in carbon assimilation and subsequent water release in the environment.

along wind currents from Asian cities and accumulates over glaciers of the Himalaya and Tibetan Plateau. BC deposited on snow absorbs more sunlight than pure snow due to significant difference between the optical properties of BC and ice. Absorption of BC on snow/ice will result in positive radiative forcing (warming) at the top of the atmosphere.

Aethalometer AE 33 is installed at an elevation of 3900 m a.s.l. in Dokriani glacier to quantify the black carbon concentration. AE 33 includes Dual-Spot measurement method which offers real-time aerosol absorption analysis at seven wavelengths and works on the principle of optical attenuation technique (Fig. 71).

Fig. 71: Aethalometer AE 33 model; installed at the Dokraini glacier.

Energy balance study in the Pindari glacier valley

A micrometeorological station (AWS) at the Pindari glacier, Kumaun Himalaya has been installed in June 2016 to collect the real time data of met-parameters to understand the detailed physical processes regulating melting behaviour of the receding glacier in the Himalaya. The magnitude and seasonal variability of different components of energy balance including Bowen ratio are shown in following figures (Figs. 72 and 73).

Modelling for meteorological parameters and glacier surface melt

An empirical relationships to estimate meteorological parameters at the glacier altitude from the data on non-glacier altitude are developed for the three meteorological parameters, (i) air temperature, (ii) relative humidity, and (iii) incoming solar (global) radiation. Data from November 2011 to May 2013 collected from Dokriani glacier met-stations are used for the study. Diffuse radiation is estimated using a well-established model through clearness index (fraction of global radiation in extra-terrestrial radiation) and diffuse fraction (fractional amount of diffuse component in incident global radiation), and then their

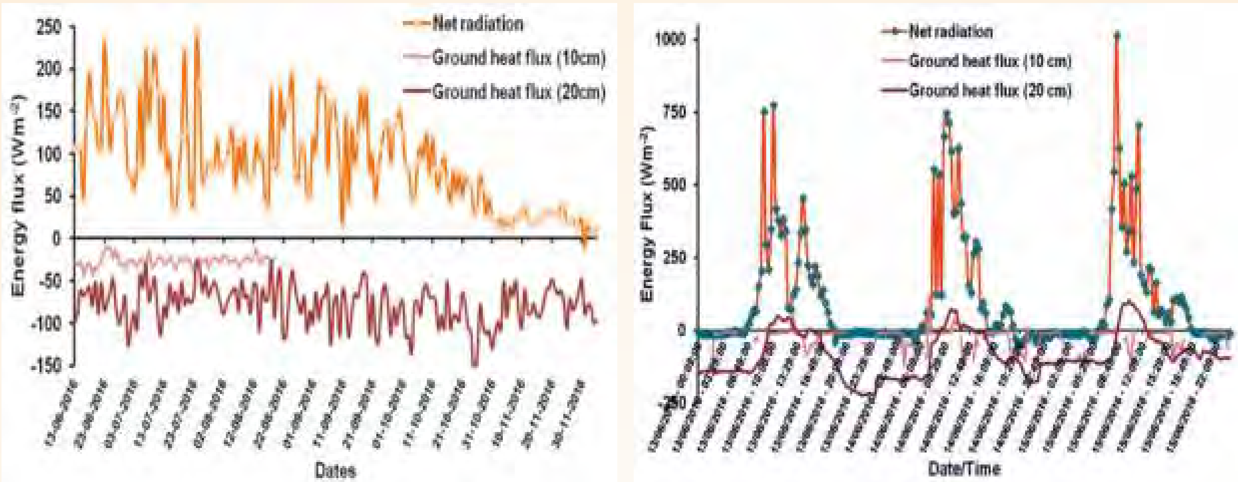

Fig. 72: Variations in net radiation (SW↓-SW↑+LW↓-LW↑) and ground heat flux at the study site during summer, monsoon and winter, and diurnal dynamics of net radiation and ground heat flux.

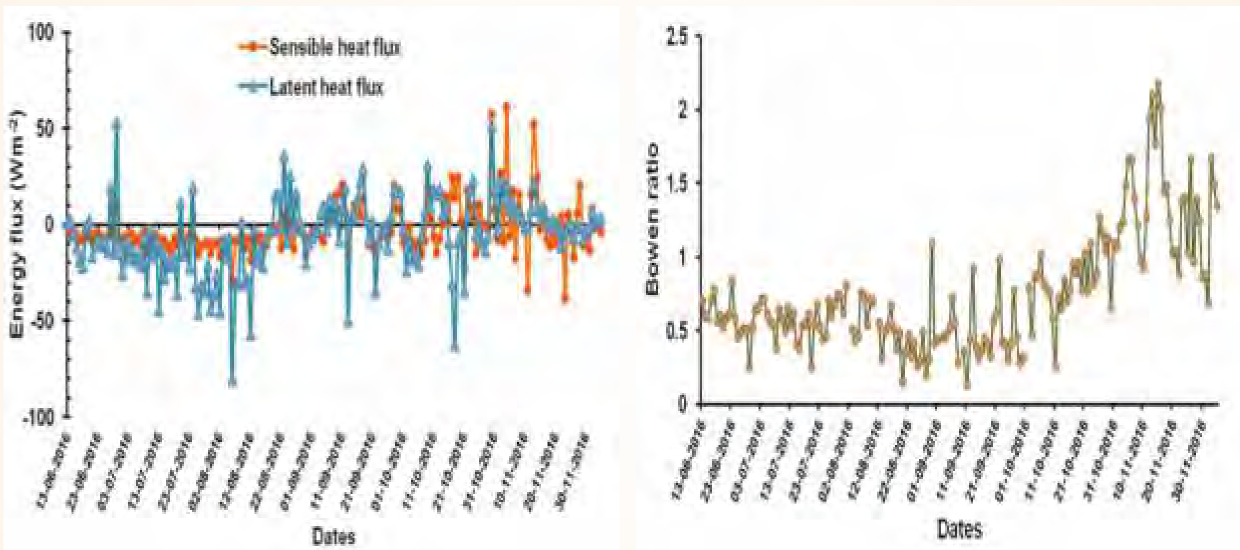

Fig. 73: Daily variation of turbulent heat flux (latent and sensible heat), and seasonal dynamics of Bowen ratio (sensible heat/ latent heat) at the Pindari glacier site.

correlation. The performance of the proposed empirical models is tested using various statistical tests which confirm the validity of these models. The study presents an effort to correlate the meteorological parameter of a non-glacierized area to a site near the glacier of Chorabari glacier catchment (Fig. 74).

In Himalayan region, there is a severe gap in the knowledge of the cryosphere-climate interaction and the impact of climate change on water resources because of its extreme and complex topography. Keeping this in view, an attempt to monitor the daily meteorological variables and surface ablation pattern of Dokriani glacier (Garhwal, Uttarakhand) is made to understand the debris covered glacier-climate interaction in the Central Himalayan region. New methods to generate the meteorological variables (temperature and rainfall) have been developed using statistical interpolation techniques. Temperature and rainfall is constructed from 4000 to 4400 m a.s.l of glacier with an interval of 100 m. The elevation 4000-4400 m a.s.l is divided into four ranges viz. 4000-4100 m a.s.l, 4100-4200 m a.s.l, 4200-4300 m a.s.l, 4300-4400 m a.s.l and data is produced for each range. The generated and experimental data on temperature and rainfall along with debris thickness are used to develop the distributed 'Enhanced T-index model' for calculating the debris-covered and debris-free snow/ice surface melt at hypsometric scale. This new approach will help

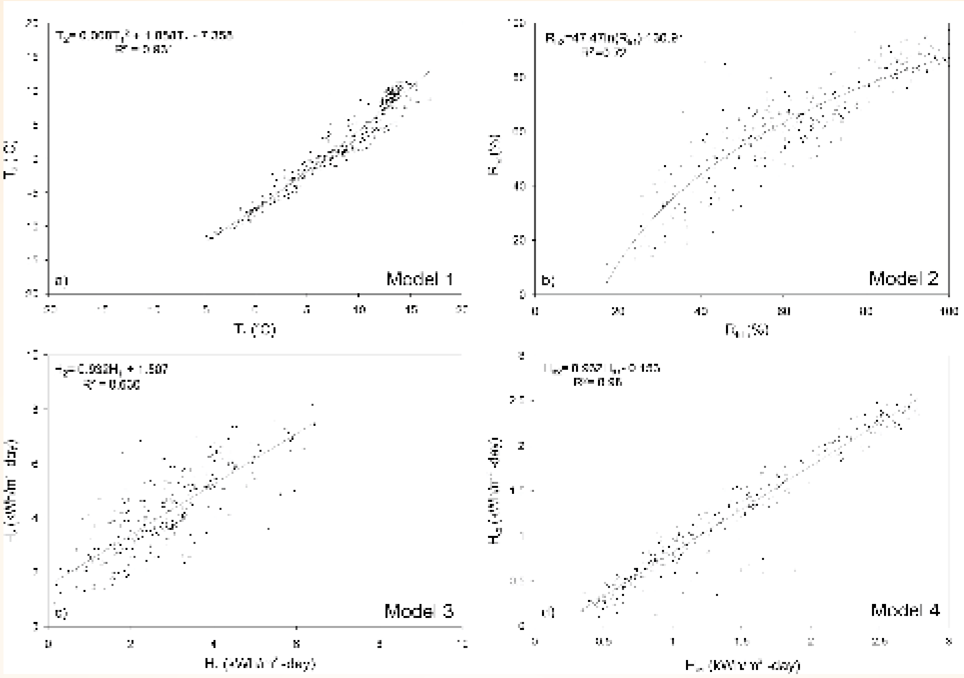

Fig. 74: Empirical equations for (a) temperature (quadratic-model 1), (b) relative humidity (logarithmic-model 2), (c) global (solar) radiation (linear - model 3), and (d) diffuse radiation (linear-model 4).

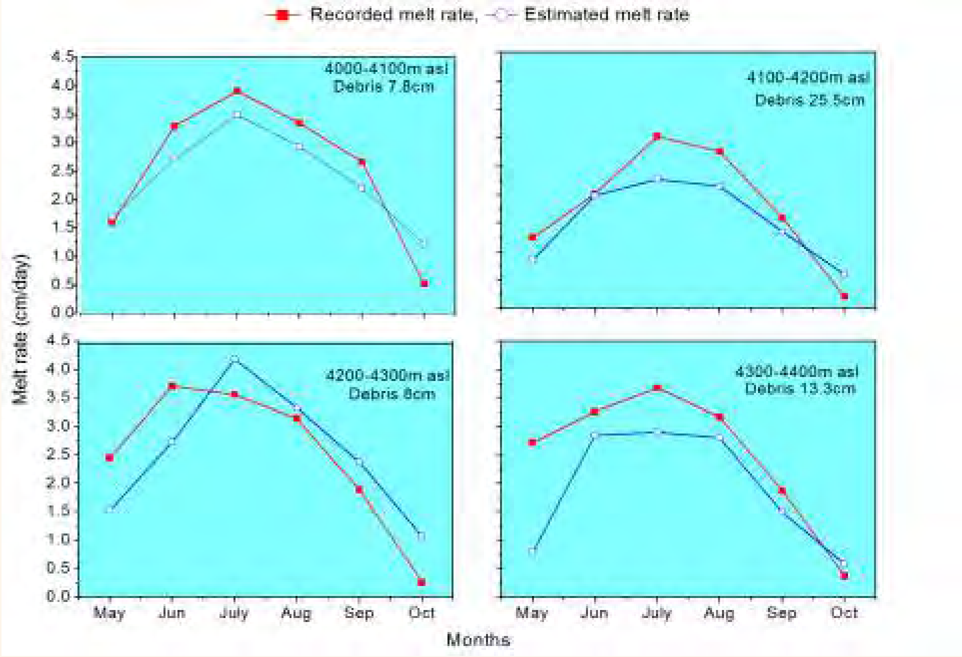

Fig. 75: Recorded and estimated melt rate (2013) for different elevation range of debris covered area of Dokriani glacier.

to investigate the influence of debris cover and altitude along with temperature and rainfall on glacier surface melting (Fig. 75).

Meteorological Observations and Analysis (2015-16)

The meteorological parameters includes Air temperature, Relative Humidity, Wind speed and direction, Shortwave Incoming and outgoing Radiation, Albedo, Longwave Incoming and outgoing Radiation and Sunshine hours collected from two AWS station (K-1 and K-2) setup at altitude of 3930m and 4270m asl respectively in the Chorabari glacier catchment. Data collected between 01 October 2015 and 30 September 2016 with some gap period have been analysed and

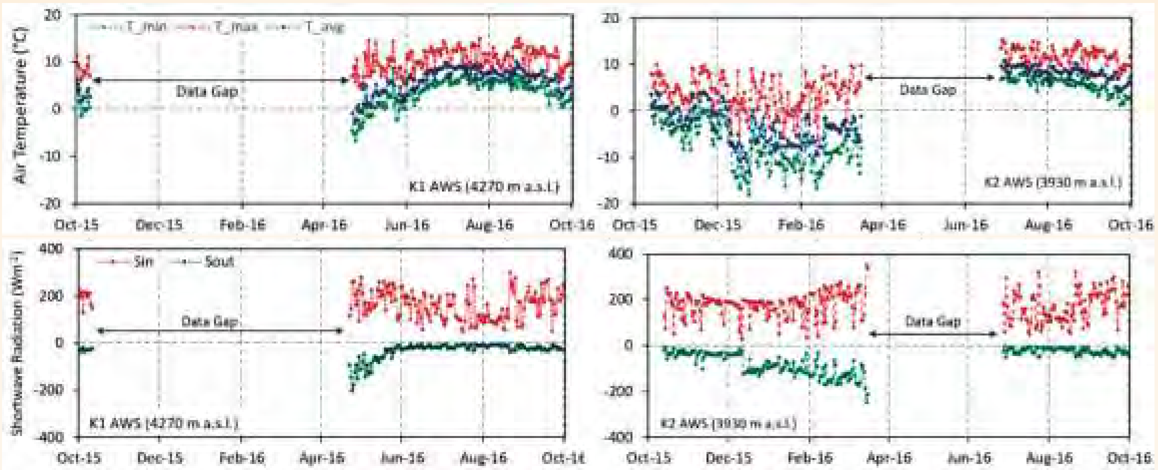

Fig. 76: Daily average temperature and radiation records observed in different stations of the Chorabari Glacier.

interpreted (Fig. 76).

Over the study period, average daily temperature was computed to be 5.86°C at K1 AWS site (melt season). Diurnal variations in temperature indicate that, generally, maximum temperature is observed around 14:00 h, while the minimum is observed in the early morning. Based on the available temperature records, it is found that July was the warmest month of the entire melt season. On average, for K1 meteorological station, the average incoming shortwave radiation was observed to be 132.3 W m^{-2} and the outgoing shortwave radiation for these corresponding months were observed to be 26.4 W m^{-2}. However, for K2 AWS site, the average incoming shortwave radiation was observed to be 173.2 W m^{-2} and average outgoing shortwave radiation was 58.7 W m^{-2}. Based on the data set, results indicate that the glacier experiences maximum radiation in the month of September and minimum in July. Similarly, during the study period, daily values of relative humidity fluctuates between 15 and 100% for both stations. The average relative humidity over the different melt seasons varied from 65 to 90%. It is also observed that the average daytime wind speed is about 4 times higher than the night time wind speed. Average wind speed for the melt season was found to be 0.9 m/s. There is some gap in data recording in both stations which may possibly be due to insufficient power supply, which is one of major problem in high altitude regions.

Isotopic characterisation of glacial melt water

A total number of 500 samples of snow/glacier melt water, ground water and river water were collected at different locations namely (i) Panchi Nala glacier, (ii) Patisou glacier, (iii) Kunjum top, (iv) Batal, (v), Chotta Darra, (vi) Chatru , (vii) Gramphu, (viii) Koksur, (ix) Tandi, and (x) Darchha bridge in Chandra -Bhaga river basin, Himchal Predesh. The results of isotope signature ($\delta^{18}O$) shows the variation from -13 to -10 ‰ for snow melt runoff, -12 and -10 ‰, for ground water runoff, whereas the isotope signature ($\delta^{18}O$) for Bhaga River varied between -14 and -10 ‰. The preliminary results indicate that the contribution of snow/glacier melt runoff in Bhaga river basin is more as compared to other components like ground water runoff and rainfall runoff.

Snow, ice and melt-water samples were also collected from Gangotri glacier during the entire ablation period for stable isotopes and geo-chemical analysis to understand the seasonal variability as well as the role of anthropogenic activities on glacier melt. The analysis of samples are under process.

During the year 2016, routine glaciological studies like stake networking for glacier mass balance, maintenance of hydrological observatory for discharge measurement was carried out in Dokriani Glacier. Samples of snow, ice, rain and melt-water were collected at daily and hourly basis for stable isotope analysis. The physiochemical characterization of the collected samples (pH, EC, DO, temperature, etc.) were also carried out in the field itself. Sediment and debris samples were also collected for particle size and shape analysis (XRD and XRF) in order to characterize the sediment generated. Snow pits were made at accumulation zone for snow density measurements and to estimate net snow accumulation (Fig. 77).

Surface dynamics studies

An integrated field and remote sensing study was performed to estimate the glacier surface elevation change and the influence of debris-thickness on glacier down-wasting on Panchhi Nala glacier, Bhaga river basin, western Himalaya. Field work was carried out on Panchhi Nala glacier during the first week of October 2016 using a handheld Garmin 64s GPS device. Six stakes were drilled into glacier surface for ablation measurement of the glacier (Fig. 78). Debris cover thickness was also measured on these points (Fig. 78). The surface elevation changes were deduced by differencing 2004 and 2013 ASTER Digital Elevation Models (DEM) which revealed an average surface lowering of -1.97±0.30 m/y. These surface lowering results will be validated from field measurements that will be made during the coming hydrological year (2017-18). Further, the estimated surface lowering was correlated with measured debris-thickness which revealed a significant control (r^2 = 0.68) of debris-thickness on local melting (Fig. 78). Debris-covered areas with a thickness of >15-18 cm were found to have experience less melting and resulted in less surface melting (thinning), whereas debris thickness <5 cm was found to accelerate the melting process and hence high

Fig. 77: Snow pit (2.6 ft depth) near the accumulation zone of Dokriani glacier for snow density measurements and collection of samples of snow and ice for isotopic and geochemical analysis.

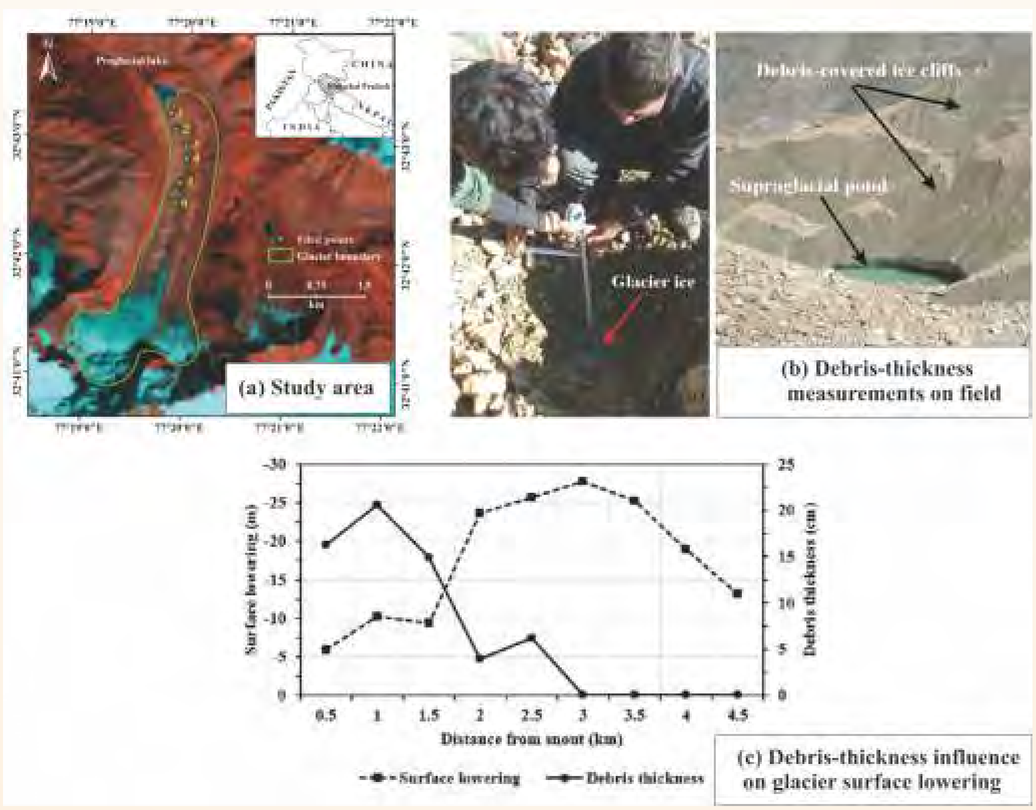

Fig. 78: (a) Stake network for ablation measurement, (b) debris-thickness measurement, and (c) influence of debris thickness on surface melting on Panchhi Nala glacier, Bhaga valley, H.P.

surface lowering. This emphasizes that the debris cover and thickness play important role in glacier surface melting, and must be considered for a better understanding of glacier response to climate change. Further, the study is continue for long term mass balance measurement and it trend for better understanding health of glaciers in context to climatic change.

Glacier lake inventory of Himachal Pradesh

In response to climatic warming, the number and volume of potentially hazardous moraine-dammed lakes in the Himalaya have increased. We have identified 958 glacier lakes (size >500 m^2) in Himachal Pradesh using satellite images (2011-2013), covering an area of 9.6±0.3 km^2. Out of these, 345 have been classified as moraine-dammed lakes (end moraine-dammed, lateral moraine-dammed, medial moraine-dammed, other moraine-dammed), having a total area of 5.1±0.2 km^2 (53.1 % of the total glacier lake area). The maximum number of glacier lakes (345 counts) are grouped under moraine-dammed lakes category, while minimum number of glacier lake is occupied by the other lakes group (38 counts and total area of 0.7±0.02 km^2) (i.e., debris-dammed lakes, artificial lakes). Altitudinal distribution of glacier lakes in Himachal Pradesh varies from 3001 m to 5614 m. A supra-glacial lake of Spiti basin shows maximum mean elevation (5614 m) in the study area. The largest lake classified as *other* moraine-dammed lake (1.0±0.03 km^2) in Himachal Pradesh is located at front of Samundra Tapu glacier in Chandra basin. The maximum number of glacier lakes is seen in Miyar basin (156 counts), whereas minimum lakes is seen in Siul basin (6 counts). In addition, maximum areas of glacier lakes are distributed in Chandra basin (2.7±0.09 km^2).

SPONSORED PROJECTS

SERB sponsored DST Project

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

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

The glacier facies/component mapping is very interesting and pertinent to glaciological studies for various reasons like, hydrological modelling, glacier related hazard studies, as an indicator of glacier health, identification of the glacier terminus, understanding the snowline dynamics, mass balance studies etc. The focus of the study is twofold, (i) to investigate the utility of a super-resolution approach to develop large scale glacier facies maps of Gangotri glacier using moderate resolution AWiFS by applying at different scale factors and, (ii) to apply the developed technique over an extended area including tributary glaciers of Gangotri glacier to facilitate monitoring of frontal changes.

With regard to meeting the first objective of the proposal related to sub-pixel mapping of the facies present on Gangotri and adjacent glaciers, 19 AWIFS, one LISS IV, one ASTER, one WorldView-2 and 2 Cartosat-1 scenes of the study area for different dates had been acquired along with the SOI toposheets (Toposheet No.'s: 53I/16, 53J/13, 53J/14, 53N/1, 53N/2, 53N/5, 53N/6 & 53N/9). Cartosat DEM version 3 (30 m) of the study area was also obtained for the present work. Initially, all the toposheets were geo-referenced and mosaicked. LISS IV imagery (5.8 m) was registered to this mosaic. Subsequently, the LISS IV and some AWiFS (56 m) images were co-registered with each other using second order polynomial transformation. The geometrically corrected ASTER, LISS IV, and AWiFS images have been rectified for the radiometric effects and converted to the top of atmospheric reflectance (TOA) from DN values. Meanwhile, it was found imperative to perform atmospheric correction on the images, since facies identification is carried out on the basis of spectral analysis using AWiFS optical data. Therefore, FLAASH atmospheric correction is being performed to derive the surface reflectance images.

Various glacial facies have been reported in literature (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. Spectral profiling was already done for snow/ice and other facies on AWIFS TOA reflectance images (dated October 5, 2006) along and across the central line of few representative glaciers well-distributed over the scene. Now, spectral profiling has been conducted on AWiFS image dated August 14, 2005. In this ablation season data, again five snow-ice facies namely dry snow, firn, wet snow (WS), ice and ice-mixed debris (IMD) were observed, however the reflectance ranges obtained here varied from the one achieved from post-ablation season image (Table 2). 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 (Philip and Ravindran, 1998; Hall et al., 1992). Figure 79a,b shows the spectral profiles of snow-ice facies obtained from ablation and post-ablation AWiFS images, respectively. Generally, reflectivity of snow-ice facies is higher in visible bands and rapidly declines in near-infrared (NIR) wavelength band, which is also reflected in ablation period derived spectral profile. In contrast, post-ablation derived

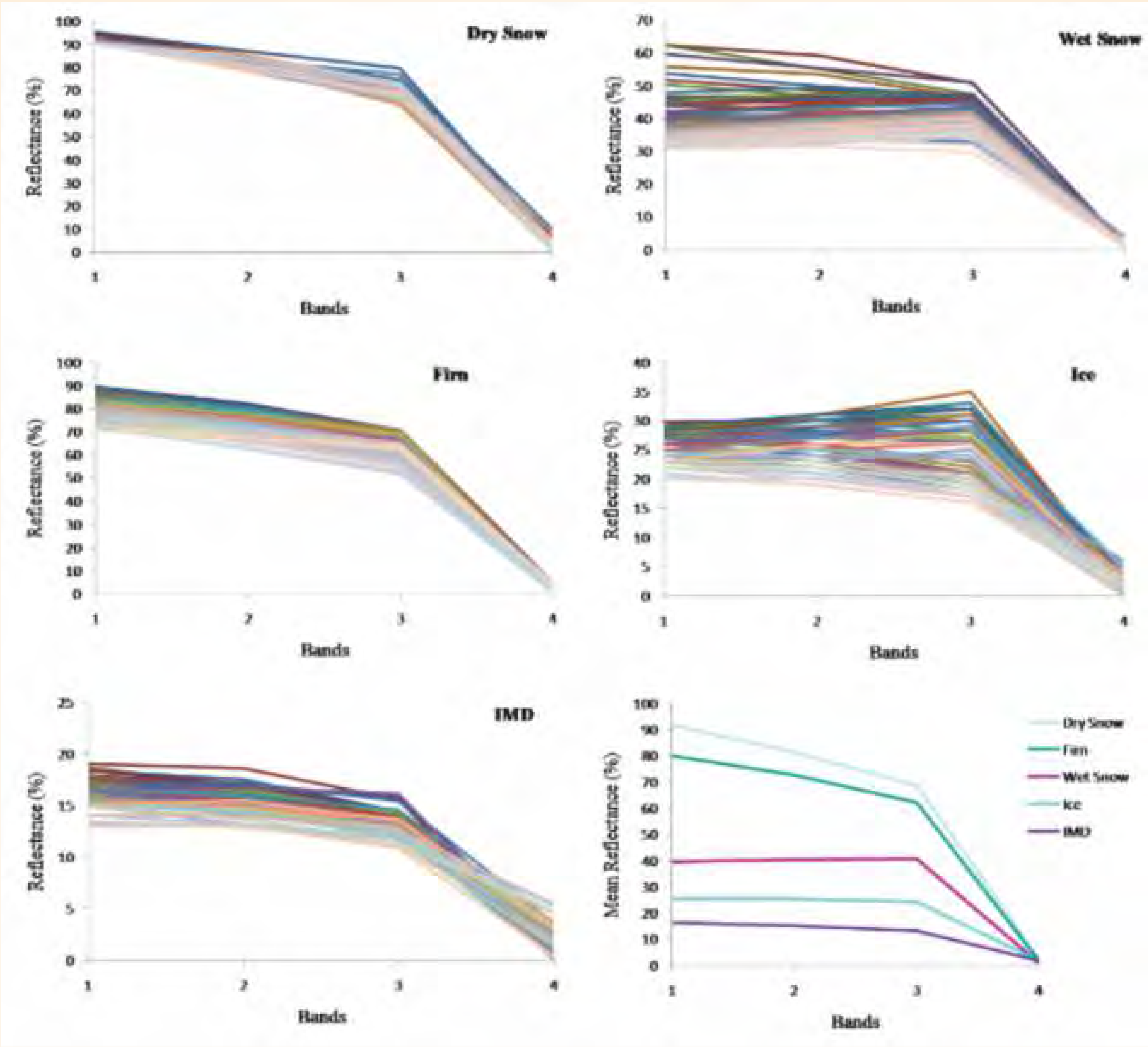

Fig. 79: (a-b) Spectral profile of various glacier facies identified on ablation and post-ablation images respectively.

Table 2: VNIR reflectance ranges of snow-ice facies during ablation and post ablation season.

Season		Dry Snow (%)	Firn (%)	Wet snow (%)	Ice (%)	Ice-mixed debris(IMD) (%)
Ablation	Visible	90-100	70-90	30-60	20-30	10-20
	NIR	70-90	60-80	30-60	20-30	10-20
Post-ablation	Visible	90-100	75-90	60-75	50-60	10-50
	NIR	90-100	70-92	60-80	50-64	10-50

spectra shows increase in reflectance of each snow-ice facie from visible to NIR bands, due to the presence of seasonal snow cover. This temporary snow cover not only alters their actual reflectance but also the actual spatial distribution of snow-ice facies. This in turn may lead to erroneous interpretation of the accumulation area, ablation area, firn line and wet snow line. From spectral profiling and visual interpretation of these images, six other facies were identified namely supraglacial debris (SGD), periglacial debris (PGD), valley-rock (VR), vegetation, shadow and water. For classification, PGD and VR were merged into single class, while shadows and water were masked out from the scene.

Spectral profiling revealed a high degree of spectral overlap between these facies. It was also observed that 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). This accounts for the need of inclusion of ancillary data in order to avoid misclassification. So, in order to facilitate better characterization of glacier facies, ancillary layers like DEM (L2), slope (L3), Green/SWIR (L4), NIR/SWIR (L5), Kinetic Temperature, KT (L6), KT/Green/SWIR (L7), KT/NIR/SWIR (L8), NDSI (L9), snow grain size index (SGI using AWiFS bands 1 and 3 (L10), and SGI using AWiFS bands 3 and 4 (L11) were used. Sub-pixel classification was first done on illuminated and shaded segments (Shukla et al., 2010) of TOA reflectance images (L1) (dated October 5, 2005) to investigate how the atmospheric correction of satellite images impacts the image classification. Three different classification algorithms namely ANNs, SVMs and SAM were implemented in order to find the most suitable sub-pixel classifier. The corresponding thematic and fraction images generated from illuminated and shaded imageries were then merged together to obtain the final thematic and fraction images. Since SVM outperformed ANN and SAM, hence SVM was further used for classification of AWiFS together with each ancillary layer mentioned above.

A subset of the ASTER image (15 m resolution, VNIR bands) containing all the facies (excluding vegetation) was extracted to manually digitize the glacier facies which were then rasterized to produce the reference map for generating reference fraction images. Another reference map was created from high resolution WorldView-2 imagery (2 m spatial resolution) covering the ablation part of study glacier. Five reference fraction images of wet snow, IMD, SGD, PGD-VR and shaded snow were generated for assessing the sub-pixel classification accuracy. The reference fraction images so generated were used to assess the accuracy of the sub-pixel output using fuzzy error matrix (FERM) based accuracy measures. The approach used by Binaghi et al. (1999) and Pontius and Cheuk (2006) was followed. The latter method produced better accuracy than the former method, thus it has been considered for determining the sub-pixel classification accuracy.

Both the qualitative and quantitative analysis of the fraction images show that SVM outperformed ANN and SAM by 4 % and 5 % respectively using ASTER reference fraction images, and by 5 % and 21 % using WorldView-2 data as soft reference data (Fig. 80).

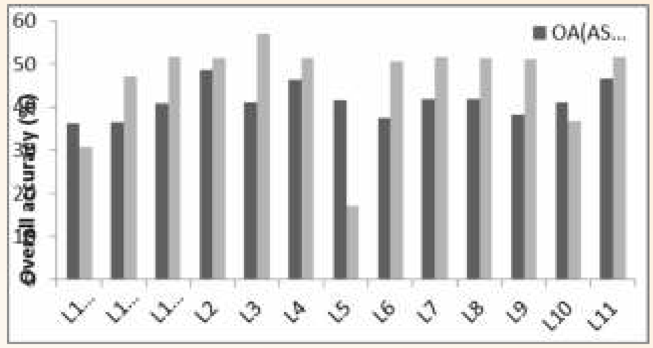

Fig. 80: Overall accuracy values derived from FERM based measures (composite operator) using ASTER and WV-2 reference dataset.

Hence, SVM was used for carrying out further classifications. Although the accuracy values are low and need to be improved, but there is a clear cut distinction between the overall performance of these classifiers. The areal estimate of each facie derived from these classifications was also compared with area derived from reference fraction images. This also showed closeness of results from SVM to the area derived from reference fraction images as compared to ANN and SAM. The use of elevation information enhanced the accuracy by 8 % on validating against ASTER soft reference data. Except for layers L5 and L8, there was an overall increasing trend in the classification accuracy. The fractional area of glacier facies in these cases also became more comparable to the reference fractional area of the facies, thus improving the classification accuracy. Assessment of accuracies using WV-2 data showed increase in accuracy values for layers L3 and L7, i.e., slope and KT/Green/SWIR ratio respectively.

Pixel Filling Algorithm (Prabhu et al., 2013) has been developed in Matlab environment and implemented for super resolution mapping. To test the algorithm, a subset of fraction images of eight different classes obtained from classifying the spectral and DEM data was taken. The output of Pixel Filling Algorithm is shown in figure 81a. Table 3 compares the snow covered area as obtained from super resolved map, reference map, NDSI and per-pixel classification map derived using spectral and DEM data.

Results show that the snow-ice covered areas derived from the super-resolved map and NDSI are close to the reference estimates, however, observing the derived maps (Fig. 81) it can be seen that super resolved map, maps several snow ice facies as compared to NDSI. In case of no snow-ice covered areas, there is a lot of mismatch. In all the case the per-pixel map is seen

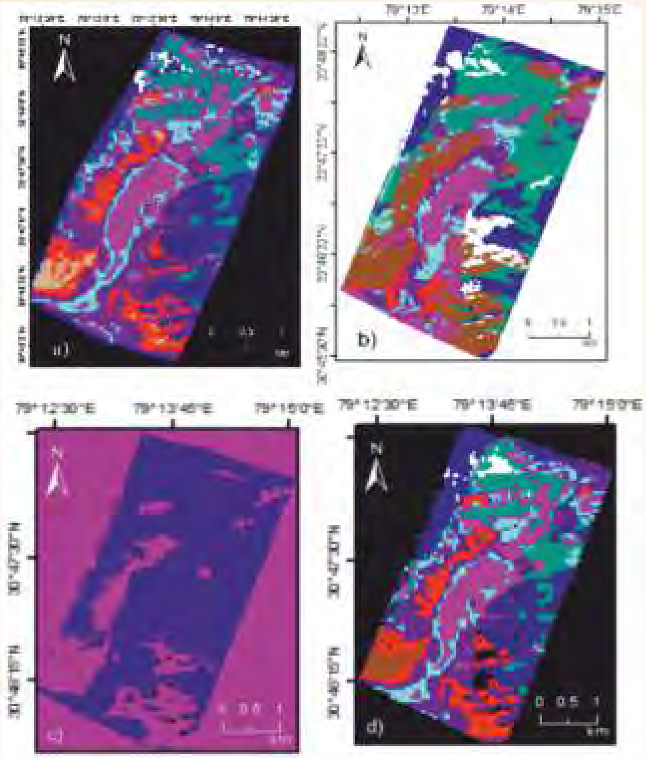

Fig. 81: Super resolved map (a) with zoom factor 5, (b) Reference map, (c) NDSI, and (d) Per-pixel classification map derived using spectral and DEM data.

Table 3: Inter-comparison of area derived from different maps obtained using spectral and DEM.

Area (sq.km)	Super resolved map	Reference map	NDSI	Per-Pixel map
SCA	9.66	10.59	11.33	12.63
Non-SCA	1.61	3.52	3.3	2.01

to grossly overestimate the areas. The super resolution approach used here needs to be further improved and spatial accuracy of these maps also needs to be assessed using the error matrix based measures. Pixel Swapping Algorithm (Atkinson, 2005) will also be developed and implemented for super resolution mapping.

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 has been selected for monitoring after 1989-1992 in order to understand the variability in hydro-meteorological parameters over two decades. The importance of such type of studies will attain considerable significance in context of the effects of climate change on hydrological regimes over Himalayan glaciers.

Meteorological Observations and Analysis

The meteorological data such as rainfall, maximum and minimum temperature, relative humidity, wind speed, wind direction and sunshine hours are measured. This data is utilized to characterize the climate of that location and to supply meteorological input for simulating the hydrological processes. A suitable site for observatories was selected by a team during their field visit in Dunagiri Glacier during June-September 2014, and a conventional meteorological observatory was established about 2 km downstream of the snout for recording parameters like temperature (Minimum, Maximum, Dry and Wet Bulb), relative humidity, rainfall and wind velocity. The thermometers were kept inside a Stevenson's screen, at a height of 2 m. Daily rainfall recorded for year 2016 during the months of June, July, August and September was 23.7**,** 132.6, 63.4 and 18.3 mm, respectively. The total annual rainfall was observed to be 238 mm. It is observed that the maximum amount of rainfall is experienced in the valley during the month of July, whilst June experienced minimum rainfall in this year. 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 for different months i.e. June, July, August and September was observed to be 18.5, 17.2, 16.2 and 16.8°C and 6.0, 4.5, 3.0 and 0.9°C, respectively. Mean monthly temperature for year 2016 was observed to be 10.7, 10.3, 9.5 and 8.7°C, for the months of June, July, August and September, respectively.

Hydrological Observations and Analysis

A gauge and discharge site has been established over the River near the snout of Dunagiri Glacier. In order to measure the water level data, an automatic water level recorder (mechanical) was utilised and was installed on an artificial well near the river bank. A stage-discharge relationship for the gauging site was developed by analysing the observed gauge and corresponding discharge data. This relationship was used to compute the hourly discharge values corresponding to the hourly gauge values for which no discharge observation were made. Figure 82 shows a stage-discharge relationship developed for ablation period (2016). Such relationships were developed for each summer/ablation season separately and were used for calculating discharge from water levels.

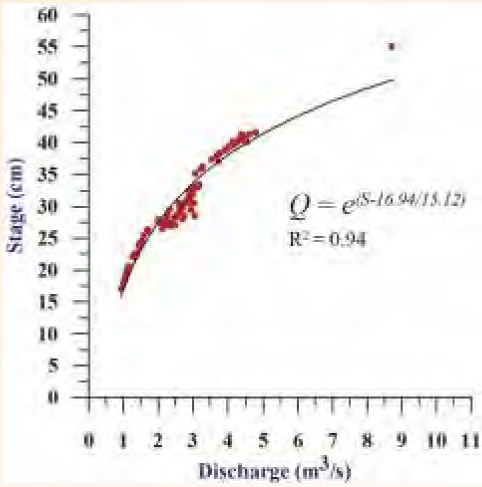

Fig. 82: Rating curve for Dunagiri Glacier melt-water stream for the year 2016.

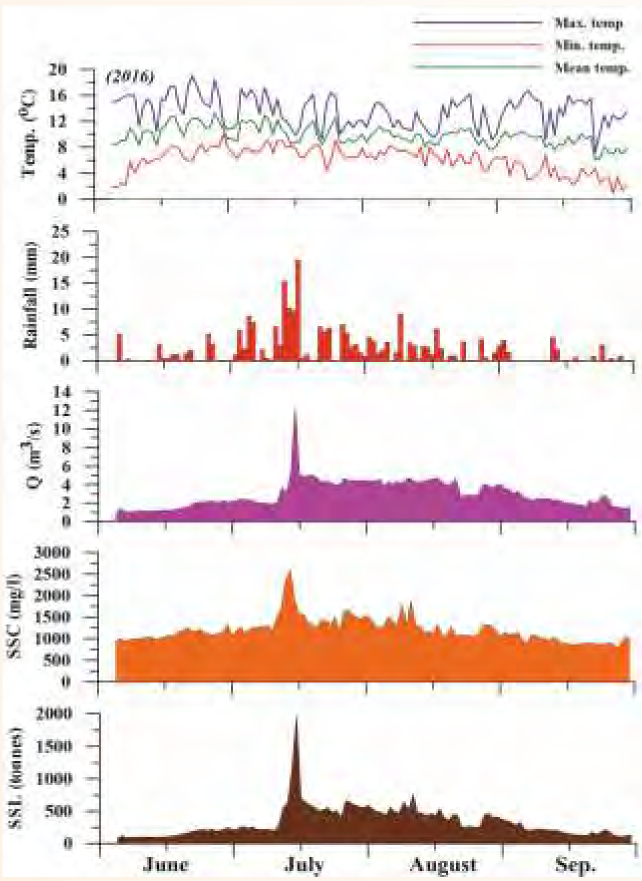

Fig. 83: Distribution of daily discharge, suspended sediment concentration and load near the snout of Dunagiri Glacier.

The computed hourly discharge values for a day are averaged in order to estimate the daily average discharge values. Monthly mean values of the discharge were computed from the daily mean values for each month of the ablation season. The mean monthly discharge observed during study period for different months i.e. June, July, August and September are 1.5, 3.8, 4.0 and 2.3 m^3/sec. The mean monthly discharge was observed to be 3.4 m^3/sec. Suspended sediment concentration in the observed discharge was high, more over it was very much variable over the melt season. Mean monthly suspended concentration for June, July, August and September during the study period was 1073.6, 1462.72, 1272.85 and 957.24 mg/l, respectively. Mean monthly total suspended loads for same months during the study period were 129.14, 476.60, 421.41 and 177.20 tonnes, respectively. Daily distribution of discharge, suspended sediment concentration and suspended sediment load are given in figure 83.

Further, the isotopic analysis of samples collected from rainfall, snow, ice and discharge are in process. The present project has been completed in March, 2017 and the monitoring of these glaciers will be continued for long term basis by the Centre for Glaciology (CFG).

SERB Project

Micrometeorological measurements and modelling experiments in the Pindari glacier

(Nilendu Singh)

To examine the energy-water exchange in the Pindari glacier, a micrometeorological station was installed in June 2016 (Fig. 84). Characterization of glacial surface energy-mass exchange processes predict melt-driven stream flow will improve the temporal resolution of melt models, while also improving the understanding on climate-glacier responses and feedbacks in one of the fastest receding in the Himalaya. The station consists of following set of sensors for continuous and automated measurements of radiation and energy-water balance components: (i) four-component net radiometer, (ii) soil heat flux plates at two-depths, (iii) three-height air

Fig. 84: Red dot (30°15'44.69"N; 79°59'57.71"E; 3800 m) indicates location of micrometeorological station (inset) in the Pindari glacier valley.

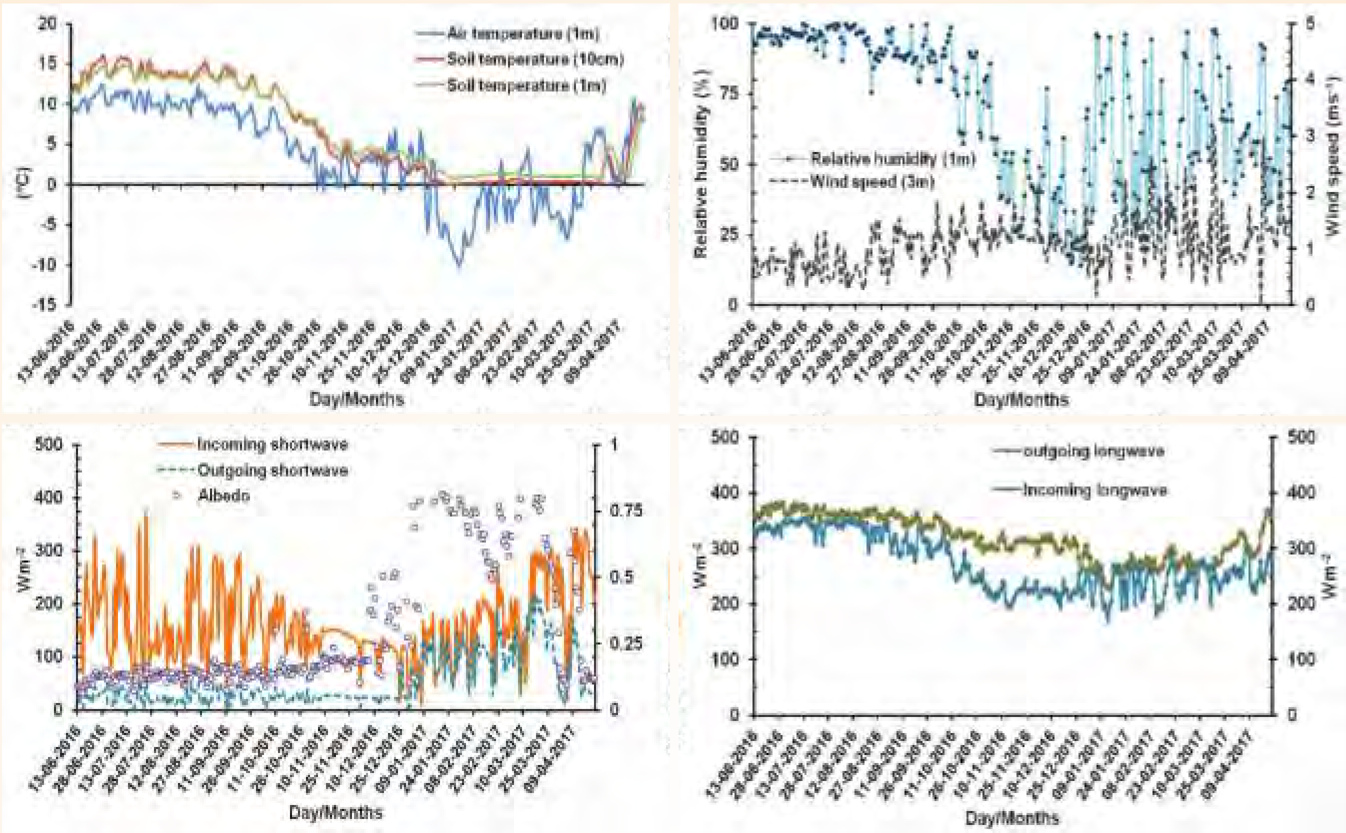

Fig. 85: Upper panel illustrates the annual behaviour of air temperature (at 1m), soil/snow temperature (at 10 cm & 1m), relative humidity (1m) and wind speed (3m) respectively. Lower panel shows radiation components dynamics including albedo for Pindari glacier valley.

temperature - relative humidity probes and anemometers for wind speed and direction, (iv) three-depth soil thermometers, (v) a rain-gauge, (vi) a pan evaporation meter, and (vii) a soil moisture sensor. A 30 channel data logger logs data every second which is averaged over 10 minutes and stored in the logger. The results on the basic micrometeorological variables for one complete annual cycle (2016-17) are presented below in figure 85.

DST Project

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

(Director of WIHG, Rajesh Sharma, D.P. Dobhal, S.K. Bartarya and Vikram Gupta)

In the first phase of the project, emphasis was given to the preparation of database for the northwestern Himalaya covering the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. Standard methodology for the collection of primary and secondary data was adopted in the present work. Though there is plenty of information available on the geological wealth of the Himalaya and the exogenic processes like landslides, cloudbursts, weathering and erosion etc., these information and data were scattered and are available in different formats. The first task was to collect all the information in a standardised format and accordingly all the secondary data will be collected and compiled from the published literature and reports. However, there remains certain gaps in the compilation of database for which collection of data directly from the field is required and will be undertaken in due course of time. Selected field survey was undertaken in the mine clusters in Bageshwar District of Kumaun, Uttarakhand.

The data collected mainly pertains to various geo-resources, like springs including geo-thermal springs, water bodies including glacial lakes, mines and minerals, and exogenic processes operating on the earth like weathering and landslides. A standard format has been designed so as to bring all the data in a single format to be used in GIS environment.

In general the geological wealth enumerate and integrate with the Himalayan eco-system. Glaciers and their environment hold an essential key to our knowledge of the present, past and future climatic and environmental conditions. These are important natural resources, which form major component of the hydrological cycle of mountains and the adjoining regions. A positive mass balance results in glacier advance while negative mass balance results in glacier retreat. Results of stream runoff and sediment studies provide valuable information about the total discharge and erosion under various conditions and also indicate the possible water flows from the glaciered areas. Moraines and other glacial deposits offer information about the records of past climate conditions and to assess the climatic changes. Variability in the ground water, spring water flow and the lake water are also due to the climatic changes or the anthropogenic reasons. The increasing water pollution is paradigm of the human intervention. Minerals with economic concentrations of useful elements have attracted the man for digging, trenching and making holes in the earth surface so that they can be extracted from the crust. The mining sector therefore has a key role to play in sustainability of the environment and conservation of biodiversity. The mineral has dual effect on the society and the sustainability of the eco-system. Often conservation programs that involve mitigation and mine site reclamation are required for landform restoration. In view that these elements of the geological wealth are significant to study of the climate change and anthropogenic intervention, it is planned to evaluate them in the Himalayan region by preparing database along with the required possible study. The coupling of these physical modules with the causative factors is likely to result in assessment of the climate change and human intervention.

NIH-DST Project

Understanding of hydrological process in Upper Ganga Basin by using Isotopic technique" awarded under Natioanl Mission for Sustaining the Himalayan Ecosystem (NMSHE)

(Rajeev Saran Ahluwalia)

The Himalayan mountain system is the source of one of the world's largest supplies of fresh water which is under threat due to serious environmental degradation and climate change. Continuing climate change is predicted to lead to major changes in the strength and timing of the Asian monsoon, inner Asian high pressure systems, and winter westerlies– the main systems affecting the climate of the Himalayan region. The impacts on river flows, groundwater recharge, natural hazards, and the ecosystem, as well as on people and their livelihoods, could be dramatic affected, although not the same in terms of rate, intensity, or direction in all parts of the region. Therefore, a thorough understanding of hydrological processes operating all along the Himalayan region is a fundamental requirement. The major objective of this project is to estimate the snow/glacier melt water, rainfall derived runoff and groundwater runoff contribution in upper Ganga river basin. This will cover the isotope and snow/glacier melt runoff modelling using different semi/distributed index models. A total number of 671 water samples including 578 stream/spring, 42 groundwater and 51 rainfall have so far been collected (Figs. 86 and 87).

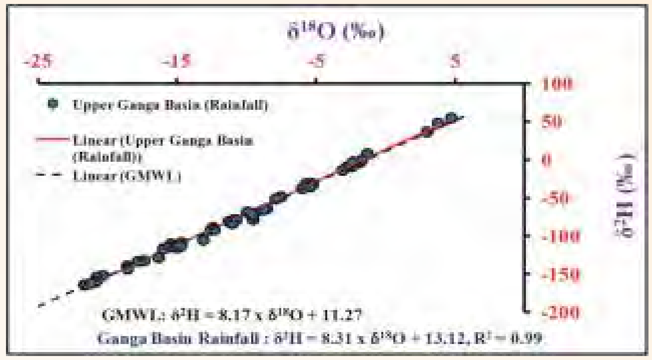

Fig. 86: Isotopic Characteristic of precipitation in study Area.

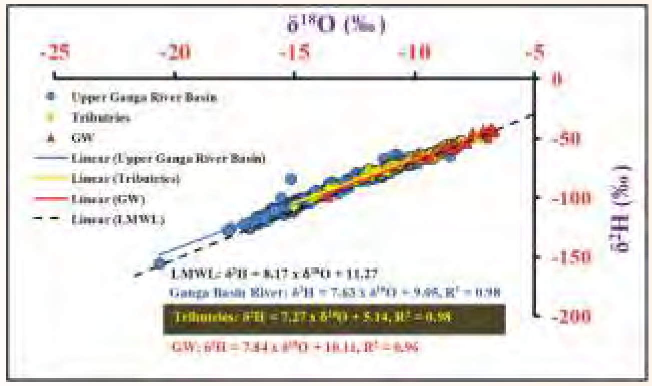

Fig. 87: Isotopic characteristic of river, tributaries and groundwater.

The results of this project will contribute to the advancement of our current understanding of the surface and subsurface water resources in the Bhagirathi/Alaknanda/Pindar River basin in particular and the hydrology of the Ganga basin in mountainous area in general. The integration of such a wide range of data using varied techniques to understand the hydrology in itself will be a significant outcome, and something that has not been attempted in any other river basin in the Himalaya.

DST Project

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

(Vikram Gupta)

During the reporting year, landslide studies in the Upper Yamuna valley, particularly between Yamunotri and Damta, have been undertake. The Kharsali village, the farthest inhabited village in the valley has been studied in detail for its slope stability analysis. The village is located near the confluence of the Yamuna River - Unta Gad on >150 m thick palaeo-landslide deposit. This old village also houses seventh century ancient Shani Temple. Most of the houses in the village are of traditional Koti Banal type architecture, consisting mainly of stone-wood combination, designed to resist earthquakes.

Field observations reveal cracks in almost all the houses, and ~5° tilting of the temple towards the north-eastern side of the village. The village is continuously being eroded at its base by the Yamuna River flowing from the northwest towards the southwest of the village and by the Unta Gad flowing towards the southwest of the village. Finite Element Method (FEM) analysis using Shear Strain Reduction (SSR) analysis carried out by Phase^2 along three different slope sections of the village reveals that the most of the slopes in the area are in meta-stable conditions. The least vulnerable area for slope failure is the southern part of the village is housing the Shani Temple. It has a critical SRF of 1.5, whereas the slope most vulnerable to failure with a critical SRF of 1.08 is located in the southern part of the Kharsali village. Since developmental activity in the form of a ropeway, connecting Kharsali village with the Yamunotri Temple is being planned, the outcome of this study would be useful to the planners in decision making.

Besides, the inventory of landslides and related mass movement activities in the area has been prepared. It has been noted that in the Higher Himalaya, there are 31 rock falls and 20 debris slides, whereas in the Lesser Himalayan, there are 10 debris slides and only 2 rock falls. Further, the landslides induced or caused by anthropogenic activities are more in number in the Lesser Himalaya and are almost negligible in the Higher Himalaya. Work has also been carried out to understand the inter-relationship between the spatial distribution of landslides, lithology and various geomorphic indices. The geomorphic indices include mainly longitudinal river profile, stream length gradient, steepness index, and ratio of valley floor width to valley height (V_f). It has been observed that (i) the landslides are more concentrated in the higher Himalayan region *cf* the lesser Himalayan region, (ii) the valley slopes in the Higher Himalaya exhibit low V_f ratio indicating narrow gorges and steep river bedrock channel and this result in higher SL index in the region, and (iii) the rock types in the Higher Himalaya are mainly erosion-resistant rocks as evidenced by their higher strength, but still large number of landslides are concentrated in this zone. The geomorphic indices thus indicate the region to be of tectonically active nature.

Indo-ISOR, Iceland-NGI, Norway collaborative Project

Commissioning of Pilot project for the use of geothermal energy

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

For the first time, under the Indo-Norwegian co-operation project coordinated by the Department of Science and Technology, Government of India, a ground source heat pump (GSHP) has been successfully installed in the guest house of Wadia Institute of Himalayan Geology (WIHG), Dehradun (Fig. 88). GSHP will be used to heat the guesthouse through renewable energy, saving a significant amount of electrical energy during the winter months. Ground source heat pump (GSHP) is a central heating and/or cooling system that transfers heat to or from the ground. Heat pumps provide winter heating by extracting heat from a source (in the present case ground water) and transferring it into a building. Ground source heat pumps employ a heat exchanger in contact with the

Fig. 88: The Indo-Norwegian team in front of a hut next to the guest house where GSHP is installed along with a borehole drilled for extracting groundwater.

SPONSORED PROJECTS

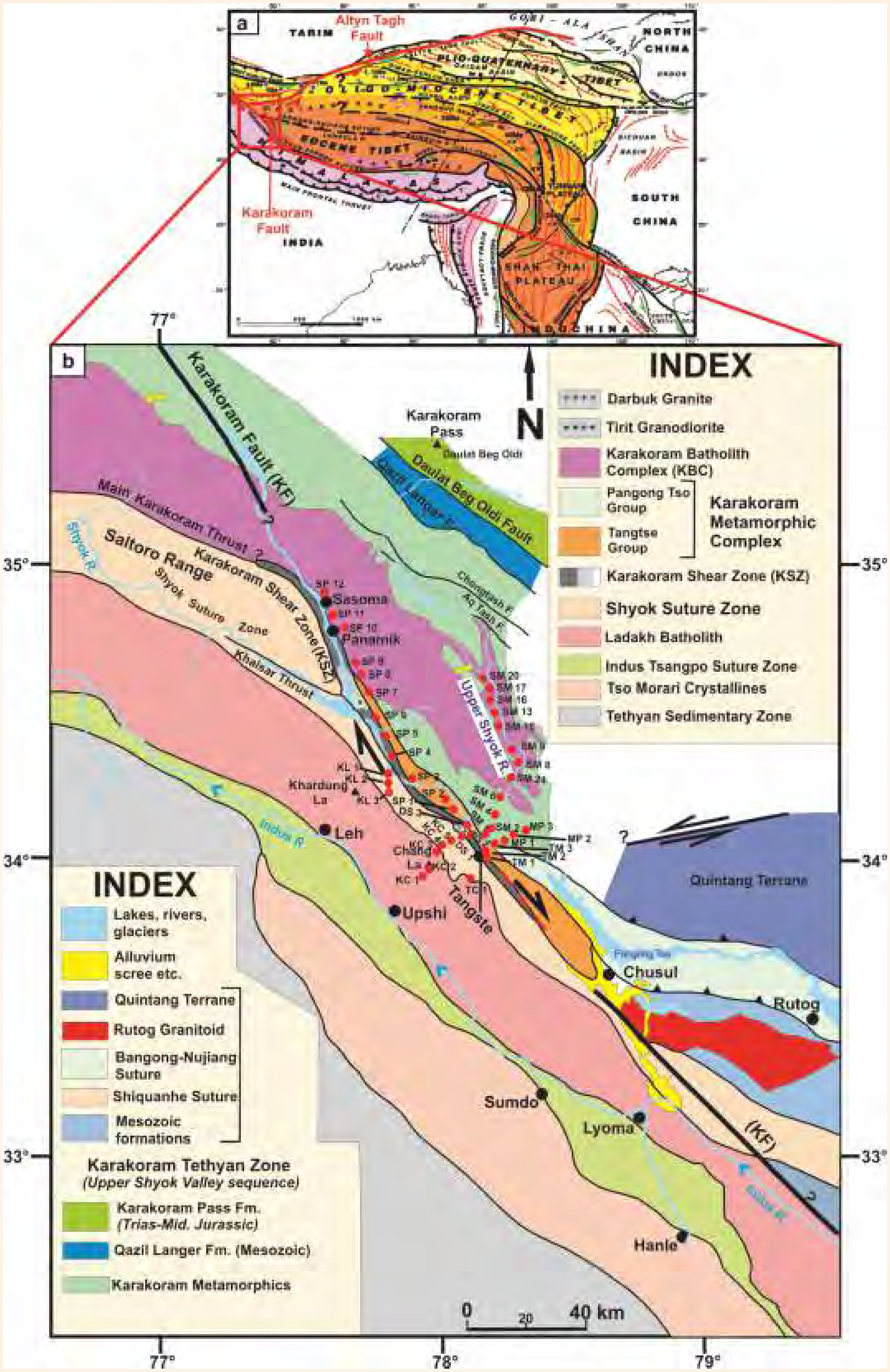

Fig. 89: (a) Location of study area in context of Himalayan-Tibetan orogenic belt, (b) Geological map (after Jain & Singh, 2009) with sample locations (red dots) for zircon U-Pb Geochronological and Fission Track Thermochronological studies.

groundwater to extract or dissipate heat. The heat pump is the central unit that becomes the heating and cooling plant for the building. Since a heat pump moves three to five times more heat energy than the electric energy it consumes, the total energy output is much greater than the electrical input. This results in net thermal efficiencies greater than 300% as compared to radiant electric heat being 100% efficient. WIHG, Dehradun, NRDMS division of DST, along with the international partners like, Norwegian Geotechnical Institute, CA NOR Kjoleindustri AS from Norway, Reykjavik University in Iceland, and Geological Survey of Iceland (ISOR) have contributed to successful installation of the GSHP.

SERB Sponsored Project

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

(Vikas)

The project aims to document the tectonic evolution and exhumation history of the SE Karakoram terrain, Ladakh, India. The study area lies in eastern Karakoram, NW India, composed of different litho-tectonic units namely: The Karakoram Shear Zone (KSZ), Karakoram Batholith (KB) and Karakoram Metamorphic complex (Fig. 89). These rock units represent the margin of south Asian Plate and lie to the north of the Shyok Suture Zone (SSZ). Geological studies have been carried out across the Trans-Himalayan Ladakh Batholith, SSZ, KSZ and KB units as well as along the strike of the Karakoram Fault (KF) as shown in figure. 89.

Eight samples including deformed and undeformed leucogranites and their host tonalite gneiss were processed for zircon U-Pb geochronology at LAMC-ICP-MS facility of the Institute (Table 4). Back-scattered electron (BSE) and cathode-luminescence (CL) images were taken using a scanning electron microscope (SEM-Zeiss EVO 40 EP) in Central Laboratory facilities of WIHG, Dehradun, India.

The obtained variable geochronological ages (~846-14 Ma) from the granitoids having specific geochemical and structural characteristics reveal: (a) evidences of subduction related volcanic arc magmatic event during 846-705 Ma from the Karakoram; (b) that the subduction of the Tethyan oceanic lithosphere beneath the southern Asian plate margin initiated at least ~165 Ma ago; and (c) twenty million years of continuous deformation along ~1000 km long lithospheric scale KF during ~35-14 Ma. Presence of deformed leucogranite dykes in a wide metamorphic sequence suggests that Karakoram Shear Zone (KSZ) is a 40-50 km broad dextral strike-slip shear zone existing in the Trans-Himalaya.

Table 4: Zircon U-Pb ages of the analysed samples from Karakoram terrain, Ladakh.

S. No.	Sample Name	Rock Type	Zircon U-Pb Age (Ma)
1	SM 1	Mylonitic Granite	167.1 to 100.3 (continuous distribution)
2	SM 2L	Leucogranite	33.5±3.5
3	SM 2M	Diorite gneiss	64.2±3.0
4	SM 4L	Leucogranite	35.68 to 14.14 & 155.7
5	SM 4G	Tonalite Gneiss	165±11
6	SM 4M	Tonalite Gneiss	832±25
7	SM 6	Leucogranite	14.7±2.1
8	SM 24	Leucogranite	14.00±0.99

Further, another set of eight samples from Karakoram Batholith have been prepared for zircon U-Pb Geochronology, while CL images for all samples have been obtained. Also, thirty six samples (74 slides) for zircon and 37 samples (51 slides) for apatite have been irradiated at FRM II nuclear reactor, Germany from the transect (a) Changla-Darbuk-Shyok section, across the KF zone, (b) Tangtse-Muglib section , across the KF zone, and (c) Shyok-Murgo section, along the KB (Fig. 89). Fission Track counting is in progress for the generation of Fission Track data from the Karakoram.

CSIR-SRA (Scientists Pool Scheme) Project

Zircon U-Pb Geochronology and Geochemistry of magmatic rocks from Lohit Plutonic Complex, Eastern Himalaya: Implication on Geodynamic evolution of the Trans-Himalayan Batholiths in the Eastern Himalayan Syntaxis, Northeast India

(R.K. Bikramaditya Singh)

The eastern limb of the Eastern Himalayan Syntaxis (EHS) is represented by the Himalayan part and the Trans-Himalayan part (Lohit Plutonic Complex- LPC), and both being separated by the Indus Psangpo Suture Zone (IPSZ). The rocks of the IPSZ represent an ophiolitic mélange, which occurs as a narrow folded belt that thrust over the Himalaya in the southwest. The ophiolitic mélange can be traced discontinuously further NW around the EHS and joins with the Tsangpo suture of southern Tibet. The mélange is comprised of serpentinised peridotites, amphibolites, metabasic volcanic rocks, sedimentary rocks intruded by basic

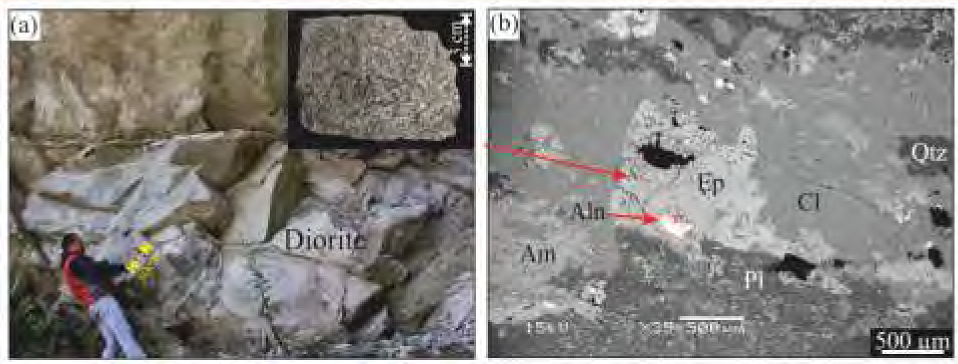

Fig. 90: (a) Field photograph showing the exposure of diorite in Lohit plutonic complex, Eastern Arunachal Himalaya with hand specimen in the inset, and (b) back scattered electron image of diorite showing mineral assemblage of plagioclase (Pl), amphibole (Am), magmatic epidote (Ep), allanite (Al), quartz (Qtz) and chlorite (Cl).

dykes and sills, crystalline limestone. The LPC is extensively exposed over large part of the Dibang and Lohit valleys of Arunachal Pradesh and tectonically overlies the Suture zone on the Lohit Thrust. The LPC is subdivided into eastern and western belts separated by the Walong Thrust. The western belt comprises diorite, gabbro and trondhjemite, while the eastern belt consists of garnet-sillimanite gneisses, marble, leucogranite with veins of aplite and pegmatite.

The gabbros are medium- to coarse-grained and are dark greenish gray in color. They show hypidiomorphic granular texture with amphibole and plagioclase as essential minerals. Accessory minerals include magmatic epidote, quartz, sphene and zircon. Secondary epidote and chlorite are also observed. Plagioclase occurs as euhedral to subhedral phenocrysts and show combination of albite twinning and Carlsbad twinning. It shows alteration to saussurite and sericite with more alteration in the core. Amphibole occurs as coarse anhedral phenocrysts and show pale brown to dark greenish brown pleochroism. It shows alteration to chrolite. Magmatic epidote is medium-grained subhedral and usually occurs as worm-like intergrowths with quartz. Dispersion of subhedral to anhedral quartz grains are also observed.

Diorite is the dominant magmatic rocks of the LPC (Fig. 90a). Sharp contact are observed between the gabbro and diorite with latter showing intrusion into the former. Diorites occur as greenish grey coarse grained rocks with phaneritic and hypidiomorphic texture. They are comprised of plagioclase, amphibole, magmatic epidote and quartz (Fig. 90b). Accessory minerals like sphene, zircon, apatite, Fe-oxide and secondary minerals (chlorite, epidote) are present. Plagioclase occurs as coarse tabular subhedral to anhedral phenocrysts. It shows polysynthetic twinning and alteration to sericite or saussurite. Fine euhedral plagioclase with less alteration is also observed. Amphibole occurs as coarse subhedral to anhedral crystals. Chloritized amphiboles are common. Magmatic epidote has coarse euhedral to subhedral habits with inclusions of allanite in some epidotes. Quartz occurs as medium to fine subhedral to anhedral intergranular crystal. Sometimes, it shows deformation features like undulose extinction, suture boundary and development of sub-grains.

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)

Field work has been carried out in the month of July-August, 2016 in and around the Pin valley of the Spiti Basin and faunal samples of Cambro-Ordovician successions were collected. The succession was measured and based on the field and laboratory observations the lithostartigraphic column is prepared. The sedimentary structures were also noticed at different levels of the measured section.

The different genera of calcareous algae were identified from the thin sections prepared so far. Besides the algae, various forms of gastropods, brachiopods, bryozoans were also identified. Preliminary studies were done which reveals various new forms of algae and bryozoans. Tentatively two assemblages were marked of algae and bryozoans which were correlated with fauna of the other known section of Kinnaur region of the same basin. The work is however, in progress to mark the inter- and intra-system boundaries within the studied section, which will refine the biostratigraphic zonation of the Cambro-Ordovician succession of the area. Still a detailed study on taxonomy on species level is under progress.

Three Dasyclades Calcareous algae were identified during the study as *Dasyporella*, *Vermiporella* and *Moniporella* from the Thango Formation of the Pin Valley of the Spiti Basin. Preliminary studies indicate that they are of middle- to late-Ordovician in age. The diversity of the fauna and the microfacies increases as we go higher in the succession. The carbonate horizons of the Pin Thango section have yielded an abundant assemblage of dasyclade algae which are useful to define the depositional environment of the sequence in the Spiti valley. In the Ordovician succession various transgressive system tracks are recorded the carbonates associated with microfacies show shallow marine settings. The top most part of the Upper Cambrian in this succession is marked by a sedimentological break. The detailed studies of this will be carried out in the next field to mark the total time gap.

The study of faunal assemblage reflects diverse group of microfossil such as bryozoans, algae, brachiopods, cephalopods and trilobite cheeks. It is for the first time when *Moniliporella* has been reported from this area. The present calcareous algae play an important role in understanding the paleoenvironment and its correlation with other regions. The micro-organism remains are poorly known so far from the Paleozoic succession of the Tethyan Himalayan regions. So their presence is of utmost importance to classify the Ordovician succession of this region, because the Ordovician succession in this area is dominated by these microorganism and very rarely we are getting trilobite cheeks. Calcareous algal remains are widespread in various facies in Ordovician carbonate complexes and it provides useful information about the paleoenvironments and can complement interpretations based on other biota and depositional textures.

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21. Gupta, V., Tandon R.S., Venkateshwarlu, B., Bhasin, R.K. & Kaynia A.M. 2017: Accelerated mass

RESEARCH PUBLICATIONS

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22. Hazarika, D., Wadhawan, M., Paul, A., Kumar, N., & Borah, K. 2017: Geometry of the Main Himalayan Thrust and Moho beneath Satluj valley, Northwest Himalaya: constraints from receiver function analysis. Journal of Geophysical Research (In press).

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Basin, Brahmaputra Catchment and retreat of the Daisaphu Glacier from 1989-2014 using satellite data. Current Science (Communicated).

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75. Srivastava, P., Kumar, A., Chaudhary, S., Meena, N., Sundriyal, Y.P., Rawat, S., Rana, N., Jayangondaperumal, R., Bisht, P., Sharma, D., Agnihotri, R., Bagri, D.S., Juyal, N., Wasson, R.J. & Ziegler, A.D.: Paleofloods records in Himalaya. Geomorphology (In press).

76. Suresh, N. & Kumar, R.: Evolution of Late Quaternary landforms in the Soan Dun, NW Sub-Himalaya-tectonic and climate influence. Basin Research (Communicated).

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Himachal Pradesh, India. Environmental Earth Sciences (Communicated).

78. Thakur, V.C., Joshi, M. & Suresh. N.: Formation of late Quaternary Kangra basin, deglaciation in Dhauladhar range, and reactivation of Jawalamukhi Thrust in Northwest Himalaya: Climate - tectonic linkage. Quaternary International (Under review).

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Technical Reports

1. Gupta, V., Bhakuni, S.S. & Venkateshwarlu, B. 2016: GPR study and Engineering Geological mapping of the Jakhri Landslide, Satluj Valley, Himachal Pradesh. Submitted to Central Scientific and Instruments Organisation (CSIO) Chandigarh, 14p.

2. Gupta, V. 2017: Final Report on the "International Symposium on Tackling the Challenge of Slope Stabilization and Landslide Prevention" published by the Govt of Uttarakhand, 24 p.

SEMINARS/SYMPOSIUM/WORKSHOP ORGANISED

1st National Geo-Research Scholars Meet (NGRSM) (June 1-4, 2016)

To promote geoscience research in the country, the Wadia Institute of Himalayan Geology organized *'1st National Geo-Research Scholars Meet (NGRSM)'* at its premises during June 1-4, 2016. It is a unique event that gave an opportunity to the young research scholars, the Ph.D. students and Post-Doctoral Fellows to present their scientific work in an open forum, and interact/exchange their research findings, ideas and experiences with other research scholars of other disciplines and institutions across the country.

The event was inaugurated by Padmashri Prof. Harsh K. Gupta, Former Director, National Geophysical Research Institute (NGRI), Hyderabad, who also delivered the inaugural lecture on the *'Earthquake: how to cope with them?'* Prof. S.K. Tandon, Chairman, Governing Body of the Institute is the President and Patron of the event, while Prof. Anil K. Gupta, Director, WIHG the Chairman. Drs. Aditya Kharya, Sameer K. Tiwari, M. Prakasam, Suman Lata Rawat, Anil Kumar and Praveen Chandra Singh the conveners of the event. The event was attended by more than 200 research scholars from 66 different organizations (Institutes, Universities, IITs, IISER etc.).

The four day long sessions included paper presentations in the following nine themes: (i) Earth surface processes and climate change (ii) Stratigraphy, sedimentology and Quaternary geochronology (iii) Geodynamics, tectonics and structural geology (iv) Environmental Geology, Engineering Geology, and Natural Hazards (v) Biogeosciences (vi) Petrology, Geochemistry and Geochronology (vii) Geophysical techniques and their applications (viii) Applications of geospatial techniques (Remote Sensing & GIS) in Earth Sciences (ix) Economic & Ore Geology and Mineral exploration.

Several keynote addressed on various topics related the theme of event were delivered by the distinguished Professors/Scientists of the country namely, Prof. S.K. Tandon (IISER, Bhopal), Prof. Rajiv Sinha (IITK, Kanpur), Prof. Sunil K. Singh (PRL, Ahmadabad), Prof. D.C. Srivastava (IITR, Roorkee), Prof. Devesh Sinha (Delhi University), Prof. Somnath Dasgupta (IISER, Kolkata), Prof. Talat Ahmad (Vice Chancellor, Jamia Millia Islamia University), Dr. V.M. Tiwari (NGRI, Hyderabad), Dr. Ajay Manglik (NGRI, Hyderabad), Dr. V.P. Dimri (NGRI, Hyderabad), Prof. M.K. Arora (IITR, Roorkee) and Prof. Santosh Kumar (Kumaun University, Nainital).

The Chief Guest Padmashri Prof. Harsh K. Gupta delivering the inugural lecture. The photo to the right shows the Group Photo of the participants.

Participant receiving award for best oral presentation from Prof. Anil K Gupta. To the right is a dance act from the culture event.

Prizes were also distributed for the best oral and poster presentations. The event also included field excursion to show the signature of the Main Boundary Thrust (MBT), led by eminent geoscientist Prof. D.C. Srivastava, IITR, Roorkee. A cultural event too has been organized for the participants.

Curtain Raiser Programme (November 28-29, 2016)

A Curtain Raiser event of the *'2nd India International Science Festival (IISF)'* was organized in its premises of Wadia Institute of Himalayan Geology, Dehradun on November 28-29, 2016. The event was formally inaugurated by Prof. D.C. Srivastava, IITR, Roorkee, who also delivered a talk on *'Science for the Masses'* and in a very lucid manner he explained the importance of Science and Innovations in the progress of the society. Prof. A.K. Gupta, Director, Wadia Institute of Himalayan Geology who presided over the function talked about the importance of IISF, and emphasized that this is a movement that has potential to transform the society. Dr. Rajesh Sharma, Convenor of the event introduced the audience with the structure of the event, while guests from Vijana Bharti, Shri Yudhveer and Shri Prajatantra spoke on the concept of the India International Science Event.

A total of 48 organizations including 11 government research organizations, 23 schools and 4 colleges/ universities participated. Numerous Guests from various institutions, schools and colleges, that includes more than 235 students and 60 teachers and scientists attended the event. The two days event included, (i) Science exhibition; (ii) Students-scientists discussion meet on 'Geosciences for Society'; (iii) Igniting young minds; (iv) Lectures on Traditional Knowledge of Science; (v) Intellects meet involving principals, teachers and scientists with focus on 'Innovation in Science Teaching'; (vi) Screening of science movies; (vii) student participation in science poetries and street plays; and (viii) visit to Geology Museum.

The concluding session was chaired by Prof. Anil K Gupta, Director, Wadia Institute of Himalayan Geology. Several prizes were awarded during the concluding session to promote the idea of *'Science for the Masses'*. On the basis of best exhibit and overall performance, the first prize was given to Scholar's Home, the second to ICFAI University, and the third to Kendriya Vidyalaya-IMA, two consolation prizes were given to UPES and DAV Public School. The Director's Special Prize went to the participants from Model School. Prof. Anil K Gupta, Director, WIHG has distributed the prize to the winners. In his concluding remarks, Prof. Anil K Gupta called upon the masses to promote young minds of the nation to be more innovative and use science in solving life's routine problems. He iterated the need to such events being organized on regular fashion. The event was well taken by media through wide coverage in various daily newspapers.


Prof. D.C. Srivastava, the Chief Guest lighting the lamp at the inaugural function. To the right the Chief Guest is seen interacting with students of the Blind School.


Students showing great enthusiasm in exhibiting their displays. To the right Prof. Anil K Gupta giving away the prizes to the winners.

AWARDS AND HONOURS

- Dr. R.J.G. Perumal received 'Prof. S.S. Merh award - 2016' conferred by Geological Society of India for his contribution in Quaternary Geology.
- Dr. Suman Lata Rawat received the 'Institute's Best Paper Award - 2015' for her joint paper published in Quaternary Science Reviews.
- Dr Rajesh Sharma has been chosen as Editor of the Special Book Volume of the 'Geological Society of London' on *'Crustal Architecture and Evolution of the Himalaya-Karakoram-Tibet Orogen'*.
- Dr. Naresh Kumar has been chosen as the Guest Editor of Special issue of Journal Quaternary International on 'Himalaya Active Tectonics'.
- Dr. P.S. Negi is the Managing Editor of the Journal of Phytotaxonomy.
- Sushil Kumar has been nominated as Section Secretary for the term 2016-17 of Solid Earth Section of 'Asia Oceania Geosciences Society (AOGS)'.

VISITS ABROAD

- Dr. Sushil Kumar visited Reno, Nevada, USA to attend the deliberations of the meeting of Seismological Society of America held during April 20-22, 2016. He also visited San Francisco, California, USA to participate in AGU Fall meeting held during December 12-16, 2016.
- Sh R. Arun Prasath, JRF visited Aussios, France to participate in the 31st Himalaya-Karakoram-Tibet Workshop held during May 5-15, 2016.
- Dr. Vikram Gupta visited Bangkok, Thailand to attend the deliberations of the Regional Meeting under Asian Programme for Regional Capacity Enhancement for Landslide Impact Mitigation (RECLAIM) held during November 21-25, 2016.
- Dr. P.K. Mukherjee visited South Africa to participate in the 35th International Geological Congress held at Cape Town, South Africa during 26th August to 4th September, 2016.

Ph.D. THESES

Name of Student	Supervisor	Title of the Thesis	University	Awarded/ Submitted
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	Awarded
Smita Gupta	Dr. Kishor Kumar Dr. R.S. Rana	Paleontological and geochemical study of Subathu succession of NW sub-Himalaya with reference to PETM and India-Asia collision	HNB Garhwal University, Srinagar	Awarded
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	HNB Garhwal University, Srinagar	Awarded
R.S. Ahluwalia	Dr. S.K. Jain Dr. S.P Rai Dr. D.P. Dobhal	Integrated Approach for Snow/Glacier melt runoff studies in Beas Basin, western Himalaya, India	Uttarakhand Tech. University, Dehradun	Awarded
Shubhra Sharma	Prof. B.S. Marh Dr. S.K. Bartarya	Palaeo landslide- induced damming and the resultant geomorphic land-scape: case study of the middle Satluj valley near Sunni/ Tattapani (Shimla-Mandi district), Himachal Pradesh, India	Himachal Pradesh University, Shimla	Awarded
Ravichandran M.	Dr. Anil K. Gupta Prof. M.K. Panigarahi	Indian Monsoon variability during the Holocene as seen in the sediments of the NE Arabian Sea	IIT-Kharagpur, Kharagpur	Awarded
Rajeeb Lochan Mishra	Dr. R.J.G. Perumal	Paleoseismic investigations along the Himalayan Frontal Thrust (HFT), between the meizoseismal zones of the 1934 Bihar-Nepal and 1950 Tibet-Assam earthquake, North Eastern Himalaya	Utkal University, Odisha	Submitted
Sanjay Singh Negi	Dr. Ajay Paul Dr. Kamal	Understanding the crustal structure of Garhwal-Kumaun Himalaya	IIT-Roorkee, Roorkee	Submitted
Anil Kumar	Dr. P. Srivastava Dr. K.S. Mishra	Late Quaternary landscape evolution along the Indus River: response to the climate and tectonics of Ladakh Himalaya	University of Petroleum and Energy Studies, Dehradun	Submitted

Watinaro Imsong	Dr. S.C. Vaideswaran Dr. Sarat Phukan	Geomorphological appraisal of neo-tectonic activities in the Shillong Plateau, Northeast India	Guwahati University, Guwahati	Submitted
Dipti Sharma	Prof. Y.P. Sundriyal Dr. P. Srivastava	Paleoclimatic reconstruction and past landslide activity in Alaknanda-Mandakini Valley	HNB Garhwal University, Srinagar	Submitted
M. Prakasam	Prof. Anil K. Gupta Dr. Sanghamitra Ray	Neogene paleoclimatic and paleoceano-graphic changes: multiproxy records from ODP Hole 722B, Owen Ridge, Northwestern Arabian Sea	IIT-Kharagpur, Kharagpur	Submitted
P. Saravanan	Prof. M. K. Panigrahi Prof. Anil K. Gupta	Centennial to millennial scale paleoceano-graphic changes in the eastern Arabian Sea during the Late Quaternary	IIT-Kharagpur, Kharagpur	Submitted
A. Velu	Prof. Anil K. Gupta Prof. M. K. Panigrahi	Neogene record of Indian monsoon variability from the Oman Margin and Owen Ridge, Northwestern Arabian Sea	IIT-Kharagpur, Kharagpur	Submitted

PARTICIPATIONS IN SEMINARS/SYMPOSIA

Meeting of *'Indian National Science Academy'* held at Jammu University, Jammu on May 14, 2016
Participant: Pradeep Srivastava

Meeting on *'National Mission for Sustaining the Himalayan Ecosystem (NMSHE)'* held at National Institute of Hydrology, Roorkee on June 1, 2016
Participant: R.S. Ahluwalia

National Seminar on *'Developments in Geosciences in the past decade - Emerging trends for the future & impact on society'* held at IIT-Kharagpur, Kharagpur during October 21-23, 2016
Participant: Bikaramaditya Singh

Annual convention of Indian Geophysical Union for *'Geosciences for sustainability'* held at Indian School of Mines (ISM-IIT) Dhanbad during November 8-10, 2016
Participant: S. Rajesh

International Conference on *'Emergence and Evolution of the Indian Foreland Basin'* held at Panjab University, Chandigarh during November 18-19, 2016
Participants: R.K. Sehgal and Kapesa Lokho

International Symposium on *'Asian Current Research on Fluid Inclusions (ACROFI)-VI 2016'* held at IIT, Bombay during November 25-27, 2016
Participant: Rajesh Sharma

Workshop on *'Frontiers in Earth & Climate Science (TWAS-ROCASA), DCCC',* held at IISc, Bangalore during December 5-7, 2016
Participant: M. Prakasam

National Symposium on *'Recent advances in Remote Sensing and GIS with special emphasis on Mountain Ecosystems'* held at IIRS, Dehradun during December 7-9, 2016
Participants: G. Philip and Aparna Shukla

'India International Science Festival' held at NPL, New Delhi during December 7-11, 2016
Participant: S.K. Rai

Training program on *'Geophysical software practices for subsurface imaging'* held at IIT-ISM, Dhanbad during December 12-17, 2016
Participant: Parveen Kumar

Brainstorming meeting for the development of a *'National Programme on Geodesy'* held at Technology Bhavan, New Delhi on December 14, 2016
Participant: G. Philip

National Conference on *'Himalayan Cryosphere (NCHC-2017)'* held at IISc, Bangalore during January 23-24, 2017
Participant: Aparna Shukla

Participated in the *'DST-SDC fourth National Workshop of States of the Indian Himalayan Region'* held at DST, New Delhi on January 30-31, 2017
Participants: Rajesh Sharma, S.K.Bartarya and Vikram Gupta

Participated in *'Science Conclave'* organised by Uttarakhand Council of Science and Technology, February 2017
Participant: Rajesh Sharma

Distinguished Instructor short course held at CSRI-NGRI, Hyderabad during February 27-28, 2017
Participant: Gautam Rawat

National workshop on *'Risk transfer: possibilities and challenges'* held at Hotel Aketa, Dehradun on March 6, 2017
Participant: P.S. Negi

Workshop on *'Climate change impact and mitigation'* held at Uttarakhand Academy of Administration, Nainital during March 7-9, 2017
Participant: S.K. Rai

'World conference on Environment' held at Vigyan Bhavan, New Delhi during March 25-26, 2017.
Participants: P.S. Negi and SK Rai

Brain storming workshop on *'Thermochronology and Himalayan Tectonics'* held at Department of Geophysics, Kurukshetra University, Kurukshetra during March 27-28, 2017
Participant: Paramjeet Singh

LECTURES DELIVERED BY INSTITUTE SCIENTISTS

Name of Scientist	Venue	Date	Topic
Dr. Sushil Kumar	Tibetan Homes School, Mussoorie	01.04.2016	Disasters and its management strategies in Uttarakhand
Dr. R.J.G. Perumal	Inter University Accelerator Centre, New Delhi	21.04.2016	Limitation of radiocarbon dating techniques in Paleoseismological investigation
Dr. P.S. Negi	Hotel Saurab, Dehradun	29.04.2016	Climate change and alternatives in development in India
Dr. R.J.G. Perumal	National Centre for Earth Science Studies, Trivandrum	15.05.2016	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
Dr. G. Philip	Government College, Kottayam	08.06.2016	Geospatial techniques for active tectonic studies
Dr. Rajesh Sharma	GSI Training Institute Hyderabad	28.06.2016	Economic Minerals in Himalaya
Dr. P.S. Negi	Hotel Aketa, Dehradun	28.06.2016	Concept of Eco-friendly village development in India
Dr. P.K. Mukherjee	Archeological Survey of India, Dehradun	11.08.2016	i) An introduction to rocks and Minerals ii) Weathering pattern in building stones
Dr. Pradeep Srivastava	SMVD University, Jammu	04.09.2016	Continental Drift, Plate Tectonics and Build-up of Himalaya
Dr. S.C. Vaideswaran	IIT-Roorkee, Roorkee	04.11.2016	Concept of pre-earthquake thermal anomaly and their remote sensing based detection
Dr. R.K. Sehgal	Panjab University, Chandigarh	19.11.2016	Cenozoic mammalian dispersal pattern and its relation to uplift of Himalaya
Dr. S.C. Vaideswaran	Guwahati University, Guwahati	23.11.2016	Remote Sensing Applications in Earthquake studies and crustal movements
Dr. Naresh Kumar	IIT-ISM, Dhanbad	13.12.2016	i) Seismic wave tomography and Earth structure ii) Earthquake source parameter determinations using SEISAN and HypoDD software, and iii) Surface wave dispersion analysis using FTAN (Frequency Time Analysis)

Dr. G. Philip	BFIT Group of Institutions, Dehradun	21.02.2017	Geospatial Technology for Active Faults and Seismic Hazard Assessment
Dr. S. Rajesh	ISRO/IIRS	21.02.2017	Geodynamics and seismicity investigations in the NW Himalaya - GNSS component
Dr. Gautam Rawat	CSRI-NGRI, Hyderabad	2.03.2017	Magnetotelluric experiments in NW Himalaya
Dr. Pradeep Srivastava	Administrative Training Institute, Nainital	21.03.2017	Climate vulnerability and paleoflood records in Himalaya
Dr. Santosh K Rai	International Centre, New Delhi	27.03.2017	Cessation of the course of River Sarasvati (Haryana): Implication to the Vedic civilization in Indian sub-continent

MEMBERSHIP

Dr. Rajesh Sharma : Member - Expert Committee of NGT for talc mining related activities in the Bageshwar District

Dr. R.J.G. Perumal : Life Membership - Geological Society of India, Bangalore.

Dr. Kishor Kumar : Life Fellow - Palaeontological Society of India
Member - Discussion List Society of Vertebrate Paleontologists, USA

Dr. Pradeep Srivastava : Member - Editorial Board of Quaternary International (Elsevier)

Dr. G. Philip : Member - Organizing Committee of the National Symposium ISRS-ISG-2016

Dr. Sushil Kumar : Member - Seismological Society of America (SSA) for the year 2016-17.
Member - Japan Geoscience Union (JpGU) for the year 2016-17.
Member - Indian Society of Earthquake Technology (ISET) for the year 2016-17
Member - American Geophysical Union (AGU), USA for the year 2016-17.

Dr. Vikram Gupta : Member - Special Expert Committee constituted by Hon'able National Green Tribunal (NGT) for construction related activities in Kasauli (Himachal Pradesh)
Member - Expert Committee constituted by Hon'able National Green Tribunal (NGT) for construction related activities in Shimla (Himachal Pradesh)

POPULAR LECTURES DELIVERED IN THE INSTITUTE

- Prof. W.D. West Memorial Lecture was delivered by Professor Talat Ahmad, Vice Chancellor, Jamia Millia Islamia, New Delhi on Sept. 30, 2016. The title of the lecture was 'Evolution of the Trans - Himalayan Terrain: constrains from Indus and Shyok Suture Zone'.

Prof. Talat Ahmad delivering the 'Prof. W.D. West Memorial Lecture'

- Prof. R.C. Misra Memorial Lecture was delivered by Prof. S K Shah (retd.), Jammu University, Jammu on March 1, 2017. The title of the lecture was 'Regional stratigraphical studies and education: Emerging Scenario'.

Prof. S.K. Shah delivering the 'Prof. R.C. Misra Memorial Lecture'

- Prof. M.R. Sahni Memorial Lecture was delivered by Prof. Jere H Lipps, University of California, Berkely, USA on March 1, 2017. The title of the Lecture was 'Palaeo Parks: Protecting and conserving fossils resources world-wide'

Prof. Jere H Lipps delivering the 'Prof. M.R. Sahni Memorial Lecture'

- Prof. D.D. Misra, Chairman, (GC & EB), IIT-ISM, Dhanbad delivered a popular lecture on 'Geoscientists, question about chronology' on July 5, 2016.

- Prof. Nigel C. Hughes, University of Bristol, UK delivered a popular lecture on 'Integrating the Cambrian geological record of the Indian subcontinent and its implications for constraining Himalayan uplift and erosion' on November 22, 2016.

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section during this year brought out the publications of (i) 'Himalayan Geology' volumes 37(2) and 38(1), (ii) 'Annual Report' of the Institute for the year 2015-16 in Hindi and English, (iii) Hindi magazine 'Ashmika' volume 22, (iv) Newsletters 'Bhugarbh Vani' volumes 6 (in four parts) and 'Drishtikon' volume 5, and (v) Abstract volume of the 1st National Geo-Research Scholars Meet-2016. Apart from this, works pertaining to printing of brochures and 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. The 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), Elsevier (Netherlands), and in Indian Citation Index (India). Thirteen new members got registered for Himalayan Geology journal under the Life Time Subscriber Scheme (LTSS) membership bring the total registered number to 464.

LIBRARY

The Library of Wadia Institute of Himalayan Geology is unique with its finest collection of books, monographs, journals, and e-books etc. on the mountain building process, geological and geophysical phenomenon with special reference to Himalaya. The collection and services offered makes it one of the best libraries in the country in the field of Earth Sciences. The Library has always remained best information access to the scientists, researchers and projects staff for their specialized research pursuits. Students from various universities/institutions and professionals across the country also visit the Library to consult thematic and rare collections that are available in the Library.

The Library has subscribed to 75 International and 38 Indian Journals. The Library is upgraded with 12 more reference books, while 16 books are received as gratis. In addition to this, more than 100 books have been added to the Hindi Collections. The Library has also more than 4000 carefully selected e-books from different publishers and learned societies on the thrust areas of research of the Institute. During 2016-17, the existing collections have been further added with more new e-books collections. For easy access and exclusive publications of the research work by WIHG, digitization of research publications have been carried out by incorporating them into the Institutional Repository (IR). The repository consists of 95 full PDF text of Prof D.N. Wadia's publications and more than 1900 PDFs of WIHG Scientist's publications which are also placed on the intranet of the Institute.

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

The Library has also a small hub of computers for the users for accessing the e-books and e-journals and other e-resources available, either subscribed by WIHG Library or available through NKRC. The WIHG scientists were provided books/journals on inter-library loan as and when required from the Libraries of other organizations situated at Dehra Dun. The Library further serves as a central facility for the reprography demand of the Institute.

S.P. NAUTIYAL MUSEUM

Museum of the Institute is the key affiliation of education and continues to generate an axis of awareness to the students and general public not only from the local areas and distant corners of India but also from abroad. The exhibits and the information provided in the Museum continued to attract the students and general public. Some of the educative exhibits include, Drifting Continents, Volcanoes, Earthquakes, Origin and Evolution of Life, Himalayan Glaciers, Landslides, Flash floods, etc. In recent times one of the major and effective attraction was the display of a Geological clock at the entrance wall of the museum. It is 10 feet x 7 feet three-dimensional model that depicts the life through ages. It shows the distribution of life in the different epochs. The other attraction is the model of extinct species of Giraffe prepared from waste material (sending the message of saving the environment) and displayed for general public along with new models of Extinct Horse and Elephant. The exhibit was also appreciated during the science outreach programme by the general public and by the dignitaries who visited the Institute. The museum thus remains the main center of attraction of the Institute for the national and international visitors. Students from different schools, universities, colleges and from other institutions visited the museum and guided tours were provided to them. During this year more than 2,400 people visited the Museum and a number of students continue to visit the museum for their respective project works.

The Museum observes Open Days on National Technology Day, Foundation Day, Founder's Day and National Science Day. Open Days for public are given wide coverage through print media, as a result of which large number of students and general public visited the museum on these occasions. As a part of awareness to general public and the students', brochures both in Hindi and in English are provided free of cost regarding the Institute activities.

TECHNICAL SERVICES

Analytical Services

The number of samples analyzed by various instruments like XRF, ICP-MS, SEM-EDX, XRD, OSL, Stable Isotope Mass Spectrometer, EPMA are as follows:

Instrument		Samples analysed	
	WIHG Users	Outside Users	Total
Palynology Lab/Total Organic Carbon Analyzer	425	Nil	425
Luminescence dating (TL/OSL) laboratory	174	12	186
XRF lab	730	583	1313
ICP-MS lab	827	805	1632
SEM-EDX lab	3003	1117	4120
XRD lab	462	136	598
EPMA (slides analyzed)	35	36	71
IRMS	1301	161	1462
LA-MC-ICPMS	220 (Liquid mode)	13 (Solid mode)	220 (Liquid mode)
(Zircon geochronology)	34 (Solid mode)	-	47 (Solid mode)
	1240 (Total Spots analysed for Zircon U-Pb ages)	330 (Total Spots analysed for Zircon U-Pb ages)	1570 (Total Spots analysed for Zircon U-Pb ages)
Mineral Separation Lab	148	15	163
LINTABTM 6 Tree-ring station (Tree-ring width measurement station)	194	-	194
Laser Particle Size Analyser	923	-	923
Vibratory Sieve analyser	32	-	32
Pipette analysis	92	-	92
Paleomagnetic Lab:			
AFD and Spinner Magnetometer	184	-	184
Magnetic Susceptibility Meter	184	-	184
Impulse Magnetizer	184	-	184
Anhystric Remanent Magnetizer	184	-	184
Kappa bridge (KLY-3S)	384	-	384

Photography Section

During the year, approximately 6000 images were clicked using digital cameras to cover the various functions organized in the Institute from time to time, including Foundation Day, Founders day, National Science Day, National Technology Day, New Year's Day, Republic day, Independence Day, Seminars/ Symposia (e.g., National Geo Scholars Meet 2016), cultural programme, and superannuation parties for Institute staff etc. Apart from this around 800 snaps were clicked for rock and fossil specimens. The colour printing of around 300 digital images was arranged from the market. Majority of scientists have cameras issued permanently to them for use in the field and laboratory, while the remaining scientists from projects and research scholars are provided cameras from a pool as and when they require it.

Drawing Section

The Drawing Section catered to the cartographic needs of the Scientists of the Institute including the sponsored projects. During the year, the section has provided 35 geological maps/structural maps/geomorphological maps/seismicity diagrams for the scientists and research scholars of the Institute. Besides, the tracing of fourteen topographic sheets/aerial photo maps was carried out along with the preparation of the two geological columns. The section has also provided name labels, thematic captions during different activities and functions of the Institute including writing work on the photo identity cards of the employees of the Institute.

Sample Preparation Laboratory

The sample preparation laboratory provided thin/ microprobe/polished sections to the requirements of the Institute Scientists and Research Scholars. During the year, the laboratory provided more than 1280 thin and polished sections to various users for carrying out microscopic, fluid inclusion and EPMA studies. The laboratory also processed crushing/grinding of more than 1260 rock samples for carrying out major, trace and REE analysis by ICPMS, XRF and XRD methods.

CELEBRATIONS

Foundation Day

The 48th Foundation Day of the Institute was celebrated in the Institute on June 29, 2016. Prof. M.P. Singh of Lucknow University was the Guest-of-Honour and Prof. Anil K Gupta, Director chaired the function. 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 Dr. Suman Lata Rawat for their joint paper on *'Late Pleistocene - Holocene vegetation and Indian summer monsoon record from the Lahaul, Northwest Himalaya, India*', published in Quaternary Science Reviews journal.

The Guest-of-Honour Prof. M.P. Singh addressing the staff and other guests on the occasion of the Foundation Day

Prof. M.P. Singh who was the Guest-of-Honour on the occasion gave away the *'2nd Prof. R.C. Misra Gold Medal in Geosciences Award'* to Dr. Seema Singh of Geology Department, Panjab University, Chandigarh. The award is given annually to the young scientists below the age of 35 years. The 'Best Workers Awards' for the Institute employees were also given away by Prof. M.P Singh and Prof. Anil K. Gupta to Sh. Rakesh Kumar, Sh. Manmohan, Sh. Vijay Ram Bhatt, Sh. Tajender Ahuja, Sh. C.B. Sharma and Sh. Ramesh Chand Rana. Letter of appreciation were also given to Sh. Girish Chander Singh, Sh. Jeevan Lal, Km. Richa Kukreja, Sh. Rahul Sharma, Sh. Neeraj Bhatt, Smt. Rajvinder Kaur and Sh. Deepak Kumar Tiwari.

Dr. Seema Singh receiving the *'2nd R.C. Misra Gold Medal'* from Prof. M.P. Singh

Dr. Suman Lata Rawat receiving the *'Best Paper Award'* from Prof. M.P. Singh

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 were 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. Mahesh Sharma, Ex-Chairman, Khadi & Village Industries Commission was the Chief Guest on the National Science Day i.e., 28th February. He delivered the 'National Science Day Lecture' on *'Science & Technology for sustainable development with a focus on Sabka Vikas'*. The lecture was attended by a large number of students from different schools, general visitors and by the Institute staff. The occasion was also marked by distribution of prizes by the Chief Guest to the winners of the Science Quiz and Hindi Essay competitions.

The Chief Guest Dr. Mahesh Sharma delivering the *'National Science Day Lecture'*, and also seen giving away the prizes to the winners.

February 29, 2017 was observed as 'Open Day' by the Institute. The laboratories and Museum were kept open to students and public on this day. A large number of school and college students, and other public from Dehradun region 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 visited by large number of students and other visitors, in which various exhibits related to the Himalayan glaciers, Earthquakes, Landslides, Origin of Life, Volcanoes, Rocks Minerals, etc., were displayed and were explained to visitors.

Technology Day

The Technology Day was celebrated in the Institute on June 14, 2016. On this occasion, the Chief Guest, Professor J.N. Goswami, Director, Physical Research Laboratory, Ahmedabad delivered the Technology Day Lecture on the topic *'From a fishing village to the Red Planet'*.

The Chief Guest Professor J.N. Goswami delivering the *'Technology Day Lecture'*

Independence Day

The Institute celebrated Independence Day on August 15, 2016. 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.

Flag Hoisting and drawing competitions for children as a part of Independence Day celebrations

Sports competitions for children as a part of Independence Day celebrations

National productivity week - 2017

Institute has organized National Productivity Week during February 12-18, 2017, which was organized by Dr. Rajesh Sharma. The mandate of the program was to increase productivity in routine office work and research output through time management. This nationwide specific drive/campaign for the National Productivity Week 2017 is *'From waste to profit through Reduce, Recycle & Reuse'*. On the occasion, an invited lecture was delivered by Prof. Shishir Kumar, Director Academic Administration, Dehradun Institute of Technology University Dehradun. The Institute also organized (i) round table discussion on increasing the scientific productivity of the research scholars/ scientists, and (ii) slogan competition on theme related to Time Management.

Prof. Shishir Kumar delivering the invited lecture on the occasion of National Productive Week celebration

International Yoga Day

International Yoga Day was celebrated in the Institute on June 21, 2016. On this occasion, more than 100 employees of the Institute practised Yoga under the directives and guidance of the International Yoga instructors Sh Sunil Lalwani and Sh Hemant Kundra of the 'Art of Living'.

Employees of the Institutes practicing Yoga on the International Yoga Day

Other activities

The Institute organized Clean Mission India programme on October 2, 2016, a National campaign event initiated by the Government of India on the birth date of the Father of our Nation as a part of Swachh Bharat Abhiyan.

Under Public awareness programme, Indian Medical Association, Dehradun on June 27, 2016 has organised *'No Tobacco Campaign'* programme in the Institute. Under this programme, Dr Sudhanshu Kalra, M.D has delivered a lecture on *'Quit Tobacco'*.

A free Heart check-up camp by Fortis Escorts Hospital was organized for the employees of the Institute on June 24, 2016.

DISTINGUISHED VISITORS TO THE INSTITUTE

- Dr. Harsh Vardhan, Hon'ble Minister of Science and Technology & Earth Sciences, Government of India.
- Justice Saha, Chief Lokayukta, Chhattisgarh.
- Prof. Harsh K Gupta, Member, Atomic Energy Regulatory Board, Former Director CSIR-NGRI, Hyderabad.
- Dr. V.P. Dimri, Former Director, CSIR-NGRI, Hyderabad.
- Professor J.N. Goswami, Director, Physical Research Laboratory, Ahmedabad.
- Prof. Talat Ahmad, Vice Chancellor, Jamia Millia Islamia University.
- Prof. S K Shah (retd.), Jammu University, Jammu.
- Dr. Jere H. Lipps from University of California, Berkely, USA.
- Prof Nigel C. Hughes, University of Bristol, UK.
- Dr. Mahesh Sharma, Ex-Chairman, Khadi and Village Industries Commission, New Delhi.
- Prof. D.D. Misra, Chairman, GC & EB, IIT-ISM, Dhanbad.
- Sh. Jaya Kumar, Secretary General, Vijnan Bharti, New Delhi.
- Prof. (Col) Shishir Kumar, Director, Academic Administration, Dehradun Institute of Technology University, Dehradun.
- Dr. Chhaya Shukla, Member, Uttarakhand Public Service Commission, Haridwar, Uttarakhand.

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, 2016. Inaugural lecture of the Pakhwara was delivered by Justice S.N. Srivastava, Lokayukt, Chattisgarh wherein he spoke on how on September 14, 1949 the Constituent Assembly of India had adopted Hindi written in Devanagari script as the "official language Rastriya Bhasha of the Republic India. Also, as a part of the lecture series during the

Justice S.N. Srivastava delivering the inaugural lecture during the Hindi Pakhwara celebration

Hindi Pakhwara celebrations, Dr. L.M.S. Palni, Dean, Graphic Era, Dehradun had delivered a lecture on 'Jaivivitta jeevan hain: jaivivitta humara jeevan hain', and Dr. Nilay Khare, Director, MoES delivered a lecture on 'Climate Change and National Effort'. 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 organized during Pakhwara. During this bi-weekly

Dr. Nilay Khare delivering the lecture

programs, the Institute employees like, Dr. Sushil Kumar, Dr. Narendra Meena, Dr. S.K. Bartarya and Dr. Rajesh Sharma had also delivered lectures in Hindi on specialized topics.

On September 28, 2016, the closing day of the Hindi Pakhwara celebrations a special lecture was delivered by the Chief Guest, Prof. Surendra Kumar, Hon'ble Vice Chancellor of Gurukul Kangri University, Hardwar. In his lecture he emphasized on publicity, extension and strengthening of Hindi language for cultural and socioeconomic development of the India through the via media of Hindi as our National Language. The lecture was followed by distribution of prizes to the winners of various events organized during the celebrations.

Prof. Surendra Kumar delivering the lecture

Keeping in view the annual program for the implementation of the official language policy of the Union of India, various steps were taken to promote use of Hindi in routine work as well as in scientific research. The scientists and staff of the Institute were time and again apprised with the various orders and constitutional provisions of official language. General orders, circulars and notices were issued in Hindi as well as in English. Various incentive schemes for encouraging progressive use of Hindi were also implemented. The Annual Report of the Institute for the year 2015-16 was published in bilingual form (Hindi and English), along with volume 22 of the in-house Hindi magazine 'Ashmika'. Also, for the promotion of Hindi among the Institute staff a good collection of Hindi books were procured in the Institute Library.

STATUS OF IMPLEMENTATION OF HINDI

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 2016-17.

6. Status of Vigilance Cases

There is one vigilance case pending during the year 2016-17.

7. Information on the RTI cases

Four applications for seeking information under the Right to Information Act, 2005 were carried forward from the previous year 2015-16.

The details of information on the RTI cases during the year 2016-17 are as under:

Details	Opening balance as on 01.04.2016	Received during the year 2016-2017	Number of cases transferred to other public authorities	Decisions where requests/ appeals were rejected	Decisions where requests/ appeals accepted
1	2	3	4	5	6
Requests for information	04	27*	02	Nil	23
First appeals	Nil	Nil	Nil	Nil	Nil

*Six applications under the Right to Information Act, 2005 were carried forward to the next financial year 2017-18.

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 2016-2017

Plan	:	Rs. 27,53,19,000.00
Non-Plan	:	Rs. 10,00,000.00
Total	:	Rs. 27,63,19,000.00

STAFF OF THE INSTITUTE AS ON 01.04.2017

Scientific Staff

1. Prof. Anil Kumar Gupta	Director
2. Dr. (Mrs.) Meera Tiwari	Scientist 'G'
3. Dr. Kishor Kumar	Scientist 'G'
4. Dr. Rajesh Sharma	Scientist 'G'
5. Dr. G. Philip	Scientist 'G'
6. Dr. B.N. Tiwari	Scientist 'G' (Retd. on 31.07.16)
7. Dr. D. Rameshwar Rao	Scientist 'G'
8. Dr. P.K. Mukharjee	Scientist 'G' (Retd. on 31.12.16)
9. Dr. S.K. Bartarya	Scientist 'G'
10. Dr. S.K. Parcha	Scientist 'F'
11. Dr. H.K. Sachan	Scientist 'F'
12. Dr. Sushil Kumar	Scientist 'F'
13. Dr. A.K. Mahajan	Scientist 'E' (On Lien)
14. Dr. D.P. Dobhal	Scientist 'E' (On Deputation)
15. Dr. Vikram Gupta	Scientist 'E'
16. Dr. Suresh N.	Scientist 'E'
17. Dr. Pradeep Srivastava	Scientist 'E'
18. Shri V. Sriram	Scientist 'E' (Retd. on 31.05.16)
19. Dr. Ajay Paul	Scientist 'E'
20. Dr. S.S. Bhakuni	Scientist 'E'
21. Dr. P.S. Negi	Scientist 'D'
22. Dr. A.K.L. Asthana	Scientist 'D'
23. Dr. R. Jayangondaperumal	Scientist 'D'
24. Dr. A.K. Singh	Scientist 'D'
25. Dr. (Mrs.) Kapesa Lokho	Scientist 'D'
26. Dr. Khaying Shing Luirei	Scientist 'D'
27. Dr. Gautam Rawat	Scientist 'D'
28. Dr. R.K. Sehgal	Scientist 'D'
29. Dr. Jayendra Singh	Scientist 'D'
30. Dr. B.K. Mukherjee	Scientist 'D'
31. Dr. Santosh Kumar Rai	Scientist 'D' (Lien vacancy)
32. Dr. Rajesh S.	Scientist 'C'
33. Dr. Naresh Kumar	Scientist 'C'
34 Dr.(Mrs) Swapnamita Ch.	Scientist 'C'
35. Dr. Devajit Hazarika	Scientist 'C'
36. Dr. Narendra K. Meena	Scientist 'C'
37. Dr. Dilip Kumar Yadav	Scientist 'C'
38. Dr. Param K.R. Gautam	Scientist 'C'
39. Dr. Kaushik Sen	Scientist 'C'
40. Dr. Satyajeet S. Thakur	Scientist 'C'
41. Dr. Manish Mehta	Scientist 'C'
42. Dr. (Ms.) Aparna Shukla	Scientist 'C'
43. Dr Sudipta Sarkar	Scientist 'B'
44. Sh. M. Prakasam	Scientist 'B'
45. Dr. Vikas	Scientist 'B'
46. Sh. Som Dutt	Scientist 'B'
47. Sh. Anil Kumar	Scientist 'B'
48. Sh. Saurabh Singhal	Scientist 'B'
49. Dr. Narendra Kumar	Scientist 'B'
50. Sh. Vinit Kumar	Scientist 'B'
51. Dr. Aditya Kharya	Scientist 'B'
52. Dr. Paramjeet Singh	Scientist 'B'
53. Dr.(Ms) Suman Lata Rawat	Scientist 'B'
54. Dr. Indu Shekhar	Scientist 'B' (Resign on 01.08.16)
55. Dr. (Mrs) Chhavi P. Pandey	Scientist 'B'
56. Dr. Parveen Kumar	Scientist 'B'
57. Dr. Aliba AO	Scientist 'B'

Technical Staff

1. Shri Saeed Ahmad	Sr. Librarian (Retd. on 31.08.16)
2. Shri M.M.S. Rawat	Sr. Tech. Officer (Retd. on 31.07.16)
3. Shri Sanjeev K. Dabral	Sr. Tech. Officer
4. Shri Chandra Shekhar	Sr. Tech. Officer
5 Shri Samay Singh	Sr. Tech. Officer
6. Shri Rakesh Kumar	Sr. Tech. Officer
7. Shri H.C. Pandey	Technical Officer
8. Shri Ravindra Singh	Technical Officer
9. Shri N.K. Juyal	Technical Officer
10. Shri T.K. Ahuja	Technical Officer
11. Shri C.B. Sharma	Assistant Engineer
12. Shri S.S. Bhandari	Librarian
13. Shri Rambir Kaushik	Asstt. Pub. & Doc. Officer
14. Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
15. Shri Bharat Singh Rana	Librarian
16. Dr. Jitendra Bhatt	Sr. Tech. Assistant
17. Shri Pankaj Chauhan	Sr. Tech. Assistant (On Deputation)
18. Shri Lokeshwar Vashistha	Sr. Lab. Technician
19. Dr. S.K. Chabak	Sr. Lab. Technician
20. Shri R.M. Sharma	Sr. Lab. Technician
21. Shri C.P. Dabral	Sr. Lab. Technician
22. Shri S.K. Thapliyal	Sr. Lab. Assistant (Retd. on 31.03.17)
23. Shri Shiv Pd. Bahuguna	Sr. Lab. Assistant
24. Shri Sashidhar Pd. Balodi	Sr. Lab. Assistant
25. Shri Rajendra Prakash	Sr. Lab. Assistant
26. Shri A.K. Gupta	Sr. Lab. Assistant (Retd. on 30.04.16)
27. Shri Tirath Raj	Sr. Lab. Assistant
28. Shri Nand Ram	Elect-cum-Pump.Optr.
29. Shri Balram Singh	Elect-cum-Pump Optr.
30. Smt. Sarita	Tech. Assistant
31. Sh. Rakesh Kumar	Tech. Assistant
32. Km. Sakshi Maurya	Tech. Assistant
33. Km. Disha Vishnoi	Tech. Assistant
34. Shri Abhimanyu Yadav	Tech. Assistant (Lien vacancy)
35. Shri Prateek Negi	Artist-cum-Modeller
36. Shri Rahul Lodh	Lab Assistant
37. Shri Nain Das	Lab. Assistant

38. Shri Navneet Kumar	Draftsman (Retd. on 31.05.16)
39. Shri B.B. Saran	Draftsman
40. Shri Tarun Jain	Draftsman
41. Shri Pankaj Semwal	Draftsman
42. Shri Santu Das	Section Cutter
43. Shri Puneet Kumar	Section Cutter
44. Shri Ram Kishor	Field-cum-Lab Attendant
45. Shri Ansuya Prasad	Field-cum-Lab Attendant
46. Shri Madhu Sudan	Field-cum-Lab Attendant (Retd. on 30.09.16)
47. Shri Hari Singh Chauhan	Field-cum-Lab Attendant
48. Shri Ravi Lal	Field-cum-Lab Attendant
49. Shri Preetam Singh	Field-cum-Lab Attendant
50. Mrs. Rama Pant	Field Attendant
51. Shri R.S. Negi	Field Attendant
52. Shri Ramesh Chandra	Field Attendant
53. Shri Khusi Ram	Field Attendant (Retd. on 31.07.16)
54. Shri Tikam Singh	Field Attendant (Retd. on 31.03.16)
55. Shri Bharosa Nand	Field Attendant (Retd. on 31.01.17)
56. Shri B.B. Panthri	Field Attendant
57. Shri M.S. Rawat	Field Attendant
58. Shri Sanjeev Kumar	Field-cum-Lab Attendant
59. Shri Deepak Tiwari	Field-cum-Lab Attendant
60. Shri Ajay K. Upadhaya	Field-cum-Lab Attendant
61. Km. Sangeeta Bora	Field-cum-Lab Attendant
62. Shri Deepak Kumar	Field-cum-Lab Attendant
63. Km. Anjali	Field-cum-Lab Attendant

Administrative Staff

1. Shri Pankaj Kumar	Registrar
2. Shri Harish Chandra	Fin. & Accounts Officer (Retd. on 31.10.16)
3. Shri A.S. Negi	Administrative Officer
4. Mrs. Manju Pant	Asstt. Fin. & Accounts Officer
5. Shri Manas Kumar Biswas	Store & Purchase Officer
6. Shri Hukam Singh	Office Superintendent (Retd. on 30.11.16)
7. Mrs. Shamlata Kaushik	Assistant (Hindi)
8. Smt. Rajvinder K. Nagpal	Stenographer
9. Shri M.C. Sharma	Assistant
10. Shri S.K. Chhettri	Assistant
11. Shri Vinod Singh Rawat	Assistant (Vol. Retd. on 01.10.16)
12. Shri Rahul Sharma	Assistant
13. Shri S.K. Srivastava	Assistant
14. Km. Shalini Negi	Stenographer
15. Km. Richa Kukreja	Stenographer
16. Mrs. Prabha Kharbanda	Upper Division Clerk
17. Shri R.C. Arya	Upper Division Clerk
18. Mrs. Kalpana Chandel	Upper Division Clerk
19. Mrs. Anita Chaudhary	Upper Division Clerk
20. Shri Shiv Singh Negi	Upper Division Clerk
21. Mrs. Neelam Chabak	Upper Division Clerk
22. Mrs. Seema Juyal	Upper Division Clerk
23. Mrs. Suman Nanda	Upper Division Clerk
24. Shri Kulwant S. Manral	Upper Division Clerk
25. Sh. Vijai Ram Bhatt	Lower Division Clerk
26. Shri Rajeev Yadav	Lower Division Clerk
27. Shri Girish Chandra Singh	Lower Division Clerk
28. Shri Deepak Jakhmola	Lower Division Clerk
29. Km. Rachna	Lower Division Clerk
30. Shri Dinesh Kumar Singh	Lower Division Clerk

Ancilary Staff

1. Shri Sohan Singh	Driver
2. Shri Shyam Singh	Driver
3. Mrs. Kamla Devi	Bearer
4. Mrs. Deveshawari Rawat	Bearer
5. Shri S.K. Gupta	Bearer
6. Mrs. Omwati	Bearer
7. Shri Jeevan Lal	Bearer
8. Shri Surendra Singh	Bearer
9. Shri Preetam	Bearer
10. Shri Ramesh Chand Rana	M.T.S.
11. Shri Pankaj Kumar	M.T.S.
12. Shri Ashish Rana	M.T.S.
13. Shri Harish Kumar Verma	M.T.S.
14. Shri Dinesh Pd. Saklani	Guest House Attendant
15. Shri Sunil Kumar	Guest House Attendant
16. Shri Mahendra Singh	Chowkidar
17. Shri Rohlu Ram	Chowkidar
18. Shri H.S. Manral	Chowkidar
19. Shri G.D. Sharma	Chowkidar
20. Shri Satya Narayan	Mali
21. Shri Ramesh	Safaiwala
22. 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 2016-17)

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 2016-17)

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 2016-17)

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 2016-17)

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

R.O.: 61-PNB Enclave, Shimla Road, Dehradun - 248 171
2nd Office: 1st Floor, Ganpati Tower, St. Jude's Chowk, Shimla Road, Dehradun-248 171
Ph: +91-9997941014, 8650141717
E-mail: fcapranay7@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, 2017 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 * Dehradun * Chartered Accountants

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

STATEMENT OF ACCOUNTS

PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

R.O.: 61-PNB Enclave, Shimla Road, Dehradun - 248 171
2nd Office: 1st Floor, Ganpati Tower, St. Jude's Chowk, Shimla Road, Dehradun-248 171
Ph: +91-9997941014, 8650141717
E-mail: fcapranay7@gmail.com

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, 2017;
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: 14th June, 2017
Place: Dehradun

STATEMENT OF ACCOUNTS

Annexure – 1 to the Consolidated Financial Statements Audit Report (FY 2016-17)

The Following observations were noticed during the course of audit for the Financial Year 2016-17. The same have been discussed with the management and comments/ explanations of the management thereon have also been observed.

Sl. No.	Comments/Observations by Chartered Accountants	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 transactions 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.	The accounts of the institute are being maintained on actual requirement and on cash basis. As such, the liability on account of retirement benefits is not being provided for.
3.	The internal control regarding Fixed Assets needs to be strengthened. The following observations are made: a) The Physical verification report of the Fixed Asset for the Financial Year 2014-2015 has been produced before us in which no shortage and excess has been detected however physical verification of Fixed Assets for the financial Year 2015-2016 and Financial Year 2016-2017 has not been undertaken.	The physical verification of Fixed Assets for F.Y. 2015-16 has already been initiated and is currently in progress. Once the settlement towards F.Y. 2015-16 is completed, the action towards physical verification of Fixed Assets for the subsequent years will be initiated.

Pranay Seth & Associates ★ Chartered Accountants ★ Dehradun

STATEMENT OF ACCOUNTS

<table>
<tr>
<td>4.</td>
<td>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, 2017. As per the management the same policy had been adopted in the previous financial years also.
b) The books are depreciated @ 15% p.a. instead of 60% p.a. on W.D.V basis as applicable to Research Institutes.</td>
<td>The observation is being noted for compliance during current Financial year (2017-18).</td>
</tr>
<tr>
<td>5.</td>
<td>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. 1,41,736/- and Staff Debtors amounting to Rs 6,26,519/- 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 1,68,008.00 has been shown as credit balance in Party debtors and Rs. 32,729/- in Staff Debtor which should be taken to receipts after following nodal procedure.</td>
<td>The Institute has made its best efforts to settle the outstanding advances lying against debtors. Most of the old outstanding advances against staff have been adjusted. The advances outstanding against staff pertain to advances for their TA/DA bills for field work which are normally adjusted after completion of that particular field work/visit.
However, some of the advances outstanding against party debtors for a number of years could not be settled and we are on the job for settlement of these advances during current F.Y. 2017-18. Further, the procedure for booking credit balance under 'Party Debtors' and 'Staff Debtors' is also under active consideration.</td>
</tr>
<tr>
<td>6.</td>
<td>During the course of audit it was observed that the institute has not deducted TDS while making payments to suppliers for instance:
<table>
<tr><th>Date</th><th>Voucher no</th><th>Nature of Payment</th><th>Amount of Payment</th></tr>
<tr><td>30.03.2017</td><td>2024C-186</td><td>IIM-NMD ATM 2016</td><td>100000.00</td></tr>
<tr><td>07.02.2017</td><td>1621C-79</td><td>Repair of</td><td>161000.00</td></tr>
</table>
</td>
<td>The deduction of TDS has been left inadvertently on certain occassions. However, it has been confirmed from respective parties that the same was being taken care by them in self assessment.</td>
</tr>
</table>

Pranay Seth & Associates
Dehradun
Chartered Accountants

		Equipment	
23.01.2017	1545C-56	Advocate	234500.00
25.11.2016	1259C-169	Stall Rent	200000.00
10.08.2016	678C-83	AMS Dating	166600.00
21.03.2017	70 WIHGGED-IIRS PROJECT	Travel	76019.00
09.11.2016	52 DSTARCHANA PROJECT	Travel	58022.00

7.	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 and WIHG-IGU Workshop 2013 for Rs. 3,32,048.00 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.	a) A financial assistance of Rs. 22.00 Lakh was sanctioned by SERB vide its letter dated 12.06.2012 for Training workshop on "Quaternary setup of Arid NW Himalaya: Main focus on Ladakh" during 18th August 2012 to 6th September, 2012 and released an amount of Rs. 20.00 Lakh in this regard as initial grant and final release was to be made on submission of final Utilization Certificate and Statement of Expenditure to SERB. However, the balance grant is pending from SERB. Now, matter is being taken up with SERB and we will again submit the copy of Utilization Certificate to get the entry reversed. b) The amounts of Rs. 41,275/- and Rs. 3,32,048/- paid towards IGU convention-2009 and WIJH-IGU workshop 2013 respectively were to be debited/booked under the Head "Seminars & Conferences" but wrongly debited against "Earmarked Funds" Head. The entry for the same shall be reversed during current F.Y. 2017-18.
8.	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.	The institute is currently publishing all the tenders on central Public Procurement Portal as well on the institute's website. E-tendering process as per Govt. of India procurement rules has already been initiated. Ten digital signatures for officials of Institute have already been obtained towards this. Other essential stages

Pranay Seth & Associates
Dehradun
Chartered Accountants

<table>
<tr><td></td><td></td><td>towards E-tendering are under progress.</td></tr>
<tr><td>9.</td><td>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. The Management of the Institute need to take urgent action.</td><td>The need for state of art user friendly and customized software for accounts section has also been felt at institute's level itself. As a result of the same, the partial updation of data in the form of software for "Payroll Management" has already been installed for payment and maintenance of records pertaining to staff salary, Pension etc. and the same is working satisfactorily.

Further, as per suggestions made by the auditors during the course of audit, the institute has purchased "Tally Software" for maintaining records of financial transactions/ ledgers etc. The shifting of all records/ledgers to Tally Software is under process and current year (2017-18) records of Financial Statement/ Balance-sheet etc shall be prepared on Tally Software. We are in the process of arranging necessary training of staff in account section for working on Tally Software.</td></tr>
<tr><td>10.</td><td>During the audit we observed that the rate of interest on GPF/CPF has been changed from 8.1% to 8% but extra payment has been made to the retired employees as the same has not been entered into the system. The detail of same is as under:
<table>
<tr><th>S. No</th><th>Name</th><th>Amount</th></tr>
<tr><td>1</td><td>Mr A K Gupta</td><td>491.00</td></tr>
<tr><td>2</td><td>MrMahinder Singh</td><td>482.00</td></tr>
<tr><td>3</td><td>Mr Ramesh</td><td>105.00</td></tr>
<tr><td>4</td><td>Mr V Sriram</td><td>2076.00</td></tr>
<tr><td>5</td><td>MrNavneet Kumar</td><td>132.00</td></tr>
<tr><td>6</td><td>MrKhusi Ram</td><td>132.00</td></tr>
<tr><td>7</td><td>Mr B N Tiwari</td><td>4085.00</td></tr>
<tr><td>8</td><td>Mr M M S Rawat</td><td>5894.00</td></tr>
<tr><td></td><td>Total</td><td>13397.00</td></tr>
</table></td><td>The process of recovery of excess paid amount has been initiated during current F.Y. 2017-18.</td></tr>
</table>

Pranay Seth & Associates
Dehradun
Chartered Accountants

	Further no recovery has been made against the outstanding balance of Rs 14850.00 in case of Mr Puran Singh Rawat and Rs 42029.00 in case of Mr Satya Prakash during the Financial Year 2016-2017.	
11.	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.	The observation has been noted for compliance during current F.Y. 2017-18. The institute is on the job for calculating expenditure upto 31.03.2017 since the incorporation of the scheme for reversal of the past amount.
12.	An amount of Rs.3,00,000/- was received from M/s Progressive Machine Tools in NGF Project which has been transferred in Consultancy account and booked as Misc Income instead of Consultancy income . Further the service tax amount due on the same has not been accounted for in the books and paid to government.	The observation has been noted for compliance during current financial year (2017-18).
13.	During the course of Audit it was observed that Rs. 46,154.00 towards Service Tax payable in Consultancy activity has not been deposited to the Govt. account out of which Rs 1427.00 stands outstanding since one year, the service tax department can levy interest and penalty on the same as per the provisions of Service Tax Act.	The amount was directly deposited in the bank account of institute and despite our best efforts the source of amount received could not be identified well in time. Hence, liability towards service tax was not discharged timely. The same was deposited in government's account as soon as it was traced during current F.Y. 2017-18.
14.	During the audit it was observed that institute has made reimbursement of expenses to employees of WIHG for the visit to NGT, it is suggested to recover the same from NGT.	The claim for expenses reimbursed to scientists of WIHG on account of their visit on behalf of NGT has already been submitted by respective scientist(s). However, the payment from NGT is still awaited. The follow up will NGT in being taken for getting the entry reversed.
15.	During the audit it was observed that the Society Registration Certificate has	The process of obtaining society registration certificate was initiated well

Pranay Seth & Associates Dehradun Chartered Accountants

STATEMENT OF ACCOUNTS

	expired on 01.09.2016, although the renewal process has been initiated but the registration certificate has not been obtained from Society Office.	within the stipulated time. However, it could not be received on time despite our best efforts. The renewed Society Registration Certificate has since been obtained.
16.	During the course of audit it was observed that Mr Uttam Singh has been suspended in November 2013 but there is CPF balance of Rs 34658.00 outstanding in the books of institute.	The institute has strong system to get a "No Due Certificate" from all the sections of office before one is relieved from his duties. The "No Due Certificate" as NIL outstanding respect of Mr. Uttam Singh has not been received As such, the amount payable to him was withheld. No request has ever been received from Mr. Uttam Singh to release the money. The balance amount can be released on demand from Mr. Uttam Singh after adhering to the due procedure.
17.	During the course of audit it was observed that Rs 65.00 has not been paid to Sales tax department against Sale of Tender.	The entry in question pertains to sales tax collected on 22.03.2017 on account of sale of tender. The same could not be deposited in government treasury inadvertently within F.Y. 2016-17. The same has now been deposited during F.Y. 2017-18.
18.	During the course of audit it was observed that the institute has deducted and paid service tax under reverse charge from the payments made to contractors but as per the service tax provisions the reverse charge is applicable only in case of Business Entity and WIHG being the society and registered under section 12AA of Income tax act 1961 is not required to deduct and pay the same.	Though WIHG is an autonomous institution and society registered under society Registration Act, 1960 yet it is instrumentally a part of Govt. of India. The service tax deducted and paid under reverse charge mechanism is basically to ensure that tax has been paid and remitted to Govt. of India. So, application of reverse charge mechanism is in the interest of Govt. of India to prevent evading of tax by the third parties.
19.	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.	Noted for compliance during current F.Y. 2017-18.

Pranay Seth & Associates
Dehradun
Chartered Accountants

<table>
<tr>
<td>20.</td>
<td>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).</td>
<td>So far, we are doing import transactions and making payment through foreign exchange remittance against genuine invoices as per payment terms. No advance of any type to parties abroad is being paid.

For payment of analysis charges through foreign remittance, the observation has been noted for future compliance and is being circulated to Group Heads for mandatory filing of Form 15CA & 15CB while sending samples for analysis.</td>
</tr>
<tr>
<td>21.</td>
<td>During the course of audit it was observed that there is outstanding demand of Rs 1,10,300.00 in traces website the year wise and Form wise break is as follows;
<table>
<tr><th>F.Y.</th><th>Quarter</th><th>Form Type</th><th>TDS demand</th></tr>
<tr><td>2007-2008</td><td>Q2</td><td>26</td><td>160.00</td></tr>
<tr><td>2009-2010</td><td>Q4</td><td>26</td><td>120.00</td></tr>
<tr><td>2016-2017</td><td>Q2</td><td>26</td><td>11490.00</td></tr>
<tr><td>2016-2017</td><td>Q3</td><td>26</td><td>10100.00</td></tr>
<tr><td>2016-2017</td><td>Q4</td><td>24</td><td>87770.00</td></tr>
<tr><td>2016-2017</td><td>Q4</td><td>26</td><td>660.00</td></tr>
</table>
The Income tax can levy interest and penalty on the above as per the provisions of Income Tax Act 1961</td>
<td>The outstanding demand of TDS pertaining to F.Y. 2016-17 has already been cleared and the process of clearing the two pending demands of Rs. 160.00 (26Q2) Rs. 120.00 (26Q4) has already been initiated.</td>
</tr>
<tr>
<td>22.</td>
<td>Following instances were observed in which ETDS return has been filed late:
<table>
<tr><th>F.Y.</th><th>Form</th><th>Due Date of Filing</th><th>Actual Date of Filing</th></tr>
<tr><td>2016-2017</td><td>24Q1</td><td>31.07.2016</td><td>22.08.2016</td></tr>
<tr><td>2016-2017</td><td>26Q1</td><td>31.07.2016</td><td>22.08.2016</td></tr>
</table>
The Income tax department can levy penalty of Rs 200.00 per day u/s 234E for the number of days of default.</td>
<td>The utmost care is always being taken to file all the returns within stipulated time. During July, 2016, due to heavy rains the internet facility of this office get disturbed and ITR could not be filed in time despite our best efforts. The delay in filing has been noted and the filing of statutory returns will be initiated well before in time during current financial year.</td>
</tr>
</table>

Pranay Seth & Associates
Dehradun
Chartered Accountants

23.	Following instances were observed in which Form 16A has been issued Late: The income tax department can levy penalty for late issue of Form 16A as per the provisions of Income Tax Act 1961.	The filing of TDS returns for third parties is based on information and documents submitted by them. Sometimes, system generates errors which needs validation and subsequent revalidations. In the absence of correct documents/ information submitted by suppliers/vendors, the correction file could not be submitted to TIN centre in time to rectify the errors generated by the system. The delay was attributed to delay in submission of correct information (i.e. wrong PAN, Name etc.) by vendors.
	We are thankful to the staff and the management 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 : 14th June, 2017** Place: Dehradun.	**(Manju Pant)** **A F & A O** **(Pankaj Kumar)** **Registrar** **(Prof. Anil Kumar Gupta)** **Director**

Form No	Due Date of Issue	Actual date of Issue of 16A
26Q1	15.08.2016	07.10.2016
26Q2	15.11.2016	02.12.2016
26Q3	15.02.2017	01.03.2017
26Q4	15.06.2017	PENDING

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31ST MARCH 2017)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	886,883,511	868,945,053
Reserves and Surplus	2	-	-
Earmaked/ Endowment Fund	3	1,483,516	2,415,919
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	6,763,614	6,473,879
TOTAL		**895,130,641**	**877,834,851**
ASSETS			
Fixed Assets	8	416,247,002	430,622,962
Investments from Earmaked/ Endowment Funds	9	47,115	43,314
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	478,836,524	447,168,575
TOTAL		**895,130,641**	**877,834,851**
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))

(MANJU PANT)
A.F & A.O

(PANKAJ KUMAR)
Registrar

(PROF ANIL K. GUPTA)
Director

Date : 14th June, 2017
Place: Dehradun

STATEMENT OF ACCOUNTS

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31ST MARCH 2017

(Amt in Rs…)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12	-	-
	Grants/ Subsidies	13	309,674,788	267,777,046
	Fees/Subscription	14	13,000	10,000
	Income from Investments	15	743,924	903,834
	Income from Royalty, Publication etc.	16	61,107	51,969
	Interest earned	17	29,639,036	32,005,220
	Other Income	18	5,985,164	5,638,108
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**346,117,019**	**306,386,177**
B	**EXPENDITURE**			
	Establishment Expenses	20	219,765,049	225,912,901
	Other Research & Administrative Expenses	21	66,557,966	50,071,841
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	7,696,060	8,591,579
	Depreciation Account	8	69,721,683	71,493,925
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	10,740	(119,398)
	Loss / (Profit) on sale of Assets	A-19	(27,920)	(35,501)
	TOTAL (B)		**363,723,578**	**355,915,347**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		(17,606,559)	(49,529,170)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	BALANCE BEING SURPLUS /(DEFICIT) CARRIED TO CORPUS FUND		**(17,606,559)**	**(49,529,170)**

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))

(MANJU PANT)
A.F & A.O

(PANKAJ KUMAR)
Registrar

(PROF ANIL K. GUPTA)
Director

Date : 14th June, 2017
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2017)

(Amt in Rs…)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	217,645,252	152,983,668
Grants - in - Aids	26	367,957,788	344,652,028
Grants - in - Aids/Other Receipts (Ear Marked)	27	434,602	764,000
Loan & Advances	28	215,803,958	181,615,351
Loan & Advances (Ear Marked)	31	8,000	36,500
Fees/Subscription	14	13,000	10,000
Income from Investments	15	743,924	903,834
Income from Royalty, Publication etc.	16	61,107	51,969
Interest earned	17	13,972,080	17,539,929
Other Income	18	5,985,164	5,638,108
Investment (L/C Margin Money)	34	22,200,000	158,724,485
		844,824,875	**862,919,872**
PAYMENTS			
Establishment Expenses	20	219,765,049	225,912,901
Other Administrative Expenses	21	66,557,966	50,071,841
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	6,054	3,826
Loans & Advances	29	228,586,729	170,817,538
Loans & Advances (Ear Marked)	32	382,211	36,500
Investment (L/C Margin Money)	35	49,700,000	102,719,383
Fixed Assets	36	55,317,803	94,657,640
Ear Marked Fund Expenses	33	-	692,002
Grant - in - Aid (Ear Marked) Refunded	30	1,250,154	362,990
Closing Balance	25	223,258,909	217,645,252
		844,824,875	**862,919,872**

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

FOR PRANAY SETH & ASSOCIATES
CHARTERED ACCOUNTANTS

Pranay Seth & Associates, Dehradun, Chartered Accountants

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

(MANJU PANT)
A.F & A.O

(PANKAJ KUMAR)
Registrar

(PROF ANIL K. GUPTA)
Director

Date : 14th June, 2017
Place: Dehradun

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2017

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
Dehradun
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

5. MISCELLANEOUS EXPENDITURE

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

6. ACCOUNTING FOR SALES & SERVICES

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

7. GOVERNMENT GRANTS / SUBSIDIES

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

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

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

(Manju Pant)	(Pankaj Kumar)	(Prof. Anil K. Gupta)
A.F. & A.O	Registrar	Director

Date : 14th June, 2017
Place: Dehradun

Pranay Seth & Associates * Chartered Accountants * Dehradun

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2017

SCHEDULE – 38: CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS

1. CONTINGENT LIABILITIES

(Amount in Rs.)

a)	Claims against the Entity not acknowledged as debts		- Nil -
b)	In respect of		
	i)	Bank Guarantees given by /on behalf of the Entity	- Nil -
	ii)	Letter of credit opened by Bank on behalf of the entity	-Nil-
	iii)	Bills discounted with banks	- Nil -
c)	Disputed demands in respect of		
	i)	Income –tax	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
Dehradun
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

6. FOREIGN CURRENCY TRANSACTIONS

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

7. The payments to auditors during the F.Y. 2016 -17 is as follows:

Remuneration to auditors		
i)	As Auditors	28,000/-
	Taxation matters	- Nil -
	For Management Services	- Nil -
	For Certification	5,000/-
ii)	Others	- Nil -

8. Separate Financial Statements have been prepared for:

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

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

10. Annexed Schedules & Annexures are an integral part of the Balance Sheet as on 31st March, 2017, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2017.

(Manju Pant)	**(Pankaj Kumar)**	**(Prof. Anil K. Gupta)**
A.F. & A.O	**Registrar**	**Director**

Date : 14th June, 2017
Place: Dehradun

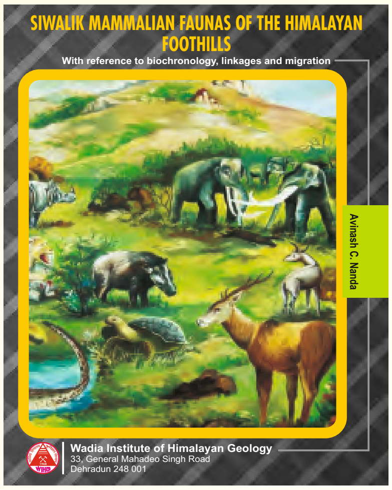
Pranay Seth & Associates
Dehradun
Chartered Accountants

STATEMENT OF ACCOUNTS

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

PUBLISHED PUBLICATIONS

NEW PUBLICATIONS



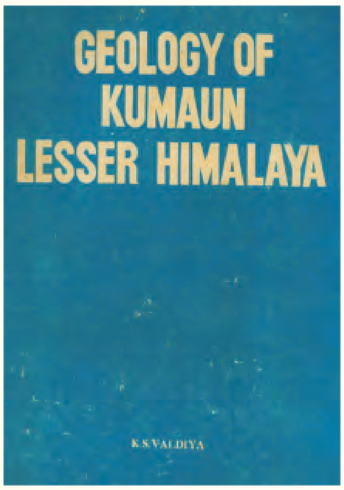
Rs.1200/- (India), US$ 100/- (Abroad)

1. Nanda, A.C. 2015: Siwalik mammalian faunas of the Himalayan foothills with reference to biochronology, linkages and migration. Wadia Institute of Himalayan Geology, Dehradun, WIHG Nonograph Series No. 2, 341p.

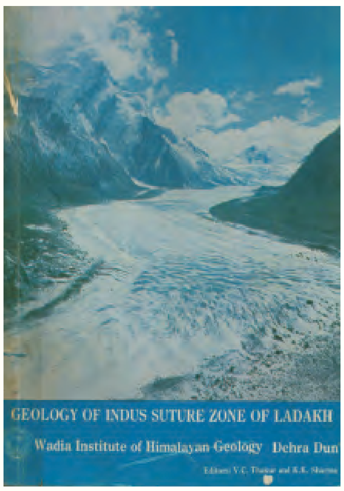
2. Bhambri, R., Mehta, M., Dobhal, D.P. & Gupta, A.K. 2015: Glacier Lake Inventory of Uttarakhand. Wadia Institute of Himalayan Geology, Dehradun, 78p.

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

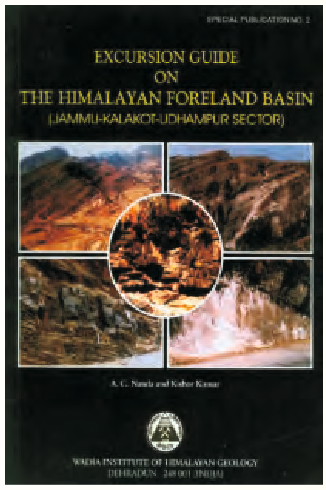
OLD PUBLICATIONS



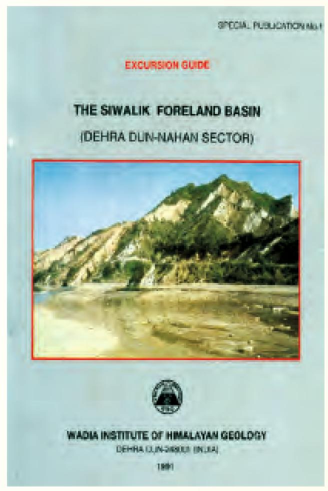
Rs.180/- (India), US$ 50/- (Abroad)



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



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



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

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

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

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

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

HIMALAYAN GEOLOGY

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

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

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

Volume 16*	(1999)	1000.00	100.00

Journal of Himalayan Geology

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

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

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

HIMALAYAN GEOLOGY

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

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

Volume 17 (1996)*

HIMALAYAN GEOLOGY

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

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

Volume 27 (2006) to Volume 30 (2009)

Volume 31 (2010) to Volume 32 (2011)*

Volume 33 (2012)

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

Volume 37 (2015) to Volume 38 (2017)

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

Volume 39 (2018)

OTHER PUBLICATIONS

Geology of Kumaun Lesser Himalaya, 1980 (by K.S. Valdiya)	Rs. 180.00 US $ 50.00
Geology of Indus Suture Zone of Ladakh, 1983 (by V.C.Thakur & K.K. Sharma)	Rs. 205.00 US $ 40.00
Bibliography on Himalayan Geology, 1975-85	Rs. 100.00 US $ 30.00
Geological Map of Western Himalaya, 1992 (by V.C. Thakur & B.S. Rawat)	Rs. 200.00 US $ 15.00
Excursion Guide :The Siwalik Foreland Basin (Dehra Dun-Nahan Sector), (WIHG Spl. Publ. 1,1991) (by Rohtash Kumar and Others)	Rs. 45.00 US $ 8.00
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