NATIONAL CONFERENCE ON EARTH SYSTEM SCIENCE WITH SPECIAL REFERENCE TO HIMALAYA: ADVANCEMENT AND CHALLENGES

May 16-18, 2018

Abstract Volume

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National Conference on Earth System Science with special reference to Himalaya: advancement and challenges
May 16-18, 2018

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Strain release in Himalaya is mainly by major earthquakes that are represented by surface faulting along the Himalayan Frontal Thrust (HFT) or by out-of-sequence faulting. In NW Himalaya, except for Surin-Mastgarh Anticline (i.e. Jammu & Kashmir Himalayan front, ~200 km long) the mountain fronts east of Beas river are characterized by emergent HFT. Hence, in order to throw light on the kinematic evolution of Surin-Mastgarh Anticline (SMA), detailed field and Anisotropy of Magnetic Susceptibility (AMS) studies were conducted. 277 cores were obtained from 23 sites across the SM anticline in two transects, Ravi and Tawi valleys.

Rock magnetic analyses were carried out in order to decipher the minerals responsible for the AMS. Most of the sites show mean magnetic susceptibility (K_m) values <500 µSI, ranging from 93.5 to 389 µSI suggesting dominance of paramagnetic minerals, except few sites show >500 µSI ranging from 549 to 972 µSI indicating ferrimagnetic mineralogy (these sites have been ignored for the interpretation due to complex origin of fabric). The relationship between degree of anisotropy (P^j) and bulk magnetic susceptibility (K_m) suggests that the AMS fabric is not governed by magnetic minerals but controlled by the deformation.

The degree of magnetic anisotropy (P^j) values range from 1.006 to 1.067. Sites from the hinge zone of SMA show slightly higher values of P^j (1.067) and sites from the northern limb have low P^j values (1.006). Closer examination of orientation of susceptibility axis reveals that a plunge of 'K_{min}' is vertical in the hinge of SMA and it becomes sub-horizontal in the limb. Similar relationship has been observed for bedding planes in the field suggesting that the AMS mimics the deformation pattern of SMA. In order to check the reason for vertical plunge of K_{min} axis, we performed a tilt correction that suggests a vertical plunge of K_{min} that is acquired during a progressive growth of SMA. Field observations along different transects indicate that SMA is going through a long ~230 km fold without fault on its either limbs, but with a high angle south dipping reverse fault along its hinge, and it lies along same strike with the Barsar Thrust of Kangra Valley (i.e. east of Beas River). A long continuous fold without fault on its either limbs indicate a detachment type of fold. Further, it is evident that K_{min} is vertical with high values of P^j at the core indicating that SMA grew by progressive limb rotation with fixed hinge.

Tectonometamorphic analysis in the basal hanging wall block of South Tibetan Detachment System along Sutlej River valley, NW Himalaya

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Tectonic fabrics and microstructures in the basal part of the low- to medium-grade metamorphics of the Haimanta Group of the Tethyan Sedimentary Sequence (TSS) have been analysed to understand the geometry and kinematics of the hanging wall block of the SW verging South Tibetan Detachment System (STDS) that marks the tectonic boundary between the high-grade Higher Himalayan Crystallines (HHC) and TSS. The Ordovician (c. 488 Ma, Marquer et al. 2000, Miller et al. 2001) Kinnaur Kailash Granite (KKG) has intruded into the Neoproterozoic calc-silicate rocks forming the top of the footwall/HHC of the STDS. It has also intruded into the metapelites of the base of the hanging wall/Haimanta rocks of the TSS. Xenoliths of both calc-silicate rocks and metapelites are present within the KKG. A series of foliation-parallel thin shear zones, and normal faults dipping towards NE have been identified. The extensional tectonics led to the development of conjugate set of normal faults and associated folds across the STD. Hanging wall bed rotation across normal faults has made sub-horizontal axial planes of earlier inclined folds. Near the base of the hanging wall block of a newly demarcated normal fault dipping towards ENE, a zone of ductile to brittle deformation, characterized by a network of intrusion of tourmaline-bearing leucogranites into the metapelites, is recognized within the Haimanta rocks. This zone is being interpreted as ~20 m wide extensional shear zone or extensional normal fault imbrication, which is interpreted to be linked with the orogen-perpendicular seismically active N-S trending Kaurik-Chango normal fault system. Tertiary tourmaline-bearing leucogranites intruded into the top of the footwall and at base of hanging wall blocks along and across the STDS, indicate their intrusion during syn- to post-kinematic deformation related to movement of rocks along the STD. Xenoliths of metapelites and vice-versa are observed within the leucogranites and metapelites. These structural elements all together, along with occurrence of leucogranites suggest crustal thinning across the STDS. Earlier the STDS was a major thrust that has tectonically transported the TSS as the Chamba nappe towards SW.

The petrographic studies of metapelites, basic lenses and leucogranites suggests that these rocks have been metamorphosed under greenschist (biotite-grade) to amphibolite facies conditions. In lower-grade metasediments, the pervasive foliation is dominated by external schistosity (S_e), which often overprints earlier internal schistosity (S_i). Both S_i and S_e are defined by biotite, muscovite, quartz, and albite of different generations. Textural and mineral assemblages seem to suggest that these low- to medium-grade rocks are likely to have developed during the Himalayan metamorphism that started with burial and crustal thickening during collision, and that formed S_i observed within large quartz crystals. With the progress of metamorphism, the normal fault propagation in the hanging wall block of the STDS gave rise to pervasive S_e and internal rotation of S_i within shear zones. Along foliation-parallel shear zones, the rotation of large quartz and plagioclase crystals show dextral-rotation resulting in the S-shaped relics of the earlier internal schistosity (S_i). The development of these kinematic indicators exhibit syn-tectonic rotation associated with normal faulting along the STDS. In the shear zones, mylonitic rocks are characterized by lenticular bedding-foliation defined by large stretched lenticular-shaped quartz, plagioclase feldspar and biotites. These crystals are wrapped around by the dominant S_e schistosity defining the axial planar schistosity of the tight to isoclinal folds. This geometrical relationship between S_1 and S_2 can be clearly seen on outcrop-scale folds. S_2 schistosity in medium-grade rock is defined by biotite flakes and kyanite blades. Very few kyanite grains are oriented perpendicular to S_2 schistosity. The metabasic lenses within metapelites show amphibolite facies mineral assemblage, which includes hornblende, plagioclase, biotite, muscovite, quartz, titanite, and chlorite. Within leucogranite veins the orientation of tourmaline crystals is perpendicular to the length of veins intruded along and oblique to the main schistosity (S_2). Tourmaline crystals appear to have crystallized along the tension release fractures formed during normal faulting resulting in foliation-parallel stretching/extension under ductile-brittle conditions.

Structure and tectonic analysis across Jutogh Thrust in Sutlej River valley, NW Himalaya: implication to active Kullu-Larji-Rampur window above Main Himalayan thrust ramp

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The further growth of Kullu-Larji-Rampur (KLR) NW-SE trending fold caused erosion of the above lying crystalline Jutogh Thrust Sheet (JTS) that propagated towards SW from its root zone along the Jutogh Thrust. This process unroofed a portion of the JTS once lied above the broad hinge zone of KLR fold and exposed the Rampur Group of rocks, which now known as the KLR window. As a result, the base of the JTS is exhumed and is demarcated by the Jutogh Thrust (JT), which has thrusted the Jeori Gneisses of the Jutogh Formation over the quartzite-metabasic sequence of the Lesser Himalayan Sequence. The displacement of rocks along the JT resulted about 2.5 km wide shear and damage zone in the basal part of the hanging wall block of the JT. Brittle faults have developed along the surface trace of the JT and also in the northern limb of the KLR window at and near the top of the foot wall block of the JT. This brittle deformation has superposed on the ductile and ductile-brittle deformation associated with the movement related with the propagation of the JTS. The basal part of the hanging wall block of the JT is characterized high strain zone as evident by the occurrence of conspicuously developed mylonitic gneisses. In the left bank of the Sutlej River a new brittle fault (Brauni nala fault) is recognized along a perennial Brauni nala joining the Sutlej from east direction. The Brauni nala fault does not cross the Sutlej River course. It implies that there already existed a NE-SW trending fracture zone or a NE-SW trending transverse fault along the present river course of the Sutlej. Thus this fault has tectonically forced the deeply incised Sutlej to flow along fault-length and formed the topography with steep valley hill slopes.

In the subsurface region of the main Himalayan seismic belt, the foci of the present seismicity events are focussed along the Main Himalayan Thrust (MHT) ramp that exists beneath the northern flank of the KLR window or beneath the surface trace of the JT. Therefore, it is interpreted that inter seismic deformation has been controlling the growth of the KLR window and the out-of-sequence thrusting along the JT. The growing window reveals active duplexing or faults active along bounding surfaces of the tectonic horses within the basal hanging wall block in the root zone of the JT and within the KLR window. It is inferred that the KLR window is a large fault bend fold growing above the 15 km deep seismogenic mid-crustal MHT ramp.

Petrogenesis and tectonic position of Chirpatya Khal and Thati Kathur granites, Kumaun Himalaya, India

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The Himalayan granitoids occur in four distinct belts on the basis of geographical distribution from north to south viz. Trans Himalayan Batholith, North Himalayan Belt, Higher Himalayan Crystallines and Lesser Himalayan Crystallines with one additional belt of northern most Karakoram Axial Batholith. The granite bodies of Chirpatya Khal and Thati Kathur fall in Higher Himalayan Crystallines also known as Central Crystalline Group (CCG) in Kumaun Himalaya and are emplaced at the contact of CCG with Lesser Himalaya along Main Central Thrust (MCT-I, ≡ Bhilangana Thrust). These granites are exposed in Laster gad and Helaun gad, tributaries of Mandakini River and in Balganga, Nailchami gad, tributaries of Bhilangana River. The Central Crystallines have granites of Paleo-Proterozoic, Pan-African Palaeozoic and Tertiary age with fair association of medium to high grade metasedimentary rocks. Notwithstanding the overprinting of pervasive Tertiary metamorphism, some of these granites of CCG have preserved the magmatic history and chemical signatures of evolution.

The earlier workers believe that Chirpatya Khal and Thati Kathur granites have intrusive relation with Garhwal Group of rocks and forms the footwall rocks for MCT-I which represent tectonic contact between the Nagnithank Formation of Garhwal Group of rocks and Bhilangana Formation of Central Crystallines. Present investigations deal with the petrological, geochemical and geochrnological aspects to ascertain the magmatic and geochemical evolution along with tectono-stratigraphic position of the Chirpatya Khal and Thati Kathur granites.

Three distinct variants have been mapped in Chirpatya Khal and Thati Kathur granites *viz*. equigranular granite, coarse grained porphyritic granite, and quartzo-feldspathic schist with one additional variety of medium to fine grained porphyritic granite in Chirpatya Khal granite body. They are intruded with large gabbroic bodies. Petrographic studies indicate sub-solvus nature of granite under appreciable hydrous conditions as evidenced by the presence of perthite texture. Some primary quartz crystals with hexagonal forms are noticed in the granite coexisting with subhedral to euhedral feldspar. It indicates their simultaneous crystallisation with the feldspar from the melt. The geochemistry shows A/CNK values >1 and presence of normative corundum. The LREE/HREE ratios in these granites are high, and it infers the evolved nature of melt. The normalised low HREE indicates the absence of garnet and other HREE bearing phases in source of the melt. The feldspar chemistry indicates that the calculated Or-content in the potash feldspar is >94 %. The plagioclase has highly evolved nature with little 'An' content indicating fractionated melt as also evidenced with negative Eu anomaly. These granites are peraluminous in nature and shows affinity with S-type granite. The major and trace elements composition indicates the granites are derived from upper crustal source. The discrimination plots proposed by Pearce et al., (1984) confirm their emplacement in syn-collisional tectonic setting. The tectonic discrimination plot proposed by Abdel-Rehman (1994) based on Al_2O_3-FeO-MgO, and Mg/Mg+Fe ratio in biotite between 0.15 – 0.27 links biotite with per-aluminous suits (S-type). The Zr geothermometry indicates that the crystallization temperature is somewhat lower and ranges from 723-837° C for these granites.

The Geochronology based on nearly consistent $^{207}Pb/^{206}Pb$ zircon ages indicates that the crystallization time of these granites more or less around 1800 My. The earlier geochronological studies based on initial $^{87}Sr/^{86}Sr$ ratio indicates the Paleoproterozoic and Mesoproterozoic ages of adjoining Bhilangana Formation. The Bhilangana Formation also shows affinity with S-type granite, peraluminous nature, presence of normative corundum, A/CNK values >1 and highly evolved nature of plagioclase feldspar. Bhilangana Formation and these two granite bodies have Paleoproterozoic crystallization ages. The geochronological similarities between the Bhilagana Formation and Chirpatya Khal-Thati Kathur granites support their mutual association. The geochemistry and mineral chemistry of both Bhilangana Formation and these granites are also in close resemblance. Hence the present study rules out the intrusion of Chirpatya Khal and Thati Kathur granites within Garhwal Group of rocks and suggests their integral relationship with Bhilangana Formation and form a tectonic contact with Garhwal Group of rocks.

Banded Chromite-Quartzite/Fuchsite Quartzite in the Archaean supracrustal sequence from the southern fringe of Singhbhum craton, Odisha

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Chromite deposits are commonly orthomagmatic and formed due to magmatic segregation in ultramafic igneous rocks associated with mafic-ultramafic layered complexes and ophiolites, with dunite, peridotite, chromitite and pyroxenite and their alteration products as common members of the suites. However, the chromite occurrence in the Archaean supracrustal sequence from the southern fringe of the Singhbhum craton/the Rengali Province around Ghutrigaon, Dhenkanal district, Odisha exhibit a distinctly dissimilar nature of association. The typical mineral assemblage formed, under a different depositional environment followed by a complex tectono-metamorphic development, comprises of Cr-spinel, quartz, fuchsite, Cr-phyllite.

The detrital origin of chromite in this area was reported by the previous researchers. From the nature of mineral association a volcanic-exhalative origin has been suggested and the evidences in this support are as follows. The voluminous volcanic tuff containing fine grains of chromite are observed to be associated with chromite bearing fuchsite quartzite/quartzite supporting massive volcanism as is elsewhere in the greenstone sequences of the Singhbhum craton. Well-developed colour banding is indicative of alternate precipitation of silica and chromite under different Eh and pH condition. Presence of current bedding suggests its precipitation in a shallow marine environment. Lack of clasts/enclaves of ultramafic/mafic rocks within quartzite and absence of minerals like olivine, pyroxene, serpentine and the typical cumulus/synneusis textures may suggest that the chromite possibly did not have an original plutonic/magmatic parentage. Fibrous broom-stick like structure observed in some grains of chromite is inferred to have formed in an exhalative environment. Occurrence of micron-size chromite grains dispersed within siliceous matrix and chromite grains marginally protruding into siliceous matrix could be an evidence of its growth during diagenesis. Grain enlargement during low grade (greenschist facies) metamorphism led to formation of megacrystic/idioblastic chromite. Small scale folds and faults, shearing and silicification are some of the post tectonic features recorded.

The foregoing observations lead to a surmise that Ghutrigaon chromite owes a SEDEX origin, largely differing from orthomagmatic chromite from its adjoining region of well-known Sukinda-Boula Naushi deposits of Odisha.

Exhumation variability within Kumaun-Garhwal region of NW-Himalaya

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The study of denudational history is the key factor to understand the evolution of the Himalayan mountain belt. In the last few decades, the spatial-temporal variation in the exhumation has grown the interest to study the denudation histories of the Himalayan mountain belt. A large number of studies have been carried-out from the Higher Himalayan Crystalline (HHC) of the Himalaya to quantify the exhumation pattern and variability. Until recently, insufficient data has been available to attempt such task at the scale of large orogeny such as Himalaya. In this work, we focused on Kumaun and Garhwal regions of the northwest Himalaya, to study the variation in exhumation rates and analysed 180 published thermochronological ages from Lesser and Higher Himalaya. The exercise provided the empirical evidence of spatial-temporal variabilities in the exhumation pattern, and also suggested that tectonics have primary control on the exhumation followed by precipitation within the regions since Miocene. The thermochronological ages published from the different sectors of the Kumaun and Garhwal region also show the regional variability i.e., younger thermochronolgical ages in the Higher Himalayan and older ages from the Lesser Himalayan Crystallines,which supports the out-of-sequence thrusting kinematics model of evolution of the Himalaya, and obtained transient exhumation rates calculated using 1-D thermal modelling are integrated to quantify the erosional history of the region.

The obtained transient exhumation rates reveal that, initially from early to late Miocene both Kumaun and Garhwal regions were uplifting with almost the same rate. Later on, the Kumaun region has experienced rapid exhumation at the rate of ~4 mma^{-1} and uplifts as a single block, whereas the Garhwal region has undergone the slow exhumation rates of ~1.5 mma^{-1}. It is also suggested that, the variability in the exhumation and thermochronological age patterns might be associated with the presence of possible structural discontinuity between the Kumaun and Garhwal regions along the major Pindar River that separates these two regions. This structural discontinuity can be considered as the northern extension of the transform faults of Indian craton. The correlation between variable transient exhumation rates show a strong feedback relationship between the tectonic and surficial processes of the northwest Himalaya from Plio-Quaternary to present.

Structural geometry and mapping of Main Central Thrust along Alaknanda and Bhagirathi river valley section

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Geological mapping and structural analysis along Alaknanda and Bhagirathi river valley in Joshimath and Gangnani region respectively is done to locate the position of Main Central Thrust zone which consist of Munsiari Thrust (MCT-I) in south and Vaikrita Thrust (MCT-II) in north. Presence of many shear sense indicators like S-C fabrics, sigma and delta porphyroblasts, sheath folds, slickenside fibers etc reveal T-SW sense of shear where the general trend of litho-tectonic units in the zone is NW-SE with NE dip. There have been few geological maps of the region indicating the rock types and position of upper and lower MCT (Valdiya, 1981; Jain et al., 2002; Jain et al., 2014) but detailed map of these regions are still unknown and position of Vaikrita Thrust is still debatable.

We have prepared the geological map of both the regions on 1:50,000 and 1:10,000 scales which not only enhance the understanding of MCT but also reveal the presence of imbricate units from footwall and hanging wall. Position of Vaikrita Thrust has been redefined in the map. Detailed mapping has been done from Langsi to Joshimath along Alaknanda river valley section and from Sainj to Gangnani along Bhagirathi river section.

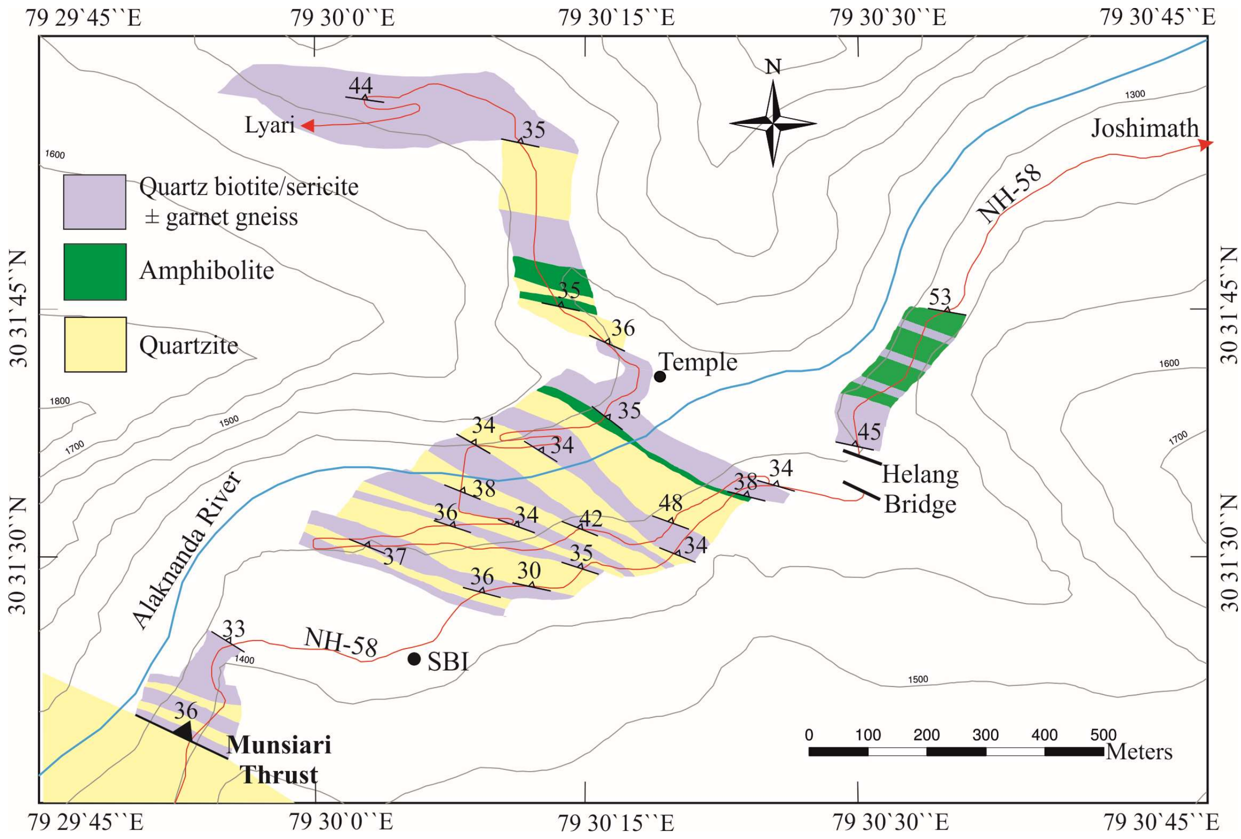

Fig: Detailed geological map of Main Central Thrust zone along Alaknanda river valley section.

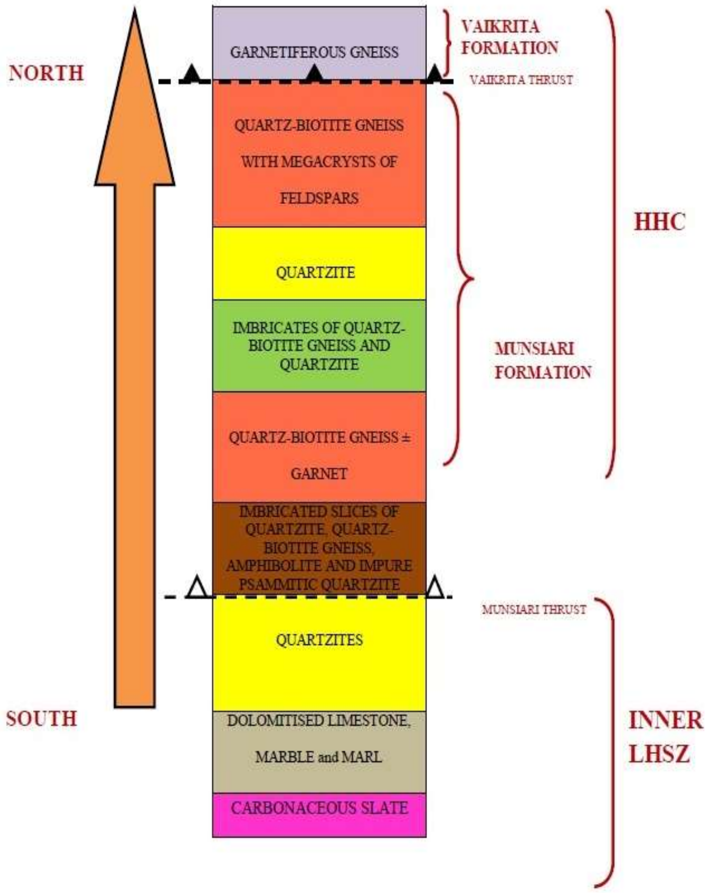

Fig: Tectonostratigraphic Succession of the study area.

Evidence of sea-floor spreading and Supra-Subduction Zone setting in the ophiolites of Tidding-Tuting Suture Zone, Arunachal Himalaya: Constraints from whole rock and mineral chemistry

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The Tidding-Tuting Suture Zone (TTSZ) is marked as the eastward continuation of the Indus-Tsangpo Suture Zone. Rock sequences of ophiolitic affinity are exposed along the Lohit and Dibang valley sections of TTSZ in Arunachal Himalaya. Correlated with the Indus ophiolites, they are considered to be the remnants of the Tethyan oceanic lithosphere, accreted during the collision of Indian and Eurasian plates. In this study, we investigate the whole rock and mineral chemical characteristics of the mafic and ultramafic rocks exposed along the Lohit and Dibang valley sections to evaluate the tectonic setting and petrogenesis of the TTSZ ophiolites. Both the valley sections comprise of a rather compressed succession of several lenticular bodies of deformed and serpentinized peridotites, mafic rocks (altered gabbros, mafic dykes), amphibolites and carbonates.

Chondrite normalised diagram for the peridotites show enrichment of LREE (La_N/Sm_N – 1.53-5.57) and the LREE/HREE values indicate low degree of fractionation (Ce_N/Yb_N – 0.36-6.65) between them. High concentration of magnesium and chromium in olivine and spinel respectively indicate that the peridotites are probably derived from a boninitic melt. REE distribution patterns for the mafic rocks however show almost flat LREE (La_N/Sm_N – 0.26-1.97) and LREE/HREE (Ce_N/Yb_N – 0.24-2.03) ratios. Geochemical studies of the peridotites suggest that they could be part of the upper layers of mantle wedge trapped during subduction of the Indian plate beneath the Eurasian plate. Associated mafic rocks showing MORB character might represent the melts derived from the peridotites by different degrees of partial melting during sea-floor spreading. These new findings thus suggest a dual origin for the TTSZ ophiolites.

Observations on the relation between Central Crystallines and Tethyan Sediments from the Malari-Lapthal traverse, Garhwal Himalaya: Highlighting few geological aspects of the Lapthal area

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The nature of the boundary between the Central Crystallines Unit (CSU) and the Tethyan Sedimentary Unit (TSU) is still controversial. Being the nearest-neighbour Himalayan-scale tectonic boundary just ahead of the collisional suture (ITS) in the direction of propagation of the mountain front, it has an integral status in the Himalayan Orogeny.

The so-called 'STDS' (South Tibetan Detachment System) is believed to be located at the juncture of these two units; it implies the existence of a normal fault system. While the existence of such detachment(s) is not questioned, many pertinent questions remain unaddressed. Without solving these, a comprehensive theory on the evolution of the Himalayas cannot be framed.

Recognition of multiple stages in MCT-emplacement and of certain imprints of pre-Himalayan tectonometamorphic episodes from the rock sequence across the MCT-Zone in the Alaknanda Valley, Higher Garhwal Himalaya

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Sustained geological studies of the rock sequence across the MCT-Zone in the Alaknanda Valley Section in higher Garhwal Himalaya have enabled clear recognition of multiple stages in the MCT-emplacement and of certain imprints of the pre-Himalayan tectonometamorphic episodes (see Table below).

Higher Himalayan Crystalline (HHC) Unit [in areas neighbouring the MCTZ]	**MCT-Zone (MCTZ)**	**Lesser Himilayan Metasediments (LHM) Unit** [in areas neighbouring the MCTZ]
• Formation of 'S_0' in pre – Himalayan, pre – metamorphic condition of the rock. • Formation of the first metamorphic foliation 'S_1' at the time of first progressive metamorphism (M1): pre-Himalayan. • Tight to isoclinal intra-folial folding (F1 ≈ D1): pre-Himalayan. • Formation of present prominent gneissosity giving rise to enhancement of S1 foliation or a new foliation, S2 and crystallization of Barrovian index minerals (M2): Immediate pre-Himalayan. • Prominent asymmetric, S-vergent, overturned folding of the gneissosity shortly after the high grade progressive metamorphism (F2=D2): Himalayan [pre- to early syn-MCT]. • Localized formation of the axial planar schistosity to the above noted meso-scale or explosure scale folding, forming 'S_3': Himalayan [early syn-MCT]. • Stretching or shearing giving rise to the main boudinage event, and the formation of stretching lineation (D3), formation of new minerals at peak phase of MCT emplacement (M3): Himalayan. • Retrograde metamorphism (M4): Himalayan [late syn-MCT]. • Development of late joint sets (D7): post-MCT.	• Formation of the first metamorphic foliation in the rock (D1 & M1). • Prominent high-grade metamorphism (M2) followed by the prominent, asymmetric, S-vergent, overturned folding (D2=F2). • Development of the present main foliation in the mylonitic and augen gneissic rocks and also of the prominent stretching lineation (D3 & M3). • Close to tight folding of the mylonitic foliation (D4). • Foliation boudinage as well as conventional boudinage in thick litho-bands (D5). • Formation of shear bands (i.e. S- C bands) and grain-scale boudinage (D3). • Vein intrusions at diverse times and orientation (D1 – D6). • Retrograde metamorphism and phyllonitization of mylonites (M4) • Onset of post – retrogressive prograde metamorphism (M5). • MCT emplacement (D2 - D5) & (M3 - M4). • Formation of high-angle discrete shear – zones often occupied by veins cutting across main foliation (D6): post-MCT • Development of late joint sets (D7): post-MCT.	• Formation of the first metamorphic foliation. M(LH)1 ≈D(LH)1. (pre-MCT & pre-Himalayan). • Folding and associated axial planar transposition foliation development. [D(LH) 2≈ M(LH)2]. (Late syn-MCT). Broadly late synchronous with D3 & M3: Himalayan. • Shearing induced structures (S-C bands in meso-scale): D5 (syn- to post-MCT) • Boudinage. D5 (late syn- to post-MCT). • Retrograde metamorphic effects are conspicuously insignificant or absent in these rocks. • Onset of prograde metamorphism after MCT-emplacement (M5). • Development of late discrete shear zones often accommodating veins (D6): post-MCT. • Development of late joint sets (D7): post-MCT.

The talk will elaborate on the evidences found and try to put these observations on a larger perspective of Himalayan Orogeny.

The Enclaves of Ladakh Plutonic complex and their relationship with Trans Himalayan magmatic arc, Ladakh, NW Himalaya

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The Indus Suture Zone marks the boundary between the Indian plate in the south and the Eurasian plate in the north and it represents the remanants of the Neo-Tethyan ocean, when ocean closed via northward subduction under Eurasian plate. Trans Himalaya magmatic arc comprised of acid and basic magmatic rocks and associated sediments. Ladakh terrane of NW Himalaya is marked by sequence of magmatic activities represented by intra-oceanic arc sequence varying from mafic to intermediate composition. The present paper focus on the geochemistry of enclaves associated with Ladakh plutonic Complex to understand their relationship with other rocks of magmatic arc.

The enclaves vary in composition ranging from basic to acidic but are predominantly andesitic basalt. They are medium to coarse grained constituted dominantly of plagioclase and quartz with varying amount of mafic phases. The less mobile incompatible trace element ratio of Nb/Y vs Zr/TiO_2 classified these enclaves as sub-alkaline type. REE and multi-element spider diagrams show enriched LILE (large ion lithophile element) and LREE and depletion of HFSE (high field strength element) including Nb, Ti and P anomalies.

The sequence of events envisaged that the enclaves in Ladakh Plutonic Complex represent initial pulses of magmatism, in response to intra-oceanic northward directed subduction of Neo-Tethyan ocean beneath an immature arc. Wide variation in chemical composition of enclaves infer that all the enclaves can not be related with single parental melt and they have complex petrogenetic history. Equivalent of Dras volcanic (Western Ladakh) in the Eastern Ladakh may have been huge pulses of granitic magma were sutured as the arc matured. The remanants of these inferred arcs are probably represented by the enclaves (Dras volcanics) in Pakistan represented by the southern portion of Kohistan arc(Kamila Amphibolite/ Chalt Volcanics).

Characterizing Mantle Derived Fluids and Evolution of Oceanic Crust Prior To Indo-Eurasia Continental Collision: Fluid Inclusion and Isotopic Studies of Ophiolitic Mélanges from Indus Suture Zone, Ladakh Himalaya

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The Quartz–calcite veins in the ophiolitic mélanges, namely, Zildat Ophiolitic Mélange (ZOM) and Shergol Ophiolitic Mélange (SOM) of Indus Suture Zone preserve signature of divergent nature of fluid activity in the late stage of formation of ophiolitic mélange. This paper presents fluid inclusion and isotope geochemistry analysis of these veins, in order to understand their fluid evolution in terms of pressure and temperature. The microstructures of quartz and calcite veins indicate deformation temperature in between 200 and 450°C. The $\delta^{13}C$ and $\delta^{18}O$ values of ZOM and SOM are within the mixing hyperbola of marine and primitive mantle field in the mixing model. The Sr and Pb isotopic values of veins from ZOM suggests MORB type of fluid source in formation of veins, which were enriched during the metasomatic event in a supra-subduction zone. Whereas, for SOM, fluids may have originated from enriched mantle (EM) and depleted MORB mantle (DMM).

It is inferred that the carbonic fluids were derived from ultramafics and oceanic crust that formed the ophiolitic mélanges rocks, which hosts these veins. These rocks are having provenance from EM and MORB, whose signature are well preserved in the quartz-calcite veins as characterized by their C-O-Sr-Pb isotopic ratios. Magmatic saline fluid is inferred to have formed in the early stages of vein formation, which was subsequently got diluted as exemplified by the presence of low saline secondary aqueous inclusions. The inferred maximum depth of emplacement of fluid was within the range of 9-15 km at 510°C-650°C.

Transpressional and transtentsional tectonic setting of the Sirohi Group metasediments

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The southwestern flanks of the Aravalli Mountain Belt in the Sirohi district of Rajasthan represents the type area of the Sirohi Group (~1000 Ma-820 Ma) of rocks, which are the youngest of the three Precambrian orogenic metasedimentary/metavolcanic sequences in northwestern India. The granitoids and granite gneisses are the basal constituents of the Sirohi metasediments. Regional scale mapping was done on 1:150000 (Fig. 1). The metasediments of Sirohi Group are exposed in a linear belt from Lodsar (Churu District) to Palanpur (Gujarat), through Didwana, Degana, Sojat, Gundoj, Nadol, Khiwandi, Morli, Sirohi, Reodar and Mandar (Fig.2). The continuity of the belt is either lost under a thick soil/sand cover in the area or masked by the intrusive Erinpura Granite. In the Type area close to Sirohi, these metasediments occur as isolated outcrops spread over a considerable region.

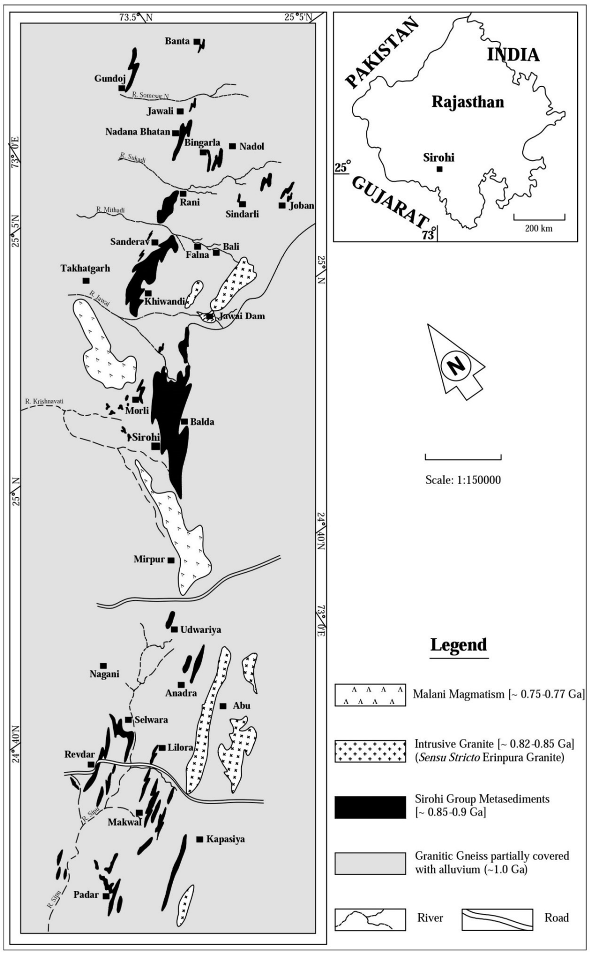

Fig. 1

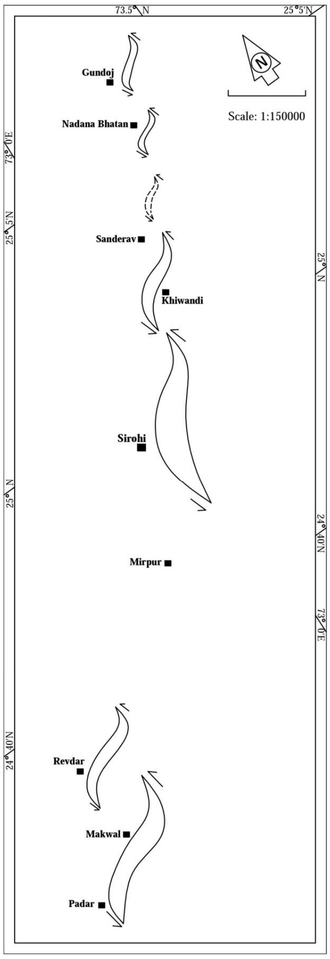

Fig. 2

The structural map of the studied region reveals that the Sirohi Group metasediment outcrops are elongated and stretched along N-S direction. The study indicates that the present map pattern is result of transpressional tectonism in the region. The Sirohi belt suffered compressional as well as transpressional tectonic regime in the last phase of orogenic cycle. The outcrops are crisscrossed by E-W faults that follow the direction of major river traces in the region. The study reveals that the outcrops of the metasediments display a northwest drifting in an enechelon distribution pattern (Fig.2). The outcrop pattern displayed by the Sirohi Group metasediments is perhaps a result of transpressional tectonics and denotes the last phase of tectonics in the region. This indicates the last phase of geodynamic resetting in the region.

The Balada granite intrusion took place at the closure of Sirohi cycle. These granities are well foliated along the regional structral trend and affected by oblique faulting. This shows that the compressional tectonic regime prevailed during the intrusion activity and continued later on. The closure of the Sirohi cycle at approximately 820 Ma, coincides with amalgamation of Rodina Supercontinent in the northwestern Indian Shield.

Petrochronology of granitoids and related rocks from Indus-Shyok Suture Zones, Trans-Himalaya, India

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Felsic magmatic pulses in the Indus Suture Zone (ISZ) and Shyok Suture Zone (SSZ) of northwest Indian Himalaya are represented by Ladakh and Tirit granitoids respectively. These grantoids invariably enlcose xenoliths and mafic to hybrid microgranular enclaves and syn-plutonic dykes. The Ladakh granitoids are calc-alkaline, largely metaluminous (I-type) to a few peralumous type, magnetite to ilmenite series granitoids whereas morcogranular enlclaves are highly metaluminous and magnetite series granitoids. Al-in-hornblende geobarometers (P= 3.35 kbar in the west, P=2.99 kbar in the central, and P=2.17 kbar in eastern parts of batholith) suggest differential unroofing of Ladakh granitoid magma chambers. U-Pb zircon data suggests coeval nature of the Ladakh granitoids and respective enclave globules encloed therein in the Kargil-Batalik-Achinathang (ca 45, 51, 54 Ma, 48.5 Ma), Leh-Karu (ca 50, 61 Ma) and Upshi-Himiya (ca 50, 58 Ma). A magmatic xenolith hosted in the Ladakh granitoids near Karu region has yielded an age of ca 518 Ma representing the Gondwana component whereas zircons from its host calc-alkaline granitoids yield a weighted mean age of ca. 51 Ma. Most Lu-Hf isotopic data of zircons have shown positive ε_{Hf}(t) values and young Hf model ages (200-400 Ma) comparable well to those observed for Gangadese Batholith, which strongly suggest involvement of juvenile magma sources in their genesis and mixing between coeval felsic and mafic magmas. However, a granitoid sample (50 Ma) in the eastern part of the batholith exhibits heterogeneous zircon Hf isotopic ratios and negative εHf(t) values suggesting contribution of ancient continental crust, probably northermost parts of the Indian lithoshpere, in their evolution. This view is further supported by a xenolith (ca 518 Ma) hosted in a Ladakh granitoid (51 Ma), which provides heterogeneous zircon Hf model ages (1685-1740 Ma) and high negative εHf(t) values pointing to the involvement of ancient continental magmatic components in the evolution of eastern part of Ladakh granitoids that must have happened after the collision. The obtained ages of ca 50-51 Ma may thus mark the one of the India-Asia collisional ages.

Tirit granitoids in the Nubra-Shyok valley are intrusive evidently into the Shyok volcanics belonging to the Shyok Formation. In this valley the northern margins of granitoids of the Ladakh batholith can also be found intrusive into the metasediments (shale/slate) and metavolcanics of the Shyok Formation. The compositions and crystallization pressures (~66 to 91 MPa) of amphiboles in the intrusive Tirit granitoid corroborate a calc-alkaline nature and solidification of Tirit granitoid melt at subvolcanic level equivalent to a minimum of 2.5 km to a maximum of 3.5 km thick overburden of Shyok volcanics. U-Pb SHRIMP zircons from the Tirit granitoids have yielded mean crystallization ages of 109.4±1.1 Ma and 105.30±0.80 Ma, which strengthen the idea of Early Cretaceous subduction beneath the Karakoram terrain. Inherited older zircon cores (278-393 Ma, 476-519-713-952 Ma and 1933 Ma) suggest a contribution from heterogeneous Palaeozoic and Proterozoic sources in the generation of the Tirit granitoids similar to those observed elsewhere in the Karakoram-Kohistan region. A mean crystallization age (105.30±0.80) of zircons in the Tirit granitoid hosting xenoliths of porphyritic volcanics places a minimum eruption age of ca. 105 Ma for the Shyok volcanics. The Ladakh granitoid, Tirit granitoids and porphyritic volcanic xenolith belong to a calc-alkaline series. Present and earlier determined ages on Tirit granitoids revealed that the subduction-related calc-alkaline magmatism in the Nubra-Shyok valley of the SSZ prevailed between 110 and 68 Ma, and hence a minimum age of Early Cretaceous can be suggested for development of the SSZ.

Geochemical and zircon age constraint on the origin of felsic volcanics in the Khardung Formation, Ladakh Himalaya, India: Implications for a continental arc magmatism in the Shyok suture zone

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The volcanics of Khardung Formation are exposed in the northern margin of Ladakh batholith along the Shyok suture zone, Ladakh Trans-Himalaya. These volcanics consists of basalts, basaltic andesites, andesites, dacites and rhyolites as volcanic suites. The interesting fact of these volcanics are the present geological position along the Shyok suture zone, which raised eyebrows of many geologists to understand whether they are part of Shyok ophiolitic sequence or pre-collisional continental arc sequence. In the last few decades' petrological studies, it has revealed the subduction origin of these volcanics, but variable thoughts still lie regarding the magma source(s) and their genesis. Earlier studies reported the partial melting of the mantle wedge as their source of generation, while other proposed their origin due to partial melting of Ladakh batholith of ca. 102-50 Ma based on field relations (Weinberg and Dunlop, 2000).

Geochemical characteristic of studied felsic volcanics (dacites, rhyolites) show the strong enrichment of LREE and LILE (Rb, Ba, K) elements, and large depletion of HFSE elements (Nb, P, Ti), with pronounced Eu negative anomalies. The new U-Pb zircon ages obtained from two rhyolite samples yielded 62.95±0.37 Ma and 66.56±0.29 Ma which are consistent with earlier reported U-Pb ages of ~67 Ma as eruption age of Khardung volcanics and 60 Ma as intrusion age of porphyritic sill (cf. Dunlop and Wysoczanski, 2002). From the studies carried out, it is inferred that the felsic volcanics of Khardung Formation were crystallized in the early stage of magmatism prior to the main collision between Indian and Asia, and were generated due to the fractional crystallization combined with crustal assimilation on an active continental margin arc setting.

Life forming? Environments preserved in Turbidites – Insights from Western Ladakh Melange

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Western Ladakh Himalaya is a natural laboratory to study accretionary process in Neo-Tethyan Indian passive margin. The area represents complete section from the shelf to deep sea and arc (Robertson, 2000). The turbidites from the western Ladakh are attributed to proximal to distal volcanic facies, associated with Dras Arc. The muddy turbidite facies deposit reported here, located nearby Kargil town, between Dras volcanics (Nindam Fore Arc) and Kargil granites, attains the attraction due to its onion type mega fracturing pattern with well-developed nucleus with whorls breaks sub-conchoidally, leading to easy friable nature of the rock. The beds moderately dipping SW, over lined by limestone deposits of Mid-Cretaceous age (Fuchs, 1979). The SEM topography shows that the conchoidal fracture development goes to micron levels. Petrographically the rock is greyish, too fine grained, consist of clay sized minerals, microcrystalline silica, alkali feldspar, relicts of ferro-magnesium minerals, iron oxides, pyrite-type and carbonaceous matter in calcic-silaceous matrix. The field occurrence, structures and petrography indicates the inter turbidite facies.

The authigenetic mineral development due to the compaction, influence the tenacity of the rock and hence the development of conchoidal fracture in the core part mantled by more fine grained- splintery fractured outer part. The higher amount of alkalis, Mg-Fe silicates point towards volcanic source probably related to the Dras.

Fossil-type structures with subrounded outline can be clearly identified during the petrographic analysis. Microcrystalline aggregate of iron mono sulphate (Framboidal type?) observed during SEM analysis, may develop at deep marine condition. Raman Spectra is acquired in the window of 200-1200 cm^{-1} using 514.5 Laser, for the identification of iron sulphates, phosphatic matter and carbonaceous material. In one observation Raman band distinctly show very weak to moderate peaks at 362, 400, 471 cm^{-1}, which corresponds to the phosphatic mineral phases. According to Wachtershauser (1990), the surface of the growing pyrite, irrespective of its mode of formation (abiogenic/biogenic) may act as a substratum to attract and bind negatively charged compounds of phosphates and carbonates, may finally form complex poly anions.

The above observations have a significance on the life forming conditions, which might have persisted during the early-mid Cretaceous turbidite formation in Neo-Tethyan ocean floor. This study further warrants detailed chemical tracer study and phase analysis.

Characterization of zircons in the Garhwal Lesser Himalayan clastic sediments: A Morphological approach

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The Proterozoic Lesser Himalayan basin is unique from the other contemporary basins of Indian sub-continent as the former has experienced the Cenozoic Himalayan orogeny.The Proterozoic Lesser Himalaya Formation consist of thick sequence of argillite, siliciclastic and metavolcanics followed by carbonate dominated shallow marine shelf succession in the top part. These clastic sediments are supposed to be sourced from the older cratons of peninsular India (such as Aravalli and Bundelkhand Craton) and retained accessory minerals such as monazite, zircon and apatite during their transportation and deposition. Due to its ability to survive magmatic, metamorphic and erosional processes, zircon is used as an important tool to infer detail information regarding the geological history and genesis of magmatic, metamorphic and sedimentary rocks. The crystal system of zircon is tetragonal, elongated prismatic crystals having length-to-width ratio within a range of 1–5. The shape of the zircon grains ranges from euhedral to subhedral.Typical internal structures shown by magnetic zircons are oscillatory zoning and/orsector zoning. However metamorphic zircon are mostly homogeneous with poor zoning, cloudy zoning, sector zoning, planar zoning, and patched zoning.The internal structure of zircon can be observed by many methods such as HF etching, backscattered electron (BSE) imaging or cathodoluminescence (CL) imaging. Among all of these techniques, CL imaging is widely used for the detailed study of internal structures of zircon.

The northern and southern parts of the Lesser Himalaya are divided on the basis of lithology, stratigraphy and tectonic settings and they are called as the Inner (ILH) and Outer Lesser Himalaya (OLH). Zircons from clastic sediments of Proterozoic Lesser Himalaya differ in their response to magmatic and metamorphic processes with respect to crystal morphology and internal structures. The samples were collected from the upper Damtha (Rautgara Fm.) and Jaunsar Group (Chandpur and Nagthat Fms) of the Lesser Himalaya. Presents work shows features seen in zircon, categorized in accordance to the processes responsible for their genesis. They are widely varied in terms of external morphology and internal textures. These differences are also recorded even among the grains of the same sample. Zircon grains show zoning pattern of magmatic as well as metamorphic characteristics.The zircon grains from both the inner and outer Lesser Himalaya show similar morphological and internal features. However the differences are observed within the grains of same sample which suggest that each formation (Rautgara, Chandpur and Nagthat) of the Lesser Himalaya are sourced from a protoliths, which underwent different processes of zircon formation as well as different degree of transportation. These difference have a bearing on the Zircon grains separated from the representative samples were analysed for their U-Pb dating. Age distribution from inner and outer part of the Lesser Himalaya shows that the U-Pb geochronology of most of these zircons provide Paleoproterozoic to Neoproterozoic ages'. Further analyses are under way to ascertain their provenance which could contributed to these Siliciclastics.

Geochemical and geochronological constraints on the evolution of Abor volcanics of Siang Window, Eastern Himalaya, India

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This abstract attempts to address some of the core issues of continuously debated Abor volcanics - when it was formed, what might be the processes of magmatism that took place at the eastern tip of the Indian continent and its role in the long journey of Indian plate movement? The Abor volcanic represent a significant outpouring of mafic volcanic unit with minor amount of felsic volcanic unit and a variety of mafic intrusive rocks. This magmatic group of rocks occupied the central section of the Siang Window which lies to the south of the Eastern Himalayan Syntaxis. Mafic units (basalt & gabbro) are enriched in large ion lithophile elements (LILE) and light rare earth elements (LREE) but depleted in high field strength elements (HFSE) concentrations. Felsic units (dacite, and rhyolite) also show similar enrichment pattern in LILE and LREE, and depleted HFSE. Typical negative Eu anomaly is observed in felsic units. High value of Nb/U (>30), low value of $(Th/Nb)_{PM}$ (≤1)and LREE enrichment pattern indicate uncontaminated nature of mafic rocks and their derivation from an enriched mantle source. However, low value of Nb/U (<10), and high value of $(Th/Nb)_{PM}$ (>4) and Th/Ta (>8) in felsic rocks suggest they are derived partially or wholly from the crust and indicate possibilities of crustal contamination during magma ascent. Except these few geochemical differences, all other geochemical patterns are similar and contemporary to each other in all the rock types of Abor volcanics which clearly implies their birth from a single magma source, but heavily fractionated and contaminated at different levels of subsurface geothermal and pressure conditions during the magma ascend. All the rock types fall in within plate tectonic setting suggest they might have been generated from a plume source. We have dated Abor volcanics as ~ 145 Ma by using zircon U-Pb isotope proxy, and this age is totally different from the previously proposed age of Permian and Upper Paleocene /Early Eocene. Therefore, we conclude that Abor Volcanics might possibly have formed at the very initial stage of Gondwana breakup.

Formation of the future Super Continents, *'Amasia & Pangaea Ultima'*: A review

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An insurrection occurred in Geology in the 1960s: Plate tectonics. The idea that continents had drifted with respect to one another had been proposed decades before, but now the mechanism became clear. Plate tectonics explains much of the structures and phenomena seen today - how ocean basin forms, widens and disappears**,** why earthquakes and volcanoes are concentrated at plate boundaries**;** and how the great mountain ranges of the world were built. The plate tectonics also describes the formation of future super continent. The Earth has been covered by giant combination of continents, called supercontinents many times in its past, and it will be again one day in the distant future. Researchers suggest that the next predicted supercontinent, dubbed Amasia, may form when the Americas and Asia both drift northward to merge, closing off the Arctic Ocean. The 'Pangaea Ultima', also referred to as 'Pangaea Proxima', 'Neopangaea', or 'Pangaea II' is a possible future supercontinent configuration. Consistent with the supercontinent cycle, 'Pangaea Ultima' could occur within the next 250 million years. To form the future super continent the land masses has already started moving from their respective places. To see how the components of supercontinents moved, scientists analyzed the impact that Earth's magnetic field has on the ancient rocks. There are also many drawbacks/limitations of this super continent which will affect our planet. Not only the human being but also the biodiversity will be affected by the formation of these future super continents. So in this paper we have discussed about both the 'Pangaea Ultima & Amasia'. How & when will they form? What will be the conditions of our planet at that time? What will be the consequences and impacts of this future super continent will discussed in this paper, also at the same time underlining the discrepancy between these two super continents.

In-situ crustal anatexis driven internal weakening of the High Himalayan wedge and its kinematic relationship with a detachment zone: An example from Kali River Valley, Kumaun Himalaya

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We investigate peak metamorphic conditions, timing of melt generation and pervasive melt migration in High Himalayan Crystalline (HHC) sequence along Kali valley, Uttarakhand by using meso- and micro-structural observations, metamorphic modelling of metapelites integrated with zircon U-Pb geochronology. Our field observations suggest initiation of partial melting at the immediate hanging wall of the Vaikrita Thrust that separates the HHC from the Lesser Himalayan rocks. Degree of partial melting of HHC rocks gradually increases towards north till the South Tibetan Detachment, which is the northern binding fault of the HHC. Eventually partial melts intrudes the Tethyan rocks at the hanging wall of the STD in the form of leucogranites. Peak metamorphic conditions of three metapelitic rocks from lower, middle and near upper structural level of HHC are determined by P-T pseudosection modelling in the NKCFMASHT system. Isopleth thermobarometry was used to quantify the peak metamorphic conditions for these three metapelitic samples. The sample from lower structural level gives the peak metamorphic condition at about ~720°C and ~9.2-9.9 kbar and this pressure-temperature conditions do not change significantly from middle to near upper structural level. Zircon U-Pb geochronology was done for that metapelitic sample from lower structural level. U-Pb chronology of zircon grains from a metapelite in the Vaikrita Thrust zone gives an age span of 500 to 2500 Ma with some young ages from the rim in the range of 21-30 Ma. One granitic gneiss from the higher structural level of the HHC gives a crystallization age of 455.7 Ma along with young rim ages of 27-32 Ma range. It is inferred that in the time span of ~21-30 Ma, the rocks from HHC along the Kali valley underwent high pressure partial melting in peak metamorphic condition that was followed by generation of leucosome and pervasive melt migration towards upper structural level of HHC. From these observations, it may be concluded that intensified melt generation and its migration towards upper structural level of High Himalayan metamorphic core complex caused internal weakening of the Himalayan wedge, which resulted in formation of a detachment zone. The partial melt has eventually emplaced within the Tethyan Rocks, migrating syn-kinematically through the STD in the form of Leucogranites. Our study suggests *in-situ* partial melting of the HHC for a very short period of time and melt migration across the STD. These observations are inconsistent with the '*Channel Flow*' hypothesis and more akin to wedge extrusion or critical taper mechanism to explain inverted metamorphism, partial melting and exhumation of the Himalayan metamorphic core complex.

Cover basement relationship in the inliers of the Aravalli rocks of southern Rajasthan

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Rajasthan comprises rock formations ranging from Archaean to Quaternary age. The oldest rocks of Archaean age that occur in Rajasthan are popularly known as Banded Gneissic Complex (BGC) or Mewar Gneiss Complex (MGC). The Banded Gneissic Complex constitutes the basement rocks over which successive metasedimentary and metavolcanic successions belonging to Aravalli Supergroup were deposited as the cover sequences.

The basement rocks are classified into three categories:

1. Mewar Gneiss Complex: the basement gneisses, which retained their pristine Archaean character, remaining virtually unaffected by deformation and metamorphism during the later Proterozoic orogenies.
2. Dominantly granitic rocks of essentially Archaean Complex (Untala and Gingla Granites) or the basement 'inlier' bodies within the outcrops of the Aravalli Supracrustals, such as the blocks of the Sarara Inlier, Ahar River Granite, the large outcrops of Berach Granite surrounded by Proterozoic Supracrustal rocks, etc.
3. The basement ensemble of gneiss – amphibolite granite, which has undergone tectonothermal reworking during the Proterozoic known as Sandmata Complex. These belts are described as Tectonothermally Reworked (TTR) Basement.

The Aravalli Supergroup of the Palaeoproterozoic age is the oldest cover succession, which evolved as ensialic rift basin – fills over the Archaean basement rocks. Udaipur region is generally considered as the 'type area' of Aravalli rocks. The features that precisely help to define the lithostratigraphic unit in this region is the presence of profound unconformity between the basement gneisses and the cover Aravalli Supergroup. The unconformity is recognized by the presence of an erosion surface representing a long hiatus.

The terrain comprising rocks of the Aravalli Supergroup is divided into three contiguous sectors:

1. The Northern Bhilwara Sector
2. The Central Udaipur Sector
3. The Southern Lunavada Sector

The metavolcanic - metasedimentary unit, which forms the base of the Aravalli Supergroup, constitutes the Delwara Formation. The Delwara Formation occurs along the western margin of the Ahar River Granite and a large outcrop of it is also present in the northern fringe of the Sarara Inlier of basement rocks.

Geochemical and petrographical studies of Triassic siliciclastic sediments from Tethys Himalaya of the Spiti region, Himachal Pradesh

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The petrography and geochemistry of the siliciclastic sediments (shales and sandstones) of Triassic age were examined to understand the provenance and paleoclimatic conditions. The microscopic examination revealed that the sandstones are medium- to coarse-grained and consist of rounded to subrounded, to subangular mono- and poly-crystalline quartz in varying amount. Quartz overgrowths are uncommonly noticed in the thin section. The lithic fragments observed are mostly of sedimentary to meta-sedimentary origin, and composed of primarily schist, chert, recrystallized rocks and carbonate fragments. Subhedral K-feldspars (microclines) and plagioclases are found with varied abundance between 0-5 % across different formations. Sub-rounded to euhedral zircon crystals, tourmaline and some opaque grains occur as chief accessory minerals in the sandstones. When the detrital modes were plotted in the Qt-F-L diagram (Fig. 1), it is evident that the samples fall in the field of recycled orogen.

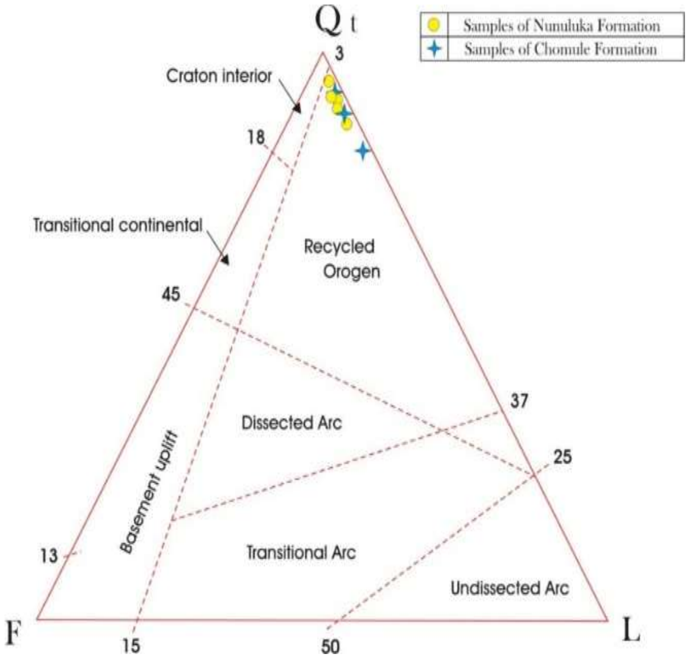

Fig. 1

Major oxide analysis of shales and sandstones are very well compared with the Upper Continental Crust (UCC), Post-Archean shales from Australia (PAAS) and North American shale composite (NASC). The chemical index of alteration (CIA) values of about 55-76 for shales and 58-86 for sandstones are exhibited (corrected CaO* contents were adopted in the formula). The wide range of CIA values shown by these rock types (55-86) indicate low to intense chemical weathering in the source area, which in turn imply variable climatic conditions that may have prevailed in the source region.

It is evident from the A-CN-K (Al_2O_3-CaO^*+Na_2O-K_2O) triangular plot (Fig. 2) that the shale samples plot around typical shale values (filled rectangle in the diagram). The spread in the samples across and along projected weathering trends in the diagram points to variable source (from andesite to granite) for these siliciclastic sedimentary sequences. Passive margin tectonic setting and felsic (quartzose sedimentary) source rocks for the clastic sediments of the Spiti area is evident when the data is plotted on various discrimination diagrams such as F1 vs F2 discriminant function diagram, and on diagrams using major element ratios (e.g., TiO_2 vs. FeO+MgO; Al_2O_3/SiO_2 vs. FeO+MgO; SiO_2 vs. K_2O/Na_2O diagrams).

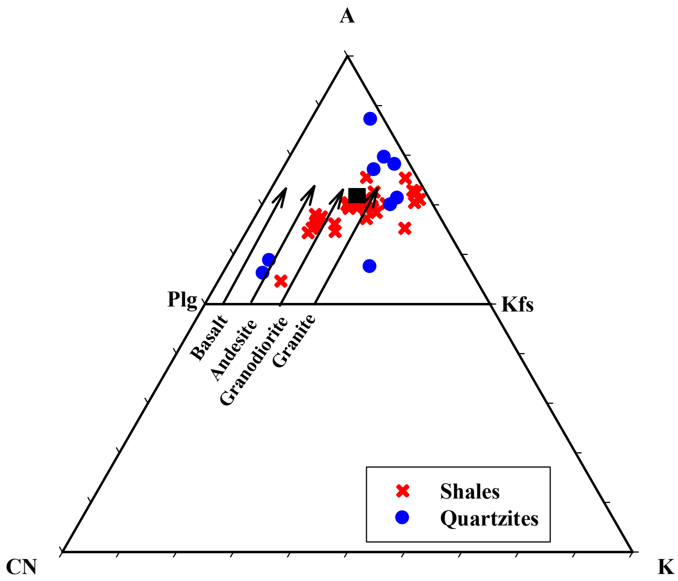
A
Plg
Kfs
CN
K
Basalt
Andesite
Granodiorite
Granite
Shales
Quartzites

Fig. 2

Significance of accessory minerals in subducted Indian crust

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Accessory minerals are the most promising proxy to reveal the geological history of a region, because they are chemically inert and retain primary signatures. We have observed accessory minerals like zircon, monazite, rutile, apatite, garnet in that zircon retains igneous, metamorphic and deformation stages and it forms successive growth rings. Apatite shows low temperature growth, and exhumation history can be seen through it. Rutile can be used to understand the exhumation and cooling ages of the rock. Not only zircon, monazite can also be targeted to track the deformation stage. In the gneisses of Indus Suture Zone, zircon is present as major accessory phase. The zircons in my sample bear varied shape and sizes. Some are euhedral with sizes between (40-200 µm) showing prismatic shape with distinct core and rim boundaries, some are showing xenocrystic cores, and some the zircon grains contain various colourful and colourless inclusions, concentrated around the nucleus. The inclusion pattern is varied from small rounded to sub-rounded shapes, ranging from 1-10 µm. These well-developed euhedral zircons may give a very old age of the rock formed during primeval times of igneous or hydrothermal origin. These euhedral and subhedral zircons are mostly located in the phenocrysts of phengite and garnet minerals. There is another variety of zircon group those show rounded shapes, their boundary is completely resorbed and inside part is also showing cloudy appearance, they also have inclusions scattered randomly and in some grains in patches, their size ranges between (20-150 µm). These rounded zircons may indicate a later growth event, that might have grown in a successive metamorphic event and followed by retrogression during exhumation, due to which they do not bear a definite crystal structure and is generally located in the matrix component of the rock, it might be called a metamict zircon/metamorphic zircon. It is not that a single accessory phase can reveal an entire geological history, but it is the precise selection of the accessory phase which can help unfold the history.

The successive growth of zircon/monazite can be targeted by using U-Pb ages in LA-ICPMS. The growth patterns shows distinct Th-U ratios revealing igneous core and rimmed by outer metamorphic margin. The study will help estimate P-T-t conditions of the rock from formation to exhumation. Isotopic tracer in the monazite and apatite can be used as a complimentary method of study. So, to get a precise P-T-t path of a rock or region accessory minerals have to be attended. To conclude, there might be a two generation growth of zircon grain in my sample, however, this can be better constrained through detailed cathode luminescence study. Through the growth of these heavy minerals we can try to understand their role on the crustal growth with time, if we can unfold the successive growth stages pin pointedly, and which is indeed a challenge.

Balanced cross sections and structural evolution of hydrocarbon bearing Digboi/Jaipur Anticline, Assam-Arakan Fold-Thrust Belt

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Digboi Oil Field was discovered in 1889, is the world's oldest continuously producing oil field. The oil field is located in the hanging wall of Naga Thrust in the frontal Naga Schuppen Belt (Evans and Mathur, 1964). Tertiary stratigraphy in the region is as follows: Palaeogene Disang and Barail Groups are overlain by Neogene Tipam sandstone, Girujan clay, Namsang beds and Dihing Formation. In the Digboi anticline, which is a north eastern extension of Jaipur anticline, Tipam sandstone is considered as the reservoir for hydrocarbon accumulation. Since the pioneering work by Evans and Mathur (1964), no detail structural work has been carried out in the Jaipur anticline in general and Digboi anticline in particular with few notable exceptions (Kent et. al., 2002). In this contribution we present six balanced and restored cross sections across Digboi anticline using surface and subsurface data. The sections lead us to develop a 3D structural model for deriving an evolutionary model for the Digboi/Jaipur anticline.

All the cross sections are based on flat ramp geometry where the Naga Thrust flat occurred within the Tikak Parbat Formation of Barail Group with initial cut off angle of about 30-35^{o}. Digboi/Jaipur anticline develops above the Naga Thrust as fault propagation fold (Suppe and Medwedeff, 1990) with high angle breakthrough. The branch line of breakthrough is at deeper stratigraphic horizon at Digboi area than in the Kusijan area towards southwest. Forelimb thinning of the Digboi anticline is required to match surface data. The cross sections in the Kusijan has similar fault propagation fold model with breakthrough, but without any angular shear maintaining a constant thicknesses of stratigraphic horizons. In Kusijan section, an imbricating blind thrust is also present associated with another anticline resulting anticline-syncline-anticline axial trace.

During restoration, first the angular shear was removed wherever present followed by restoration of the Naga Thrust. By comparing the restored and deformed cross sections, shortening and displacement along the Naga Thrust have been estimated. The 3D model deduced from the correlation of all the cross sections reveals that Naga Thrust is continuous from Kusijan to Digboi area. The blind fault in the hanging wall of the Naga Thrust in the Kusijan area is a rejoining splay from Naga Thrust. Lower Member of Tipam Sandstone Formation crops out in Kusijan area and western part of Digboi Oil field. Towards the eastern end of the Digboi anticline, younger member of Tipam Sandstone Formation and Girujan clay are found which indicates that the displacement along the Naga Thrust is decreasing from Kusijan to the north eastern end.

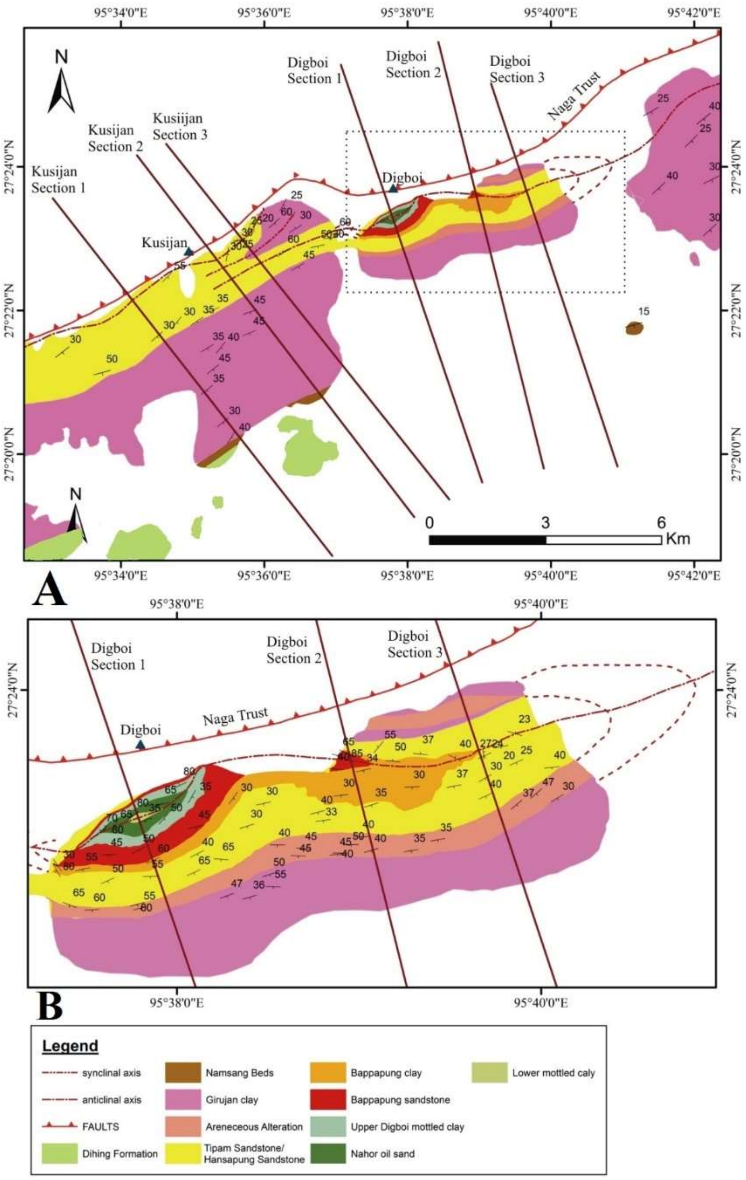

Fig: (A) Geological map of Jaipur Anticline. Rectangle encloses the area of Digboi Oil Field. (B) Geological map of Digboi Oil Field (Modified after Corps, 1949; Kent *et. al*., 2002 and OIL).

U-Pb geochronology, petrography and geochemistry of granite gneisses from Inner Lesser Himalayan Crystallines of Bhagirathi Valley, Garhwal Himalaya reveal Paleoproterozoic arc magmatism related to formation of Columbia Supercontinent

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The Bhatwari Gneiss of Bhagirathi Valley of Garhwal Himalaya is a Paleoproterozoic crystalline from the Inner Lesser Himalayan Sequence. On the basis of field and petrographic analyses we have classified the Bhatwari Gneiss in two parts: the monzonitic gneiss in the southern part, which we named Lower Bhatwari Gneiss and the felsic granitic gneiss in the northern part we named Upper Bhatwari Gneiss. The geochemical signatures show monzonitic protolith for the Lower Bhatwari Gneiss and granitic protolith for the Upper Bhatwari Gneiss. The difference in chemical composition of these granitoids result from the major input of source materials. Upper Bhatwari Gneiss is S-type and calc-alkaline show presence of muscovite and biotite; high SiO_2; K-oxide levels are quite high; molar A/CNK ratio > 1; high Rb content with low Sr content, which indicates their derivation from crustal materials, while Lower Bhatwari Gneiss is I-type and alkaline and has a high Ca and Na content, having a source region poor in Rb, high Fe-Mg content, metaluminous composition with the Upper Bhatwari Gneiss being more fractionated. Trace element concentration suggests volcanic arc setting for the Lower Bhatwari Gneiss and within plate setting for the Upper Bhatwari Gneiss. LREE/HREE patterns along with enrichment of LILE relative to HFSE elements indicates a subduction related arc magmatism setup. U-Pb geochronology of one sample from the Lower Bhatwari Gneiss gives an upper intercept age of 1983.7±5.0 Ma (n=7, MSWD=1.8). One sample from the Upper Bhatwari Gneiss gives an upper intercept age of 1915±15 Ma (n=11, MSWD=1.18). This integrated geochemical and geochronological study concluded that Bhatwari Gneiss is a relic of an interactive zone of magmatic arc/syn-collisional magmatism with related back-arc rifting spanning almost ~100 Ma during active subduction of North Indian Continental Margin in the Proterozoic times and this arc magmatism is related to the formation of the Supercontinent Columbia.

Partial melting and intrusion of crustal derived granites within the Tran-Himalayan Ladakh Magmatic Arc help constrain the timing of India-Eurasia Collision

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The trans-Himalayan Ladakh Magmatic Arc is a result of subduction of the Tethyan Oceanic plate under the Eurasian continent, prior to Himalayan orogeny. Formation of the LMA was followed by complete consumption of the Tethys and onset of India-Eurasia Continental collision. Timing of this collision has always been a matter of great debate with inferred ages ranging from ~65 to ~23 Ma.

Here, we present results from geochronological and geochemical studies carried out on a small migmatitic part within the LMA and adjacent two-mica 'S-Type' granite body that intruded the LMA. Meososome part of the migmatites gives a crystallization age of the protolith as 66±1.5 Ma with two younger clusters at 62.1±1.3 Ma and 50.0±2.9 Ma. On the other hand, the leucosomes of this migmatites gives a crystallization age of 55.31±1.5 Ma having older xenocrystic zircon of ~70 Ma ages. Hf isotopic analysis of zircon from the leucosome shows positive $\varepsilon_{Hf}(t)$ values ranging from 7 to 15, comparable to that of the LMA. The two-mica granite gives 2 closely spaced age spectra of 38.1±1.1 Ma (n=7) and 34.31±0.48 Ma (n=4). This two-mica granite also contains xenocrysts of Palaeozoic ages. As the leucosomes has a high and positive $\varepsilon_{Hf}(t)$ and also does not contain any Paleozoic xenocrysts, which can be attributed to Indian continental crust, it can be inferred that the 55-50 Ma migmatization of the LMA took place before India-Eurasia collision. The two mica granite, having component of Indian continental crust, is an indicator of S-type granite magmatism related to India–Eurasia continental collision at 35-40 Ma.

Effect of carbon on element analysis of carbonaceous silicate rocks by WD-XRF: An evaluation of error and its correction

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Geological samples, such as soils, sediments, and environmental samples often contain high total carbon that poses difficulty in the precise analysis of major oxide by WDXRF (Wavelength Dispersive X-Ray Fluorescence) technique. Presence of carbon in the matrix in excess of ~5% results in pronounced enhancement of fluorescent X-ray intensity of analyte leading to overestimation by >10% depending upon carbon content present in the sample. The error due to overestimation is not significant at up to 2-3 wt% carbon in the sample but can be as high as 5-40% when the carbon content is high (>5-10%). The high Z-elements have a more severe effect than lighter elements. The enhancement in the fluorescent X-rays intensity is due to the decrease in bulk absorption coefficient in presence of the lighter element which is inversely proportional to measured fluorescent intensity. The error introduced by overestimation exhibits a linear correlation with the carbon content and increases with increasing carbon content in the sample. External correction factors, therefore, derived from this linear relationships were applied to the test samples that reasonably improved the accuracies of estimation within the acceptable limit. Precise measurement of Carbon X-rays is commonly not used in routine analysis of silicate samples, which limits the use of restricting internal matrix correction for carbon and other analyte. The same effect is also observed for trace element analysis by WDXRF in presence of sufficient amount of carbon in the matrix.

The implication of the present study is that the Reference Materials (RMs), such as soils, sediments, and environmental samples, with high and variable carbon content, are inappropriate as calibration standards if measurement of carbon fluorescent X-rays and corresponding matrix correction for presence of carbon is not part of the routine protocol for WD-XRF analysis. Another implication of this study is that the analysis of sediment core samples by portable XRF (pXRF) also poses difficulty when the sample contains significant amounts of carbon. These external correction factors can also be used for such type of analyses (if carbon content in the sample is known) for getting better results.

Occurrence of garnetiferous metamorphic rocks of Tethyan Himalayan Sequence around Jaspa granite pluton, Lahaul NW Himalaya: implication of Himalayan metamorphism and tectonics

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Investigations have been carried out on the metamorphic aspect of the magmatic enclaves, and pelitic xenoliths of the Tethys Himalayan country rocks that occur in the host Jaspa granite pluton outcropped in the Lahaul area, NW Himalaya. This Palaeozoic Jaspa granite pluton is outcropped as a sheet-like plutonic body in the Keylong-Darcha route along the Bhaga River, Himachal Pradesh. It encloses genetically related magmatic enclaves ranging in size from a few centimeters to tens of centimeters sporadically distributed in it. The contact between magmatic enclaves and the host granite is however, defused. The granite body also encloses the rare pelitic xenoliths of Batal Formation of Haimanta group, and it shows bedding and sharp contact with the host granite. The magmatic enclaves and the pelitic xenoliths in the host Jaspa granite possess the mineral assemblage that includes, biotite, muscovite, plagioclase, quartz, tourmaline, garnet, K-feldspar and accessory minerals like chlorite, epidote, sphene, opaques and apatite.

Garnet occurs in the magmatic enclaves as well as pelitic xenoliths of the Tethys Himalayan rock. A relatively larger garnets are commonly anhedral in shape, whereas small garnets are commonly euhedral. The chemical composition of the garnet shows that it is rich in spessartine and grossularite content. Sphene occurs either as solitary grains scattered in the matrix or as an inclusion in the biotite. Corona of sphene were observed around ilmenite within the biotite. The occurrence of such texture indicates that the rocks have attained the low-grade metamorphic conditions. Tourmaline was observed in the host granite, mafic enclaves and pelitic xenoliths, also in one of the pelitic xenolith samples, the tourmaline occurs in contact with garnet indicating the coeval development of both the minerals.

The core and the rim compositions of the garnet-bearing samples of magmatic enclave and pelitic xenolith were analysed to understand the metamorphic conditions of the rocks using geothermobarometers. The *P-T* pseudosection modelling and the *P-T* estimates obtained from conventional geothermobarometry show that the Tethys Himalayan rocks exposed in and around the Jaspa granite have undergone peak metamorphic temperature conditions in the range of 400-531°C and pressures in the range of 5.7-8.6 kbar. The metamorphic study of magmatic enclaves and pelitic xenoliths embedded in the Jaspa Granite further shows that, they have undergone garnet-grade Cenozoic metamorphism due to localised perturbation of high-temperature isotherms in the Tethys Himalaya, and that the Tethys Himalaya in the study area shows right-way-up metamorphic field gradient, in consistence to that observed in the Beas river valley lying south of the study area.

Yttrium-zoning in garnet vis-à-vis the relative stability of monazite and allanite in metapelites from the MCTZ and HHCS of the Alaknanda valley, NW Himalaya

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The inverted metamorphic sequence in the Main Central Thrust Zone (MCTZ) and the overlying Higher Himalayan Crystalline Sequence (HHCS) along the Alaknanda valley in NW Himalaya have been studied with respect to Yttrium (Y) zoning in garnet vis-à-vis the stability of accessory like monazite and allanite in metapelites. The common mineral assemblage of the MCTZ rocks is grt-chl-bt-ms-pl-qtz-tour-aln, whereas the HHCS are kyanite bearing with a mineral assemblage of ky-ms-bt-pl-qtz-tour±aln.

It is observed that the garnet porphyroblasts of the metapelites from the MCTZ show chemical zoning of Y concentrations. The Y concentration of the garnet porphyroblasts decrease from the core to rim. The Y_2O_3 of ~0.42 wt. % is recorded within a narrow core of the garnets, while its wide rim zone shows the Y_2O_3 content that falls below the detection limit (BDL). On the other hand, the garnets in the adjacent HHCS metapelites show Y_2O_3 content below detection limit to 0.07 wt. %. The accessory, allanite which occurs as inclusions in garnet as well as in the rock's matrix in all the MCTZ samples and also in one the HHCS sample studied shows Y_2O_3 concentrations of <3.45 wt. %. Also, it has been observed that with increasing structural level across the MCTZ, the ΣLREE content of allanite increases first and then decreases, which is complemented by variation in the Al content of the mineral. This compositional variation is linked to the modal abundance of garnet in the rocks. The other accessory mineral, the monazite that occurs in some of the MCTZ and HHCS samples shows Y_2O_3 concentrations of ~1.62 wt. %.

The garnet porphyroblasts from the MCTZ rocks not only show strong chemical zoning of Y but also zoning of major elements. It shows decreasing of X_{sps} and increasing X_{Mg} and X_{prp} from the core to the rim, which is typical of garnets growing during a prograde metamorphism. The formation of Y-rich core and Y-poor rim along with the major element zoning suggests that the Y zoning has developed during prograde metamorphism. The present study further shows that the garnet-bearing assemblage in the Alaknanda valley has developed from a chl-bt bearing assemblage, as evident from the presence of chlorite, biotite and muscovite as inclusions in garnet porphyroblasts. The most likely garnet-forming reaction would be: chlorite + muscovite = garnet + biotite + quartz + H_2O. *P-T* pseudosection modelling shows that garnet starts to appear in this assemblage at ~500ºC and <5 kbar pressure. *P-T* pseudosection modelling of an MCTZ sample further shows that Y-zoning in garnets developed during prograde metamorphism in the *P-T* ranges of ~5.3-7.3 kbar and ~500-580ºC. The Y depletion in the rim of zoned garnets has most likely resulted from sequestration of Y by allanite, which became a stable phase after the formation of the garnet core.

Theme II
Climate Changes and Geological Processes

Marphometric Analysis of the Mandakini River Basin, Chitrakoot District, Uttar Pradesh Using Remote Sensing and GIS Technique

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Assessment of the morphometric parameters imposes preparation of drainage map, ordering of the various streams, measurement of the catchments area and perimeter, length of drainage map, length of drainage channels, drainage density and frequency, bifurcation ratio, circulatory ratio and constant channel maintenance, which helps to understand the nature of drainage basin and also to plan the water resource management. Present study illustrates the relevance of Geographic Information Systems (GIS) to examine the morphometric analysis of the Mandakini (Paiswani) river basin, Chitrakoot District, Uttar Pradesh.

The Mandakini river starts near Itwa Khas village of Panna district, Madhya Pradesh and makes confluence with the Yamuna river near Kankota village of Banda district, Uttar Pradesh. Along this traverse it covers 349.05 Km. In topographic sheet of Survey of India (63C/16), the Mandakini (famous local name) river is named as Paiswani river. The watershed of the Mandakini river envelops an area of 856.6 km^2 in the Vindhyan Supergroup. The MW (Mandakini watershed) in general, exhibits a dominantly dendritic pattern; while parallel, trellis patterns co-exist. The MW and the sub-watersheds are exhibiting mature geomorphic stage which is characterized by a relatively higher length of overland flow value. The variability in stream length ratio among successive stream orders is a reflection of differences between slope and topography and hence is an important control on discharge and erosional stage of the watersheds. Rho values and elongated shape of the basin suggested higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge. Basin relief is an important factor in understanding denudation characteristics of the basin. The larger R values are result of the paleo and neo tectonic regimen of the study area.

Geological controls on the occurrence of groundwater and springs in the Himalaya

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In Himalaya groundwater manifested in the form of springs are the main sources of water for drinking and household consumption besides rivers, streams, lakes, ponds etc. These springs also serves as the principal source of water for human existence, backing the perennial flows available in groundwater fed small rivers and streams. Direct infiltration of rainwater and snow at higher altitude through joints, fractures and weathered zones is the main cause of recharge to the springs. Six hydrogeological units can be recognized across the Himalaya. The capacity of absorption and retention of water of each unit is very distinct.

1. *Fractured hard rocks* having secondary porosity and permeability, and characterized by springs and seepages.
2. *Fluvial and Colluvial deposits*, lying along the lower and middle valley slopes in lower reaches of the river or near the confluence of two streams in the form of fans and terraces, old valley fill or lake deposits and old landslides deposits which are highly porous and permeable and therefore hold sufficient quantities of ground water.
3. *Karst Aquifer* characterized by joint controlled cavities and channels in dolomite and limestone.
4. *Permeable Sandstone of Siwalik* present in Outer or Sub Himalayan region characterized by permeable sandstone inter-bedded with mudstone which acts as aquiclude and thus helped in the development of springs and perched aquifers.
5. *Piedmont Alluvial Plains* present all along the foothills of Himalaya. The vast zones of alluvial sediments were deposited in two distinct morphological units viz. Bhabhar and Tarai. While piedmont fan (*Bhabhar*) is characterized by deep water table and poor yield of groundwater, the *Tarai* zone has good ground water potential. The water table is present at very shallow levels.
6. *Intermontane Basins* Within the Siwaliks, there are intermontane synformal valleys locally known as Dun in the western and central part of the Himalaya such as Pinjor Dun, DehraDun, Kota Dun etc. These intermontane basins have high ground water potential and the multilayered water bearing horizons are present in unconfined and confined conditions.

Fault, fractures, joints, slope characteristics, landforms, lineaments and karstic features control the spring's formation. Accordingly, the springs have been classified according to their genesis and the factors controlling their formation. These include:
1) *Lineament - fault controlled springs, 2) Colluvial related springs, 3) Fluvial related springs, 4) Fracture - joint related spring, 5) Karsts related springs 6) Contact Springs of the Siwalik rocks.*_ Each type has different discharges, which vary from 1 to 2600 LPM (peak discharge). The hydrochemistry and characteristics of spring zones indicated shallow, moderate and deep groundwater flow system.

In recent year's survey conducted in Uttrakhand and Sikkim Himalaya shows reduction in the discharge of springs and in streams fed by springs. Some of the springs either dried up or have become seasonal. The complex geology, seismicity, high seasonal variations in precipitation and runoff, steep and inaccessible slopes, changing land use in the watersheds, population pressure, degradation of land and forests, are some of the factors, which place tremendous constraints on the discharge potential of springs and streams of the region. The decrease in average annual rainfall and change in rainfall pattern have its effects on the efficiency and efficacy of water recharge system specially in aquifers which are the main sources of water for springs.

Active faults in the basal hanging wall block of South Tibetan Detachment along Sutlej River valley, NW Himalaya

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Active faults are recognized in the basal part of the hanging wall block of the SW-verging South Tibetan Detachment (STD). The STD demarcates the tectonic boundary between the Cambro-Ordovician Kinnaur Kailash Granite (footwall block) intruding into the Meso-Neoproterozoic high-grade calc-silicate rocks of the Higher Himalayan Crystallines (HHC), and Neoproterozoic low-to medium-grade metapelites (hanging wall block) of the Haimanta Group of the Tethyan Sedimentary Sequence. It is a normal fault of listric geometry across which the NNW-SSE flowing major Sutlej River suddenly swings and becomes E-W within a wide zone of E-W trending normal fault imbrication. Associated with the STD, a major conjugate normal fault mapped at 3 km NE of STD, is recognized at a knee band where NNW-SSE flow of the Sutlej River changes towards the west. Fault dips steeply towards SW, and is marked by the presence of a linear series of elongated fault scarps up to 110 m high. NW part of this fault forms a NW-SE trending fault ridge and splays into two faults towards NW whereas its SE part coincides with a major NW-SE flowing Tirung Khad. A set of fresh-looking recent and old triangular facets have developed along hill slopes of the right bank of Tirung Khad. The fault, here named as the Tirung Khad Fault (TKF), trends NW-SE that is parallel to the STD. At knee band where the Sutlej River crosses the TKF, the river course becomes gorged and narrow (50 m) and further towards west the course widens (300 m). The region between SW-dipping TKF and NE-dipping STD has sagged. In this region recurrence of mass movement takes place in SW-facing hill slope along right bank of E-W flowing Sutlej River. In fact this fault is a conjugate fault genetically associated with the STD. Along the TKF-length the hill slopes show recurrence of mass movement. Facing towards south a triangular slip-circle of active mass movement is bounded by normal faults from all sides. Attitude of western margin fault is 34°/N82E, fault parallel to E-W Sutlej River valley has attitude 50°/N5W, and a set of faults along hill slope (with 40 m fall) of left bank of Sutlej dips 24°-45° towards S50E. Hanging wall block of the STD is incised by wide river course with at least two level river terraces along E-W flowing Sutlej. This site of deposition forms the hanging wall block of a normal fault dipping 34° towards N82E. River gradient is low in the STD zone. Hanging wall bed rotation across listric STD and associated normal faults has made sub-horizontal axial planes of earlier inclined folds. This process shaped the nearby topography according to the fault geometry and changed the angle of hill slopes that are prone of mass movement in the fault zones.

Morphometric analysis has been carried out in the STD zone to interpret the morphology of valley floor and its river profile. The values point towards different tectonic conditions which prevailed in the hanging wall and footwall blocks of the STD. The computed ratio of valley floor width to valley height (Vf) has higher value (0.453) in the hanging wall block while a relatively lower value (0.126) is obtained from the footwall block. These values corroborate the field observations where there is relative difference in the shape of the valley evolved on either block of the STD. Broader valleys are observed upstream of the STD. The values of stream length gradient index (SL), steepness index (Ks) and longitudinal profiles also indicate control of active tectonics on the longitudinal profiles of the Sutlej River. Knick points are observed at 6 km, 12 km and 22 km and these points also have higher SL and Ks values and spikes. The knick point at 6 km upstream from the STD is at surface trace of normal fault, and the knick point at 12 km coincides with the STD while knick point at 22 km towards downstream represents one of the narrowest valley sections. The study area falls near southern terminal of transverse Kaurik-Chango Fault (K-CF) system. Therefore, the intermittent reactivation of faults is interpreted to be linked with orogen-perpendicular, seismically active, N-S trending K-C normal fault system.

Identification of Neotectonics variability along Sabarmati Basin, Gujarat, Western India using integrated River gradient magnitude analysis

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This paper presents an estimation of the tectonic uplift and subsidence along the ~323 km long longitudinal course of Sabarmati River using the river gradient magnitude analysis. Recent studies based on satellite imagery analysis show the deduction of surface deformation along a river channel. The synergic study of the DEM with terrain modeling and Geoinformatics system (GIS) can bring many new possibilities in geoscience. Hacks method for SL-index is possessing gradient changes caused by mining and because of rock strength and there is no control on data points collected for interpolation which ultimately reduces the accuracy close to lithological units. After the modifications of Hack's SL-index method to overcome the disadvantages, Gorazd Žibret has made a novel method named as GLA method. The GLA method is a very novel tool to detect neotectonics movement at the local scale. Further, in this method, there is no need for the excessive computing and modeling as it is very effectively covered by uncomplicated mathematics. The river profile adjusts quickly over a geological time to follow an exponential decrease in elevation along the course of the river. However, we used high-resolution CARTOSAT-1 data to find out the tectonic variability within the longitudinal length of Sabarmati River. The terrain and tilt effects have been removed by planimetrical correction and orthorectification of DEM in GIS platform. We collected more than ~ 23000 data points (at 100 m grid interval) along the Sabarmati River to estimate surface deformation. We used the simple trigonometric method to analyse slope angles for every grid point and the results have been estimated using the method proposed by Gorazd Žibret (2016). The estimated results of GLA magnitude are well corroborated with the published results of Sabarmati river basin. Our estimates show that the upper and central portion of Sabarmati basin have undergone more active surface deformation compared to lower reaches. Towards the lower reaches subsidence has been noticed, which could be related to eustatic changes during middle to late Holocene.

Reconstruction of glacier behavior and natural hazards based on tree-ring data from the Himalaya

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Tree ring data is a good proxy for analyzing glacier movements flood events. The inverse relationship broadly between the meteorological parameters controlling the glacier mass balance (MB) and the tree-ring width of climatically sensitive species provides a basis for reconstructing the mass balance and climate from tree ring data. Generally, both conifers and broad-leaved trees/ shrubs growing close to the snout of the Himalayan glaciers would be suitable for such analysis. Several exploratory attempts to investigate the relationship of tree-ring width and recent changes in glacier MB have showed that tree growths were low during the years of positive glacial MB. However no attempts have been made in those studies to reconstruct the MB. Only recently a detailed analysis based on tree-ring data from trees growing in the upper tree line zone, reconstructed the MB dating back to 1615 for the Western Himalayan glaciers. Results reveal that the later phase of the Little Ice Age was substantially briefer and weaker in the Himalaya than in the Arctic and subarctic regions. Natural hazards and related human disasters are common in many parts of the Himalayan region. A common hazard in this region is flood. To mitigate future loss of lives and properties due to this hazard, a better understanding of drivers and processes underlying the natural disaster is needed. For that long-term records based on proxies would help in the modeling of disasters with physically-based models in order to define recurrence intervals and magnitudes of natural processes as well as to understand the climatic, physical or anthropogenic roles. Trees impacted by or other disasters exhibit growth disturbances in their growth-ring series, marked reduction in annual ring width and/or the reaction wood formation and formation of callus tissue or formation of tangential rows of traumatic resin ducts (TRDs). These signals of disturbances provide information for spatio-temporal reconstruction of past natural hazard activity and are a means to date and document past disasters. Paleofloods reconstructions from 1795 -2014 CE provide a regional scenario of flood frequency in the Kullu valley. This provides a long term record to assess the risk related to flood in this region.

Reconstruction of late Quaternary glaciation history of Kosa and Kamet glaciers in Central Himalaya, Uttarakhand

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To define the timing, extent and factors responsible for the Quaternary glaciation in the Himalaya-Tibetan orogen, many studies have been carried out. These studies are providing abundant evidence for significant glacial advances throughout the last several glacial cycles. Earlier studies were having the hypothesis that the factor responsible for the glaciations in the monsoon dominated region is precipitation and reached their maximum extension during the early stage of the cycle. The recent studies are showing that throughout most of the Himalayan-Tibetan regions, significant glacier advances occurred during the Late-glacial with minor advances in some regions during the mid-Holocene and LIA and the driving factor for these glaciations is lower temperature. The poor chronological control in the Himalayan-Tibetan orogen, however, makes it difficult to construct correlations across the region, which in turn, makes it hard to evaluate the relative importance of different climatic mechanisms that force glaciations across the Himalayan-Tibetan orogen. Keeping this in view, we have undertaken a geomorphological and chronological study in the Kosa valley situated in the ISM dominated Higher Himalaya and Kamet valley in the transitional zone of the ISM and Westerlies in the Tethyan Himalaya. In Kosa valley, four events of glaciation have been identified. The oldest and undated moraine is ascribed as the LGM, followed by the glaciation of early mid Holocene and Late Holocene. Whereas in the Kamet valley, the most extensive glaciation is marked by MIS-III followed by LGM and late Holocene glaciation. The results of the present study show that the glaciation pattern in both the valleys are coinciding with the cooling events of the northern Hemisphere. The events of glaciation in both the valley are controlled mainly by the lowered temperature with reduced precipitation. There is a need to study glacial successions in the form of moraine which have the greatest potential to be examined in detail using newly developing numerical dating and geomorphic method to derive high-resolution terrestrial records of glaciation that will help in paleoclimate reconstruction for high altitude regions.

Understanding the sediment behavior and discharge pattern in two adjacent glaciated valleys of the Central Himalaya, India

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Glaciers are prominent landscapes on the earth and one of the very efficient agents of erosion in the Himalaya. Being dynamic and tough in nature they erode, transport and deposit huge amount of sediments every year. Majority of the glaciers have debris-covered ablation tongues, and sediments delivered from these glaciers often dominate the downstream river reaches and induce large siltation problems in the hydropower plants setup downstream. This study deals with the sediment behavior and discharge pattern of the two adjacent glacier valleys of the Central Himalaya, namely, Pindar and Kafni. The Pindari and Kafni glaciers lie in the Pindar valley, and drain into the Alaknanda River (upper Ganga basin) in the Bagehswar district of Uttarakhand state. The total length of Pindari Glacier is about ~5.9 km and it covers an area of 9.6 km^2. Whereas the length and area of Kafni glacier are 4.21 km and 3.3 km2, respectively. The whole Pindar basin occupies a total area of about ~173 km^2, extended over an altitude range of ~2570 to 6183 m (asl). Moreover, the Pindari glacier is one of the most retreating glaciers in the central Himalaya region. In this study, discharge and suspended sediment concentrations (SSC) in the melt water of Pindari and Kafni glaciers have been carried out in ablation period (May-Oct, 2017) at daily and hourly intervals basis. The suspended sediment samples and discharge data have been collected at Dwali station, at the confluence of Pindar and Kafni streams at 2570 m a.s.l. for six consecutive months (May- Oct). The monthly distribution of SSC and its inconsistency from Pindari to Kafni on monthly and hourly basis has been analyzed. Mean monthly SSC of Pindari glacier for May, June, July, August, September and October is found to be ~326, ~2358, ~4321, ~4681, ~2509 and ~453 mg/l, respectively. The SSC of Kafni glacier for the same months are found to be ~112, ~1008, ~2816, ~3210, ~1957 and ~269 mg/l, respectively. The maximum SSC in melt water has been found in July and August (29.50% and 31.95% respectively) in the Pinder stream. Likewise, the maximum SSC has also been observed in the month of July and August i.e., 30.05% and 34.25% respectively for Kafni stream. Results indicate that the contribution of the suspend sediment transportation for the whole Pindar basin from Pindari and Kafni glaciers is 60.98% and 39.02%, respectively. The SSC delivery ratio of Pindari and Kafni glaciers shows that the Pindari glacier discharge and sediment rate is 1.5 times higher than the Kafni glacier. The discharge and sediment pattern have exhibited good correlation with *in-situ* meteorological data. Our hourly results show that the maximum discharge and sediment transportation rate occurred between 1400 hrs to 1600 hrs in the both glaciated valleys. These preliminary results, though indicative, are helpful in developing an understanding about discharge and sediment behavior in the most retreating glacier valley in the region where the field based data is scarce.

Drainage basin morphometry for quantifying the erosion potential of sub-basins in the Subarnarekha River Basin, Eastern India

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Fluvial systems are highly sensitive to the prevailing conditions of lithology, tectonics and climate. Any change in the erosional and discharge regime will be invariably reflected in the form of morphological adjustments by the river. The fluvial morphometric parameters, therefore, have been studied all over the globe for ascertaining the erosional susceptibility of a river basin to erosion. Since the advent of the digital elevation models (DEM), many large rivers basins have been studied with respect to their morphometric attributes. The present study has used these attributes (relief, surface, shape and drainage texture) for assessing the erosional potentialities of the Subarnarekha River Basin in Eastern India. The Subarnarekha River is a predominantly east flowing river, which originates near the Nagri Village (23° 18´ N and 85° 11´ E), drains the southeastern portion of the Chhotanagpur Plateau and crosses the Dalma Hill Range to reach its confluence at the Bay of Bengal after flowing through a distance of about 400 km. The Kharkai, Garra, Gurma, Dimna Jhor, Kharsoti, Dulung, Kanchi, Karkari, Raru, Sobha, etc. are some of the major tributaries of the River Subarnarekha. This is basically a DEM based approach wherein the 30 m SRTM DEM data have been analysed in an ArcGIS environment. The study endeavors to quantify the erosion potential of the river basin under consideration on the basis of the morphometric parameters. After extracting these parameters of each sub-basin, the Principal Component Analysis (PCA) was carried out in the SPSS software. Wallis (1965) is of the opinion that the explained variance should be very high (99% approximately), while building models by the PCA technique. Therefore, in this analysis, eight principal components were extracted with a cumulative explained variance of 99%. The total loading for each parameter was obtained taking into consideration their component loadings, weighted in accordance with the explained variance of the individual component. Here two new indices are proposed for assessing the erosion potential namely, the Index of Erosion Potential (IEP) and Potential Erosion Yield Index (PEYI) computed after giving weightage to each morphometric parameter on the basis of Principal Component Analysis (PCA). In all, 25 sub-basins, having smaller to larger areal coverage, have been extracted for ascertaining the erosion potential. It has been found that although the river predominantly flows over an ancient surface, there are some sub-basins which are characterized by relatively higher potentiality of erosion. Secondly, the spatial variations of the proposed indices can be explained with respect to lithology.

Evolution of sediment pulse in a mountainous river – a case study from the Alaknanda River Basin, Northwestern Himalaya

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In mountainous rivers, high sediment transport rates are often observed during an extreme event (i.e. cloud burst, flash flood, GLOF, LLOF, earthquake, dam failure etc.). Amplified sediment transport rates are elicited by addition of large sediment flux and high discharge (due to voluminous precipitation), which is known as sediment pulse. Sediment pulses can modify landscape by depositing and eroding sediments along the channels, affecting human population and riparian ecosystem. Such sediment pulse was also observed during an extreme event in the Alaknanda River basin during 15th-20th June, 2013. Two different valleys i.e. the Kedarnath and Srinagar valley confronted high sediment transfer during the extreme event and presented promising sites to study evolution of a sediment pulse. For the present study, we used field data, satellite imageries, published literature and geomorphological mapping to study evolution and pattern of the sediment pulse. We observed that in the Kedarnath valley, different river reaches (viz. Chorabari Lake and Glacier moraines up to 3970 m asl, Kedarnath town, Rambara, Gaurikund, Ghodapadav, Sonprayag and Sitapur) showed diverse sediment pulse patterns i.e. translative, dispersive and translative-dispersive pattern. In the Srinagar valley, abundance of the legacy sediments resulted in dispersive sediment pulse pattern. During propagation of these sediment pulse, significant landscape modifications were observed in the Alaknanda River basin affecting largely populated towns and river ecosystem.

Multiproxy record of past 170 year climate and ecological changes from NW Himalayan lake sediments core (Renuka Lake), India

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Climatic and ecological changes in the ^{210}Pb-dated sediment core (Renuka Lake) of the past 170 years were investigated using multipoxy approaches e.g Diatoms, Chrysophycean cyst, grain size, Total Organic Carbon (TOC) and geochemistry. Total of seven benthic (*Navicula, Gomphonema, Cocconeis, Rhopalodia, Cymbella, Eunotia and Mastogloia*) and one planktonic (*Aulacoseira*) diatoms form were recovered.

It has been observed that between 1840-1900AD, the lake was not favourable for growth of algae i.e, diatoms and Chrysophycean cyst, probably due to low productivity or inability to preserve diatoms. The first appearance of diatoms and Chrysophycean cyst recorded from 1903AD that corresponds to an increase in rainfall of the region (Sirmour at Nahan, HP). The population of diatom has drastically increased in the 1940AD, which coincides with "the great acceleration of 1940s"; where an increase in temperature has been recorded worldwide. The mean grain size, TOC and geochemistry results also support the diatoms response. The Total organic carbon percentage during this time increased from 9% to 12% which indicate higher productivity. Aluminium also ascended and reached its maxima in core i.e, 7.76% exhibiting high terrigenous input from the catchment. The mean grain size shows increasing trend and average mean grain size during this period is 13.34 µm, which is slightly higher than the core average value. A phase of increasing productivity after 1940s that ranges up to the 1972AD has been inferred from the expanded population of *Aulacoseira ambigua (Grunow) Simonsen* and Chrysophycean Cyst. This could possibly be due to warm water condition and an eutrophic–meso-trophic lake. From 1972 to 2007AD, the decrease in the diatoms and Chrysophycean cyst population seems to be associated with anthropogenic activity near lake such as construction of retaining wall in the periphery of the Lake etc. that prevented the nutrient input to the lake from the catchment. The diatom response of Renuka Lake to global warming also correlates with the Northern Hemisphere temperature records.

Recent changes in the frontal portion of the Kangriz glacier: a field based approach

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Himalayan glaciers are one of the major sources of freshwater availability for the sustenance and livelihood of the downstream communities. Shrinkage of the glaciers and the associated hydrological changes pose a significant problem for the regional-scale water budget and resource management. Also, presence of debris cover influences the melting characteristics of the glacier by reducing the glacier surface albedo and, thereby, enhancing the melting rate of glacier. Henceforth, evaluation of glacio-hydrological parameters along with the impact of debris cover on the rate of melting is essential in order to understand the variability in Himalayan river hydrology caused by the glacial dimensional changes and ongoing climate perturbations. In the present study, frontal portion of the Kangriz glacier has been investigated through two field surveys conducted in September 2016 and September 2017, to estimate the surface elevation change (SEC), debris cover and meltwater discharge. From the glaciological field investigation, we find that the glacier front has undergone an average lowering of ~148 ±34 cm during the period 2016-2017. Also, the glacier is observed to have lowered down by an average of ~ 49 ±19 cm during the 13 days' time interval of our field investigation last year, 2018 i.e., from 10–23 Sep 2017. If the surface changes of the glacier front are assumed to be equivalent for both the hydrological years, then the results suggest that nearly one third of melting occurred in just 13 days of the September month, which makes this duration probably the peak ablation time amongst the summer months (July, August and September). Also, the quantum of ice melt was found to be inversely influenced (r = -0.84) by the debris thickness during the period 2016-2017. An overall volume of water discharged during the 15 day time period, i.e., 11-26 Sep, 2017 is 7.91 $*10^6$ m^3. The mean daily discharge data also showed a reasonable positive correlation (r= 0.78) with the Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature (LST) data extracted for the 15-day time period, indicating the direct dependency of the former on land surface temperature conditions of the region. Besides, during our field visit we also observed sudden episodes of snout degenerating such as frequent ice blocks break-off, breaching of supraglacial pond and formation of moulin which correlated well with the changing meltwater discharge pattern estimated during the 15 day time period. This study reiterates the fact that being the largest glacier in the Suru basin, the Kangriz glacier needs to be continuously monitored in order to understand its glacio-hydrological conditions.

Ravine formation and its erosion rate estimation in the Marginal Ganga plain, India

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Yamuna and its tributaries show a dense ravine system, which gives a look of "Miniature Mountains" with high drainage density and deep dissection leading to steep slopes (> 80°). Agricultural economies face severe threat due to loss of fertile soil because of expanding gullies and ravine activity. The study area is a part of the Marginal Ganga plain (MGP) along the ravines of the Yamuna and Dhasan rivers. The study focuses on (i) quantification of the amount of soil eroded from ravine erosion and specific sediment yield (SSY), (ii) finding the role, if any, of clay mineralogy in accelerating the ravine erosion, (iii) understanding the tectonic or climate role in the growth of ravines. Two digital elevation models (DEM) were prepared, one from the Daulatpur area situated along Yamuna by the RTK survey and another from CARTOSAT-1 stereo images for the Jigni area situated along the Dhasan river. Erosion rate was calculated by comparing the present day surface to pre-ravined modeled surface. The luminescence dates from several sections from the MGP bracketed the section from 100-14 ka. Earlier studies suggest that the incision of most of the rivers in the Ganga Plain, Gujarat Plain and Central Peninsular plains took place during the Early Holocene optimum at ~14-12 ka. Therefore to calculate the erosion rates and sediment yield from the ravines, we consider the top age to be 14 ka, since then the modern ravines development started taking place. The maximum specific sediment yield (SSY) in the Marginal Ganga Plain (MGP) ranges between 600±100 t/km^2/yr and 1600±200 t/km^2/yr. The correspondence between the orientation of ravines and fractures signifies the role of extensional stress regime of foredeep in formation of these ravines. The clay mineralogy suggests that the main clay minerals present in soil are smectite, pedogenic chlorite, illite and kaolinite. Most of the soil in the MGP consists of smectite, a swelling clay mineral that can initiate cracks and accelerate ravine growth which may be an added factor for ravine initiation.

Relative tectonic active evaluation in the zone of Berinag Kumaun Lesser Himalaya, India

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Tectonic reactivation along the major boundary thrusts and subsidiary thrust/faults in the Himalaya during the Quaternary period has resulted in the rejuvenation of landforms. Considering the role of neotectonic activity in the hazardous Kumaun region, we aim to study the neotectonically formed landscape along the Kulur River valley, a non glacier fed tributary of the Saryu River in the zone of the Berinag Thrust (BT). The field evidences encompassing a variety of geomorphic indicators, e.g., unpaired fluvial terraces, palaeo river channels, alluvial fans, active and stabilized landslides, lineaments, waterfalls, alignment of springs, deeply dissected hills, straight/meandering course of rivers/streams, V-shaped valleys, triangular fault facets and water logged/river ponding along with integrated values of eight morphometric parameters and Stream Steepness (K_s) indices characterize the modification of landscape in the Kulur River valley. The computed morphometric parameters in the Kulur River drainage and its tributaries show that the basin has been tilted and uplifted forming V-shaped valleys along with deformed and disequilibrium longitudinal profile, thereof, suggesting it to be controlled by lithology and tectonics. Based on the response of active tectonics in the form of geomorphic features and quantitative measurements of river channels, the entire basin has been divided into three segments in which the northern and southern segments are active compared to the middle sector. A possible NNE-SSW trending lineament/fault, running parallel to the Kulur River has been observed in the upper catchment and is characterized by fluvial terraces, river ponding and deflection and offsetting of drainage with rectangular pattern, etc. This may have given rise to the widening and straightening of river courses which provide the favorable room for river ponding, resulting in the deposition of about 2 m thick lacustrine mud deposit.

Morphotetonics of North Koel River Basin using remote sensing and GIS techniques

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Morphotectonic analysis using remote sensing and GIS have been used to obtain information that influences hydrographic basins, predominantly these are modifications of tectonic elements and the quantitative description of landforms. Discrimination of morphotectonic indices of active tectonics of the North Koel river basin has analyses of asymmetry factor, basin relief, gradient, basin elongation ratio, drainage density analysis, and drainage pattern analysis, which have been completed for each drainage basin using remote sensing and GIS techniques. North Koel River is one of the major North-West flowing tributary of the Son River Basin of north central India. The North Koel river rises on the Ranchi plateau near Kutku (Jharkhand), and it meets the Son River a few miles north-west of Haidarnagar (Jharkhand). The length of North Koel River basin is ~260 km. The quantitative analysis of watershed development of the North Koel river basin and its six sixth order sub-watersheds was carried out using the SRTM data. The drainage area of North Koel watershed is 16123 sq km and the drainage pattern is dendritic. The bifurcation ratio and drainage density suggest that the area has not been affected much by structural disturbances. The bifurcation ratio and high gradient ratio indicate an undulated topography with steeper stream gradient in some parts of the basin. The bifurcation ratio indicates limited relationship amongst the hydrographic networks that are considered diagnostic of tectonic (and/or neotectonic) imprints on the drainage network in the study area. The elongated nature of north Koel watershed, characterized by the shape parameters, reflects a dominant control of regional linear tectonic element.

Black Carbon Aerosols measurement at Dokraini Glacier, Central Himalaya, India

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Aerosols are tiny particles suspended in the air originating from volcanoes, dust storms, forest and grassland fires, burning of fossil fuel, etc. Out of the total amount of aerosols in our atmosphere, nearly 10 percent are produced by the human activities.

Black carbon (BC) aerosols are formed through the incomplete combustion of fossil fuels, bio fuel and biomass. Human activity produces a large fraction of emitted BC, which as an atmospheric pollutant has serious health impact. BC has a long atmospheric lifetime of several days to week depending upon meteorological conditions and travels along wind currents from Asian cities and accumulates over Tibetan Plateau and Himalaya foothills. It is found higher in the summer season than in monsoon season. During summer, dust and soot are highly loaded over the Himalaya. In high altitude stations, BC mass concentration is minimum in mid-night and early morning while it is maximum in the afternoon. This is because after sunshine, air temperature increases and hence convective activities of surface lifted the dust particles from valley.

BC plays a crucial role in the global as well regional climatic change process, contributing significantly to atmospheric warming. The effect of anthropogenic BC aerosols on snow albedo and lifetime is the subject of interest due to its consequences for regional and global climate forcing. Deposition of BC aerosols on highly reflecting surfaces like snow or ice reduces the surface albedo significantly resulting in positive radiative forcing (warming) at the top of atmosphere which leads to a dire need for black carbon study in glacial environment. BC aerosols over the Himalaya and glaciers have been a topic of prime scientific interest. Measurements of BC on snow have been reported for several locations of Tibetan plateau and south-eastern Himalaya but not much measurement in central Himalaya, particularly in glaciers.

An Aethalometer (AE 33) was installed at an elevation of 3900 m a.s.l. at Dokriani Glacier on October 16 2015 to quantify the black carbon concentration. Aethalometer is based on measurement of light absorption on filter loaded with aerosols. 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.

Data from Nov 2015 to June 2016 are analyzed for the Dokraini Glacier, Central Himalaya. Maximum average BC concentration was found in May, 2016 with an amount of 1694 ng/m^3 which might be due to the forest fire, increased anthropogenic activities and vehicles' movement in the nearby localized areas. On the other hand, minimum average BC concentration of 350 ng/m^3 is observed in the month of November 2015 as after rainy season, atmospheric dust is washed out and chances of forest fire are decreased.

The amount of energy trapped in the atmosphere due to BC in the shortwave region gets converted into heat and is known as Aerosol Heating Rate (AHR) which is also computed at Dokraini Glacier and is found highest in April.

Behaviour of Indian Summer Monsoon (ISM) and Indian Winter Monsoon (IWM) during mid to late Holocene in North Western Himalaya, India

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A high resolution $\delta^{18}O$ and $\delta^{13}C$ record from a U-Th dated stalagmite from Sainji Cave ($30^0$16'07"N: $79^0$18'14''E; altitude 1478 m) located in Gairsain Tehsil, Chamoli district, Uttarakhand reflects the variation in the precipitation amount of the Indian Summer Monsoon (ISM) and Indian Winter Monsoon (IWM) for the period of Mid to late Holocene. This record of the stalagmite based high resolution climatic changes is presented using a suite of proxies, e.g., mineralogy, U/Th dating, growth rate, and $\delta^{18}O$ and $\delta^{13}C$ variations. The chronology of the 26 cm long SA-1, stalagmite was constructed using a StalAge model on eight 230 Th/U dates and covers a time span of ca. 4.0 to 0.2 ka BP. The $\delta^{18}O$ and $\delta^{13}C$ values range from -2.1 to -8.9‰ and -3.41 to 3.67‰, respectively. The $\delta^{18}O$ values show a large variation, compared to the areas dominated by a single monsoon, and this can be ascribed to the two sources of moisture (e.g., ISM and IWM) in the study area during the Upper Holocene. The sample is mainly composed of aragonite except for the upper 1 cm and the section below 20 cm which is calcite.

The results of $\delta^{18}O$ demonstrate mainly four sectors: (i) a period of 4 ka BP-3ka BP reflecting the reduction in precipitation with 3.2 ka BP period marked as the lowest precipitation, (ii) period between 3 ka BP-2 ka BP, showing increase in precipitation with a 2.1 ka BP as higher precipitation, (iii) 2.0 ka BP-0.8 ka BP period reflecting two dry periods at 1 ka BP and 0.8 ka BP, (iv) the last stage indicates an increasing trend in precipitation with 0.25 ka BP (1700 AD) as the highest precipitation. A gradual failure of the precipitation from 4.0 ka BP to ~3.2 ka BP in our record can be linked with continuing deterioration and deurbanisation of the Harappan/Indus civilization from ca. 4.0 ka BP onwards which completely collapsed between ca. 3.5 and 3.0 ka BP. The stronger IWM may also have resulted in the highest precipitation between 0.5 and 0.25 ka BP (1450-1700 AD; a part of the LIA) in contrast to the weakening of the Indian Summer Monsoon in peninsular India.

Source-sink relationship between Indus river system and Indus Fan: a multiple proxy record from Indus fan sediment Site U1457

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Arabian Sea sediment were collected from International Ocean Discovery Program (IODP) Site U1457, drilled at the proximal part of the Indus Fan in the Laxmi Basin. The primary objective of Expedition 355 was to better understand the role of Indian (southwest) summer monsoon on weathering and erosion of the Himalaya and its link to mountain building processes. Multiple proxy data from grain size characterization, environmental magnetic parameters and elemental ratios has been used to understand these objectives.

The oxygen isotope stratigraphy of the sediment core provided sedimentation rates, which varies from 2.67 to 10.79 cm/kyr in the top 11.9 m.

Variations in mean grain size along with sand, silt and clay percent of last 200 ka show excursions in sand and silt with the mean grain size at various depths. The increase in sand percentage can be linked with (1) high energy turbidity current in the upper fan area leading to the erosion of coarser sediments, (2) enhanced sediment flux from the feeder channels (Indus and Narmada River), or (3) avulsion of the fan lobes to this part of the submarine fan. The bulk magnetic susceptibility and frequency dependent magnetic susceptibility are controlled by the fine silt fraction, suggesting the presence of superparamagnetic magnetic minerals. The magnetic susceptibility and χARM indicate clay-sized magnetic minerals. A sudden shift in the magnetic parameter before ~168 ka might suggest change in sediment source (dominancy of Indus River or Narmada River).

Grain size characterization, magnetic parameters along with geochemistry are used to trace the terrigenous and biogenic sediment input into the proximal part of the Indus Fan. The increase in the Y, Ti and Nd suggest increases in terrigenous input in the Arabian Sea at ~60 – 82, ~102 – 113 and ~134 – 148 ka. Ba/Ti indicated the biogenic input with is further well correlated with the low Cd concentration (used as a proxy of anoxic conditions). Cd shows poor correlation with elemental concentrations linked to higher terrigenous sediment input, which indicate low discharge conditions in the supplying rivers (Indus and Narmada River) at ~88–101, ~118–131 and ~148–156 ka).

Hydrologically controlled aggradation and incision of the upper Indus valley, Ladakh Himalaya, during the late Pleistocene

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River systems in the Himalaya have been studied extensively to understand the aggradation and incision but still the debate continues vis-à-vis climatic conditions causing enhanced sediment load driven by increased discharge during wetter climate lead to river aggradation or incision. In this study gravel and valley geometric data (imbrication gravels in the Gh facies) enables to estimate the paleo-discharge of aggraded sedimentary sequences along the upper Indus River in several sections between Mahe and Spituk. Discharge estimates derived from these valley fill sequences vary from 834 to 4457 $m^3 s^{-1}$ during 47-23 ka. Syn-incision discharge estimated from SWDs at Nimu along the Indus River is 19030-47,954 $m^3 s^{-1}$ between 14 and 10 ka suggesting a mega flood in warm and wetter climatic phase. During this mega flood, the discharge of the Indus was ten-fold than the aggradation discharge suggesting the sediment flushing from lower order drainages, hillsides erosion, and sediment mantled in glacial deposits in the glacial-interglacial transition phase. Thus, the river aggrades during the transitional climatic phases (from colder to wetter), when it has higher competence and carrying capacity and incises during the wetter climatic conditions when it has higher capacity to flush the aggraded sediment piles.

Morphometric Analysis of Chambal Badlands and Siwalik-Bhabhar Himalayan Foothills Ravines: A Comparative Study

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Badlands are deeply dissected erosional landscapes developed over soft rock terrain and commonly found in uplifted semiarid setting. Most distinct characteristic of the badlands is high drainage density due to gully erosion and sparse vegetation. In India, Badland-Ravine topography has developed in four major areas namely, Yamuna-Chambal Ravine, the Gujarat Ravines, Chhota Nagpur, Bihar Ravines, and Siwalik and Bhabhar Ravines in the western Himalayan foothills. Aim of the present study is to compare Badlands of Chambal basin and the Siwalik-Bhabhar Ravines in the western Himalayan foothills based on their morphometric analysis. Extent of these study areas are adopted from Sharma (1980). SRTM DEM of 30 m spatial resolution of the study areas are used for morphometric analysis, for which eight morphometric parameters namely, Relative Stream Power Index (RSPI), Sediment Transport Index (STI), Wetness Index (WI), Topographic Ruggedness Index (TRI), Map Gully Depth, Drainage pattern, Plan Curvature (PC), and Profile Curvature are used in the study. Analysis of the results suggests much higher secondary terrain attribute values (i.e. RSPI, STI, WI, TRI, PC, and profile curvature) for the Chambal badlands as compared to the Siwalik-Bhabhar Ravines, indicating different characteristics of the two systems. The significance of the study is that we can understand behaviours of theses badlands. Different values will be helpful in understanding the quantitative evaluation of form characteristics of the landform units.

Style and timing of Quaternary glaciation in a semi-arid region: a case study from the Suru River basin, western Himalaya

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The rapid rate of global warming presently underway highlights the necessity for a better understanding of abrupt climatic changes. Climate is a ruling force in our lives, with economic, political, and societal significances to both individuals and nations. Glaciers are important tools in palaeoclimatic reconstructions. In regions of high glacier prevalence and density, glacial antiquities provide tremendous signs of the past climate and insights in to the spatial variability of changes. To understand the style and timing of Quaternary glaciation in the semi-arid region of western Himalaya, a detailed glacial geomorphological mapping was conducted during field visits from 2015 to 2017 which was aided by topographic map (1:50,000 prepared by the Survey of India, ed. 1962), interpretation of satellite images (SRTM DEM, Sentinel MSI 2017 (10 m resolution) and Google Earth image) and Differential GPS survey. To reconstruct the moraine morphostratigraphy, features such as crest morphology (sharp to round crested), including different stages of glaciation and deglaciation occurring all along the valley were mapped. In addition to this, 40 moraine sediment samples for Optically Stimulated Luminescence (OSL) dating were collected to reconstruct the paleo-extent of the glaciers and understand the past-climatic variations in the study area. We observed >15 and >5 phases of recessional moraines in Durung-Drung and Pensilungpa glaciers, respectively. The lateral moraines extend up to 4800 m asl in Durung-Drung and 5100 m asl in Pensilungpa glaciers. In the downstream valley, these moraines can be traced below 3900 m asl in Doda and 4000 m asl in Suru basins. The extent of the oldest stage of lateral moraine of Durung-Drung Glacier is traceable to down valley floor below the altitude of 3900 at a distance of about 9 km from the present snout, where the tributary glacier merges with the main trunk. Whereas, the traces of the first stage of Pensilungpa Glacier lateral moraine is observed at the 4090 m asl, ~8 km from the present snout. On the basis of detailed mapping of glacial moraines, we identified five stages of glacial advance in the basin between Marine isotope stage 3/4 (MIS 3/4) and MIS-1. The study suggest that the older stage-I glaciation occurred during the cool and wet MIS 3/4 dated ~33 ± 6ka. The stage II glaciation began with the onset of LGM (MIS 2). Stage III represents the Younger Dryas (YD) cooling stage, whereas, the stage IV and V glaciations occurred during the early Holocene cooling event and late Holocene (MIS 1), respectively dated between 2 to 8 ka.

Quaternary landforms associated with Main Boundary Thrust and Himalayan Frontal Thrust in Ramnagar area, Kumaun sub-Himalaya: implication on reactivation of the thrusts

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Landforms across the Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT) in Ramnagar area, Kumaun sub-Himalaya are studied. Geomorphic analyses of landforms indicate their spatial and temporal relationship with the boundary thrusts and associated transverse faults. Mapping of geomorphic features and structural analysis of the MBT and HFT establish an intimate relationship between evolution of development of landforms and thrusting of rocks. Reactivation of the MBT and HFT in time and space have rejuvenated the landscape at and near the thrust zones.

In the MBT zone, the swerving of the channels, linear development of elongated depressions, topographic break, presence of escarpments, uplifted ground surfaces, occurrence of dormant and active landslides and formation of V-shaped valleys are observed. Neoproterozoic Lesser Himalayan rocks have over-ridden the recent landslide debris along subsidiary steep fault associated with the vertical-dipping MBT. In the mountain front, the HFT is topographically represented by an escarpment trending ESE-WNW. In the HFT zone, four levels of terraces are present with the highest terrace being a strath terrace. The surface trace of the HFT shows relative offsetting along the N-S trending Ramnagar transverse fault coinciding with the Kosi River valley. Uplift of the hanging wall block near the HFT has resulted in subsidence away from the HFT towards the NE. During this process the transverse streams incised the uplifted surfaces. Rivers and streams realigning with the bedrock structure suggest tectonic control of tectonic elements on the tectonic forcing of drainage pattern. Neotectonic activity along the Intra-Siwalik thrust has offset a terrace surface into two surfaces separated by a fault scarp of about 50 m height. The dip amount of the bedrocks in the HFT region varies from gentle to steep towards the NW/N-E/ESE. Both the normal and reverse faults are recognized in the bedrocks. In the thrust zones the general trend of lineaments is E-W and these are concentrated in the thrust zones.Two transverse faults form straight lineaments across the HFT. Tectonic activity during the deposition of the Upper Siwalik rocks is also evident from the occurrence of liquefaction features. The soft-sediment deformation structures are observed in fine-to medium-grained friable sandstones. Structures include up-welled structures (with vertical to inclined bedding planes), dykes, faults (reverse and normal), folds, psuedonodules, and laminations.

Are Peat deposits from Ladakh (Northwest Himalaya) showing declining wetness and reduced carbon sequestration in high altitude wetlands?

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Himalaya is one of the major landform on the Earth's Surface which regulates climatic changes over vast geographical regions hosting thick human populations on widely varying time scales. Paleoclimate studies are central in extracting useful information needed for the understanding the present climatic challenges and possibly modelling the future scenarios. Owing to tougher challenges for human occupation, higher Himalayas offer suitable geological repositories for unearthing past variations in climate with minimal anthropogenic impact. The present study aims at reconstructing palaeo-vegetation history in the wetlands of north-west Himalayas, using a 1.22 meter long sediment core raised from the Shakti village of Ladakh region of India (77°49'14.8"E, 33°59'34.2" N). Visually the section appeared well-preserved lithology with presence of dark-gray sedimentary-layers. To quantify variations in organic productivity along with its efficient preservation, we measured total organic carbon content (TOC) in the core sub-samples (taken at ~2 cm interval). The TOC content varies from 0.1 to 18.8 (wt%) (Fig-1). Intriguingly, TOC values were found to be higher with the increasing depth from surface. Deeper layers in fact showed signatures of good preservation of organic matter with TOC contents varying from ~14 to 18 (wt. %), well supported with relatively darker (blackish) colour of the sediment profile (Fig-1A). While Radiocarbon dating on the organic rich samples are under way, we consider here downward depth from surface as index of increasing depositional ages and make primary assessments. It could be observed that higher depths (~50cm) the productivity of organic matter and its preservation appears to be highly efficient which may be indicative of a reducing environment and/or high sediment flux. Deposition history of these layers likely to be wet with higher carbon sequestration rates. In contrast, the upper section of the sequence shows a relatively gray layers indicating a drier phase with lower carbon sequestration by surface soil (TOC values ranging from 0.1 to 2 %). Organic productivity over high reaches of western Himalaya is often limited by N inventory and higher carbon sequestration rates have been found associated with warmer and wetter environment. We measured sediment $\delta^{13}C$ to infer past changes in nature of organic productivity. We observe a sudden decrease in $\delta^{13}C$ at ~50 cm depth (Fig-1), which could be interpreted in terms of either a change in vegetation type or major change in carbon sequestration rates. If the entire section fall within the Holocene (last 10,000 years) we do not anticipate (i) a major change in vegetation type (from C4 to C3 type of vegetation) and (ii) significant change in ambient CO_2 concentrations. If so, it is likely that carbon sequestration rates can manifest themselves in the observed $\delta^{13}C$ changes. In this scenario, enriched $\delta^{13}C$ values in the lower (wetter?) part of the sediment profile (Fig-1) could be due to more efficient carbon pumping in surface productivity as observed by Srivastava et al. (2017) in the Kedarnath area. Low organic content in the upper sediment layers may have some effect of oxidative loss, however, we surmise lower organic productivity is due to lesser wetness (rainfall) and decreased carbon sequestration. More proxy measurements such as N isotopes, major and trace element analyses could provide better understanding of present biogeochemical cycles. As the Laddakh area is considered as highly vulnerable to slight changes in monsoonal strength, especially interplay between southwest monsoon and westerlies, it would be interesting to find out environmental conditions promoting/ impeding carbon sequestration rates by high altitude wetlands.

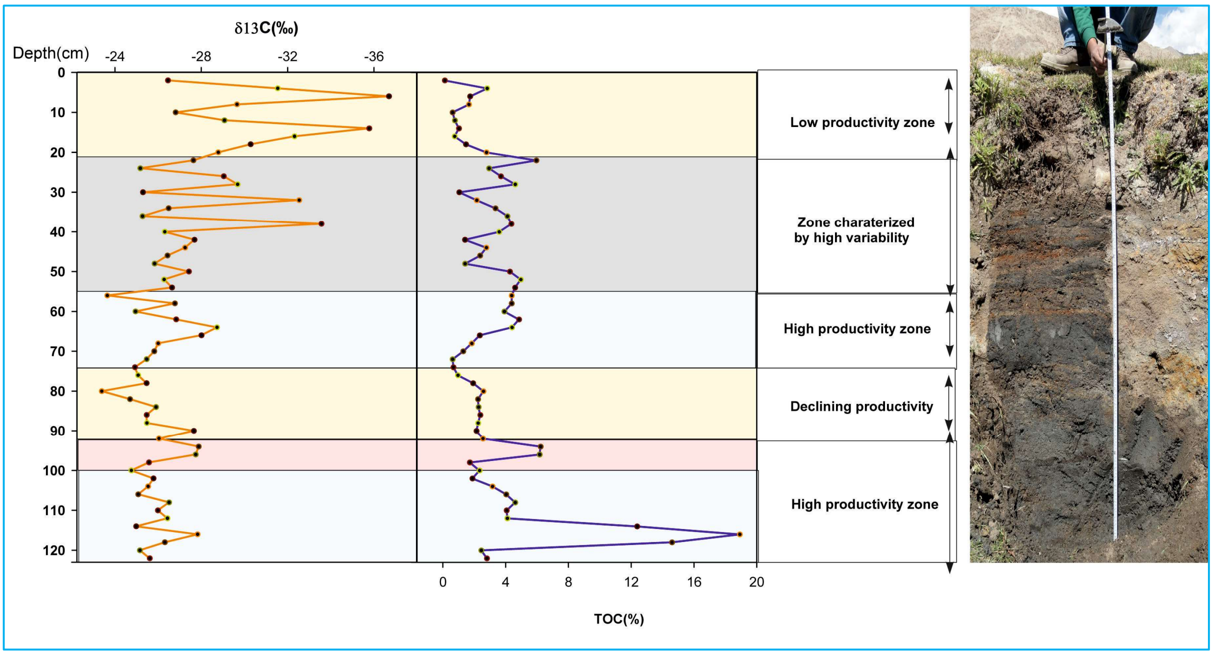

Fig1: Showing the profile of the sediment core of the Shakti valley along with the variation of carbon isotopeand TOC against the profile.

Investigations on ambient black carbon aerosols in Alpine ecosystem of north western Indian Himalaya

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Black carbon (BC) is a product of incomplete combustion of fossil fuels and biomass, and is produced through various anthropogenic as well as natural activities. The presence of BC over the Himalaya significantly modulates the atmospheric radiative energy balance and raises the surface temperature which subsequently affects the Alpine ecosystem features and associated natural resources, such as glaciers, snowline and treelines, Alpine flora and fauna including overall pristine environment. Since, the BC is considered the second most important anthropogenic agent for climate change and a primary tracer for air pollution it has a role in deflection of Himalayan precipitation system. Therefore, increasing concentration of BC in the atmosphere has now become a matter of serious concern, especially in the High Himalayan glaciated region that has the most vulnerable ecosystem. However, due to poor logistic support and harsh climatic conditions, base line data on ambient BC is unavailable for Alpine ecosystem. To investigate the ambient BC concentration in glacial vicinity, two all-weather BC-measuring stations were established in Chirbasa (3600 m asl) and Bhojbasa (3800 m asl) near the Gangotri Glacier. The BC measurement is being done with the help of portable Aethalometer AE-33-7 permanently installed at observation sites along with solar power system having 0.8KW capacity and 12V 100Ah tubular gel batteries. In order to protect the underground batteries from extreme low temperatures (-37^{0}C to -34^{0}C), special insulation boxes were designed. The aethalometer is based on "Dual Spot" technology and analyses carbon on 7 different wavelengths between 370 – 950 nm UV and IR and has a BC measurement range of 0.01 to 100 μg/m^3. The measurement frequency of aethalometer is fixed 1 minute with flow rate of 5 lpm.

The 12 months BC data (Jan.-Dec. 2016) at Chirbasa station presents monthly and seasonal variability. Data shows that maximum BC concentration was 1899 ng/m^3 biomass burning with 1180 ng/m^3 black carbon during the month of May and minimum concentration of 168 ng/m^3 biomass burning and 123 ng/m^3 black carbon was recorded in the month of August. Field investigation suggests that both natural as well as anthropogenic factors contribute BC aerosols. The lowest BC concentration was recorded during the month of August followed by the December and it is observed that due to the absence of tourist activities and forest fire incidences along with rain wash of the pollutants-aerosols from atmosphere during rainy season, the BC concentration in the atmosphere remains at lowest level. The annual BC average at Chirbasa is 0.90 μ gm/ m^3 which is far below then the nearest stations viz., Nainital with 1.40 μ gm/ m^3 and Kullu with 4.60 μ gm/ m^3. These reported BC concentration are far below from the respirable pollutants limit i.e, 60 μ gm/m^3 set by the Indian National Ambient Air Quality Standard and World Health Organization i.e, 25 μ gm/cubic meter.

To mitigate the implications of BC, its origin form anthropogenic as well as natural sources need to be reduced by providing sustainable and eco-friendly alternate arrangements for the BC generating activities, besides public awareness through education, interaction and training on potential consequence of BC.

Natural Hazards in the Himalayan Regions: Consequences and Impact on the Society

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Natural hazards are naturally occurring physical phenomena caused either by rapid or slow onset events which can be Geophysical (earthquakes, landslides, tsunamis and volcanic activity), Hydrological (avalanches and floods), Climatological (extreme temperatures, drought and wildfires), Meteorological (cyclones and storms/wave surges) or Biological (disease epidemics and insect/animal plagues). Himalaya, as a region, has always been susceptible to disaster, due to the neo-tectonic Mountain-building process, like earthquakes, landslides, floods, etc. The spread of reckless developmental activities has transformed many natural disasters into man-made events. Such calamities play a grave negative socio-economic role on the national economy and exert additional pressure on an already strained national economy. Earthquake, landslide, cloud burst, forest fire, floods and flash floods in mountains are the natural disasters, which are regularly taking place in this region. Technological or man-made hazards also take place in this region in the form of forest fire, industrial accidents, etc. Major natural disasters can and do have severe negative short-run economic impacts. Disasters also appear to have adverse longer-term consequences for economic growth, development and poverty reduction. But, negative impacts are not inevitable. Vulnerability is shifting quickly, especially in countries experiencing economic transformation- rapid growth, urbanization and related technical and social changes. This paper includes various natural disasters taking place in this area and the science behind it. The significance of these disasters and their impact on human being as well as on the environment is discussed, and finally preventive measures needed to control these natural hazards so as to minimize the loss are discussed.

Upshot of global climate change on the tectonic movements and Himalayan glaciers: a caution to the current generation

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In most of the cases climate change plays like an important reagent, whether it may be agriculture, pollution, food security, plate tectonics or any other phenomena. Since industrialization, human activities have significantly altered the atmospheric composition, leading to climate change of an unprecedented character. The global mean temperature is expected to increase between 1.4 to 5.8ºC over the next hundred years. The consequences of this change in global climate are already being witnessed in the Himalayan glaciers and glacial lakes. The Himalayan glaciers are retreating at rates ranging from 10 to 60 meters per year and many small glaciers have already disappeared. Similarly, the horizontal and vertical displacements associated with plate tectonics play a fundamental role in climate change over a wide range of timescales. Tectonic processes also have important indirect climatic effects through their control on geochemical cycling and on the composition of atmosphere and ocean. On a larger time-scale, plate tectonics have a strong influence on the climate system, for example by blocking or opening large oceans straits, such as the Drake Passage between South America and Antarctica or the southern ocean between Australia and the Antarctic landmass. Both directly influenced the Antarctic Circumpolar current, the strongest ocean circulation, thus causing a complete change in the patterns of the global ocean circulations. So in this paper, we have focused mainly on the effects of climate change on plate tectonics, effects of moving plates on climate change, effect of climate change on Himalayan glaciers, how the Himalayan glaciers are affecting the Indian plate, their consequences and impacts as well as what are the necessary steps needed to be taken to surmount the challenges, etc.

Geochemical, Sm-Nd and Pb isotopic studies on beach monazites from southwestern coast of India

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The placer monazites from the southwestern coast of India are used to understand the growth history of monazites, their bearing on tectono-thermal evolution of the source rocks and timing of continental crust formation in various segments of Western Ghats dissected by Moyar, Palghat-Cauvery and Achankovil shear zones. The sediment samples were collected from the southwestern coat of India and further involved gravity, density and magnetic separation. The monazites were handpicked with the help of binocular microscope and analyzed by Electron Micro-Probe Analyzer (EPMA) and ID-Thermal Ionization Mass Spectrometry (TIMS) for minera,l chemical and isotopic studies. The core and rim chemical signatures in beach placer monazites from Kanyakumari coast can be linked with melting and melt-crystallization. EPMA U-Pb placer monazites yielded two age populations (576 Ma and 531 Ma), which perfectly fit with peak Pan-African metamorphism at 570 Ma (core) and retrograde metamorphism at 535 Ma (rim) for the Trivandrum Granulite Block of WG. The Pb-Pb age of 543±76 Ma on placer monazites from TB is similar to the age of retrograde metamorphism determined based on EPMA data. Thus, EPMA U-Pb monazite crystallization age and Pb-Pb model age of monazite addressed different Pan-African high metamorphic events in Trivandrum Block.

The measured $\varepsilon_{Nd\,(t=550Ma)}$ values (-15.7 to -28.1) and T_{DM} model ages (1.8-3.2 Ga) of monazites are similar to the Nd isotopic character of charnockite, gneisses and granites of the SGT. Thus, the placer monazites imprint the granulite facies metamorphism at 550 Ma and crustal evolution occurred during Paleoproterozoic in the hinderland source rocks of WG, that forms a part of the SGT. Monazites from northern Kerala coast yield highly negative ε_{Nd} values and higher TDM model ages (> 3000) compared to the southern Kerala coast. The ε_{Nd} values are similar to charnockites and enderbites, the potential host rocks, for an age of 2420 Ma, which is the time of granulite facies metamorphism in the Northern Granulite Terrain. Nd model ages for these monazites give three distinct age clusters, i) 2.2 Ga (Palaeoproterozoic), ii) 2.8-3.3 Ga (Palaeoarchean to Mesoarchean), iii) 3.5-3.7 Ga (Eo-Palaeoarchean). This indicates that the source region for these monazites consisting of Coorg massif and Northern Granulite Terrain had distinctly older crustal evolutionary history than granulite terrains occurring south of the Palghat-Cauvery shear zone.

Landscape evolution and sediment provenance of the Zanskar Valley, Ladakh Himalaya

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Zanskar River is a major tributary of Indus River system, flowing northeasterly and traversing through the Higher Himalayan crystallines, Tethyan sedimentaries and Indus Molasse. The rocks of Zanskar ranges are largely of continental origin, which were uplifted and deformed via several north verging thrusts, in which Zanskar counter thrust, Choksti and Indus-Bazgo thrusts are important. Two major tributaries of Zanskar, namely, Tsrap-chu and Doda flow in the headwaters, along the strike of the South Tibetan Detachment System (STDs) and join to form the Zanskar River at Padum village. Geomorphically, Zanskar valley is divisible into the upper and lower catchments that are separated by ~60 km long deep and narrow gorge. In the upper Zanskar, alluvial fan, valley fill and strath terraces configure landforms with paleo-lake deposits in the embayment of fans. The lower catchment, exhibits mainly valley fill and strath terraces. Using morphostratigraphy, geomorphometric indices and sedimentological investigations with luminescence and detrital zircon techniques, correlation between Quaternary landforms preserved in the upper and lower Zanskar catchments with respect to climatic and tectonic variables is defined. Chronology suggests diachronous aggradation in the upper and lower Zanskar catchments. In the upper Zanskar, large scale valley aggradation and fan progradation and flooding are coeval between 40-18 ka where as in the lower Zanskar fill terraces aggraded ~40 ka and 25-12 ka before present. Strath terrace in the upper catchment is dated >50ka; however, in the lower catchment, earlier workers reported ages of strath as ~ 206 ka (Bloth et al. 2014) and 55 ka (Kumar and Srivastava 2017). The longitudinal profile of the Zanskar River shows several convexities, associated with high value of SL gradient index, which may be attributed to tectonic uplift and high energy fluvial regime. The detrital zircon chronology of two flood deposits located separately in the upper and lower Zanskar suggest sediment being supplied selectively from 800 Ma crystallines and 500 Ma old granites exposed in headwaters.

Paleoclimate and paleotemperature changes in the NW Arabian Sea during the last 60,000 years

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Previous paleoclimate and model studies suggest that the Indian summer monsoon (ISM) is a major and important climatic feature of the Earth, which plays a significant role in the shaping of the live-hoods of the South Asian region. In this study, we present new data sets of *Globigeria bulloides* (%), stable isotopes ($\delta^{18}O$, $\delta^{13}C$) of *Globigerinoides ruber*, and emerging novel proxy of clumped isotope (Δ_{47}) of *Orbulina univera* from the ODP Hole 727B, NW Arabian Sea, to understand the Indian monsoon variability and paleotemperature changes during the last 60, 000 years. The traditional ISM proxy *G. bulloides* (%) show two stronger ISM phases during MIS 3 (~60 to 25 ka BP) and MIS 1 (14 ka to Recent), and one weaker ISM phase during the MIS 2 (Last Glacial Maximum and Younger Dryas) at 25 to 14 ky BP. The planktic foraminifera *G. ruber* and *O. universa* have been selected for the stable and clumped isotope analysis based on their relative abundances in the samples and ecology. The results of stable isotope ($\delta^{18}O$) analysis of *G. ruber* show enriched values during the MIS 2 and depleted values during the MIS 3 and MIS 1. The clumped isotope (Δ_{47}) based paleothermometry data suggest that the sea surface temperature (SST) value of ~20±2°C during the LGM and MIS 2, while maximum temperature of 32±2°C during MIS-3 (55-25 ky BP). Around 17°C sea surface temperature variation was occurring between the MIS 2 and MIS 3. The decreased *G. bulloides* (%), enrichment of $\delta^{18}O$ and SST drop during MIS 2 suggest that there was weakening of ISM, decrease of northern hemisphere solar insolation, and increases of growth of the earth's ice sheet.

Organic Carbon records of Climate Changes since Mid-Holocene from Garhwal, Uttarakhand Himalaya

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The lake and peat sediments are important palaeovegetation and palaeoclimate archive owing to its enrichment in the organic carbon which aids in precise dating and it also exhibits wide range of climatically sensitive palaeoclimate proxies including organic carbon. In the present study, total organic carbon (TOC) and loss on ignition (LOI) were measured to reconstruct organic paleoproductivity and palaeoclimatic signatures over the last ~5930 cal yrs BP from Bedni lake sediments of Chamoli Garhwal, Uttarakhand Himalaya,. The fluctuations in LOI and TOC values during ~5930 cal yrs BP, show unequal cyclic changes of ISM variability in the Garhwal region. From ~5930 to 2830 cal yrs BP, increasing LOI and TOC percentages indicate higher productivity under warm- wet climate conditions in region. Subsequently, a short two hundred years period of climate deterioration is observed with decrease in LOI and TOC values from ~2830 to 2630 cal yrs BP. The gradual increase in organic content (LOI and TOC) from ~2630 to 1750 cal yrs BP indicates the prevalence of wet and warm climatic conditions with strong ISM as indicated by the increased vegetation growth in the lake and catchment area of Bedni lake. A period from ~1750 to 1010 cal yrs BP has witnessed the reduced monsoonal precipitation. Whereas, from ~1010 to 500 cal yrs BP (AD 940 to 1450), the increasing trend of TOC and LOI suggests higher lake productivity with amelioration in climatic condition. From ~500 to 320 cal yrs BP (AD 1450 to 1630) the decrease LOI and TOC suggests deterioration in climate from warm moist to cool dry conditions. Since, 319 cal yrs BP to Present (AD 1630 onwards) the minor increase in TOC and LOI percentages indicates improved warm wet conditions in the Garhwal region.

Isotopes, Archaeology, climate and Sustainability of Human civilization

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Globally, more so in India, the boundary between Arcaheology and Mythology is often blurred. Normally as a subject Archaeology is also kept outside the domain of Geosciences. In reality the time domain of archaeology corresponds to Pleistocene and Holocene epochs. With the technological advancements, the connections between human evolution, culture and climate change are being deeply probed. New techniques in chronology, stable and radiogenic isotope tracing of processes are providing information that are not only fascinating but also have relevance to ongoing climate change and future of current human epoch 'Anthropocene'. The talk will principally focus on few case studies of a p p l i c a t i o n o f stable isotope tracers in studying archaeological events and processes and how the lessons from past can help us in building a sustainable planet.

Grain size effect on multi-element concentrations closely linked to instrumental record of precipitation during the past fifty years in the sediments from Rewalsar Lake, H.P., India

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To study the effect of precipitation over grain-size distribution and grain-size effect on multi-element concentrations down the sediment column of Rewalsar Lake depositional basin (Mandi, Himachal Pradesh), around two meters (0 – 2 m below lake floor) of sediment cores were analyzed for sediment grain-size distribution pattern using Laser Particle Size Analyzer (LPSA) and trace elements concentrations by ICP–MS. The results show that the temporal distribution pattern of sediment grain-size closely followed the instrumental record of precipitation. With gradual increase in precipitation from 1960 AD to 2012 AD, the coarser sediment particles also increased in volume percent up the sediment column, while, on the other hand, the clay-sized particles decreased down the column. The results further show that sediment texture played a controlling role on the concentrations and the temporal distribution of the trace elements. Most of the trace elements have their highest concentrations in the fine-grained clay sediments of the sediment column, in comparison with the silt and sand dominated sediments, with clay minerals possibly playing an important role. Thus, the precipitation controlled grain-size distribution, while grain-size controlled trace element distribution in the Rewalsar Lake basin during the past fifty years.

Study of Pleistocene Antarctic Radiolaria from Leg 119 Site 738B Southern Ocean Region

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The paper presents a detailed record of Antarctic Pleistocene radiolaria from Leg 119 Site 738B, Southern Ocean Region. The area is located on a large sedimentary drift of Latitude 62 42.54'S and Longitude 82 47.25'E and samples were collected at a water depth of 2252.5m (Fig.1). Twenty five radiolarian species were identified from twenty samples which includes sixteen Spumellarians and nine nasselarians. Their systematic palaeontology is given which is having distribution, abundance, remark and range of radiolarian taxa. The study shows that most of species belong to Pleistocene age like *Antarctissa cylindrica*, *Antarctissa denticulata*, *Cycladophora bicornis bicornis, Cycladophora davisiana, Cycladophora pliocenica, Saccospyris antarctica, Saccospyris preantarctica, Spongopyle osculosa* and *Spongotrochus glacialis.* Two radiolarian zones were demarcated on the basis of appearance / disappearance of the species - Psi and Chi zones Further, they were correlated with Caulet (1991) as NR1 and NR2. Further, it is observed that studied section belongs ~0.8 Ma

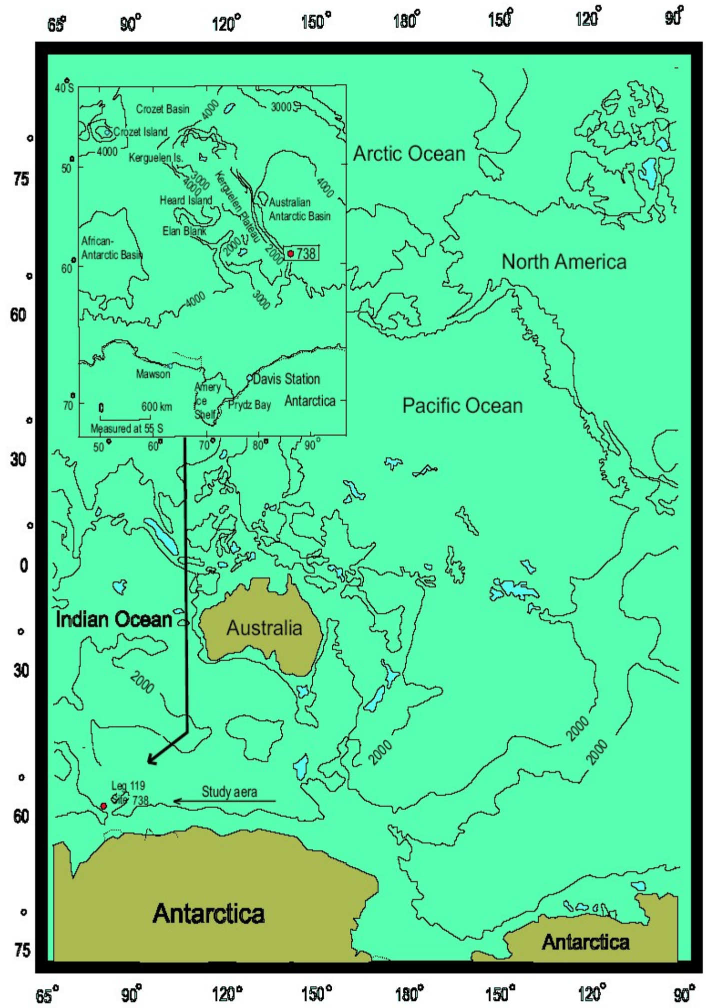

Fig: 1: Location map showing position of study area (Leg 119 Site 738B).

Record of ~3000 yrs of climate of the Western Himalaya: A multi proxy approach

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Himalaya and its surrounding region, which supports a fifth of the global population and bears significant impact on the economy, is sensitive to climatic oscillations. The flood of 2010 in Leh and June 2013 disaster in Uttarakhand that claimed thousands of human lives and destroyed property worth billions are recent examples to quote. Frequency of such events will increase or decrease and whether or not it rides on monsoon variability is an understanding that requires longer climate records.

This study presents ~3000 yrs of the past climate record inferred from the multi proxy study of a ~1.2 m thick peat deposit from Ladakh. The deposit, constrained by five ^{14}C-AMS dates, is composed of an organic rich fine grained sedimentary unit representing steadily accumulating biomass, serves as a good archive for the past climate with an appreciable resolution of ~35 yrs. We measured pollen, environmental magnetism, TOC (total organic carbon), TN (total nitrogen) and stable isotopes of C (carbon) and N (nitrogen). The results indicate that period from ~700 BC to ~100 AD is warm and humid as inferred from increase in aquatic pollen, A/C value and arboreal elements and magnetic susceptibility and depleted ƌ^{15}N. This is followed by a dry spell from ~100-1300 AD as indicated by reduced A/C, aquatic pollen, and arboreal pollen with correspondingly decreased magnetic susceptibility and enrichment of ƌ^{15}N. Further, the record shows amelioration from ~1300 AD. A peculiar behaviour of Mn and Fe is seen during ~300 BC to ~400 AD showing depletion of both while magnetic susceptibility rises and ƌ^{18}O and ƌ^{15}N gets depleted which is inferred to be as a reducing condition when it gets waterlogged as a consequence of increased humidity and warmth. This paper aims to unravel the complex processes responsible for climatic oscillations in the NW Himalaya and broadly the Indian-subcontinent which includes the migration of ITCZ, mid latitude westerlies, sub-tropical monsoon as well as other major oceanic and atmospheric circulations.

$\delta^{18}O$ tree-ring isotope based June-July precipitation variability during the last 273 years in western Himalaya, India

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South Asian summer monsoon rainfall (June-September) variability, which governs socioeconomic conditions of the second most populated country of the world, is not well known in long-term perspective. To understand the precipitation variability during the monsoon months we have developed three $\delta^{18}O$ isotope tree-ring chronologies from two conifer (*Abies pindrow* and *Picea smithiana*) and one broadleaf deciduous species (*Aesculus indica*) growing in Tela camp, Dokriani Glacier area, Uttarakhand, western Himalaya. Cross-correlation analyses among isotope chronologies of the region and regional precipitation series developed using six meteorological stations showed significant relationship with June and July precipitation. This relationship was further used to develop June-July precipitation record extending back to AD 1743. Reconstructed June-July precipitation series (AD 1743-2015) revealed continuous decreasing trend since AD 1743 with driest period in the late 20th and early 21st century in the last 273 years. Such decreasing trend was also observed in monsoon precipitation data of different regions of India. Tree-ring isotope proxies from the neighbouring regions also indicated decreasing trend in monsoon rainfall as revealed in the present study. Consistency in proxy and monsoon records from different regions underscores the utility of the reconstructed June-July precipitation in understanding the south Asian monsoon variability in a long-term perspective.

Classification and Characterization of meander cutoffs present in the Ghaghara river basin on the basis of morphometric parameters

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Meander cutoffs/Oxbow lakes are very significant part of fluvial system but its studies are very limited although it provides information regarding the processes affecting the river and the nature of evolution of the oxbow lakes themselves. It also gives reliable informations as regard to river dynamics, controlled by tectonic deformations, climate changes and sea level fluctuations. Ghaghara river is one of the largest tributary of the Ganga river. It originated from the Himalaya and merges into the Ganga on Gangetic plains. The river deposits lots of sediment along its course when it enters into the Gangetic plain. It has developed oxbow lake system along its course. There are variable shapes and sizes of oxbow lakes present along the Ghaghara river. Different oxbow lakes are defined and classified by using morphometric techniques, which are based on the cutoff shape, dimensions, variable component, degree of complexities, degree of cutoff limb closure and cutoff symmetry. In the present work the axial length, channel axis, major cutoff limb, minor cutoff limb, limb length, cutoff length, and meander cutoff of Ghaghara river have been identified and measured in Arc GIS10 platform. There are several classifications of oxbow lakes on the basis of interpretation of data. The first classification is based on the degree of complexities; in this oxbow lakes are Simple, Compound and Complex types. The second classification is based on degree of closure of cutoff limb; in this oxbow lakes are Open, Normal and Closed types. Another classification is based on combinations of previous two classifications. This study is important as it may be used to understand the river migration dynamics and it can be extended further for different user community for ground water perspective and management.

Middle Pleistocene to Holocene Paleoclimatic record from Japan and East China Sea and its possible linkage with uplift of Himalaya Tibetan Plateau and Glacio-eustatic Sea level changes

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The uplift of the Himalaya Tibetan Plateau [HTP] heightened the land-sea thermal contrast that led to the major changes in the Asian monsoon system. The elevations of the Himalayan-Tibetan region and its snow cover plays major role in the development of Asian monsoons since middle to late Miocene. Various proxy records suggested that the uplift of the HTP, whose topography reached to the present height by Pliocene caused initiation and intensification of Indian Monsoon System. Continental proxy records from various locations of Asia suggest that the uplift of northern Tibet started during the late Pliocene and simultaneously uplift of Himalaya restarted during the late Pliocene to Pleistocene which continued till present impacting global climate and Asian monsoon.

The Plio-Pleistocene uplift of the HTP has enhanced the extent and altitude of topographic barrier, influenced significantly the course, intensity and amplified variability of westerly jet circulation impacting sediment characteristics of northern Japan Sea as marked by alternations of dark and light sediment layers that are co-relatable with millennial scale Dansgaard-Oeschger (D-O) events. The effect of HTP on monsoon is reflected by the Yangzte river discharge and characteristics of terrigenous sediments deposited in East China Sea.

In this study we are presenting the multi proxy record by analysing the sediment core recovered from the Japan and East China Sea during the IODP expedition 346. The multi proxy data from three sites (U1423, U1426 and U1429) shows orbital scale variability in palaeoclimatic record, which may have possible linkages with HTP uplift, and/or glacio-eustatic sea level changes. The ages were constrained using C-14 dates, tephra chronology and initial ages suggested by the science party.

The studied Japan sea sites were more influenced by the glacio-eustatic sea level changes and strongly respond to the global ice volume change and paleoclimatic shift to 100 kyr cycles after the middle Pleistocene transition. While benthic, planktic and geochemical proxies of East China Sea show changes in response to variability in East Asian monsoon along with strength and intensity of Kuroshio Warm Current.

Paleoclimate variability in the NW Himalaya over the past three millennia

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High resolution proxy studies from the continental deposits such as lakes and speleothems during the Holocene have provided important clues to the drastic changes in the past climatic conditions across the Indian subcontinent. However, the timing, duration, regional pattern and causes of these climatic fluctuations are not well understood. Here, we present the results of our investigations on the radiocarbon dated core sediments from the Rewalsar Lake (Mandi, Himachal Pradesh, India; 31.6322° N, 76.8332° E) based on the isotopic and grain size studies. Climatically, Rewalsar Lake is situated in the transition zone between the mid-latitude westerlies and the Indian summer monsoon. The catchment of the lake area (~1.7 km^2) mainly comprises fine grained sandstone, grey siltstone, shales and fine spikes of mica seen in the siltstone (Das and Haake 2003). Our results suggest that the productivity of the lake is a complex one and governed by two main processes: i) In-situ productivity, and ii) Anthropogenic activities. The nitrogen value during the period of AD 1200-1400 suggests an extreme eutrophication, which led to stratification in the lake and absorption of atmospheric nitrogen. The most recent climatic events – the Medieval Warm Period, Little Ice Age and Roman Warm Period are constrained based on the grain size variations and the behavior of isotope. Furthermore, based on the global climate record the climate variability in the region is largely controlled by solar insolation.

Understanding Connectivity Structure of the Ganga Basin

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Supporting over 4.5 million people, Ganga is one of the most important basins of the world. In order to understand the dynamics of the Ganga River basin, its necessary to comprehend and define connectivity structure of the basin. Previous connectivity analysis have shown that there exists a non-coherence amongst various datasets such as sediment budgets, isotopic data etc. This study attempts to develop a comprehensive understanding of the Ganga basin connectivity structure by identifying various compartments and processes operating in them.

It is observed that extreme events play an important role in the upstream reaches of the basin; these events may sometimes be related to the rainfall and at times with other processes such as Glacial Lake Outburst Flows (GLOF). High magnitude and low frequency events (extreme events) seems to be carrying out more work than the relatively low magnitude high frequency event (moderate events); however, more data is required to corroborate this observation. Compartments linking Upstream and middle reaches of the river vary in terms of dominant processes - the process of avulsion in eastern Ganga basin rivers are dominant whereas these processes are absent in the western Ganga basin rivers. The distal compartment of the Ganga basin is controlled by the sea level fluctuations and it has shown large variability in terms of volume of sediment carried by the Himalayan rivers. There remains several caveats in the thorough understanding of the connectivity structure of the Ganga basin, which includes unknowns such as percentage of contribution by craton rivers in total water and sediment flux of the Ganga basin, rate of sediment production, rate of sediment flux, relationship between rainfall and discharge of the rivers, percentage of groundwater contribution to river discharge, residence period of sediments in each compartment etc.

The connectivity structure of the basin becomes more complex when we introduce changes made by the anthropogenic activities. The changes brought to the connectivity structure of the basin not only impact the hydrological and sediment connectivity but it also impacts the aquatic and riparian ecosystem. The study suggests that a robust connectivity structure of the Ganga basin can help in better flood and river management.

Signatures of climatic variability during Quaternary period from *Rarh* plains in eastern India

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The alluvial landscape holds the potential for developing a detailed record of a long history of fluvial response to climate change throughout the Quaternary which can be established through the study of fluvial archives and depositional style. Thus morphology and sedimentological content of the alluvial plains give valuable information on alterations in the fluvial regime with Quaternary climate changes. The valley-fill deposits of the *Rarh* plains (part of the lower Ganga plains) in western Bengal Basin offer an opportunity to understand the climate imprints on them. Such climate changes during the Holocene are well documented and quantified by several researchers from the western Ganga-Brahmaputra deltaic (GBD) plains. The Pleistocene palaeoclimate of this fluvio-deltaic plain including Damodar-Ajay-Kopai plains in these connections has not been attempted.

The present study focuses on reconstruction the Quaternary palaeoclimatic history of the *Rarh* plains using sedimentology, stratigraphy, geomorphological analysis and luminescence chronology of the fluvio-deltaic successions. Luminescence ages are obtained by sampling the cliff and trenched sections of the Ajay (Nelegarh), Damodar (Barjora) and Kopai (Kamalakantapur) rivers and from drill core samples from some parts of the Ajay (Panduk) and Damodar (Barjora) valley. Comparison with more than twenty published TL/OSL or ^{14}C dates from western Bengal Basin and Ganga-Brahmaputra Delta (GBD) plains show that the sedimentary records in this area are significantly older. In the *Rarh* plains, sediments 10 m below surface, yield an age varying between 10 and 29 ka whereas those occurring at a depth of 15-20 m are mostly 69 to 86 ka old. The data also revealed that during 90-82 ka (end of MIS-5), the lower Gangetic plain and associated deltaic plain experienced aggradational fluvial activities due to higher sea level and frequent climatic fluctuations and continued till 74-64 ka. In addition, decreasing precipitation and sea-level lowering (>100 m) during Last Glacial Maximum (24-14 ka) is reported from the western GBD. It has been postulated that these result in a relatively stable landscape and pedogenesis, and that in turn has prompted the formation of a pedocal soil and caliches nodules in the strata (<29 ka). This complex interaction between environmental change and earth surface processes provides an important framework for examining the influence of the dynamic parameters that leads to landscape evolution.

Solar influence on Indian summer monsoon variability during the last two millennia

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High resolution paleoclimate records are key to understand the natural forcing of climate change scenario. Such records will improve our understandings of future climate variability in a warming world. The present study represents the changes in the Indian summer monsoon (ISM) strength during ~116 BC to 1751 AD using oxygen isotopic signatures as preserved in a speleothem sample collected from the Mawmluh cave, Meghalaya. Our records indicate strong ISM conditions from 116 BC to 440AD. Abrupt weak summer monsoon conditions appeared between AD 440 and 568 coinciding with the decrease in solar insolation during the Roman Dark Period. Strong/Weak summer monsoon conditions were also observed during the Medieval Warm Period/Little Ice Age. The weakest monsoon conditions were observed during the 17th century AD. The warming/cooling of northern hemisphere temperature coincides with the strong/weak summer monsoon conditions in India.

Evolution of Pangong Tso Delta: a 2 ka trajectory of climate responses in high altitude lake, Ladakh

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The *Pangong Tso* is a high-altitude brackish water lake located at an altitude of 4,350 m in the arid, rain shadow of the Himalayan mountain chain in the Karakoram Range. It is 134 km long and extends from India to China, where 60% of the lake lies and its hydrology is largely controlled by melt/rain water supply and water loss via evaporation and groundwater recharge. It is dominated by precipitation from the Indian Summer Monsoon that occurs during June-September months.

Several streams carrying the melt water join the lake and build a fan that grades basin ward into a lake delta. The lake level lowering in the recent past has resulted into formation of four mappable strands and the incision of inlet streams has provided good exposure of past deltaic sequence. Thus a study combining the mapping of lake strands, sedimentology of delta sequence and chronology has potential to provide an opportunity to understand the evolution of high-altitude lakes and their responses to varying climate.

High-resolution mapping of the lake periphery suggested presence of 4 lake strands with the highest being located at ~6 m above the present day lake-level. The exposures of palaeodeltaic deposits exhibit a sequence involving a typical bottomset, foreset and the topset. The foresets are identifiable into 4 different depositional episodes of progressively smaller magnitudes that are younging lake ward. These depositional episodes, in terms of relief correspond to four lake strands. Internally, each deltaic lobe is composed of horizontally bedded poorly sorted gravel, lensoidal fine sands making the topset and parallel laminated alternate sand and silt exhibiting the scoured channel, making the foreset. The foresets dip 5-10° in the basin ward direction, and converge to make the flat bottomsets. These lobes are characterised by varying degree of bioturbation and energy conditions as evident from grain size composition. The TOC and LOI data provide an insight into the decreasing biological productivity (lowered of TOC values) and corresponding increase in the IC (Inorganic Carbon), which also indicates a progressive increase in evaporation and salinity of the lake.

Interestingly, the topset of the highest strand shows preserved molluscan shell bed and occurrence of a hearth implying anthropogenic activity. The shells, identified as *Radix* sp provide an opportunity for sclerochronological oxygen and carbon isotope studies to understand the seasonality of that time plain. The stable isotope data of the $\delta^{18}O$ values from each growth line of the *Radix* shell from the topmost strand, (which because of its life cycle of one year) fingerprint the relative contribution of melt water and/or Summer Monsoon sourced moistures. Chronology based on 3 Luminescence and 1 ^{14}C radiocarbon age suggest that the deltaic sequence evolved around 2,000 years B.P. The study indicates that at ~2000 yr BP the lake level was 6 m higher than the present level and salinity was lower to support fresh water molluscs, and the delta formation occurred in four phases that are identified as strands. The presentation will discuss the results in detail.

Evolution of Quaternary landforms in the Kota Dun, Kumaon Sub-Himalaya

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Late Quaternary alluvial fans deposited in the Kota Dun, a structural valley bounded by Siwalik mountains in the north and south in the Kumaon Sub-Himalaya, were studied to understand the response of climate and tectonics for their evolution. The Kota Dun extends in NW-SE direction for about 21 km between rivers Kosi in the west and Baur in the east and have an average width of about 5km. Four alluvial fans were identified, of these the Kotabagh and Dechauri fans have been studied. These fans originate from Siwalik mountains in the north. The Dechauri Fan was deposited by Baur River, presently flowing along the eastern margin of the fan whereas the Kotabagh Fan was deposited by Dabka River, presently flowing along the western margin of the fan. The fans were entrenched by respective streams and successive terraces were formed on the eastern margin of the Dechauri Fan and on the western margin of Kotabagh Fan. Five levels of terraces were observed in the Dechauri Fan whereas two levels were identified in the Kotabagh Fan. The sedimentary fill forming the fans comprises dominantly of gravels followed by sand and mud. The clasts are subrounded to rounded, pebble to boulder sized, clast to matrix supported and occurs as a sheet to channelized deposit. The fans comprise quartzite, sandstone, carbonate and phyllite clasts derived from the hinterland. To constrain the ages of deposition using Optically Stimulated Luminescence (OSL) dating, samples were collected from the exposed sections of the Kotabag Fan and from the top of the Dechauri Fan. Based on quartz OSL ages, the aggradation phase is spanned between >26 and 11 ka. At the proximal part of the fans, the Lower Siwalik Subgroup rock is riding over the fan sequences along the NW-SE trending Dhikala Thrust and displaced fan sequences are observed in the hanging wall of the thrust. The topmost surface of the Kotabagh and Dechauri fans shows about 40 m vertical offset, whereas the subsequent lower surface shows only 30 m offset. This suggests intermittent tectonic activity along Dhikala Thrust. The tectonic activity has created accommodation space for deposition and subsequently displaced the fan head sediments. However, we believe that the abandonment of the fan sequence has occurred due to the increased SW monsoon precipitation during the late Pleistocene to Holocene shift-in-climate.

Geomorphic evidences of Neotectonic activity inferred from the River Offset and Paleolake in the Lower Goriganga River: Higher Central Kumaun Himalaya

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The Kumaun Himalaya falls in the seismic gap and is seismotectonically one of the most responsive sectors of the Himalayan arc. The detailed drainage and geological analysis of landforms for about ~30 km between Lumti and Joljibi, along the lower reaches of Goriganga River was carried out in order to understand the tectonic and climatic history of the area. The present geomorphic signatures in aggregation with conventional field supported by geomorphic indices are analyzed to identify the role of neotectonic activity in shaping the valley floor landform development along the Goriganga River in the Higher Central Himalaya. The valley floor morphology in the vicinity of major thrusts gives rise to accommodation space for aggradation of recent fluvial sediments. Development of various neotectonic features like starth terraces, Off-streams, truncated saddles, disrupted terraces and paleo lakes, has given evidences about recent tectonic activities associated with the Main Central Thrust (MCT), Berinag Thrust (BT) and the Munsiari Thrust (MT). Cut-and-fill terraces with thick alluvial cover, debris flow terraces and alluvial fan terraces are the significant aggradational landforms observed within the valley that provide signatures of past climatic records. Digital analysis of remote sensing data and field investigations have been carried out together to understand the morphotectonic evolution in this region. To assess the tectonic activities in the area, we analyzed stream-gradient index (SL), steepness index (Ks), longitudinal profile and GLA magnitude analysis to map the spatial variability in tectonic processes. The various geomorphic landforms are physically examined to explain the different phases of aggradation / incision in response to the tectonic activity during the late Quaternary along the river. We have also incorporated a new technique of GLA method to understand the surface deformation pattern within the valley, whose positive and negative values show the uplift and subsidence in the area, respectively. A comparison of contour maps generated from the SL and KS data and the GLA values show us the regions of high and low tectonic activities.

Extracting the longest channel in the Ganga River Basin

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In Mythology, traditionally and culturally, the Ganga River has been shown to originate from the Gangotri Glacier (Gaumukh). In the literature, its mentioned length varies from slightly over 2500 km to 2650 km. In these studies, the source of the river is assumed to be at Gaumukh, and mouth at the outfall of the Meghna River (also known as Lower Meghna) into the Bay of Bengal. The name 'Ganga' is used after the Bhagirathi River makes confluence with the Alaknanda River at Devprayag. In the Ganga River Basin, the axial river has more than one headwater and so it is difficult to define the source. Moreover, after the Farakka barrage, the Ganga bifurcates into distributaries (Hooghly and Meghna) giving rise to different routes to the embouchure. This makes it difficult to extract its actual length.

In the present study, the Ganga River Basin is analyzed by considering the basics of geomorphology in defining length and master stream. The United States Geological Survey (USGS) states that, 'a river's length may be considered as the distance from its mouth to the most distant headwater source (irrespective of stream name), or from the mouth to the headwaters of the stream commonly identified as the source stream. So, the precise length of a river can be determined by the position of its headwater/source (farthest upstream point in a drainage network) and its embouchure (mouth). Another important parameter of a river is its discharge and some workers believe that the stream that carries the largest volume of water should be the main stem. The mean annual discharge of the Ganga River is 16,648 m^3/sec and thus, it occupies the ninth position among the world's largest rivers. Among the major Indian rivers, the Ganga is ranked second (after Brahmaputra) in terms of discharge and sediment load. The above data and information have been embedded deeply into our literature and Ganga is now considered as the trunk river of the basin. In spite of the Ganga being the most important river culturally, its length is hardly measured with scientific rigor. The present study demonstrates that the Ganga is not the longest river in the Ganga Basin (geomorphologically). The longest river segment is when the source point of the Tons River is considered and measured up to the confluence with the Brahmaputra River. It yields a length of 2758 km, which elevates the global ranking of the Ganga River to 31st position.

Development of soil profile in Himalayan sector -Elemental mobility and its micro climatic condition

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The higher intensity of weathering with time and limited erosion leads to development of soil profiles. Soil is defined as a distinct colluvial material that is derived from the underlying bed rocks which alter chemically due to the surface processes in the development of different layers. In the Himalayan region sustainability of a soil profile is very difficult due to excessive rate of erosion.

We have identified two such soil profiles namely, Kopardhar Soil Profile (KSP) and Dhopardhar Soil Profile (DSP) developed on the Ramgarh Group of rocks of Bhilangna valley of Garhwal Himalaya. These rocks are peraluminus S-type granite and are of Early Proterozoic age. The mineralogical constituents are the predominant factors controlling the mobility of major elements in transforming rock to soil. In addition, trace and Rare Earth Elements (REEs) mobilization are discussed to understand the dissolution of primary minerals and development of various phases of secondary minerals.

In the KSP section, major oxides show very limited variation from least altered rock to regolith, however sudden enhancement of Ti is noticed in the top soil (regolith) whereas the DSP section exhibits large variation in terms of major oxides. Calculated Chemical Index of Alteration (CIA) of KSP ranges between 65 (least altered rock) to 77 (regolith) and in the DSP section CIA varies between 64 and 74 and clustered into two distinct group in A- CN-K ternary plot. However, a majority of KSP samples follow the weathering path and plot along A-CN tie line. In general trace elements are depleted except enrichment of Rb in both the sections. REE concentrations of KSP and DSP sections show enrichment from least altered rock to regolith. Distinct positive Ce anomalies suggest a reducing environment.

Based on geochemical study, it is suggested that KSP and DSP profiles have suffered reducing environment followed by oxidation, which is directly proportionate/correlatable to rainfall during the development of soil profile. This is very important in terms of understanding the microclimate of the region.

The *n*-alkane and amino acid distribution of surface sediments from Ahansar Lake, Kashmir valley (India): Assessment of organic matter sources and implications for understanding the past environmental changes

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In the present study, we have focussed on the surface sediments of Ahansar Lake (Kashmir) to understand the fate and sources of organic matter by investigating lipid biomarker and amino acid distribution. Additionally, elemental (TOC, TN, C/N) and stable isotopic (δ15N) compositions were also measured on the various potential organic matter (OM) sources such as aquatic and terrestrial plants, catchment and lake surface sediments to disentangle organic matter sources and evaluate their use for paleo-environmental reconstructions.

The *n*-alkane distribution of catchment sediments and modern vegetation indicates a strong odd over even predominance characterized by the presence of higher chain lengths (*n*-C27 to *n*-C33), whereas the lake surface sediments show a high concentration (ca. 80%) of short chain (*n*-C15 to *n*-C21) n-alkanes derived from aquatic productivity. The spatial variability of n-alkane indices (P-aqueous (Paq) and terrestrial versus aquatic ratio) in Ahansar Lake suggesting their applicability as proxies for both various vegetation sources. The relatively low C/N ratios with high amino acid (AA) content show the enhanced aquatic productivity of the lake. This study provides the utilization of coupled molecular organic geochemical proxies and stable isotopic composition to reconstruct past environmental changes from the region.

Tree-ring based temperature reconstruction from Sikkim Northeast India

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The growth of high-elevation vegetation, on threshold of climatic limit, is very sensitive to climate derangement, the biodiversity is bound to be altered under the ongoing climate change. The weather records from the Himalayan region in northeast of India are very sparse and limited to past few decades. Due to the scarcity of weather records our understanding on climate change pattern and vegetation response in high elevation eastern Himalayan region is very restricted. High-resolution long-term proxy climate records from Sikkim, eastern Himalayan region should help in understanding the relevance of regional forcing and its implications. Using ring-width chronology of *Larix griffithiana* (Larch) from high-elevation North Sikkim (Lachen and Lachung) the mean late summer (July-August-September (JAS)) temperature extending back to AD 1852 has been reconstructed. The important finding of the reconstructed mean JAS temperature is warming since 1930s and 1996-2005 being the warmest period in context of the past ~150 years. The warming trend reported in our temperature reconstruction is consistent with other indicator of climate change such as plant species migration to higher ranges and accelerated glacier retreats in Sikkim. For understanding of regional climate variability in north east India is needed to expand climate records

Theme III
Geological Resource Potentials

Investigating the Minerals used in Ayurvedic Medicines

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The use of minerals and metals in modern pharmaceuticals and drugs constitutes a specialized branch of geology and pharmacology, and is known since ancient time. However, the knowledge has not been explored, investigated and processed. It is difficult to convert the minerals and metals in bio-assimilable products. Rasa Shastra, a branch of Ayurveda, explains about various compounds prepared using metals and minerals, animal products and herbs. It is estimated that around 15-25 % of medicinal products used in traditional Indian systems of medicine are made from Rasa, i.e. metals and minerals. The combination of metallic and herbal products together forms herbo-mineral formulations or *Rasaushadhies*. The ancient Indian scholars of Ayurveda recognized and documented the importance of metals and many minerals in various substances significant for therapeutic benefits, but their use has been limited to the classical texts. The procedures needed for the purification of metals and minerals including some of the poisonous substances are standard in the classical ancient Indian works. Well-defined procedures are required to prepare powder of medicinal usage called *'bhasmas'*, so that these become highly effective for medicinal purpose. This knowledge about medicinal use of metals and minerals for diverse ailments is now again attaining importance. As a result some herbo-mineral formulations to treat various diseases are in focus. The various metals, minerals and related substances used in Rasa Shastra have been classified into *Maharasa, Uprasa, Sadharanrasa, loha, Updhatu, Ratnas* and *Upratnas*. A slow, persistent and micro scale processing was in practice for preparation of the therapeutically useful compounds from metals and minerals.

A mixing of various herbs and minerals at different stages, and the typical preparation procedures are considered to enhance the properties of the compounds and improvement in their therapeutic values. The various substances used in the medicinal formulations are converted into micro size form so that it can readily absorb in body. *Rasaaushadhies* are quick performing, efficacious in lower dose, have longer shelf life and are easily palatable. *Rasaushadhies* when used internally with proper regimen and dosage have proved highly effective in curing many acute and chronic diseases and aided in promoting healthy life of an individual. The interaction between medicinal herbs and the metal or mineral used during formulations is of high significance as it may increase or reduce the pharmacological and/or toxicological effects. The use of adequate mineral is not well addressed, and most minerals commercially available are not tested and certified. The minerals like ochre, sulphur, orpiment, realgar, lead minerals and alunite are commonly used for medicinal purpose and are focus of the present study. These minerals were tested in the present study using petrography, SEM-EDS and micro Raman spectroscopy. It is evident that there is discrepancy in the obtained laboratory results and the minerals titles given to the samples of minerals delivered for the medicinal processing.

Water Quality analysis of different territory in Kumaun Region Uttarakhand Himalaya Preliminary Work

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Water is a prime natural resource, a basic human need and an asset; it is needed in all aspects of life and health, for producing food, industrial activities, energy generation, maintenance of environment, substance of life and development**.** The relationship between environment and the development are the most burring issues in the present time. The purpose of this study is quantitatively evaluate the hydrological and hydro geochemical factors that influence as concentration in the shallow groundwater of Uttrakhand districts, In my Preliminary work 137 different Hand pump water samples were collected from four districts of Pithoragarh, Almora, Chamoli, Udham Singh Nagar during February-March (2018). Groundwater sample were analyzed till now for 8 physico-chemical parameters (Arsenic content, pH, cond., TDS, DO, mV, Salinity, Temp.). Overall report of four District are good in these area average Arsenic content are 0-10 ppb and average pH is 7.52, average cond. is 0.318 mS, average TDS is 0.209 ppt, average mV is -23.78 mV, average DO is 4.98 ppm, average salinity is 0.17 ppt. If we find some harmful dissolved material in these samples of area then we shall suggest the some appropriate ideas to reduce that solvent in drinking water. This approach will improve the quality of drinking water in that area.

Himalayan rivers link only supplement to solution

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The water supply scenario increasingly stressed owing to rising demand despite static annual availability of 4000 cubic kilometer (CKM) mainly from rains and from trans-border rivers. The supplies is augmented by storing water in dams or extracting from underground source or by harnessing natural rivers flow. But, these measures are insufficient to meet the demands and failure of monsoon in large pockets of the country which also complicates the supply positions. To address the challenge, the proposed Inter Linking of River (ILR) scheme mainly envisages transfer of maximum 200 CKM flood water every year from perennial Himalayan rivers to Peninsular rivers by massive modification of the existing system at an presently astronomical cost of Rs. 20 lakh crores!, which by the time scheme proposed to be completed say in 2050, the cost may go up easily by three times. The obvious beneficiaries of water transfer are agricultural and urban sectors. However, geotechnical and social hurdles may prove to be stumbling blocks along with monsoonal pitfalls and geological logistic problems such as sediment management, seepage, swamp development, micro and macro climatic changes etc. Growing population and agricultural output would nullify this herculean exercise on account of limited resource availability.

Supplement to Himalayan waters could be inexhaustible water of surrounding coasts of Peninsular India. All over the world, processed sea water is utilized for urban and industrial requirements, with local limited efforts in our country also. A preliminary cost analysis of the desalinated water reveals that, utilizing available latest technology; same transferred quantity may be produced in the very conservative rate of interest earned from investment incurred on linking of rivers. It is proposed to evaluate option of desalinated water around coastal towns and cities to begin with later scope of utilization be expanded for interior region as well as agriculture requiring low usage of waters and limited implementation of linking scheme focusing on severely problematic areas of central and south India or mega growth centers like Hyderabad and Bengaluru.

Changes in spatiotemporal pattern of high-mountain lakes of Sikkim, Eastern Himalaya from 1975 to 2017

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Climate change has resulted in significant variation in glacial environment. Consequently glaciers all over the world have experienced negative mass balance in recent decades only with few exceptions (e.g. Karakoram; Western Kunlun). Himalaya, amasses largest number of mountain glaciers in the world which are distributed across its ~2000 km east-west stretch. There is significant inter- and intra-region variability in glacier response with mass loss being relatively higher in the eastern Himalaya which is corroborated by the recent large-scale remote sensing studies. This has triggered the dynamic evolution of high-mountain lakes with a higher concentration in the Eastern Himalaya. These lakes may pose a serious threat to downstream areas, warranting their systematic and regular monitoring. This study presents the first temporal inventory of glacial and high-altitude lakes in the Sikkim, Eastern Himalaya for four points in time i.e., 1975, 1991, 2000 and 2017 using Hexagon, TM, ETM+ and OLI images, respectively. First, a baseline data was generated for the year 2000 and then the multi-temporal lake changes were assessed. The annual mapping of SGLs was also performed for four consecutive years (2014-2017) to analyze their nature and occurrence pattern. The results show an existence of 463 glacial and high-altitude lakes (>0.003 km^2) in the year 2000 which were grouped into four classes: supraglacial (SGL; 50) pro/peri glacial lake in contact with glacier (PGLC; 35), pro/peri glacial lake away from glacier (PGLA; 112) and other lakes (OL; 266). The mean size of lakes is 0.06 km^2 and about 87% lakes have area <0.1 km^2. The number of lakes increased (by 9%) from 425 in 1975 to 466 in 2017, accompanied by a rapid areal expansion from 25.17±1.90 km^2 to 31.24±2.36 km^2 (24%). The maximum expansion in number (106%) and area (138%) was observed in SGLs, followed by PGLCs (number: 34%; area: 90%). Contrarily no significant change was found in other lakes. The annual SGL mapping reveals that their number (area) increased from 81 (5,43,153 m^2) to 96 (8,40,973 m^2) between 2014 and 2017. Occurrence pattern of SGLs shows that maximum number of lakes (>80%) are persistent in nature, followed by drain-out (15-20%) and recurring type lakes (7-8%). The new-formed lakes (9-17%) were consistently noticed in all the years (2014-2017). The results of this study underline that regional climate is accelerating the cryosphere thawing and if the current trend continues, further glacier melting will likely occur. Therefore, formation of new lakes and expansion of existing lakes is expected in the study area leading to increase in potential of glacial lake outburst floods. Thereby, persistent attention should be paid to the influences of climatic change in the region.

Estimation of Snow and Glacier melt Contribution in the Parvati Basin at Bhuntar, Himachal Pradesh, India

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A large amount of freshwater is available in the form of snow and glaciers in basins located in high mountainous areas. The estimation of the snow and glacier contribution in the annual runoff of various rivers is necessary for the development and efficient management of water resources, which include flood forecasting, reservoir operation, design of hydraulic structures, etc. The planning of new multi-purpose projects further emphasizes the need for reliable estimates of snow and glacier runoff. Keeping in view the importance and scope of such estimates, in the present study an attempt has been made to estimate the snow and glacier-melt contribution in the Parvati river at Bhuntar dam in Himachal Pradesh, India. The water balance approach has been used to estimate the average contribution of snow and glacier melt runoff in the annual flow of the Parvati river. The total water budget of the basin has been calculated for a period of 10 years (2000-2009). The total volume of flow for the above-mentioned period has been computed using measured discharge data of the Parvati river at Bhuntar. Evaporation losses estimated only from the mean daily temperature and daily dew point temperature. The results of the analysis show that the snow and glacier-melt runoff contributes about 73.5% to the annual flow of the Parvati river at Bhuntar. About 71% of the Parvati river basin area is covered with snow during winter (March) and about 29% remains snow free area.

Temporal changes of Swetvarn and Thelu glaciers from 1962 to 2017 in Gangotri catchment area, Garhwal Himalaya, India

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The health of the glaciers has become one of the most serious concerned in the current prospective. The literature reviews and records suggest that the averaged mass balance of almost all glaciers and ice caps is negative globally, except for Karakoram glaciers. The current study emphases on the temporal fluctuation of Swetvarn and Thelu glaciers in the Gangotri catchment, by using Survey of India topographic map (1962) along with multi-dated satellite data (LANDSAT MSS, 1976; LANDSAT TM/ETM$^+$, 1990-1999; LISS IV, 2012-2017). Results closely reveal that both the glaciers are continuously shrinking with variable rate of retreat. From 1962 to 1997 Thelu glacier has lost 0.77 km^2 (0.016 km^2 a^{-1} from 1962 to 1990; 0.011 km^2 a^{-1} from 1990 to 2012; 0.014 km^2 a^{-1} from 2012 to 2017), while the Swetvarn lost 2.73 km^2 (0.062 km^2 a^{-1} from 1962 to 1990; 0.022 km^2 a^{-1} from 1990 to 2012; 0.042 km^2 a^{-1} from 2012 to 2017) the total glaciated area, respectively. The rate of melting of both the glaciers was high from 1962 to 1990 time, because the central Himalaya received less precipitation during this time period. The supervised classification of the multi-dated satellite data also reveals that the continuous decrease in the glacial surface from 1976 onwards. The ELA of Thelu glacier shows ~ -360 m total shift from 1962 to 2017 while the ELA of Swetvarn has been shifted ~ -1040 m from 1962 to 2017. Over all the study discloses that there is continuous retreat of almost all the glaciers of Gangotri catchment area with variable rate of melt.

Preservation of natural resources in Himalayan Region: a contemporary challenge to the enduring Government

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Air, water, soil, forests, animals, etc., that are provided by nature or occur naturally are called natural resources. These natural resources are making the country economically strong. Some of these natural resources like sunlight and wind are renewable resources. This means that they can be used again and again without being exhausted. But some like forests, minerals, oil, etc., are non-renewable resources. Day by day these non-renewable natural resources are decreasing. The relatively recent geological origin, the Himalayan region is rich in natural resources. Its biodiversity of elusive plant and animal species, its mineral resources, the water availability in this section is under the threat of destruction, expanding agricultural land and rural population resulted in diminishing forest area. Expanding economic activity and population growth are the two basic factors behind increases in energy consumption. In a state like J&K, where economic growth is necessary and population growth is increasing, energy demand will continue to rise in the years to come. Energy consumption patterns and the rise in demand, their sources, and ways in which they are harnessed and utilized have implications for the environment and natural resources, which ultimately affect overall development of the whole country. Progress in environmental management has been slow and natural resource degradation remains at the core of many problems. Climate change will add a new stress to ecosystems and socioeconomic systems already affected by poverty and natural resources depletion and unsustainable management practices needs an immediate attention of the scientific community. *Several* occurrences of metallic minerals and deposits of non-metallic minerals and construction material are reported from the state. Incidences of gold mineralization have been reported in quartz veins in Kupwara district, in shear zones traversing Ladakh granitoid and as sporadic placers in Kargil district. Some old workings developed for copper have been reported from Anantnag and Baramulla districts. Stibnite mineralization has been reported from quartz veins traversing limestone in Zanskar valley of Ladakh. However, due to illegal mining, political issues, poor environment we are not able to use it in the welfare of mankind.

We need to conserve and preserve these Himalayan resources or soon they will be exhausted. This paper hence deals with natural resources across the Himalayan region, their availability, the way in which they are destroying by the human being, Environmental and other issues also, and what are the preventive measures that has been taken and need to be taken etc.

Studies on the ore potential of Deccan volcanics from Proterozoic Bhima basin from Mangalwedha Taluka, Solapur district, Maharashtra, India

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The pessimistic attitude of exploratory Geologist on metallogenic potential of Deccan trap may possibly be due to lack of data on surface indications of mineralization and optimistic thinking about their coexistence with Archean and Proterozoic rock. Thus, the Deccan volcanics have not been considered seriously as a possible host for base metal, precious and Platinum Group of minerals. A case study of rocks from Proterozoic Bhima basin is been presented here with their details on field occurrences, nature of deposition, structural control, and their alteration behavior. Three episodic metallogenic fluid activities are recognized from the study area. The earliest activity is represented by the mineralization of Cu, Fe, Pb, Mo, Bi and Au in minor amount that is found in strata bound meta-volcanics and associated meta-sediments, with chemical control for their deposition. The later epithermal activity is restricted to shear zones, faults and intersection of lineaments, where the space was available for deposition along fracture breccias and cross-cutting veins, exhibiting their structural control. Mineralization is associated with wall rock alteration represented by silicification, sasuritization, chloritization, pyritization, tourmalinization, arsenopyritization is noteworthy in the areas where Gold and Platinum minerals are in abundance. The mineralization in Paleo-cinders and Tuffacious meta-acidic rocks found to have the presence of Platinum Group of minerals associated with Gold and mostly represent their pneumatolitic parentage.

The dominant role of Cl- and CO_2- and S-, HS-legants is presumed during ascending movement of mineralizing media in early phase mineralization, while that of fugacity of CO_2 and boiling during pressure release is considered responsible for forcible deposition of precious metals in cinder.

The mechanically concentrated auriferous placer deposits are not uncommon in Bhima basin these are commonly found in depositional sites at curvilinear course. Paleo-placers found along the changed course of river due to seismo-tectonic activity are found to be relatively rich in concentration of Gold and Platinum Group of minerals compared to those studied from present river course. Samples collected from three different environs of mineral occurrences when subjected to pulverization, panning concentration, and then to amalgamation, supplemented with fire assay study, revealed presence of Gold and Platinum Group of minerals along with Cu, Fe, Mo, AS, Pb and Ni minerals. So, it is warranted that more systematic study is needed to know precisely their concentration, their prognosticated reserves, their economic potentials, and variation in depth. Thus, the study invites attention of all exploration Geologists interested in precious mineral studied on these new inventory ore occurrences.

The unusual mineralization in Uchich area, Parvati valley, Himachal Himalaya

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Uchich in the Parvati valley of Himachal Himalaya lies at the northwester extension of Larji-Kulu-Rampur window. The area is covered by the Proterozoic rocks of Banjar and Kulu Formations/Chail Formation, wherein the rocks of Chail Formation are thrusted over Manikaran Quartzite of Banjar Formation along Chail/Kulu Thrust. The Chail Formation comprises of garnetiferous schists, mica- schists, bands of gneisses, slates, phyllites, quartzite together with occasional bands of carboniferous schists, whereas Banjar Formation consists of massive quartzite, phyllites, slates and chlorite- phyllites. The contact zone of Chail and Banjar Formation mainly along the hanging wall side on the right bank of Parvati River and south of the Uchich village, is marked by the presence of sulphide mineralization. Polymetallic sulphide mineralisation in the area occurs in hard, metamorphosed and highly jointed vitreous massive Manikaran Quartzite as breccia fillings and veins along shear zone. The mineral assemblage include pyrite, arsenopyrite, galena and minor chalcopyrite. SEM-EDS data is largely consistent with major Fe and S with usual presence of 2 to about 15% As in pyrite. Sn is also noticed in one analysis. Presence of scorodite, an alteration product of arsenopyrite, has also been verified by the Micro Raman data. It is evident that the mineralogy of the ore assemblage is complex and unusual, as two unidentified non-stoichiometric ore minerals are also noticed in Raman results.

The fluid inclusion study of mineralized quartz show four types of fluid inclusions: (i) multiphase saline aqueous inclusions, (ii) monophase carbonic inclusions, (iii) aqueous- carbonic inclusions and (iv) aqueous- biphase inclusions. High saline aqueous inclusions with a large solid daughter crystal and liquid >gas are uncommon and restricted. Carbonic monophase dark colour inclusions coexist with aqeous-carbonic inclusions in groups and trails, which at times cut across the grain boudaries. Many inclusions are also present in the trails which terminate within the grain boundary as well as in random distribution. They are most common in the studied samples. Their micro Raman spectroscopy confirm the presence of CO_2, however no evidence of CH_4 and/or N_2 was recorded. Presence of water is also confirmed through Raman data. The wide distribution pattern may be indicating a syn- to post-ore nature of the fluid in these inclusions. In the aqueous- carbonic inclusions the liquid – liquid meniscus at room temperature is common, suggesting low density of the carbonic fluid. Together with monophase carbonic inclusions, the proportion of carbonic and aqueous phase widely varying from 60:40 to and 20:80, points to immiscibility in fluid. The ore mineralization is interpreted to be result of the unmixing of carbonic-aqueous fluid, and the high saline fluid was in limited flux. Late aqueous inclusions are linked to rrecrystallization of vein quartz characterized by the presence of incipient neograin and annealing texture.

Contrasting characteristics of bauxite and associated litho-units from two Geo-environments: An infrared spectroscopic study

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Bauxite and its associated litho-units such as lithomarge and laterite from two different geological setting, one developed over khondalite and the other over volcanic tuff, exposed at different locales of Odisha, were investigated using FTIR spectroscopic technique. In view of more or less similar mineral assemblages in both the sets of sample, as obtained from their XRD pattern, characterization by an alternative technique was attempted. FTIR spectra of Laterite, Bauxite (medium-grade and high-grade) and Lithomarge from the two set-ups are classified into three broad bands of the spectrum, viz. 400-1250 cm^{-1}, 1250-3000 cm^{-1} and 3000-4000 cm^{-1}. Synthesis of these spectral bands has brought out differences between various litho-units, developed under two dissimilar geo-environments.

The spectral peaks at 458, 514, 2007 and 3450 cm^{-1} in lithomarge and peaks at 691 and 770 cm^{-1} in laterite are only noticed in khondalite hosted sample, and are assigned to quartz. In the same set up, additional peaks at 580 and 1011 cm^{-1} in lithomarge are assigned to orthoclase. Presence of quartz and orthoclase are otherwise not detected in their respective XRD pattern. The peaks at 3652 and 3694 cm^{-1}, diagnostic of kaolinite, is sharp and strong in lithomarge and laterite, derived from a tuffaceous pedigree, but are conspicuous by their absence in khondalite. In medium-grade type of khondalite hosted bauxite, presence of kaolinite is indicated from the peak at 1011 cm^{-1}. The spectral bands of high-grade bauxite in khondalite hosted and tuff hosted broadly matches with each other, though in later type the peaks are stronger and sharper in nature. Further, two peaks at 1098 and 1592 cm^{-1} that occur only in later types are attributed to diaspore. The peaks at 796 and 1631 cm^{-1}, characteristic of goethite appear in laterite sample. However, the former peak is relatively stronger in khondalite hosted laterite, while the other peak appears broad suggesting predominance of goethite over its other counterpart.

The above findings demonstrate that FTIR study can be considered as a useful tool to recognize minor minerals present in various litho-units of bauxite deposit developed over different host rocks. In the present context, record of quartz and feldspar in lithomarge and laterite attest its khondalite parentage, while strong and sharp peaks and presence of diaspore in tuff-hosted bauxite point to their high-grade nature and attainment of maturity during bauxitisation process.

Recent snow cover trends in the Upper Indus sub-basin, Jammu and Kashmir

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Snow cover in the Himalayas has been undergoing rapid fluctuations in response to global warming. Regionally, snow cover has a crucial role in influencing the micro-climate and water budget. Literature suggests that in the Upper Indus (UI) basin, snowmelt alone contributes up to half of the annual runoff budget. Despite its significance, the variability and the current status of snow cover in this basin have been poorly understood. Overcoming the limitations of conventional surveys, remote sensing has allowed the detection of spatio-temporal patterns of snow cover. This study pertains to the recent trends in snow cover in the UI sub-basin during the time period of 2009-2017.

The time series snow cover area (SCA) in the UI sub-basin has been derived from MODIS 8 day composite reflectance products using Normalized Difference Snow Index (NDSI) thresholding technique. The time series data has been analysed on an inter-annual, seasonal and monthly basis. Results show that the SCA varied from a maximum of ~60813.5 km^2 to a minimum of 2167.5 km^2 amounting to 86.8 % and 3.1 % respectively of the total sub-basin area (~69991 km^2). Both of these extremities occurred in the year 2017. Analysis on the seasonality removed time series data also indicates rapid fluctuations in the SCA from 2015 onwards which is consistent with recent studies that suggests extreme snow cover variations. Observations from the snow depletion curves (SDC) suggests that SCA has consistently increased during the study period except in the hydrological years 2010-2012 and 2015-2016. Moreover, it has been observed that peak of maximum snow cover that usually corresponded to the month of February shifted to January and March during the years 2013-2014 and 2015-2016 respectively. The lowest snow cover has been witnessed during the peak winter of 2015-2016 whereas the highest snow cover extent has been found in the fore (2014-2015) and aft (2016-2017) years and these could be probable indications of impacts of climate change affecting the region. Overall, average snow cover trend for all the years has been indicating a slight insignificant decreasing trend (significance (p) = 0.694 at 95% confidence, Mann Kendall tau (τ) = 0.036). Seasonally, the winter, autumn and summer trends shows a slight decline in the SCA whereas a slight increase in the spring SCA. Similarly, monthly snow cover variations reveal that the maximum snow cover occurs in the month of February except in 2009 and 2015 and the minimum snow cover occurs about the month of August for all years. Short term assessment of snow cover variability trends implies complex snow cover patterns especially in the recent years where extreme fluctuations are predominant.

Delineating different Glacial Lakes in Bhutan using Earth Observation Data

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The mapping and monitoring of different types of Glacial lakes through Geospatial technique is not only vital to show the impact of climate change on the Glacier but also to alleviate hazards which are resultant of out bursting of Glacial lake and catastrophic to human lives. The main goal of the present work was to map different types of glacial lakes in Bhutan during years 1989, 2000 and 2017. During this research, Landsat-TM of 1989, Landsat ETM+ of 2000 and Landsat 8-OLI satellite image of 2017 were used to estimate the changes in the glacial lakes and inventory study. Several glacial lakes i.e. moraine dammed lake, supra glacial lake, lateral moraine lake, erosional lake, medial moraine lake and end moraine lake were mapped within these period and found a rapid increase in the number of glacial lakes during 1989 to 2017. The number of glacial lakes in 1989 was increased from 213 to 436 in 2017. It was also observed that the spatial dimension of some of the glacial lakes were also increased. The study reveals that there was 5 end moraine lakes, 40 lateral moraine lakes, 50 supra glacial lakes, 239 erosional lakes and 15 other moraine dammed lakes in year 2017.

Impact of land use and land cover changes on the groundwater regimes in Una district, Outer Himalaya, India

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Land use and land cover changes (LULC) during last few decades have affected the groundwater availability and quality of potable water throughout the world. The Una district in H.P. has experienced a rapid change in the industrial and urban groundwater dependence and increased irrigational practices during last few decades that has adversely affected the groundwater regimes. Since agriculture is the main occupation of the local people in the district, groundwater has been extensively used for irrigation. The present study is an attempt to assess the effect of land use land cover (LULC) and precipitation changes on the groundwater regime over last three decades in the Una Basin of Himachal Pradesh. To achieve that, Remote Sensing data from Landsat 5 TM (year 1999 and 2009) and Landsat 8 (year 2015) were utilized for the purpose of LULC changes. Precipitation data of 41 years (year 1973 to 2013) and hydrological data (Static Water Level (SWL) and discharge in lpm) were used to assess the changes in the rainfall pattern, fall/rise in groundwater level and discharge in the wells, and the factors influencing them. Cyclic changes in precipitation pattern have been observed except in year 1989 which has received abnormally high rainfall. An increase in area of agricultural land (19%), settlement (~300%), and the dense forest (25%) has been observed in the basin for the year 1999, 2009 and 2015. The SWL at few locations has lowered with time while it has risen from the year 1999 to 2013 at other locations indicating the change in recharge conditions in the region. An increase in the SWL from the 2010-2013 at few locations in the valley fill region may have resulted due to the secondary recharge of aquifers through irrigation canals, seepages, infiltration of irrigational wastewater and water logging in the fields. All these factors have resulted in an increase in the concentration of Na^+ and Cl^- ions in the water. The results are further substantiated by comparing the hydrochemical data for the year 1999 and 2015. The concentration of Na^+ and Cl^- has increased in the groundwater as a result of waterlogging. Further, during the year 1999 and 2015 nitrate (average 12.8 mg/l to 16 mg/l) and fluoride concentration (average 0.3 to 0.9) has also increased because of the excessive use of fertilizers in the agricultural fields. The increasing trend of nitrate concentrations in water in successive years since the year 1994 supports the changes observed in an agricultural pattern in LULC maps for the years 1999, 2009 and 2015. The results divulge that the groundwater quality has deteriorated in the district due to an increase in industrial and agricultural activities. There is a need to conjunctive use of water for future uses through appropriate water management practices.

Evaluating snow cover area (SCA) in relation with terrain and meteorological attributes of Dokriani Glacier catchment, Central Himalaya

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Snow cover plays an important role in mountain hydrology, flow availability of river systems and avalanche events. The comprehensive study on spatio-temporal distribution of snow cover is limited due to inaccessible and rough terrain of the Indian Himalayan region (IHR). The present study is an integrated effort, based on remote sensing and meteorological input, to estimate areal extent of snow cover. The datasets from satellite series (Landsat (5 TM and 8 OLI) and Sentinel) and from three automatic weather stations (AWSs) were analyzed, to understand the topographic (elevation, slope and aspect) and meteorological (i.e. temperature) control on snow cover area (SCA). Results reveal that coefficient of variation (CV) was prominent below the elevation ~5000 m asl, providing the rapid depletion of snow and its significant contribution in total run-off; while less variability in CV was observed at higher elevations. Likewise, CV was found to be high for southern aspects as compared to northern aspects. Furthermore, correlation between snow cover variations and temperature threshold, commonly known as isotherms (0, 1 and 2°C) was analyzed by a regression method using near-surface temperature lapse rate (NSTLR) of the catchment. The NSTLR varies substantially during all the seasons, with steepest in pre-monsoon and shallowest in monsoon season. The monthly isotherms were close to the snowline observed by remote sensing, suggesting that near-surface temperature may be used as a proxy to represent depletion in SCA during most of the ablation months. Conversely, monthly as well as hourly isotherms deviate largely from snowline during accumulation months, showing that temperature has no direct control over snow accumulation due to large differences between minimum and maximum temperature at different altitudes. The observed and extrapolated temperature was always positive during three months (June, July and August) in ablation area. In conjunction of temperature with snow cover extent, elevation zone above 5300 m asl preserve snow throughout the seasons, suggesting a close proximity with equilibrium line altitude (ELA) of Dokriani Glacier catchment (DGC). Snow cover assessment and monitoring is an important for evaluating water discharge, and analyzing climatic variability.

Impact of radiometric resolution on snow and ice facies identification

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In the context of increasing our understanding of glacier changes in a variable climate, an accurate and detailed mapping of glaciers is must. This helps in determining firn line and snout positions, accumulation and ablation areas and overall mass balance of glaciers required for understanding the glacier dynamics and monitoring the climate system. Remote sensing (RS) technology has significant applications in such glaciological studies. Although optical RS data is now available at low or free cost, it's imperative to opt for radiometrically well-suited data for proper discrimination of glacier facies. This study was therefore undertaken to investigate the impact of radiometric resolutions on the proper identification of snow-ice facies present on the surface of Gangotri and neighbouring glaciers. Two Advanced Wide Field Sensor (AWiFS) images, two Landsat Thematic Mapper (TM) images (each of ablation and post-ablation seasons) and one Sentinel-2A Multispectral Instrument (MSI) image (ablation season) were taken and converted to topographically corrected surface reflectances. Spectral profiling of snow-ice facies helped in the identification of three different snow facies (fresh and slightly metamorphosed snow (FS), wet-snow (WS) and firn) and two ice facies (ice and ice-mixed debris (IMD)) from AWiFS and MSI data. Validation with available field spectral measurements of snow-ice facies and published data indicated that higher quantization (12-bit) like in AWiFS and MSI ablation data reflects the true spectra of snow-ice facies and is thus beneficial for detailed mapping of glacier facies. Comparatively, the low radiometric resolution TM (8-bit) ablation data showed lower green reflectances of snow-facies (<70% for FS, <60% for WS, <40% for firn and <34% for ice) and more spectral overlap between firn and ice in red and NIR bands. FS usually has a visible reflectance of >70% and >80% during ablation and post-ablation seasons. However, FS samples from TM ablation data showed anomalous spectra with constant reflectance values of ~58% in red band due to the sensor saturation as the respective digital number values in its raw image in VNIR bands were found to be 255 (the maximum value). Similar findings were observed for some WS samples.. Unlike high radiometric resolution post-ablation data, low radiometric resolution TM post-ablation data is unable to discriminate between different snow-ice facies present beneath the seasonal snow. Saturation was observed at green and red bands showing the reflectance of 70% and 64% respectively for all the snow-covered facies. For ablation data, higher mean entropy values were observed for AWiFS (~0.61 ±0.94) than Sentinel (~0.58 ±0.90) followed by TM (0.46 ±0.86) in VNIR bands. This implies that high radiometric resolution data contain more spatial information and are thus well-suited for the detailed zonation of glaciers.

Theme IV
Science of Natural Hazards

Bioengineering and early warning system for mitigation of Surbhi Resort Landslide, Mussoorie Hills, Uttarakhand Lesser Himalaya, India

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Recent cloud bursts and Glacial Lake Outburst Flood (GLOF) in the Uttarakhand Himalaya have triggered catastrophic landslides. Heavy monsoon precipitation lashed Uttarakhand causing devastation and series of new landslides in the region. Surbhi Resort Landslide is located near the hill station of Mussoorie in Garhwal Himalaya, India, in Upper Krol Limestone. After intense rain in August 1998, the Krol sedimentary deposits suddenly gave way as a deep-seated landslide, blocking the main Mussoorie-Kempty artery for 15 days. In 2005, the velocity of the slide was determined to be 4-14 mm/year by previous workers, thus still active with a modest intensity. However, since huge amounts of quaternary debris are still lying on the slope, another high intensity rainfall or cloud burst could trigger another large-scale failure. Recently, Venkateswarlu and Tewari (2014), Bryanne and Tewari (2014), Singh et al. (2015) and Gupta et al. (2015) have done various geotechnical studies and geological modelling of the rock and soil samples from the Surbhi landslide zone and have concluded on the inherent instability of the slide andit's vulnerability to increased pore water pressure. Hence it's mitigation measures are focused on lowering the ground water table using horizontal drains at the row of the slide zone and installing proper road drains along the Mussoorie-Kempty road. This would generate an additional discharge which has to be channeled down Rangaon-ka-Khala, the natural channel, down the slope to Aglar River flowing in the valley below. To prevent further surface erosion, Rangaon-ka-Khala must be bioengineered with shrubs and grasses such as *Eriophorum comosum, Saccharum spontanum, Pogonatherum spp.* and *Woodfordia fruticosa* while the surrounding slope must be reforested with *Quercus leucotrichophora, Alnus napelensis, Pinus spp.* and *Cedrus spp.* Check dams must be constructed on the entire 3.5 km stretch of Rangaon-ka-khala to lower the velocity of the water. This could be done either as gabions or in the form of live fascines of *Salix tetrasperma* or *Dalbergia sissoo*. Further, in the absence of mitigation measures, it is suggested that an early warning system should be set in place based on the intensity and antecedent rainfall in the area. Mathew et al. (2015) conclude that intense rainfall of 12 mm/h for less than 10 hours or a long time rainfall for more than 12 hours with intensity of 4 mm is sufficient to trigger landslide in lower Himalaya. It is suggested that these mitigation measures and bioengineering plantation would certainly help stabilize the Surbhi landslide area to prevent further disaster in future and that a warning message could be send to limit the impact. These measures may also be applicable for the other active landslide zones in the NW (Jammu & Kashmir) and NE (Darjiling – Sikkim) Himalaya.

Structural and joint set analysis of rocks of Anantnag district, NW Himalayas and its implications to seismotectonics

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Himalayan Mountain Range is the earth's most impressive and spectacular example of geological architecture. The tectonic evolution of the Himalaya is due to a series of continent-continent collision events. The Himalayan compressional tectonic setting has deformed different lithology's of the Kashmir valley that leads to formation of various types of structural features in the form of Folds, faults, Lineation's, Foliations etc. Geological structures are usually the result of the powerful tectonic forces that occur within the earth. The interaction of rocks with these forces is responsible for their present shape and disposition. The present study was carried out to study the detailed lithology of the area, to collect the structural data of the rocks of the study area, to prepare geological mp finally to interpret the tectonic setup of the area. Field study was carried out to collect lithological and structural data from study area. Study area shows diverse type of lithology's ranging in age from Palaeozoic sedimentary to recent alluvium with Panjal Traps and Agglomeratic slates as the dominant formations. In the Lab work structural data was plotted on lithological map and interpreted by using Stereographic projections. Mean orientation of all the joint sets and structural features present were plotted which gives two dominant orientations of the joint data as J1 and J2. J1 is oriented as 28°/33° SE and J2 is oriented as 157°/48° SW. Analysis of joints gave orientation of the maximum principal stress direction ($\sigma 1$) as 19° azimuth and orientation of minimum principal direction ($\sigma 3$) as 289° azimuth. This implies that the maximum principal stress direction ($\sigma 1$) aligned NE and the minimum principal stress direction ($\sigma 3$) aligned NW direction during the time of formation of these joints, which infers the NE movement and convergence of Indian plate with Eurasian plate.

Assessment of strength parameters of selected failure zones in Lesser Himalayan stretch, Kalsi-Sankari road, Uttarakhand

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The route from Kalsi to Sankari is located in high relief and weak region of Dehradun and Uttarkashi districts, Uttarakhand and is frequently ravaged by the varying scale of slope failure phenomenon. Besides a tourist route connecting Har ki Dun, this is an important route for defence purpose as it moves via Chakrata. It also links number of other villages and is crucial for their daily supplies and business. Moreover, being a gateway to Govind National Park, Jaundhar and Banderpunch glaciers, it is vital attraction to trekkers and nature lovers.

It crosses almost whole of the Lesser Himalayan zone which has underwent extensive brittle and ductile deformation by folding and faulting. Several slide zones within this 175km route were identified and based on the discontinuity orientation, structural features and debris materials, they are recognised as planar, wedge or circular failure types. Present study intends to assess the shear strength parameters of identified circular failure slide zones for their stability analysis.

Shear strength, characterised by the angle of internal friction and cohesion, is one of the basic geotechnical parameters that can describe the mechanical characteristics of materials in terms of their stability. Cohesion and angle of internal friction are internal mechanisms that resist shear stress in slope materials and are measure of the ability of materials to withstand shear stress. Their values are determined experimentally by direct shear test. Each soil sample is tested four times for its shear strength at different normal stresses. A graph is plotted between shear strength at failure of four tests and normal stress. From this graph, fitting equation for expressing the relationship of shear strength and normal stress is used to estimate cohesion and angle of internal friction. At the end of each direct shear test, graph expresses shear stress as a function of normal load according to the Coulomb's formula where vertical stress applied to the sample is involved and the shear strength components, cohesion and the angle of internal friction are deducted from the graph.

The values of the angle of internal friction obtained in the present study vary in a wide interval from 16° to 46° while cohesion varies between 0.04 and 0.80 kg/cm^2. Such a wide variation of u and c is due to the relatively inconsistent grain size distribution and mineralogical composition as well as the density of the material under study. With different internal friction angles, the process of slope failure changes significantly. If the soil is dense, initially higher values for the angle of internal friction will be measured, but with increasing amounts of strain, the angle will decline. The resistive forces from cohesion and friction are also decreased due to the effect of water during rainfall and adverse effect of other factors such as steep slope, jointed and fractured rocks, high relief, fragile lithology and weathering.

Contamination pattern of heavy metals in roadside topsoil along the major highways passing through Lucknow District, Uttar Pradesh, India

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In present study spatial distribution and contamination assessment of heavy metals in roadside topsoils along the three main highways of Lucknow disrict was conducted. A total of 270 surface soil samples were collected along the highways during winter, summer and monsoon season at three different distances from the highways. The soil samples were digested by $HClO_4$, HF, HNO_3 followed by atomic absorption spectrophotometer for the analysis of heavy metals. Mean concentrations of Pb, Zn, Cd, Ni, Cu in surface soils being 13.22±5.15, 64.78±21.60, 0.16±0.07, 4.80±1.82, 12.27±5.35 and respectively. Results show that concentration of heavy metals tends to decrease with increasing distance from the highways. Highly significant positive correlations were found for Zn/Cu, Zn/Pb, & Cd/Ni suggest that the major common source is vehicular activities. Overall decreasing order for heavy metal contamination for all distances is as follows: Zn> Cu >Pb>Cd>Ni Pollution load index is more than double for all three highways. Concentrations of metals in surface soils are in safe limits of Indian standard for agriculture soil but higher than the background values. Alkaline range of soil pH from 7.12-8.82 shows alkaline dust depositions in surface soils and organic carbon % values from 130.12-638.00 suggests that road side surface soil is important sink of nearby organic matter.

Great earthquake is real along Himalayan Frontal Thrust: Insight to the 1950 (Mw 8.6) Tibet-Assam earthquake

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We report here a primary evidence of the 1950 great earthquake surface rupture that was hitherto considered to have occurred on blind fault. Paleoseismic trench at Pasighat town (95.33°E; 28.07°N) along the mountain front of eastern syntaxis with a fallout isotope (Cs^{137}) and AMS radiocarbon dating clearly indicate that the 1950 earthquake ruptured the Himalayan front. Considering a dip of 30-35° for the causative fault along with estimated vertical separation as observed in the trench exposure, we interpret that 4.1 m high scarp at Pasighat has been produced due to co-seismic slips of ~7±0.9 m during the 1950 earthquake (Priyanka et al., 2017).The smaller height of a scarp striking ENE-WNW and it becomes NS at the trenched site signifies that the 1950 earthquake occurred on an oblique thrust fault and not by a low-angle thrust (Chen & Molnar, 1977) or a strike slip (Ben-Menahem et al., 1974) or by a normal fault (Tandon, 1955). Undoubtedly, Himalayan great earthquakes are not blind and release most of the elastic shortening across the Sub-Himalayan range. Presence of radio caesium beneath the faulted cultural surface along with aerosol back trajectory modelling provides the first transcontinental transport of radioactivity from the twin cities Hiroshima-Nagasaki atomic bombing (6^{th} and 9^{th} August, 1945) to Indian subcontinent.

Deduction of surface deformation in Soan Dun area of 1905 Kangra earthquake zone in NW Himalaya: A geomorphic approach

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The northwestern Himalayan front of India has been witnessing recurrent earthquakes including a large continental one in 1905 of magnitude 7.7 the Kangra earthquake. It is suggested that the topographic build up in Himalayan domain is controlled by crustal strain accomodations along the various thrusts. We carriedout geomorphic, river gradient anomaly (GLA) analysis and estimated fault parameters along with Interferometric Synthetic Aperture Radar (In-SAR) measurements to understand the style of surface deformation. We combined results of geodetic, geological, geomorphological, and In-SAR to constrain the uplift and subsidence between Main Frontal Thrust and Main Boundary Fault zones. The estimated results of fault parameters show that the horizontal shortening of northwest Himalaya is higher than the vertical uplift. The estimated range of GLA magnitude analysis for the uplifted region vary from -9.21 to -0.77, whereas the deformed subsided region shows 5.48 to 26.60 respectively. The results of positive and negative GLA magnitude are harmonious with the results of In-SAR measurements. The depicted range of deformation in the area ranges between -3.13 to +3.14 mm/y, where the positive and negative values of phases are correlated with the ground uplift and subsidence. The rate of deformation observed from Persistent Scatterer Interferometry (PSI) phase velocity is well corroborated with the chronologically constrained uplift rates 3.4 ± 0.3 mm/y. The results of surface geomorphic features such as folded, tilted and uplifted terraces, truncation of alluvial fans, offset of channels, fault scarp and displacement of fluvial sediments suggests active nature of the area.

Seismic attributes: Aid in fault visualization, Jaisalmer Basin

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Seismic attributes form an integral part of qualitative interpretative tool that facilitates structural and stratigraphic interpretation as well as offers clues to the lithology type and fluid content estimation with a potential benefit of detailed reservoir characterization. For instance, fault structures which have been classified into seismically resolvable and sub-seismic scale (subtle) faults can be interpreted more effectively with the aid of seismic attribute. In this paper, the study of the fault patterns and seismic attributes was carried out in the Jaisalmer Basin using a 3D seismic data covering more than 1000 km^2 of eastern belt of the Indus Basin. This study aimed at improving the visualization of faults in the study area using different seismic attributes. Major faults in NNW-SSE direction with few antithetic faults and other minor faults were identified manually on the seismic cube. The seismic volume was subjected to several stages of post-stack processing to enhance discontinuities. Filters were then applied to enhance faults and fractures visualization. Finally, different structure attributes such as structural, dip and curvature was calculated on the volume. These final attributes show detailed geometry of the fault system as well as numerous subtle lineaments in the study area. The integration of the attributes has increased confidence in the seismic mapping of the faults and the other numerous subtle lineaments, which were earlier difficult to identify on the seismic cube. Different attribute of the seismic volume preserve subtle structural details and permit a more robust interpretation of the structures.

Appropriate fault mapping reduces the risk of drilling dry hole, resulting from missed fault by conventional seismic interpretation; seismic attribute analysis can be integrated into the standard practice of hydrocarbon Exploration and Production Company.

Status of earthquake precursory studies based on the last ten years observations at MPGO, Ghuttu

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For over ten years, continuous observations of different geophysical parameters are being integrated at Multi-Parametric Geophysical Observatory (MPGO), Ghuttu, Garhwal Himalaya under the National program of earthquake precursory studies. MPGO, a remote site away from cultural noise is situated in the central part of the seismic gap between the epicentres of the 1905 Kangra earthquake (Mw 7.8) and 1934 Bihar-Nepal earthquake (M 8.2). It is located immediately to the south of the Main Central Thrust (MCT) within the High Himalayan Seismic Belt (HHSB) where the India-Eurasia plates are locked and accumulating strain for a future great earthquake. The observatory is designed to record anomalous variations related to seismic event characterization based on stress-induced changes in density, magnetization, resistivity, seismic wave velocity, crustal deformation, electromagnetic emission, radon gas emission in soil and water along with fluctuations in hydrological parameters. Temporal variations of almost all dataset are influenced not only by the earthquake occurrence but also due to short and long term periodical phenomenon. These effect are basically described as background fluctuations such as the effect of solar-terrestrial phenomena, geomagnetic variations, atmospheric and hydrological effects etc. A long period continuous data dataset has been generated based on which data-adoptive techniques are developed to estimate and eliminate the background variations. For example, temporal variations of radon data are studied and the effects of temperature, pressure and rainfall on this data are analyzed in detail. Similarly, the effects of solar-terrestrial phenomena are removed from the magnetic data sets by using different techniques and multi-stations. The temporal variations of gravity and GPS time series are evaluated by extraditing hydrological loading effects due to rainfall occurrence. GPS measurements of MPGO Ghuttu and other five stations of Garhwal-Kumaun Himalaya provide evidence of active deformation and strain accumulation for future major and great earthquake.

A careful scrutiny of the MPGO data revealed prominent precursory signatures in radon concentration, soil temperature and unambiguous co-seismic gravity jump related to the Mw 7.8 Gorkha Nepal earthquake of April 25, 2015. Similarly, radon fluxes show some definite trend that can be viewed as pre- and co-seismic changes related to the Mw 5.0 Kharshali event of 2007 and few other nearby moderate magnitude earthquakes. Sudden anomalous changes of geomagnetic field intensity and dynamic waveform, lasting from several days before to a week after the earthquake, appear to be a manifestation of thermal agitation on the magnetization of rocks around the earthquake source region. Unambiguous co-seismic gravity jump reported in some cases of moderate magnitude earthquakes are perhaps related to the changes in volumetric strain in the hypocenter zone. Although, the expected big size earthquake at local distance around the observatory is not of during this period, however, we report pre- and co-seismic changes during the time of occurrence of few moderate magnitude earthquakes. Overall results show a few cases of anomalous changes in geophysical time series which may be explained through dilatancy-diffusion model of earthquake generation and occurrence processes. Long term monitoring and increasing measurements at supporting sites will strengthen the result.

The relationship between the occurrences of landslides and geomorphic indices in the Bhagirathi River Valley, NW Himalaya

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The Himalaya, having more than 95% of its landmass under mountainous terrain, is plagued by numerous landslides, owing to its propensity towards unstable geological and structural setting, and steep slopes combined with severe weather conditions. Most of these landslides occur during or immediately after the monsoon season. Studies indicate that every year there are about two landslides in one square km area in the Uttarakhand Himalaya. 1998 Surabhi Resort (near Mussoorie) landslide, 2003 Varunavat Parvat (near Uttarkashi) landslide, 2005 landslides in the Satluj valley associated with Pareechu lake outburst, 2013 numerous landslides in the Yamuna, Alaknanda and Bhagirathi valleys, 2014 Balia Nala (Nainital township) landslide are some of the recently struck and disastrous landslides that have caused great loss of life and property in the region. According to an estimate an average loss of ~ 400-500 crores Indian Rupees incurs every year due to landslides and associated phenomena.

The Bhagirathi river valley located in the north-western Himalaya have also witnessed numerous landslides. These are mainly caused by weak and shattered rocks, steep slope, and anthropogenic activities in the form of construction/widening or roads, along with the increased incidences of extreme rainfall in the area. In the present study, area between Uttarkashi and Gangotri in the Bhagirathi valley has been assessed for the relationship between landslides and various geological and geomorphological parameters. Geologically, the area mainly comprises Lesser Himalaya and Higher Himalaya separated from one another by the Main Central Thrust (MCT) zone, and the MCT zone is divisible into Lower Crystallines (Chail Group), Middle Crystallines (Jutogh Group) and the Higher Himalayan Crystallines (Vaikrita Group). In general, the valley slopes in the area are steep ranging between 55° to 90°.

The spatial distribution of landslides have been prepared using numerous satellite images and extensive field visits. In order to assess the present tectonic activity, various geomorphic indices such as steepness index, stream length gradient index, hypsometric curve, hypsometry integral and valley width-to-height ratio (V_f ratio) of the area have been calculated using remote sensing and GIS techniques. ALOS PALSAR DEM having spatial resolution of 12.5 m have been used for the purpose.

It has been observed that all the geomorphic indices point towards youthful landscape and tectonically active region. It has been observed that most of the landslides in the region are concentrated wherever there is abrupt change in stream length gradient, steepness index, and V_f ratio. Further ~ 50 % of the landslides are concentrated in the narrow MCT zone of about 20 km wide and near the Jhala Fault. All these point towards the strong positive relationship between the distribution of landslides and structural and geomorphic set up of the area.

An integrated approach for deducting active deformation and geometric relation of faulted ground surfaces in the foreland region of Central Indo-Nepal Himalaya: A geomorphic approach

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The neotectonic activity in the Himalayan belt is manifested by intense faulting, folding and titling of recent deposits in the foreland basin. The foreland basin in the central segment of Himalayan domain gave rise to the accommodation space for aggradation of the Quaternary alluvial landforms Alluvial fan deposits and fluvial terraces are the significant aggradational landforms observed along the river valleys within the foreland basin, indicating tectonic activity and past climatic records. To assess tectonic activities in the area, we used conventional geomorphic parameters namely, stream-gradient index (*SL*), and steepness index (Ks). A novel method called river Gradient Length Anomaly (GLA) analysis was applied to deduct uplift and subsidence at the intersection between drainage basin and active thrust. The anomalies obtained are termed GL-anomalies, and are considered as segments, where actual river gradient ($\Delta h/\Delta L$) deviates significantly from the predicted one (Žibret & Žibret, 2016). The deviations occurred along the river course can be attributed to active tectonic movement along thrust/fault or because of erosion/sedimentation processes. The south flowing rivers (Sarda, Kauriala, Girwa and Babai River) in the study area flow across the major Himalayan thrusts such as Main boundary thrust, Ramgarh thrust and Himalayan frontal fault. SL values range between 0.9 - 4153 and Ks ranges from 0.1 to 173. This anomalous rise in the values for SL and Ks index points towards ongoing tectonics in the basin. For a reverse fault with a normal scarp, the relationship between vertical displacement of the reverse fault, the vertical separation of the ground surface and the scarp height is $VD \leq VS \leq SH$ (Xiaodong et.al. 2015). The same relationship is obtained for all the scarps studied for the area and therefore can be inferred as normal scarps of thrust fault. This also implies that scarps dip in the direction of slope of the ground surface. The horizontal displacement is approximately 1.7 times the vertical displacement in the study area which again suggests the presence of active erosional forces. The estimated results of fault parameters show that the horizontal shortening is higher than the vertical uplift. Various streams show major lateral offset along 3 different segments of the faults, one of which is HFT. Slip rate of these faulted segments is 1.21 mm/y, 2.65 mm/y and 1.084 mm/y. Based on fault slip parameter, and abnormal GLA, SL and Ks analysis, a new E-W oriented active fault structure have been inferred, which passes through the Paliakalan, Kohalpur, Tikapur, Beldandi, Dhangadhi, Isanagar, Nanpara, and Rajur locations.

Conventional geomorphic parameters and geometrical relationship of faults studied using LANDSAT data produced the results which indicate presence of prominent tectonic activity in the central section of foreland basin of Indo-Nepal region, in the recent times.

Active fault mapping in the Assam Seismic Gap, Eastern Himalayan Front, India

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The Assam Seismic Gap (Khatri, 1987) has witnessed a long seismic quiescence since the great 1950 Tibet-Assam earthquake. Historical accounts of eastern Himalayan segment, report major historical earthquakes in 1697 and 1714 (Iyengar et al., 1999). Owing to its improper connectivity over the last decades, this segment of the Himalaya has long remained inadequately explored by geoscientists. So, a major concern is that the strain accumulated in this segment might reactivate the active faults through large or great earthquakes in the future. In this regard, it is essential to identify the potential active faults in this area which will provide a basic data for future earthquake geology research. Toward these issues a detailed account of newly identified active faults are presented between the Manas and Dhanshiri Rivers, Assam.

Truncation of the youngest geomorphic terraces along active fault clearly elucidates that the area has been subjected to a recent deformation. Our field investigation on geomorphic expressions and structures along the active faults suggest that in the eastern Himalayan front the deformation is being consumed largely by a thrust sheet translation rather than fault-related folds, unlike that of the central and western Himalayas. The fault scarp geometry reveals north-dipping thrust faults. North facing scarps (back thrust) are also observed in conjugation with the south facing scarps along the Himalayan frontal thrust. However, these fault scarps are formed due to a single or multiple earthquake events remains to be investigated. The presence of active faults in this segment suggests that the area is prone to seismic risk.

Lineament Extraction and analysis to study active tectonics by comparison of Sentiel-2 and Landsat-8 data, in parts of Haryana HFT

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The lineaments mapping acquires much interest in the geological studies. It is considered as a very important structural and geological indicator to determine general and local tectonic trends and fractures zones in the rocks. In this study, automatic extraction and digital analysis of lineaments has beenn attempted for the tectonic studies in the parts of Haryana HFT. HFT demarcates a sharp physiographic and active tectonic boundary between Himalayn foothills and recent alluvial plain. The study area includes three sites Chandikotla (Lat- 30°45' 06.03" N, Long- 76°53' 52.94"E), Khetpurali (30° 40' 35.73" N, 76° 59' 58.53" E,) and Sabilpur (30° 39' 32.00" N, 76° 59' 04.10"E) in Pachkula district of Haryana along HFT.

This study aims to compare lineaments extracted from Sentinel-2 and Landsat-8 data. However, being higher resolution Sentinel -2 data have been used for further analysis to understand tectonic activity. The analysis is carried out by using the Lineament Extraction (LINE) module of PCI Geomatica to extract the lineaments present in the region. The software ArcGIS 10.3 and ENVI 5.3 is used for image enhancement processing and Rockwork 16 for the rose diagram. Drainage network and Hill shade map were prepared from Cartosat DEM. The lineament extracted from the Sentinel data is less noisy and show a higher precision than the Landsat image. Three geospatial analyses are applied in order to evaluate the lineaments i.e length, density, and orientation analysis. Rose diagram was prepared to understand directional changes taking place in the vicinity of the area. It is observed from lineament map and the rose diagram that predominant direction of lineaments is in NE-SW direction followed by E-W direction lineaments. The overlaying of detected lineaments, drainage and hill shade relief map illustrates their spatial and directional relation. Concordance of some straight drainage and lineaments represents faults. Visual interpretation of Lineament with drainage pattern and hillshade map clearly infers that the study area is strongly tectonically controlled. The study results of lineaments and rose diagram integrated with drainage and hill shade map has thrown light on tectonic activity prevalent in the region.

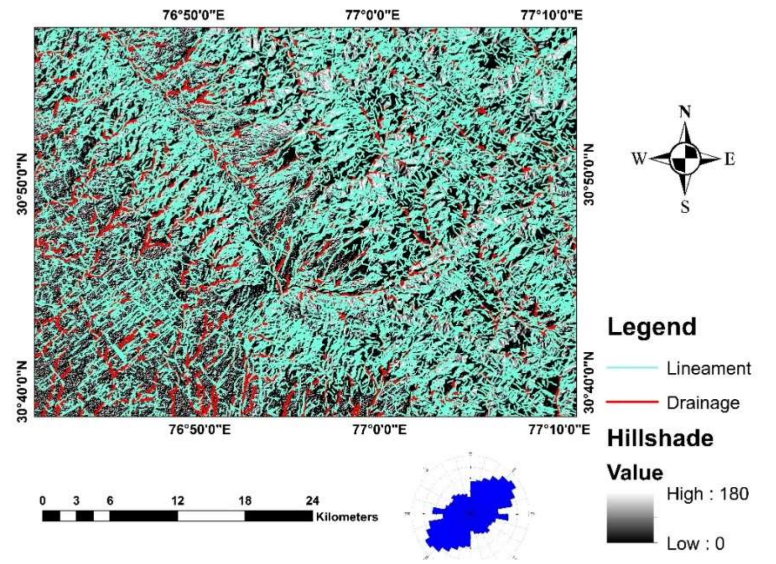

Fig. 1: Showing integrated map - lineament, drainage and hill shade.

Accelerating water cycle and cloudbursts in the *Central-Western* Himalaya

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Recent enhanced *r*ainfall extremes and cloudbursts in the Himalaya are associated with serious economic, social, and environmental change. The anomalous source of moisture that fosters and sustains extreme events in the monsoon-dominated Himalayan valleys remains to be understood to develop mitigation strategies. Our multi-proxy evidences indicate a prominent expansion and enhanced water release by the deciduous species relative to more water-conservative evergreen conifers in the Central-Western Himalayan (CWH) valleys. This enhanced evapotranspiration ignites mesoscale (valley-scale) convective systems, leading to increased incidences of rainfall extremes and cloudbursts. Our results also demonstrate an anthropogenic impact on recent water cycle acceleration in the CWH. We anticipate that promoting conifers could reduce atmospheric vapour loading and thus the magnitude of extreme events. This seminal study could be useful to develop early warning system for sudden valley rainstorms, besides understanding the climate-carbon feedbacks, albedo and greenhouse forcings on the melting of Himalayan glaciers.

An attempt to predict the disaster in making: a case study of Himalayan tectono-climate precursor

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The Himalayas blessed us by recharging water requirements throughout the year with the help of south-western monsoon and westerlies. Now days, the river basin besides being a natural system has become a dustbin for the waste created by the anthropogenic activities. Especially, the middle and lower reaches of the river basin is mostly wrecked during sanctifying the sewage of our cities, but in the youth age the river is still competent enough to sanctify itself by its own defence mechanisms such as frequent flood and/or flash flood events. During this sanctification process of river to be incessant leads to the loss of lives and properties in the invaded region of the river, the Kedarnath Disaster (2013) is just a recent example.

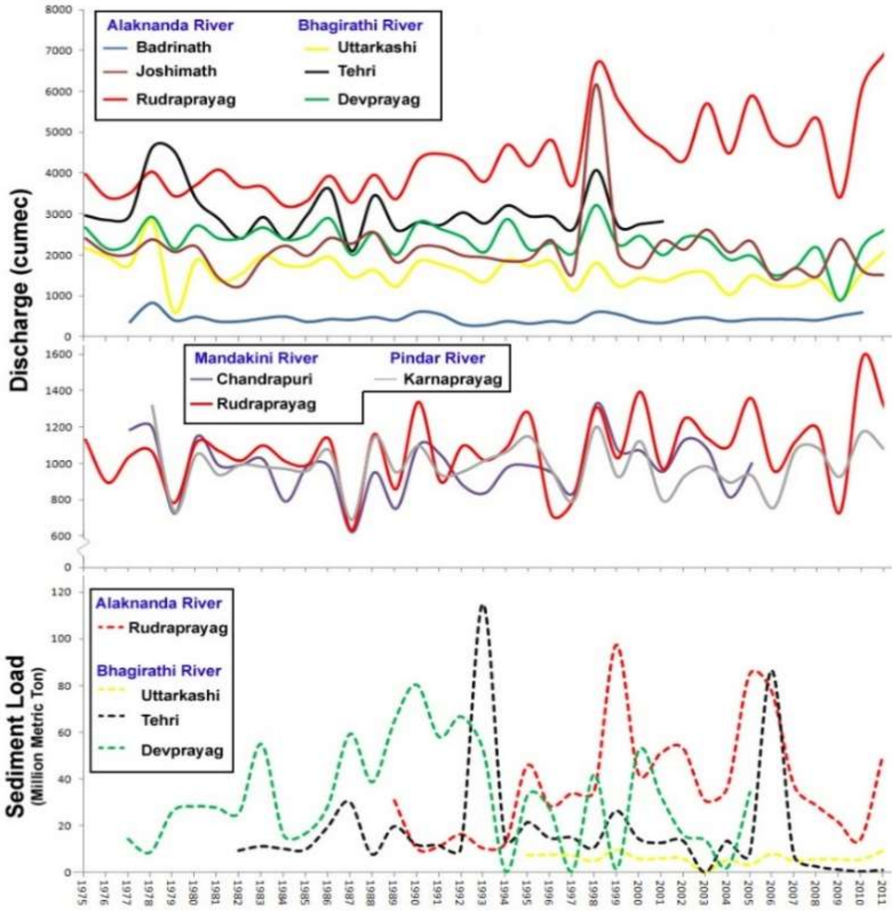

Fig. 1: Discharge and Sediment load values of the basin showing a positive correlation *(note the peaks correlate well with the reported extreme events of 1998, 2005 and 2010).*

The river basin is augmented by rainfall and snowmelt, which is replicated as flow of water volume/discharge. In the present study, an attempt is made to correlate the pouring nectar (the discharge) and the disasters (or the extreme events) occurred in the Upper Ganga River Basin. The available data from stations Karnaprayag, Rudraprayag (Alaknanda), Rudraprayag (Mandakini), Chandrapuri, Tehri and

Devprayag indicate the high discharge values in the orographic front (MCT in the upper reach) during the year 1998, 2005 and 2010 which lead to anomalous discharge and sediment load. However, the glacial melts contribution towards the accentuated discharge and sediment load cannot be ruled out, especially in Chorbari Bamak glacier, Satopanth and Bhagirathi Kharak Glacier, Khatling Glacier, Tiprabamak Glacier, Gangotri and Dokraini glacial region. Thus, in the years 1998, 2005 and 2010 the area received high river discharge and sediment loads (e.g. the sediment load was 2.5 and 1.5 times of the average value in 2010 in the Alaknanda and Bhagirathi river basins respectively) which could be cumulative effect of high glacial melt and high precipitations (Fig. 1). The higher Himalayan reaches experienced a number of extreme events (reported by different agencies such as GSI) which clustered themselves in the years 1998, 2005 and 2010 indicating a direct correlation between the precipitation, sediment load and incidences of extreme events. The results show the anomalously high discharge value is mostly replica of an extreme event in the region. This replica can be treated as intimation of upcoming chaos for preparedness and proper management.

Study of two landslides on strategically important Gangtok-Nathula road (NH-10A), east district, Sikkim: causes & remedial suggestions

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The Gangtok-Nathula Road (NH-10A) is a stratigically very important road connecting India with China and further to Kailash Mansarovar. This road exposes a number of major and minor landslide zones between the stretch from Chandmari upto Tsomgo Lake. Some of the important landslide zones along this stretch are the Chandmari, 5th Mile, 8th Mile, 13th Mile and 17th Mile landslide zones. The present study compares the nature and behaviour of two landslides zones i.e. 5th Mile and 8th Mile located on the Gangtok-Nathula Road. The 5th Mile and the 8th Mile landslide zones are located at about 8.5 km and 13 km, respectively from Gangtok on NH-10A (Gangtok-Nathula road) falling in Survey of India Toposheet No. 78A/11 on the way to Nathula Pass. The 5th Mile landslide got activated on 8th June 2013 as reported in prominent newspapers. The 8th Mile landslide zone is a very old one which has been active since last several decades. Both these landslide zones are major trouble spots on the NH-10A (Gangtok-Nathula Road), particularly during the monsoon, causing disruption of the vehicular traffic along the Indo-China Trade route as well as movement of Army.

In the light of the above facts, both these landslide zones were taken up for detailed site specific study between 2016 and 2018 with an objective to understand causative factors, failure mechanism, dynamicity of the affected slope and to formulate mitigative measures.

The main rock type exposed in both the landslide zones are granite gneiss, banded gneiss/streaky gneiss, white to grey quartzite, biotite schist of Chungthang Formation and Kanchenjunga Granite gneiss of Central Crystalline Gneissic Complex (CCGC) of Central Himalayas with occasional presence of amphibolites and pegmatites as intrusives.

The 5th Mile landslide's failure direction is S30°E with slope angle of 55° due SE and the slide zone has approximate dimensions of 410 m (L) x 340 m (W) x 260 m (H) with run-out distance of 220 m. The exposed rocks were under high stress prior to the activation of the slide due to the presence of a major NNW-SSE trending regional lineament along the slide zone as evidenced from the systematic study open source Google Imageries and it was further aggravated by the 18th September, 2011, Sikkim Earthquake. The unplanned cutting and blasting in the inherently weak rockmass and older metastable paleoslide debris material during the construction of a new alternate road connecting 3rd Mile with 13th Mile further deteriorated the rockmass. Improper dumping of road cut debris on the steep slopes and nalas added dead load to the vulnerable slope. Heavy monsoonal rainfall saturated the freshly cut and exposed rock slope, loose, older metastable paleoslide and road cut debris. It resulted in the failure of the slope and collapse of a major portion of the newly constructed road benches.

The 8th mile Landslide zone is complex in nature. The direction of the landslide is S20°W with slope angle of 45-50° due SW. The slide zone has approximate dimensions of 1200 m (L) x 310 m (W) x 500 m (H). The run-out distance is 650 m. It is a reactivated, enlarging landslide, where overburden material of earlier paleoslide and boulders of surrounding bedrock are involved in the mass movement. It has been further aggravated by the 18th September, 2011, Sikkim Earthquake, incessant rainfall, toe erosion by two adjacent nalas meeting just below the NH-10A in the central part of the slide zone and subsequent widening of the road.

Kinematic stability analysis for the 5th Mile Landslide shows that rockmass fall under SMR Class-II-good and Class-III-fair (after Romana,1985) indicating stable to partially stable slopes with the possibility of some block failures and Planar failure along some joints and many wedges. Kinematic stability analysis of the 8th Mile Landslide shows that the rockmass fall under SMR Class-III and Class-IV (fair to poor) (after Romana, 1985) indicating partially stable to unstable slope with possibility of Planar failure along some joints with many small to big wedges. The SMR classification and kinematic analyses therefore imply that the exposed rocks are vulnerable to failure. On the basis of geotechnical and quantitative studies of both landslide zones, various recommendations for arresting the landslides like, contour and toe drains, chute drains, gabions, retaining walls of various dimensions, channelization of nalas, rock bolting and shotcreting were suggested as per the site conditions.

Landslide inventory and susceptibility mapping in Rupin watershed of Tons valley, Garhwal Himalaya, Uttarakhand

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The study area is bounded between 31°21’23” N to 31°21’54” N latitude and 77°57’39” E to 78°18’36” E longitude covering area of 545 km^2 which is part of Lesser and Higher Himalaya. Rupin River is important tributary of Tons river, originates from a glacier Jaundhar Barak and Bandarpunch at head of the famous Har-ki-Dun valley in the north-eastern part of the Tons catchment. Geologically, the Rupin watershed comprise of Vaikrata, Almora, Dudhatoli, Jaunsar and Garhwal Groups containing granite, quartzite, limestone, shale, phyllite and basic rocks. This research work is focused on Landslide mapping for landslide change detection and the preparation of landslide inventory, using geospatial approach. In this work weighted overlay method is used for landslide susceptibility and mapping considers parameters like, thematic layer geology, geomorphology, lineament density, drainage density, drainage frequency, drainage texture, land use/land cover, NDVI, slope, slope aspect, curvature, built-up area, roads etc. A landslide inventory is being prepared on the basis of pre- and post-Uttarakhand disaster of 2013 using high resolution satellite data (LISS-IV). A total of 150 landslides were identified in pre-disaster situation through (2011) and 221 were identified in post-disaster (2014). Emphasis of damage assessment was carried out with respect to settlement, road and agricultural land. Landslide susceptibility map shows Very Low (37%), Low (36%), High (21%) and Very High (6%) susceptibility zones, while vulnerability map has Very Low (33%), Low (26%), High (35%) and Very High (6%) classes. The final risk was obtained by multiplying the susceptibility map and vulnerability map in the raster calculator of Arc GIS. From the studies carried out FOUR risk zones were identified from the map, namely (i) Very Low (58%), (ii) Low (31%), (iii) High (7%), and (iv) Very High (4%). Landslide susceptibility zonation (LSZ), vulnerability and risk mapping are important for disaster management and planning development activities in the Himalayan regions.

Geological and geotechnical characterization of the Khotila landslide in Dharchula Region, NE Kumaun Himalaya

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On 4 October 2016, a severe landslide had occurred in the vicinity of Khotila village in Dharchula, region of NE Kumaun Himalaya. The landslide had occurred at the end of the monsoon season when the slope was completely saturated. It has been noted that the area received about two times more rainfall during 2016 monsoon than the rainfall during 2015 monsoon. Geotechnical testing classify the soil overlying the slope as ‘soft soil’ with compressive strength of 42 kPa and friction angle of 27.4° and having > 97 % sand and silt size particles and < 3% clay size particles. Mineralogically, the soil dominantly constitutes quartz, muscovite and clinochore.

The landslide has partially blocked the flow of Kali river that serve as a boundary between India and Nepal and is endangering the habitants of the Khotila and Bangabagar villages, situated downstream in the Indian and Nepalese side of the Himalaya. In order to understand the stability of the failed slope, finite element modeling of the landslide has been carried out that points towards the unstable conditions in future.

Disaster Prone Valleys of Uttarakhand –A case study of Mandakini Valley

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With continued northward movement of Indian plate, Himalaya remains an actively deforming, uplifting and geomorphologically fragile terrain. The GPS data acquired by several workers from the Himalaya indicates that the convergence rate of Central Himalaya is higher as compare to Northern and Eastern Himalaya. Due to thick pile of the Quaternary sediments it is often difficult to see the manifestation of tectonic activities on the landforms. Mandakini valley that falls in the Central Himalaya has witnessed two earthquakes of >5 magnitude in 2017 and several tremors below magnitude of 3 indicating that the valley is tectonically active and its uplift process contributing in the process of erosion at slower rate. Climatically also Mandakini valley is highly sensitive the Okhimath rain gauge station measured 2500 mm rainfall annually for last >20 years. Due to high rainfall followed by cloud burst the valley badly suffered severe damaged in 1998 (Madhyamaheswar cloudburst), 2001 (Byung-phata cloud burst), 2012 (Okhimath cloudburst) and 2013 Kedarnath disaster are few examples to quote. Geomorphological analysis of the valley indicates that the valley is comparatively narrow, landforms are highly sensitive to water action and geologically this valley is traversed many faults and thrust out of which the prominent are Alaknanda Fault, Ramgarh Thrust, Munsiari thrust, Vaikrita thrust and Pindari thrust.

Besides many landslides few chronic and complex landslides are developed in the valley which are active, notably, the Byung sinking zone on the NH 109 which is active since 2001, and sinking cum landslide zone developed at Kunjethi village in Kali valley which is tributary of Mandakini. These two landslides are require a real time monitoring, as these landslides, under suitable conditions, may activate and block Byung and Kali river and form temporary lake. These lakes on bearch may be the cause for plenty of damage in Mandakini as well lower Alaknanda valley and may create havoc in the further downstream. Higher Himalaya, besides Quaternary sediments stores enormous amount of unconsolidated sediments generated by glacial and fluvial processes may slide and transported to downstream in form of debris flows, come another event of high rainfall like 2013 kedarnath disaster. However there is no denial that human intervention and unscientific approach in the name of development of the area making the problem of slope failure in Himalaya more chronic. We have capable scientific and engineering institutions skilled of devising methods for mitigating the magnitude of destruction caused by the recurrent landslides slides during the monsoon. Unfortunately, the lack of coordination between the scientific/academic institutions and the field implementing agencies contributes to such devastations. To address the problem a sincere and continuous monitoring of the potential zones are required beside that anthropogenic interventions are required to be scientific and a close coordination are required between scientific / academic institutes and the field implementing agencies.

Neoproterozoic (Ediacaran) Krol Carbonates of the Lesser Himalaya, India: with reference to Paleoclimate and Geotechnical Study of the Landslides

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The Lesser Himalaya is bounded to the south by the Main Boundary Thrust and to the north by the Main Central Thrust.The two sedimentary basins of the Lesser Himalaya are located in between these thrusts. The older sedimentary belt in the inner part known as Deoban Group and the outer younger belt in contact with Main Boundary Thrust is called Krol Belt. The Krol belt sedimentary rocks of the Lesser Himalaya have been assigned Neoproterozoic (Ediacaran) age on the basis of Ediacaran metazoans, vendotaenids, stromatolites, acritarchs and carbon isotope chemostratigraphy.Krol carbonates were deposited over the Blaini Formation (Blainian), a Neoproterozoic glacial diamictite bed in the Mussoorie syncline. Blaini Formation is a marker bed of the Lesser Himalaya and corresponds to the global glaciation during the Neoproterozoic well known as Snow Ball Earth.The paleoclimate during Neoproterozoic changed from the cooling phase to warming phase and warm water carbonates were deposited globally.The warm water Krol belt carbonates extensively deposited from Solan in the Himachal Himalaya to the Nainital in the Uttarakhand Himalaya, stretching over a distance of 350 km.The Mussoorie –Garhwal Synclines are located in the central part of the Krol basin. The Krol Formation is characterized mainly by limestone.siltstone,slates and dolomites. The Upper Krol C is predominantly bluish brecciated limestone with ooids, intraclasts, and vuggy fenestral limestone. Stromatolites are well developed in the cherty limestone and the common forms include stratified and columnar types. Detailed sedimentological and petrographic studies of the Krol carbonates from the Uttarakhand Lesser Himalaya suggest a shallow marine tidal flat depositional environment of deposition which is also supported by the carbon isotope chemostratigraphy.

Landslides are frequently occurring in the Krol carbonates of the Uttarakhand Lesser Himalaya. Recent geotechnical studies by the present authors near the Surbhi Resort situated on Mussoorie- Kempty road have suggested that the main cause of the landslide is high intensity rainfall during monsoon.The mitigation suggested for the slope instability focuses on improved drainage on slopes.Retention walls method of mitigation may not be applicable to this region due to high slope angle.Bioengineering (regeneration of the natural vegetation) on the slope is recommended for providing stability for surface erosion processes. Mussoorie – Kempty road is under constant threat of subsidence and increased moisture on the slope from the ongoing developmental projects, tourism and fast urbanization will have drastic and disasterous effects on subsidence. Landslides occurring in other areas of the tectonically active Uttarakhand Himalaya are discussed with special reference to triggering factors and mitigation.

Theme V
Sedimentary basins, stratigraphy and past life of Himalaya

Significant pre-Siwalik Miocene fauna from NW Himalaya, India

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In the Indian part of Outer western Himalaya, Dharmsala Group (Kangra Valley)/ Murree Group (Jammu) and Dagshai/ Kasauli formations (Simla Hills) are fauna–wise rather poorly known stratigraphic entities in clear contrast to the older and younger Subathu (Marine) and Siwalik (freshwater) beds. respectively that are palaeontologically well known stratigraphic entities on the southern side of the western Himalaya.

Only sporadic occurrences of fossils, especially vertebrates have been reported from these successions. The first record of a vertebrate fossil from the Kasauli Formation (Himachal Pradesh) was made by Arya et al. (2004) who described a fragmentary Rhinoceratid molar. *Prodeinotherium orlovii* from the Upper Dharmsala was described by Tiwari et al. (2006). An isolated rodent premolar (*Hodsahibia azrae*) from the Upper Dharmsala was reported by Bhandari and Tiwari (2014). A lonely cricetid rodent molar (*Primus microps*) and scanty fossils of several larger vertebrates, including rhinocerotids, crocodilians and a lizard were described from the Murree succession in Jammu area by Kumar and Kad (2002, 2003).

The Dagshai and Kasauli formations and the co-eval Murree succession represent a part of Lower Tertiary sedimentary sequence between the marine Subathu and freshwater Siwalik Group. Their study from the view point of palaeontology will enhance our knowledge of early Miocene vertebrate biostratigraphy of the region (Dagshai-Kasauli) to a great extent.

Biostratigraphy and depositional history of the Sylhet limestone and Kopili Formation of Mikir Hills, Assam: A Review

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In NE India the Tertiary rocks are differentiated into two facies: basin and shelf sediments. This differentiation is mainly marked in the Eocene strata. The shelf sediments occur in regions northwest of Halflong-Disang and Naga thrusts along the southern foothills of Garo, Khasi-Jaintia and Mikir-North Cachar Hills. The basinal facies are exposed in the eastern part of Naga-Manipur and Mizo Hills. Our area of interest falls in the Dillai Parbat in southeastern Mikir Hills which exposes a part of the Eocene Sylhet limestone. The Sylhet Limestone Formation is rich in larger as well as several smaller foraminifers. Earlier researchers have done significant work in the biostratigraphic zonation of the succession. Yet, a lot more information can be derived from the region for solving the mysteries of the geological past. Our main focus in the Dillai Parbat where the limestone is exposed in a quarry is due to the abundances of fossil occurrences. It is our sincere attempt to identify the gaps of the previous studies and fill the knowledge gap in years to come with new data sets. A multi-fossil proxy study is required to refine biostratigraphic scheme and subsequent paleoenvironmental conditions of deposition and to work out the paleogeography of the Mikir Hills in terms of collision of India and micro-Burma plates. Additionally, field based lithofacies analysis of the carbonate succession will be useful to workout depositional history in conjunction with paleontological data in a time frame work. For climatic studies, early-middle Eocene climatic optimum (MECO) represents a significant climatic reversal in the midst of the long term cooling which can be identified in these successions. Demarcation of Sylhet-Kopili (middle Eocene-late Eocene boundary) in areas near the Dillai Parbat is another field of interest. The foraminiferal zones which will be refined in the present study will be calibrated with the global standard larger foraminiferal zonation. Overall, these studies will be helpful in establishing a global correlation and tectonic evolution of the region.

Petrography and geochemistry of Carboniferous clastic sedimentary rocks from Kashmir region, Tethys Himalaya

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The sandstones of the shale-sandstone association of Carboniferous sequence pertaining to Lider Group of rocks in the Kashmir area are subjected to detailed petrographic and geochemical investigations. Compositionally, the sandstones are classified as quartz-arenite and sub-litharenite with abundant quartz grains and varying amounts of other minerals including feldspar and muscovite; whereas zircon, tourmaline and iron oxides occur as heavy minerals. The petrographic studies consisting of point counts show the presence of quartz as a dominant framework mineral with varying amounts of rock fragments (mainly chert, phyllite, gneissic components) and minor feldspars. The data plots in the fields of cratonic interior and recycled orogen in the Qt (quartz)-F (feldspar)-L (lithic fragments) triangular diagram, indicating the derivation of sediments mostly from stable cratons. The nature of feldspar observed in thin sections is mostly altered (to clay). K-feldspars found in thin sections are mostly microclines with varied abundance between 0-10 percent across different formations. Subhedral plagioclase grains with albite twins occur in some thin sections and seem to be linked to samples with relatively smaller grain sizes. These petrographical observations are substantiated by the geochemical characteristics of the studied sandstones where the chemical index of alteration (CIA) values range from 53 to 77 with an average of 70, suggesting that these sediments have experienced low to moderate degree of weathering in the source area. The geochemical concentrations of sandstones are very well compared with the Upper Continental Crust (UCC), Post-Archean shales from Australia (PAAS) and North American shale composite (NASC). However, the sandstones depict lower concentrations (particularly trace elements) when compared to the standard values, reflecting the quartz dilution effect and low abundance of trace element- bearing minerals such as feldspars, mica and heavy minerals. The integrated studies of petrography (including the mineral contents and their essential features) and major element chemistry comprising the elemental concentration and their significant ratios suggest that the sandstones from the Tethys Himalaya Kashmir area, have been derived most probably from a felsic (granitic) dominant source.

Sedimentary Successions in the Pre- Himalayan Basin

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The Himalayan orogen is confined within an extensive record of the pre- syn -and post -Himalayan sedimentation. A sizeable portion of the sedimentary successions is Proterozoic in age with Phanerozoic cover. The Proterozoic Himalayan basin is unique compared to other contemporary basins of Indian sub-continent because it has witnessed the Tertiary Himalayan orogeny. Regardless of studies spanning over a century, the Proterozoic sedimentary successions in the Himalayan orogen lacks the genuine sedimentological details. The issues discussed are – i) Stratigraphic correlation, ii) occurrence of two types of siliciclastics, iii) Rifting and seismic signatures , iv) Status of Lesser Himalayan basin with the cratonic block, v) Cryogenic event, and vi) Marine – continental depositional set up. Litho-events documented in the Late Palaeoproterozoic to Early Palaeozoic sedimentary succession of the Lesser and Tethys Himalayan part are: i) Palaeoproterozoic Argillite = Siliciclastic, ii) Mesoproterozoic Calcareous(limestone) > Argillite, iii) Neoproterozic Argillite = Siliciclastic, and iv) Late Neoproterozic- Early Palaeozoic Mixed Siliciclastic - Argillite – Calcareous (limestone).

The central Lesser Himalayan (Garhwal and Kumaun) Proterozoic succession has been segregated into two: the southern Outer Lesser Himalaya (OLH) represent the younger rocks (Neoproterozoic) and northern Inner Lesser Himalaya (ILH) represent the older rocks (Palaeoproterozoic-Mesoproterozoic). The steady coarsening up succession coupled with sub- aerially erupted volcanics and incidences of numerous gravelly beds suggest unstable shallowing basin. The compositional consistency of OLH and ILH siliciclastics hint towards comparable source area lithology (the Aravalli-Delhi Supergroup and less commonly the BGC and BG). The presence of alluvial fan facies along the Tons Thrust possibly hints towards the existence of a palaeo-high (horst) region of the rifted basin between the OLH and the ILH. The Proterozoic stratigraphy in the Himalayan orogen has proximity and resemblance with the Vindhyan basin, which rests unconformably on the Bundelkhand and Aravalli cratons and has a lot of similarities in sedimentation pattern with the Lesser Himalayan basin. Therefore, it will be appropriate to consider the Himalayan Proterozoic succession as a part of the Aravalli- Bundelkhand craton.

Geochemistry of Upper Jurassic siliciclastic sediments of Giumal Formation of Spiti region, Himachal Pradesh, Tethys Himalaya

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Petrographical and Major oxides analysis of Upper Jurassic – Lower Cretaceous siliciclastic rocks of Giumal Formation from the Spiti region were carried out to infer their Provenance, Paleo-weathering and depositional setting. Giumal Formation consists of alternating bands of sandstone and shale having gradational contact with underlying Spiti Formation. Sandstone in the study area is quartzarenite to quartzwacke in composition and made up of poorly sorted, rounded, subrounded to subangular. Petrography shows mono- and polycrystalline quartz (85 - 90%) and feldspar (0 – 5%) of moderate sphericity. Streched quartz showing undulose extinction is common. Lithic fragments consist of muscovite, chert, carbonate and recrystallized rock fragments. Pigmentary gluconite, biotite, euhedral zircon, tourmaline, rutile and some opaque grains occurs as chief accessory minerals in sandstone. After plotting of detrital modes in the Qt-F-L diagram, samples fall in recycled orogen. Major oxide analysis of shales and sandstone are very well compared with the Upper Continental Crust (UCC), Post-Archean shales from Australia (PAAS) and North American shale composite (NASC). Shale samples show most oxide concentration are more or less same as PAAS and NASC with minor depletion of MnO, CaO and Na_2O. Giumal sandstones show similar concentration of SiO_2 and TiO_2 relative to UCC but strongly depleted in Al_2O_3, Na_2O, Fe_2O_3 and MgO. The depletion of Na_2O relative to the UCC values suggest severe loss of plagioclase feldspar during weathering. Chemical index of alteration (CIA) values range from 55-87, Plagioclase index of alteration (PIA) range from 61-96 and A–CN–K (Al_2O_3 - CaO + Na_2O - K_2O) relationships indicate that probably low to intense chemical weathering in the source area.

The deposition of shales in the Proterozoic Central Lesser Himalaya: A petrographical attribute

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The shales constitute more than sixty percent of world's sediments and are often found associated with the coarser clastics. Their wide presence has still not grained importance in petrographic studies as compared to the coarser clastic rocks owing to their finer grain size and friable nature. The advancement in the petrographic techniques has surprisingly still not lead to advancement in the shale study except by a few workers. Increase of various less time consuming analytical methods adds on to the lack of petrographic practice. These analytical techniques are compositional driven. However, the textural aspects go unidentified.

The shales of the Proterozoic Lesser Himalaya have barely gained attention for their petrographical aspects. The shales carefully studied for their textural aspects over composition provide better understanding of deposition. The present work is an attempt to introduce various textures revealed by the shale petrography of the Proterozoic Lesser Himalaya (Central Himalayas) and their importance in deciphering their depositional environment. Petrographically, shales are found associated mainly with the siliciclastic rocks. The shale beds are parallel, sub parallel to tapering in nature with wavy base and some scour fills with coarser material. The presence of wavy, wrinkled, continuous, non-continuous microbial mats, normal graded bedding, micro-cross laminations in shale indicate a shallow marine environment all together for the Proterozoic Lesser Himalaya (Central Himalaya). The presence of rip up clasts indicates link to the post depositional changes. The depositional environment deciphered by shale petrography is comparable to the other sedimentological studies done in the area. The shale if focused ideally and in combination with the clastics provides expansion to the understanding of the depositional set up.

Stratigraphy and sedimentology of Late Cenozoic Himalayan Foreland between rivers Ganga and Ravi

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The Late Cenozoic succession of the foreland basin consists of three stratigraphic successions: (i) the first is ~13 to 10 Ma old Lower Siwalik having sandstone-mudstone couplets with more than 50% mudstone derived from northerly source representing a significant time interval of low sediment accumulation with high accommodation space, (ii) the second is overlying ~10 to 6 Ma old sandstone dominated Middle Siwalik, which was deposited by large braided streams having low accommodation space, and (iii) the third is overlying ~6 to 0.5 Ma old Upper Siwalik, which consist of conglomerate and shows variable fluvial architecture and accommodation space. Spatial variation in fluvial architecture from Dehradun to Kangra sub-basin and within the sub-basin could not be constrained through simple proxy climate, and perhaps differential tectonic deformation along boundary thrusts, their imbricate thrust and transverse lineament could be responsible. Stratigraphic coarsening from mudstone to sandstone to conglomerate dominated succession from Lower to Upper Siwalik is common in all the sub-basins.

The Kangra Sub-basin (KSB) shows SW (in the SE part) and SE (in the NW part) draining axial river system during the Middle Siwalik time. However, the NW part of the basin also exhibits inter-fingering of axial and piedmont drainage where later dominates in the up section after ~8.7 Ma. Finally, the axial river is dislodged from the basin in response to the advancement of alluvial fans after ~5.7 Ma. This vertical stacking of axial and alluvial slope deposits suggests periodic on- and off-lapping of facies due to lateral migration (toward and away from basin margin) of axial river. Whereas both Middle and Upper Siwaliks (from 12 to 3 Ma; upper age is ambiguous) in the SE part were deposited by westerly flowing axial river. On the other hand fluvial architecture of the Dehradun sub-basin (DSB) between 9.7 and 5 Ma exhibits thick multistoried sandstone complex (900 to 1200 m thick). This succession was deposited by southerly flowing transverse trunk drainage in the form of fluvial mega fan. After ~5 Ma the palaeo-channel re-organized towards the SW with influx of conglomerate of the Upper Siwalik alluvial fan. The Lesser and part of the Higher Himalayan region acted as a source area for these sediments as indicated by clast composition data. The Subathu sub-basin (SSB) however, shows variation in the depositional milieu. The basin registered SE flowing axial river deposits before 5 Ma but after this, it was covered by SW flowing trunk and S-SE flowing piedmont drainage. These two systems inter-finger between 4.8 to 1.77 Ma and trunk drainage dislodged in response to S-SE advancement of alluvial fan of the alluvial-slope after 1.77 Ma. This data reveals a great lateral variation in stratigraphy and sedimentation pattern at various scales across the three sub-basins (KSB, SSB and DSB). Further, there is no similarity even for the two re-entrant basins (KSB and DSB), except that the re-entrants are characteristic features of high energy Middle and Upper Siwalik sedimentation compared to the characteristically low energy overbank dominated sedimentation in the SSB salient basin. This is obviously due to higher available accommodation space and larger area of the hinterland orogenic belt for the re-entrants compared to salient. Stratigraphic evidence suggests that differential tectonic movement, sedimentation rate and basin subsidence, coupled with climatic variation, were responsible for the contrasting fluvial facies in these sub-basins.

Eocene foraminifera from the Naga Hills of Manipur, Indo-Burma Range (IBR)

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The Disang Group covers much of the Naga Hills, eastern and central Manipur and Sadiya Frontier Tract. It further extends northeastwards to as far as the Pangsau Pass in Arunachal Pradesh and in the Hukawng valley of upper Burma. It is the oldest exposed successioin of the Central Naga Hills with NNW–SSE trending ridges and valleys. Tectonically, it is limited to the west by the Disang Thrust. Stratigraphic position of the Disang Group has not been properly understood and its true stratigraphic sequence has not been defined due to paucity of definitely recognisable and indigenous fossils in the main belt of Disang. The stratigraphical divisions in the basinal facies of the Tertiary sequences in the region were based almost entirely on lithology with little paleontological control. Although study of the geology of the region started more than a century ago, the basic questions remain unanswered. Many previous workers in the region have regarded the Disang Group as either rarely fossiliferous or barren. The age of the formation is ambiguous as different ages are suggested by various workers based on sporadic occurrences of fossils across the region. Considerable diligence and perseverance is required to locate fossiliferous localities as the region is highly tectonised, structurally disrupted and covered with thick vegetation. Therefore, the main objective of this study is to present a detailed study of the Eocene foraminifera from the Upper Disang Formation and to infer its biostratigraphic age and paleoenvironmental significance within the Neo-Tethys realm in the Indo-Burma orogenic suture zone.

Depositional model for Late Jurassic and Early Cretaceous sequences of Jaisalmer Basin, Rajasthan

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The western Rajasthan shelf located to the west of Aravalli ranges constitutes three important basins viz., Jaisalmer, Bikaner-Nagaur and Barmer. Each basin has unique geological and sedimentation history, although at some point of time, there were some common elements. The Jaisalmer Basin has well documented Mesozoic and Cenozoic sedimentation history. Bikaner-Nagaur and Barmer basins, however, are primarily Paleozoic and Cenozoic basins, respectively.

Various workers have carried out studies on the depositional environment of the stratigraphic units based on outcrop studies and on sub-surface well data. The Lathi Formation (Early Jurassic) comprises fluvial, deltaic, lacustrine, and marginal-marine sediments. The Jaisalmer Formation has deposited in a wide spectrum of marine environments ranging from inner shelf to upper shore facies. The Baisakhi-Badesar Formation has been dated Early Oxfordian to Early Tithonian and deposited in 30-50 m bathymetry in western part of the study area. The Pariwar Formation has been dated as Neocomian to Aptian on the basis of foraminiferal studies and deposited in near shore to inner neritic (30-50 m bathymetry) set up. The Goru Formation marks the second transgressive cycle of Mesozoic sedimentation. The Lower Goru Formation belongs to Albian age and deposited in 40-100 m bathymetry. The richly fossiliferous Cretaceous sediments have been dated as Hauterivian at the base and Santonian toward the top and are separated from the Cenozoic by a pronounced hiatus, i.e., KT boundary.

The sedimentation during the Mesozoic started with the deposition of Triassic sediments. The sediments of the Lathi Formation indicate a change in depositional environment form fluvial, deltaic to shallow marine environment. The overlying sediments of the Jaisalmer Formation were deposited in overall shallow marine conditions. It was followed by partial withdrawal of the sea in NW and SW part of the basin, which resulted in deposition of Baishakhi-Badesar Formation in a deltaic set up. The Pariwar Formation was also dominated by a fluvio-deltaic set up during the deposition. The end of Pariwar Formation witnessed a marine transgression throughout the basin, during which Lower Goru sediments were deposited.

This study was taken up to analyse the sedimentological, paleontological and palynological data generated over the years for the Late Jurassic and Cretaceous sediments in the Jaisalmer Basin. This data was integrated with other G & G data to decipher the regional depositional set up and to understand the disposition of the geological strata, depositional features and identification of the potential areas of hydrocarbon entrapment based on identified depositional setting for different stratigraphic units during the Late Jurassic – Cretaceous sediments.

Biostratigraphy and paleoenvironment of the Cambrian-Ordovician succession of Spiti Basin

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The Lower Paleozoic rocks exposed in Spiti Basin of the Tethys Himalaya reveal rich and moderately diverse assemblages of microfossils. These assemblages include trilobite, cyanobacteria, algae, brachiopods, gastropoda, microproblematica, bryozoans and trace fossils. Most of the taxa described from these successions are reported first time. On the basis of Ichnofossil assemblages three ichofacies have been marked in the Lower Cambrian successions, which are as *Cruziana*, *Skolithos* and *Nereites* ichnofacies. These ichnofacies indicate anaerobic to dysaerobic to aerobic trends of the ichnofauna. On the basis of the trilobite fauna different zones and level were marked, which range in age from Middle to early Upper Cambrian. These zones in their stratigraphic order of occurrence are as the *Oryctocephalus indicus* Zone, interval 1 of no zonation, and the *Bhargavia prakritika* Level (Cambrian Series 3, Stage 5).The *Oryctocephalus indicus* Zone is based on the FAD (First appearance datum) and LAD (Last appearance datum). The Ordovician succession yielded a number of microfossils, among which important are the calcareous algae (Dasycladacles), bryozoans, crinoids stems, broken fragments of cephalopods, lamellibranches, hyolithids, brachiopods, fragmentary remains of arthropods and trace fossil. The calcareous algae *Dasyporella silurica*, *Moniliporella multipora* and *Vermiporella fragilis*. are described from the first time from Thango Formation, Pin Valley. These calcareous algae are reported for the first time from the Ordovician (Dapingian to Darriwilian) Thango Formation of the Spiti Basin succession of northern India (Pin Valley, Tethys Himalaya). The genus *Moniliporella multipora* was reported for the first time from the entire Spiti Basin. This algal assemblage is broadly comparable to that of the immediately overlying Pin Formation in the Spiti Basin. The calcareous algae is mainly associated with the Ordovician fauna reported from Tarim Basin and Kazakhstan, which is of significant biogeographical and biostratigraphical importance. The calcareous algae indicates a shallow marine depositional environment for the Thango Formation.

Past global Permo-Carboniferous cryospheric event from the Sikkim- Darjeeling Lesser Himalaya, India

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The Lower Gondwana palaeoglaciation event (cryogenic diamictites) of Gondwana cryosphere is well preserved in the Sikkim- Darjeeling and Arunachal Lesser Himalaya of NE India. The present paper records and describes the glacial diamictite facies and detailed petrographic study from different diamictite occurrences in Sikkim –Darjeeling Himalaya. The Lower Gondwana sediments were deposited during the early Permian marine transgression in different parts of the NW and NE Lesser Himalaya. The signatures of the Permo-Carboniferous global cryospheric event are well preserved in the Tatapani area of the Rangit window in south Sikkim Lesser Himalaya. In the Darjeeling Himalaya the Lower Permian Gondwana diamictite beds vary from 8-10 m in thickness and are well exposed near the west side of Lish River. The diamictites are interbedded with 5-8 m thick fine grained sandstones. The clasts of diamictite are characterized by dark coloured poorly sorted, sub-angular grains of quartz, feldspar, mica and lithic fragments in a fine silty matrix. In some sections the clasts of chert and stromatolitic dolomite belonging to the Buxa Dolomite are also observed. We have recorded many large stromatolitic boulders embedded in the consolidated diamictite beds. The detailed petrographic and microfacies study of diamictites reveals matrix supported pebble and gravel with cemented shaly-silty facies together with rythmites which strongly indicate a glacio-marine depositional environment. A comparison and correlation of major lithofacies and microfacies variation in the Lower Gondwana diamictites from the Lish River section near North Kali Thrust and Rangit window, South Sikkim has been done. The glaciodynamic process and nature of movement of these glacial ice sheets in different basins during early Permian times in the NE Himalaya has been explained. We have also attempted for the first time to develop a cryogenic model for the global Permo-carboniferous glaciation in the southern Hemisphere and its relation with the Himalayan Gondwana cryosphere.

Provenance and change in tectonic activities from Eocene to Oligocene in the Indo-Myanmar Ranges (NE India)

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The Disang and the Barail successions represent the flysch and sub-flycsh sediments of the Indo-Myanmar Ranges. The Disang Group occupies a vast area of Manipur and extends in parts of Arunachal Pradesh, Nagaland, small portion of North Cachar Hills (Assam) and continues up to Chin Hill Ranges of Myanmar. The Barails are also well exposed in Manipur, Nagaland, North Cachar Hills (Assam), Meghalaya, Arunachal Pradesh and in the Sylhet basin of Bangladesh. ICV vs. CIA, TiO_2 vs. Al_2O_3 and K_2O/Na_2O vs. Fe_2O_3+MgO diagrams reveal that sediments from Arunachal Pradesh and Nagaland region are more weathered and recycled than those from Manipur region. Geochemical study suggests that towards the north (Nagaland) the Eocene-Oligocene sediments were derived dominantly from felsic source rock with high degree of chemical weathering and towards south (Manipur), the sediments were derived from multiple source rocks with variable degree of chemical weathering. Geochemistry of Laisong (early Oligocene) sediments indicates multiple source rocks and degree of weathering is from low to high. The basin was large and tectonic activity was intense during the early Oligocene. In the Middle Oligocene time during the deposition of Jenam, the sediments within the basin are uniform and the sediment supply is from both felsic as well as mafic source rock with higher degree of chemical weathering. Towards the younger Renji, the sediment contributions were from the felsic and mafic source rock and low degree of chemical weathering. Change in provenance and tectonic activities in this region were related to passive rifting and crustal stretching, which lead to the formation of the Indo-Myanmar basin, which was initiated sometime towards the close of Mesozoic Era (Late Cretaceous). The stretching was possibly followed by the deposition of a huge pile of Disang and Barail sediments during the Eocene and the Oligocene, respectively representing the flysch and sub-flycsh sediments of the Indo-Myanmar Ranges.

Status of the red bed successions exposed at the base of the Siwalik Group of NW India and a palaeobiogeographic analysis of the Siwalik mammalian faunas

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A reassessment of the age of the red bed successions exposed at the base of the Siwalik Group of NW India has been attempted. Lithologically, these red bed successions are characterized by thickly bedded red to reddish brown, purplish and dark chocolate mudstones with alternations of grey and brown, fine to medium grained sandstones. Though the red bed successions are encountered in several sections, the important localities which have yielded significant vertebrate fossils include: Ramnagar (J & K), Dunera (Punjab), Nurpur and Haritalyangar (H P). Most of the earlier workers referred the red bed successions of the above mentioned localities to the Lower Siwalik. But in the present study, based on faunal interpretation, it is noticed that except Ramnagar, the successions of the other localities represent the Middle Siwalik. Ramnagar assemblage is characterized by typical Lower Siwalik fauna including: *Antemus chinjiensis, Megacricetodon* cf. *sivalensis, Kanisamys* cf. *potwarensis, Eomellivora necrophila, Vishnuonyx chinjiensis, Viverra chinjiensis, Hippopotamodon haydeni, Conohyus chinjiensis, Anthracotherium punjabiense, Dorcabune anthracotherioides, Giraffa Priscilla*. No magentostratigraphic studies have yet been carried out in this area. From Dunera locality *Dorcatherium minus* and *Giraffokeryx* sp. were reported and the magnetostratigraphic studies suggest an age range between 12.40 to 5.89 Ma. Very recently this author has noticed the presence of ?*Hipparion* from this section. *Hipparion* is a marker fossil for the Middle Siwalik and thus indicates that a part of the red bed succession of Dunera represents the Middle Siwalik. Further, the red beds of Nurpur have yielded typical marker fossils of Middle Siwalik including *Cormohipparion theobaldi, Hippopotamodon vinayaki* and *Hydaspitherium megacephalum*. The magnetostratigraphic studies also support a Middle Siwalik age to Nurpur red beds. The red bed succession of Haritalyangar is referred to as the Nahan Sandstone and a very scanty fauna represented by *Trilophodon macrognathus* and *Tragocerus punjabicus* is known from here. Both of these forms are cosmopolitan in nature and range from Lower to Middle Siwalik. The magnetostratigraphic studies also indicate that a part of the Nahan Sandstone represents the Middle Siwalik. Besides commenting on the status of the red bed successions of the Siwalik Group of NW India, a palaeobiogeographic analysis of the Siwalik mammalian fauna has also been attempted.

Lithostratigraphy and trace fossils from the Paleogene belt of Parwanoo-Subathu sector of Shimla Hills, Himachal Pradesh, India

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The lithostratigraphy of the Paleogene belt of the Outer Himalaya in the Shimla Hills is represented by the Paleocene to Lower Miocene age marine to fluvial rocks of the Sirmur Group which is divisible into the Subathu, Dagshai and Kasauli formations in younging order in Parwanoo-Subathu area of the Himachal Himalaya, India. The shallow marine fossil bearing rocks of the Subathu Formation overlie the various Proterozoic lithostratigraphic units like the Simla Group, Krol Group, Baliana Group, Shali Group/Deoban Group and others with an unconformable contact having a thin layer of oxidized and ferruginised laterite, indicating prevalence of warm tropical climate before deposition of these shallow transgressive marine rocks. The Subathu Formation grades upward into fluvial type alternate sequence of reddish-purple mudstone and fine to medium grained, reddish-brown sandstone of the Dagshai Formation along with intervention of multiple palaeosol horizons. The rocks of the Dagshai Formation are overlain by the plant fossil bearing fluvial sequence of medium to coarse grained, massive, multistory, greenish-grey micaceous sandstone and minor grey-orange mudstone of the Kasauli Formation. The Kasauli Formation has a transitional contact with the underlying Dagshai Formation. In response of southward leading deformation front of the Himalayan orogeny due to collision tectonics of the Indian and Eurasian plates, the para-autochthonous Paleogene fold-thrust belt exposed between the northerly dipping Main Boundary Thrust (MBT)/Krol Thrust in north and the Main Boundary Fault (MBF) in south shows repetition of a few formations of the Sirmur Group along Parwanoo-Dharampur-Barog section of the Himachal Himalaya. The abundance of vertical, cylindrical burrows of *Skolithos linearis, S. annulatus, S. ingen, S. bulbus*, *Ophiomorpha* esp., *Thallasinoides paradoxides,* etc. within the upper part of the Subathu Formation suggests lower intertidal zone to subtidal environment. The Ichnofossil assemblages beds with association *Skolithos-Thallasinoids-Ophiomorpha* is representative of littoral zone, intertidal to subtidal environment of deposition.

Palynofacies analysis of Siwalik sediments of Bangana area of Una district, Himachal Pradesh

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The present paper deals with the palynofacies analysis of Siwalik sediments of Bangana area, Una district, Himachal Pradesh. For the recovery of dispersed organic matter the samples were treated with standard technique using hydrochloric and hydrofluoric acids. The palynofacies analysis of these rocks reveal that amorphous organic matter represents the dominant type of organic matter followed by non-opaque and opaque phytoclasts, biodegraded terrestrial organic matter and palynomorphs. The dominance of amorphous organic matter indicates the prevalence of reducing conditions particularly during the deposition of Siwalik sediments of the area, whereas the high percentage of phytoclasts suggests luxuriant flora in the vicinity of basin. The angularity of the opaque phytoclasts indicates that the sediments were not transported from a very distant source area. Considerable amount of fungal hyphae and fungal spores indicate humid and warm conditions at the time of deposition, which also suggest that there was thick vegetation with adequate foliage providing suitable substrate for fungal growth. Reasonable number of bisaccate pollen grains (gymnospermous) recovered from the sediments may have been driven by wind or fluvial agencies from the nearby high altitude areas. On the basis of above observations it may be concluded that the dispersed organic matter recovered from these sediments was deposited under quiet and low energy fluvial environment.

Forcing factors of the late Paleocene (57.9) and early Eocene (54.7 Ma) transgressions and latest middle Eocene (41. 3-38.0 Ma) regression on the Indian subcontinent

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Cenozoic Era was the turning point in the geological history of the Indian subcontinent when India experienced maximum isolation before it collided with Asia and there occurred a great mountain building activity shaping the Himalaya. In the Cenozoic Era, the sedimentation commenced in the late Paleocene (~57.9 Ma) in the pericratonic basins of the western India as well as the foreland basins of the Himalaya that mark the beginning of a major transgression on the Indian subcontinent. Till now, it is not clear whether this transgression was forced by tectonics or climate. We have interpreted that the primary driver for this transgression was the regional tectonics that marks the beginning of the India-Asia convergence. Another transgression occurred at the Paleocene –Eocene boundary with the accumulation of the fossiliferous limestones in many sections. This transgression has been global and influenced by the global warming at the EETM. A major regression of similar magnitude occurred during the latest middle Eocene (41.3-38.0 Ma) that corresponds to global sea-level fall. This regression is global and can be identified even in the Cenozoic basins developed within the African plate. It is interpreted that this regression was driven by the global cooling during the latest middle Eocene/late Eocene possibly associated with the nucleation of the Antarctica ice-sheets coupled with the uplift of the Himalaya.

Facies architecture and depositional environments of the middle Eocene (Lutetian) Harudi Formation, Kachchh, Western India

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The 11.5 m thick, 1.4 km long and 0.5 km wide, ESE – WNW oriented cliff section (N 23°31′32″ E 68°41′00″) exposed across Harudi – Baranda road is extensively studied for its facies development and based on their characteristics and stacking pattern depositional environments of the middle Eocene (Lutetian) Harudi Formation are inferred. Two cycles of grey mudstone alongwith nodular limestone – coquina limestone – gypsiferous mudstone facies overlain by 2 m thick coal seam in the lower part of the succession suggest sedimentation in coastal quiet-water lagoonal to tidal flat and marshy environments, while glauconitic shale, bioclastic packstone and gypsiferous foraminiferal packstone facies in the upper part of the Harudi Formation suggest sedimentation on middle- to inner-shelf and tidal flat depositional environments. In all, three shallowing-upward cycles have been identified in the studied outcrops and based on that lagoonal – middle shelf – inner shelf – tidal flat depositional environments are suggested for the middle Eocene Harudi Formation.

Paleogene algal- foraminiferal carbonate sedimentation in the shallow eastern Tethys Sea, Shillong Plateau, Meghalaya

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The Sylhet Limestone Group in Meghalaya (North-East India) comprises thick successions of Paleogene carbonates ranging from Late Paleocene to Early Eocene. Rich assemblages of larger benthic foraminifera and coralline algae occur extensively in these shallow water carbonate deposits. The present study deals with the paleobiology and paleobiogeography of the Lakadong Limestone (lower unit) and the Umlatodoh Limestone (middle unit) of the Sylhet Limestone Group. These two limestone units represent a major Tethyan marine transgression during the Paleocene in the South Shillong Plateau. The extension of western Tethys sea from Europe to Asian region, India–Asia collision and uplift of the Himalaya took place during the Paleocene-Eocene time (50 Ma). The Sylhet Limestone Group was deposited in a prolonged marine transgressive phase. A large transgression occurred during the Upper Paleocene when an arm of sea from the Eastern Tethys covered extensively the Shillong Plateau. Subsequently, two major marine transgressions covered the Shillong Plateau during Early Eocene which is represented by the Umlatodoh Limestone. The Middle Eocene to Early Upper Eocene is represented by the Prang Limestone.

The larger benthic foraminifera are commonly represented by the assemblage *Alveolina* sp., *Assilina* sp., *Nummulites* sp., *Miliolid* sp., *Ranikothalia* sp., *Discocyclina* sp., and *Rotalid* sp. The algal assemblages include *Sporolithon* sp., *Lithophyllum* sp., *Jania* sp., *Corallina* sp., and *Distichoplax biserialis*. Umlatodoh Formation has yielded mainly larger foraminifera and calcareous algae. Important species include *Alveolina* sp., *Assilina* sp., *Discocyclina* sp., *Nummulites* sp., *Helimeda* sp., *Sporolithon* sp. *Ovulites* sp. and *Spongites* sp., along with some bioclasts. Global correlation and paleobiogeography of the eastern Meghalayan and western Tethyan sea is discussed based on above studies. The similarities between NE India, NW Himalaya, Ladakh, Karakoram, and Southern Tibet suggest that all these regions belonged to a single faunal province during the Late Cretaceous – Eocene period.

Theme VI
Geophysical studies in the Himalaya and Indian subcontinent

Fault Kinematics and Seismotectonics of the Garhwal Himalaya: Insights from Moment Tensor and Stress Tensor Inversions of local earthquakes

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The Garhwal Himalaya (Fig.1), which located in a seismic Gap i.e Central Seismic Gap, is an ideal place to study the kinematics and Seismotectonics of the Himalaya. The region displays all the major litho-tectonic zones of the Himalaya Collision zone, which formed by the collision of India and Eurasia continental plates that occurred not more than 5.7 million year ago. The convergence is still continuing at a rate of 37-44 mm per year and this accumulated strain energy often produces the small-to-great earthquakes along its 2500 km of plate boundary.

In the present study, the Micro-seismicity of the Garhwal Himalaya, the Earthquake focal mechanisms determined from Moment Tensor inversion technique and the Stress Inversions have been studied to understand the kinematics and Seismotectonics of the Himalayan fold-and-thrust belt. We then coupled our results with the recent subsurface images for the understanding of the Kinematics and Seismotectonic aspects of the region. The results show that the region has a variety of faulting mechanism which includes thrust, strike-slip and normal faulting. In which, the thrust style of faulting mechanism is dominating, owing to the under-thrusting of the Indian plate beneath the Eurasian plate. But, the thrusting is largely controlled and confined to the detachment around the mid-crustal ramp. The solutions show shallow plunging NNW-SSE directed P-axis similar to the results of Stress Inversion of these moment tensor solutions with the principle horizontal stress orientated parallel to the relative motion of the Indian plate (Fig.1). Also, there are few earthquakes located around the crust-mantle boundary i.e the Mohorovicic discontinuity. In the upper crust, the principle stress is the only dominating stress which can be seen from the Mohr circle diagram and high shape ratio. The study also shows that the normal faults are relatively dominating in the sub Himalaya and the outer lesser Himalaya. The low b-value (frequency-magnitude relationship) and high D_c-value (Fractal) suggests that the region is under stress and a potential zone for major or great earthquakes in the near future and also heterogeneous. We also suggest that majority of the earthquakes (around 75%) in this region are concentrated in the upper crust around the mid-crustal ramp, which is a major continuous structure throughout the Himalaya. And the region around the crust-mantle boundary is also seismogenic.

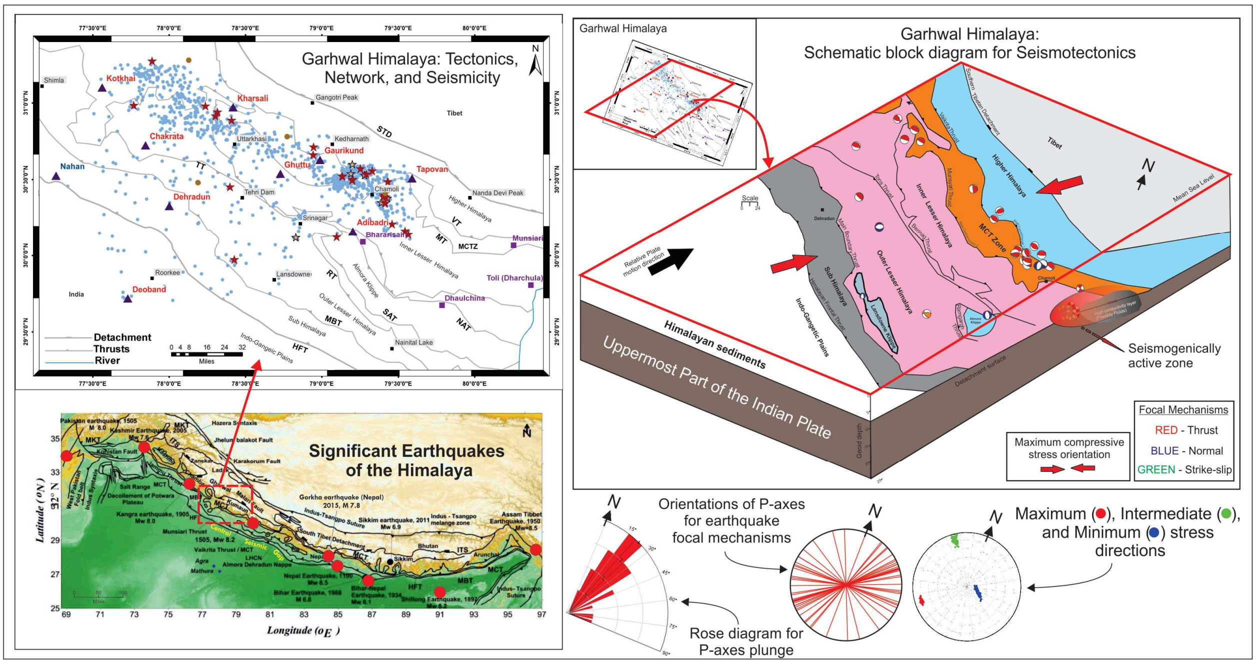

Fig.1: Shows location of study area in the Himalaya and schematic block diagram showing the major results of the study.

Frequency Analysis of Earthquakes in 1^0x1^0 of NW Himalaya during 2007-2017

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The NW Himalaya is the seismically one of the most active region in India. Wadia Institute of Himalaya Geology, Dehradun regular monitoring seismic activity of NW Himalaya. In this study we have analysed the frequency of earthquakes recorded WIHG VSAT Network during the instrumental period of WIHG i.e. 2007 on words. The frequency of earthquakes divides in 1^0x1^0 grid of NW Himalaya, window is taken 28^0N – 34^0N in latitude and 74^0E – 82^0E in longitude of NW Himalaya. The completeness and uniformity of catalogue have been statistically tested. The database is completed for the period 2007 to 2017 for earthquakes with magnitude >2.5. Divided earthquakes frequency in 1^0x1^0 has been analyzed. The epicenters shows three major clusters centered over the Kangra, Garhwal and Kumaon Himalaya with a well-defined seismic quiescence zone over NCR sector. It is indicated increasing the frequency of seismicity in proportionate towards southern regional tectonics of the Himalaya. This indicates that Kumaon region is more seismically active.

Seismicity map and local seismic wave velocity beneath Kachchh and Saurashtra of Gujarat region using local earthquakes of 2016

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Kachchh basin is the only region of India in seismic zone V beside Himalayan Region. Major part of Kachchh is called Kachchh Mainland Unit (KMU). Recent studies have suggested that E-W trending Kachchh Mainland Fault (KMF), Katrol Hill Fault (KHF), South Wagad Fault (SWF), North Wagad Fault (NWF) are the most seismically active faults in KMU and are capable of generating large magnitude earthquake in the near future. The fault intersections make the zone more vulnerable of high stress release making it a zone for potentially disastrous earthquakes. We have determined the seismicity map, average local seismic wave velocities, crossover distance and Vp/Vs ratio beneath the Kachchh and Saurashtra region of Gujarat using the natural earthquake data recorded by broadband seismographs during January 2016 to May 2016. The present study has used 246 local earthquake events of magnitude 1 to 4. The events which have registered a minimum of 6 Pg, Sg and Pn, Sn arrivals were selected for inversion of their hypocenters. Velocity model of Mandal et al., 2006 is used for the location of earthquakes and 22 stations within 5 to 350 km from the epicenters.

HypoDD method (Waldhouser and Ellsworth, 2000; Waldhauser, 2001) is used to improve the resolution of hypocenters. The hypocenter locations were further constrained by relocating all the 246 earthquakes, which exploits similarities in the event-station paths of a closely spaced cluster of events recorded at a relatively farther distance. All the rms values are less than 0.1 s which mean the errors in accuracy in Hypocenters location is less than 700 m. Seismicity map shows two main clusters in Kutch and Saurashtra region.

Our study shows that direct P-wave and S-wave is propagating with 6.72±0.02 (km/s), 6.71±0.04 (km/s) and 3.81±0.01 (km/s), 3.83±0.03 (km/s) velocity, and Refracted P-wave and S-wave is propagating with 8.11±0.07 (km/s), 8.12±0.10 (km/s) and 4.73±0.04 (km/s), 4.69±0.06 (km/s), respectively in Kachchh and Saurashtra. The cross-over distance is 130 km and Vp/Vs ratio (1.73) is abstracted from P and S wave arrival time data from our network using Wadati Method.

Our study indicates the stress is accumulating in crust beneath Kutch and Saurashtra of Gujarat Region. The study shows that the mid and deep crust of Saurashtra and Kachchh is of mafic characteristic. This might indicate the imprints of rifting and plume effect.

Geoelectrical signatures along the Satluj Valley, Northwest Himalaya, India

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In order to understand the deep crustal structures and Geometry of Main Himalayan Thrust (MHT) beneath the Satluj valley, magnetotelluric (MT) investigation at 22 MT sites have been carried out by different field campaigns. The profile along the Satluj valley in North West Himalaya is important, as the southern end of the profile crosses Nahan salient and Northern part of the profile cut across Kaurik-Chango Rift, a zone of concentrated seismicity. Collected MT time series data were robustly processed for an apparent resistivity curves using median as the robust estimators. At few stations, electric field recordings were very noisy perhaps due to ongoing hydro-electricity projects and unbalanced power network of the region reflecting larger error bars in estimated impedance tensors. The apparent resistivity curves were analyzed for dimensionality and decomposition. Swift skew and Bahr's phase sensitive skew indicate the complexity of geoelectrical structure, as none of site response of entire period band can be classified as strictly 2-D. Variation of skew parameters therefore suggest that dimensionality of the subsurface geoelectrical structure is band limited and varying depth wise. Modeling of the rotated impedances in the tectonic framework of the region is attempted and a shallow dipping mid crustal conductor is observed at an approximate depth of 5-10 km. The work presents the subsurface resistivity variation along the profile obtained after rotating impedances in the tectonic framework of region and will briefly discuss the tectonic significance of major thrusts along the Satluj profile.

Average crustal thickness and Poisson's ratio beneath a broadband seismological profile along the Kali River Valley, Kumaun Himalaya

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Crustal thickness and Poisson's ratios were estimated at 13 broadband seismic stations established along the Kali river valley, Kumaun (Central) Himalaya. The seismological profile stretches from Indo-Gangetic Plain (IGP) in the south to Higher Himalaya in the north, passing through the Sub-Himalaya and Lesser Himalaya. The receiver function (RF) method has been adopted to study the structure and composition of the crust beneath the profile, and Time domain iterative deconvolution method has been adopted for RF computation. The H-k stacking method has been adopted to analyze the RFs for obtaining average crustal thickness and Poisson's ratio of the crust beneath each station. The study reveals that the crustal thickness beneath the IGP is ~38 km which gradually increases up to ~43 km at the northern most station located in the Higher Himalaya. The Poison's ratio (η) varies within the range 0.23-0.28. Low values of η are recorded in the Sub-Himalaya and Inner Lesser Himalaya, which supports more of felsic composition in the region, as compared to exceptionally high η value in the Dharchula region (~0.28) of the Outer Lesser Himalaya. Such high Poisson's ratio cannot be explained by presence of any solid or dry crustal rocks. The extremely high Poisson's ratio value is interpreted as due to possible presence of mid-crustal fluid/partial melts beneath the region. Also, local data analysis of about 200 earthquakes during 2016-17 show a large number of micro-to-moderate magnitude earthquakes forming a cluster at shallow down to mid-crustal depths beneath the region. Presence of fluids influences the rheological property, thus modulating the mechanical and shear strength of crustal rocks, producing cluster of observed seismicity beneath the Dharchula region.

Quantitative evaluation of weathering effect of valley on ground motion characteristics

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A study of effect of valley-weathering on the ground motion characteristics and associated differential ground motion (DGM) is documented in this paper. A forth-order-accurate staggered-grid finite-difference (FD) program has been used for the simulation of SH-wave viscoelastic responses of the various considered valley models. Simulated results revealed that the defocusing caused by valley is frequency-independent in contrast to the ridge-focusing. ASA decreased from trough to the top of the elliptical valleys in contrast to the triangular valleys, where there is an increase of ASA. Overall, the amplification/de-amplification pattern was larger in case of triangular valleys as compared to the elliptical valleys. Based on the simulated responses of the weathered triangular and elliptical valleys, it can be concluded that the dwelling along the flanks of a non-weathered elliptical valleys is safer than the triangular valleys for the earthquake point of view. But, inverse inference is in case of both the weathered elliptical and triangular valleys.

Integrated Geophysical Techniques for Subsurface Imaging of Active Deformation: Case Studies in the Northwestern Himalaya

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Non-invasive geophysical techniques were employed across three active faults identified between the Himalayan Frontal Thrust and the Main Boundary Thrust in the northwestern Himalaya to understand shallow subsurface geological structures and their nature in relation to active tectonics. The combination of high-resolution Ground Penetrating Radar (GPR), Induced Polarization Resistivity (IPR) techniques with different acquisition parameters and *multichannel analysis of surface waves* (*MASW*) studies have found to be advantageous in obtaining high-resolution imaging of structures in the shallow subsurface. Repeated surveys comprising of different arrays were carried out using Lippman 4point light hp earth resistivity meter consisting of 40 electrodes. 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 depth of GPR profiles acquired across fault scarp vary from 3m to 10m depending on the antenna frequency and subsurface soil condition. With 200/600 MHz dual frequency antenna, high resolution subsurface image with penetration depth up to 5m were obtained. The 2D profiles interpretation reveals correlation between GPR anomaly and fault plane. MASW seismic data (using roll along technique) was acquired at shot stations evenly spaced along a continuous transect using 48 channel geophones with 2.5m spacing between geophone and 8 Kg hammer to create the seismic energy. The MASW 2D V_s section was interpreted to identify dipping beds in northeast direction consistent with local geologic mapping. This low-velocity zone between 55 to 0m coincides with the location of the thrust-fault zone and is interpreted as the seismic expression of the fault zone. The study has also established a strong correlation existing between field 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 paleoearthquake occurred in the area.

Trench excavation surveys were also carried out across Bhauwala Active Fault in the Central Doon Valley and across the Bharli Active Fault in the Trans Yamuna segment of the Doon Valley. Subsurface imaging carried out across these fault systems by GPR and IPR surveys have confirmed the deformation due to faulting. The integrated approach argues for judicious use of the GPR, IPR and MASW techniques to delineate subsurface geology across various faults in the Himalayan terrain to comprehend the area which are structurally complex and lithologically dissimilar.

Site response study based on H/V method using strong motion data: Case study of Kumaun Himalaya, India

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In this work, site response study is made in highly mountain terrains of Kumaun Himalaya, India by using H/V method (H/V is ratio of Fourier spectrum of horizontal and vertical component of the strong motion record). A total of 230 acceleration records of 110 local earthquakes recorded at fourteen different stations in Kumaun Himalaya region during the year 2006-2013 are utilized to estimate site response in this region. The purpose of this study is to quantify the site amplification in the frequency range of 0.01-10 Hz. In particular, S-wave part of acceleration record is used to estimate site amplification by using H/V method given by Nakamura (1989) and latter modified by Lermo and Chavez-Garcia (1993). A 20 sec window of S-wave is considered for all the records to estimate the spectrum. This window length is selected after many trials of 5, 10 and 20 sec, which provide better stability and frequency resolution along with the computational efficiency. The spectrum is computed for North-South (NS), East-West (EW) and vertical (Z) component separately. In this work, Fourier amplitude spectrum of horizontal component is divided by the spectrum of the vertical component. The horizontal spectrum is obtained by square root of the sum of square of NS and EW component. Several events are considered at a single station to estimate final resonance frequency. The H/V is computed for each event at a particular station and average H/V is attained from these individual ratios. The average H/V ratio provides the final resonance frequency corresponding to maximum amplitude of spectral ratio.

It is perceived that the obtained resonance frequencies vary from one station to another. Different stations provide different values of resonance frequency that ranges from 0.7 to 7.99 Hz. A close resemblance is observed between resonance frequency and rock type i.e. stations of high values of resonance frequencies are situated at high compact rocks as comparison to the stations of low values. It is noted that as we move from south to north side of the present study area the range of resonance frequency is increasing, and this increasing trend may be the signature of increasing grade of compactness of the rock from south to north.

Magnetotelluric signature of Tso-Morari dome at Indus-Tsangpo Suture zone in NW Himalaya, India

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The Tso-Morari Crystalline (TMC) is a significant litho-unit between the north Indian continental margin and the south of the ISZ. In the northern region, the TMC dips towards NE while in the southern region it dips towards SW and therefore this region is referred as Tso-Morari dome. It has been observed that the TMC is High pressure eclogitefacies metamorphism that suggests a deep subduction of the Indian Plate underneath the Eurasian Plate (Mukherjee &Sachan 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 Zildat Ophiolitic Melange.

The Magneto telluric (MT) method is used for deciphering subsurface geoelectrical characterization of Tso-Morari dome along a profile. The purpose of subsurface geoelectrical characterization of the TMC in the study area is to gain insight and develop an understanding about the evolution of TMC dome and about seismicity in the region. The MT data quality is quite high and robust processing of time series provide smooth apparent resistivity curves up to 1000 sec. Variation of sounding curves suggests complex resistivity structure along the profile. Although, dimensionality analysis using WALDIM tool suggest variable dimensionality depending upon the period and location of site but there is 3D/2D suggestions for responses over number of periods. Two dimensional resistivity model is obtained after rotation of impedance tensor to N43^{o}W. The model suggests decoupled upper and lower crust, indicative about evolution Tso-Morari dome. The poster will discuss different features of geoelectrical model and this significance in terms of surrounding tectonic regime.

Estimation of Potential of seismic hazard in the Western Himalayan segment of the Northwest Himalayan, India

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In this study the Seismic potential of the western Himalayan segment (30-33°N; 76- 80°E) of the Northwest Himalayan, India has been estimated in order to evaluate the potential of seismic hazard in this region. As the tectonic variations and associated Seismic potential of the study region to produce great earthquakes are closely related to the earthquake hypocenter distributions in the study area, so in this exercise firstly we constrained the hypocentral locations with higher accuracy and lesser error. As evidenced from the previously carried out research work in the present study region *(Khattri et al., 1989; Kumar et al., 2009, Mukhopadhyay & Sharma 2010)* symbolise greater variations in spatial distribution of hypocentral locations due to some reasons such as non-availability of local crustal velocity model and lesser number of seismic stations operated and utilized for acquiring the seismic data. The present study has attempted with an objective to reduce the variations in hypocentral parameters incorporating the current local crustal velocity model derived utilizing 20 seismic stations. In this study we have relocated 343 earthquakes triggered in the NW Himalaya during 2004 and 2013 using 765 P-phase and 713 S-phase. We have also determined moment tensor solutions for 8 (Mw>4.0) earthquakes using waveform inversion. The advantage of utilizing the waveform inversion technique, which utilizes low frequencies, thus, it makes modelling of waveforms less dependent on the inherently incomplete knowledge of the crustal structure. This method is highly advantageous in determining the exact fault plane characteristics pertaining to its Strike angle, Dip angle and rake or slip of the earthquake focus over other methods such as FPFIT, P-wave first motion polarization methods which require a greater number of stations and wide azimuthal coverage of earthquake hypocenter to determine the fault plane characteristics of the desired earthquake event.

The geometry of the MHT plane has also been deduced in this study which varies along the strike of the Himalaya in flat and ramp segments with a dip ranging from 4° to 19° below the HFT in south to STD in the north. There are also two new crustal ramps reported in this study having a depth range from 12 to 22 km below the MCT (31.0°N, 77.5°E) and 28 to 40 km beneath the STD (32.2°N, 78.4°E) respectively. The earthquake potential prevailing in the western Himalayan seismic gap lying between the epicentral zone of the 1905 Kangra earthquake and the 1975 Kinnaur earthquake has also been estimated utilizing the method of Kanamori (1983). The total amount of energy released since the last great event has estimated is only a fraction (3-5%) of the accumulated total energy (95-98%). This indicates that the energy stored in this region can generate in future an earthquake of Mw > 8.0.

Topography correction applied to magnetotelluric data from Sikkim Himalayas

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Magnetotelluric (MT) method is one of the powerful tools to investigate the deep crustal image of mountainous regions such as Himalayas. Topographic variations due to irregular surface terrain distort the resistivity curves and hence may not give accurate interpretation of magnetotelluric data. The two-dimensional (2-D) topographic effects in Transverse Magnetic (TM) mode is only galvanic whereas inductive in Transverse Electric (TE) mode, thus TM mode responses is much more important than TE mode responses in 2-D. In three-dimensional (3-D), the topography effect is both galvanic and inductive in each element of impedance tensor and hence the interpretation is complicated. We investigate the effects of three-dimensional (3-D) topography for a hill model and present the impedance tensor correction algorithm to reduce the topographic effects in MT data. The distortion caused by surface topography effectively decreases by using homogeneous background resistivity in impedance correction method. Also, in this study, we analyze the response of ramp, distance from topographic edges, conductive and resistive dykes. The new correction method is applied to the real data from Sikkim Himalayas, which brought out the true nature of the basement in this region.

Kinematics of the Himalayan Frontal Thrust and the adjoining Ganga Tear Fault from GPS Observations

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The Himalayan Frontal Thrust (HFT) is the youngest member of the Himalayan active thrust fault system that marks a topographic separation between the Siwalik ranges and the alluvial filled Indo-Gangetic plain. Being an active southernmost Plate Boundary structure among the Himalayan thrust belts; it accommodates most of the N-S crustal shortening. The east-west orienting Siwalik topographic highs were broken by a transverse tear fault and the river Ganges is at present flowing along the NE-SW strike of the tear, and hence made the name Ganga Tear Fault (GTF). In this work, the objective is to know the present day kinematics of the HFT and how that kinematics is regulating the active fault movement along the strike of the adjoining Ganga Tear.

We investigate the Arc parallel and Arc perpendicular kinematics of the HFT in association with the GTF using the Global Positioning System (GPS) data. GPS data from 33 continuously operating stations, both from IGS and Wadia Institute local network for a span of 8 years from 2010 to 2017 has been used in this study. The data were processed using the GAMIT/GLOBK software and the velocities were estimated in the Indian Reference Frame. The Arc parallel and Arc perpendicular velocities of three permanent GPS stations – two are situated at the south and the other at the north of HFT – have been estimated by forming a unique lone triangular network of three stations. The two south of HFT stations; namely, BIHA (Biharigah) and HARI (Haridwar) are located at the either sides of GTF in the NW and SE blocks respectively, and hence their velocities represent the relative movements of blocks across the GTF.

Results show that, irrespective of their locations either at the footwall or in the hanging wall of HFT, all stations have their velocities towards SE. But their relative magnitudes are more for the case of frontal stations. Thus, the resultant horizontal velocities of frontal stations BIHA and HARI are 4.21 ± 0.58 mm/yr and 2.86 ± 0.23 mm/yr respectively towards Southeast direction. While at the north of HFT, the Dehradun station shows a velocity of 2.34 ± 0.38 mm/yr. Calculation of along and across the arc relative velocities at the either side of GTF shows the block at the northwestern side of the Tear Fault is moving faster towards SE with respect to the southeastern block, and hence the present day active movement of GTF is sub-parallel to along the Arc movement of the HFT. In general, at present the kinematic movement of the HFT is dominated by along the Arc movement and hence the much anticipated movement along the strike of the Ganga Tear is abysmally low. The relative faster movement of the northwestern block of the GTF than the southeastern block would be the reason for the deviation of the river course towards south from the nearly perpendicular (NE-SW) abuttal at the Hanging wall of the frontal thrust.

Central Seismic Gap and probable zone of large earthquake in North West Himalaya

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The region between the 1905 Kangra earthquake and 1934 Bihar Nepal great earthquakes, termed as Central Seismic Gap (CSG), is seismically active. The strain energy accumulation in this region evaluated from the GPS instruments indicates that this region has the potential to generate a great earthquake in near future. The seismicity and source parameters studies has been carried out to evaluate the probable zone for future great earthquake.

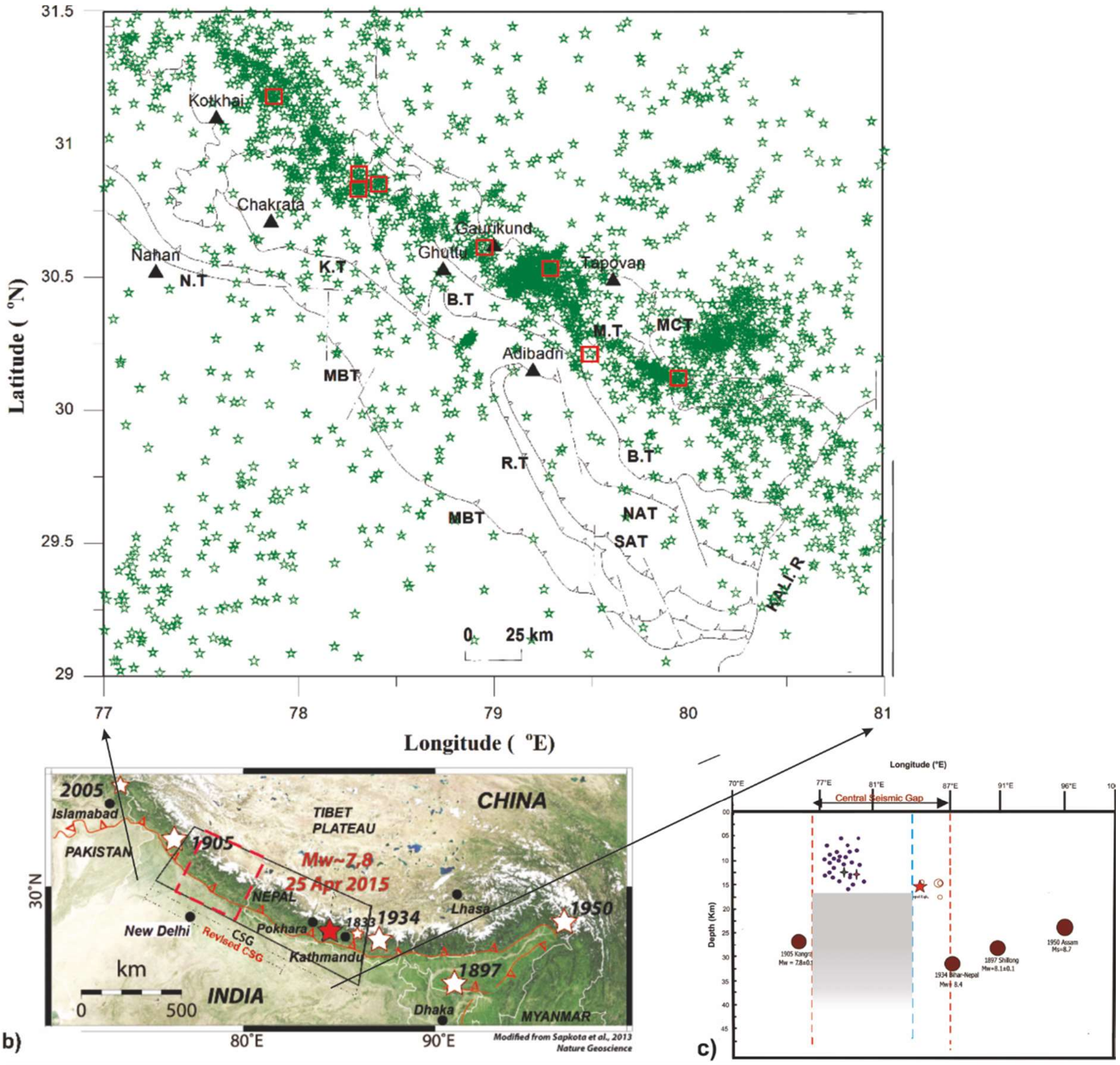

Fig. 1: (a) Seismicity (2007-2016), Events ☆ 1.8≤ M_L ≤ 4.0, □ M_L ≥ 4.1 recorded by Broadband seismic network, ▲seismic stations, MBT: Main Boundary Thrust, TT: Tons Thrust, BT: Berinag Thrust, RT: Ramgarh Thrust, NAT: North Almora Thrust, SAT: South Almora Thruts, MT: Munsiari Thrust, MCT Main Central Thrust (b) Study region ☆ great earthquakes (c) Grey shaded portion is the probable zone for future great earthquake, ● great earthquakes, micro-earthquakes, ★Nepal earthquake, ○ aftershocks of Nepal earthquake.

The focal depths of the four great earthquakes in Himalaya in India lies below the Main Himalayan thrust (MHT) and the focal depth of micro-earthquakes of this region, occurring during 2007 to 2016, lie at 10-25 km depth. Analysis of P-wave spectra yields seismic moments in the range of 2.40x10e11 to 4.23x10e14 Nm. The stress drop values of 80% of the events lie between 1-10 bars and majority of the events show thrust mechanism. The depth-wise locations and characteristics of seismicity reveals that the region above the detachment continues to release energy in the form of smaller magnitude earthquakes while the strain is continuously accumulating at the ramp or the zone below the plane of detachment. The epicentral location map shows that the seismicity of this region is concentrated in a narrow zone south of Main Central Thrust. It has two prominent clusters (i) near Uttarkashi, and (ii) near Chamoli. The MT studies show fluids near detachment below Chamoli region and the frictional coefficient worked out for this region is low.

The stress drop budget analysis, which comprises of (i) low stress drop values of the current seismicity in CSG, and (ii) the stress drop (~230 bars) of the M7.8 Nepal earthquake, suggests that the region below the 25 km depth in the western part of Nepal Earthquake (shown as shaded grey, in Fig. 1) could be the probable source zone for the future strain energy release in the form of a great earthquake.

Delineating precursor day windows of major earthquakes using GPS measured differential Total Electron Content (TEC) Analysis

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Earthquakes are natural calamities known to cause mass destruction on large scale. Any earthquake warning technique may be helpful in saving a lot of lives. Therefore, Earthquake Precursor studies have become quite important in recent times. Studying changes in the concentration of charged particles in the ionosphere can reveal clear precursor, days prior to the earthquake in the form of total electron content (TEC) levels. In this work we examine the Ionospheric TEC observed by a network of the Global Positioning System (GPS) receivers in selected areas of study which include Mexico, Japan and Nepal. Calculations based on the variation of TEC are aimed at revealing the signatures in the ionosphere before the earthquake in the form of differential TEC low anomalies which have been modelled for major events in Mexico, Japan and Nepal from 2014 to 2017. We base our study in the Mexico region and compare the results with Japan and Nepal events. While observing the differential TEC graph of major Earthquakes of Mexico in 2014, 2015 and 2017, we observed a pattern of rise and fall in the Differential TEC values. This shows a fall in the interval range of 8-9 days, 15-18 days and 24-27 days along with rise on rest of the days before the occurrence of a Major Earthquake. We highlight the procedure to model such anomalies by using time averaging method to construct Differential TEC profiles and picking up anomalous high and low values of differential TEC for different regions. We also discuss the TEC signatures that form recurring day windows of differential TEC lows before major earthquakes (Mw 6.0+).

Geoelectrical imaging for active tectonics studies

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Dependence of ground resistivity upon mineral content, porosity, degree of water saturation in the rock and fluid content, make it ideal for imaging and understanding subsurface. We attempt to use this method of subsurface imaging for active tectonics studies at Kala Amb region in the northwestern frontal Himalaya. The site is selected across an already established active fault system based on a trench excavation survey. An Electrical Resistivity Tomography (ERT) 2D profile survey was conducted along two profiles in Kala Amb region parallel to the already excavated trench with the target of delineating subsurface extensions of identified features (in trench section) and in the resistivity section as well. The study also helped to understand the efficacy of this method for the recognition and geometrical characterisation of active faults across morphotectonic scarps or fault traces in a region which experienced late Quaternary tectonic activity. In this survey, total 188 meter length at each profile is covered with 48 electrodes having 4 meter electrode spacing. Schulmberger-Wenner configuration is considered for recording electrical potential and induced potential. Apparent resistivity is calculated using these observed potentials, and the apparent resistivities are inverted for 2D resistivity section. Iterative Incomplete Gauss newton method were used to solve the least square equations of inversion scheme. Smoothness constraints were applied on model resistivity values as well as model perturbation vectors also. The final inversion is achieved in 5 iterations with absolute error 2.2 of convergence. The inverted resistivity model has lateral and vertical resistivity variations according to lateral and vertical extent of different depositional units in the area. The presence of north dipping fault at 54 m distance from zero electrode position toward south clearly distinguishes two separate lithological units. Beside this, the liquefaction feature identified in the trench wall section appear to be originated from a depth greater than 36 m. Also the similarity of resistivity features and difference in elevation of two profiles allow us to interpret spatial continuity of subsurface features and identify the thickness of deposit over river bed level. The paper aims to discuss and display above mentioned methodology, resistivity section and correlation with trench section, although limited due to difference in spatial scale.

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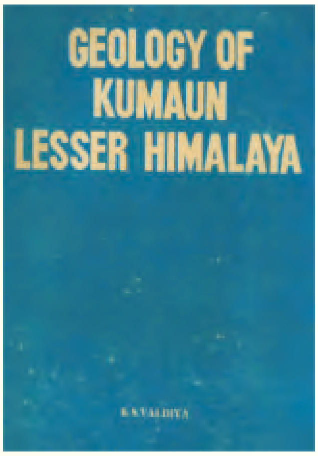

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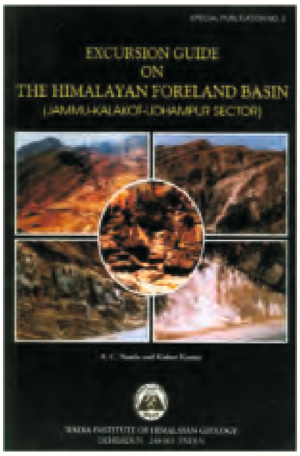

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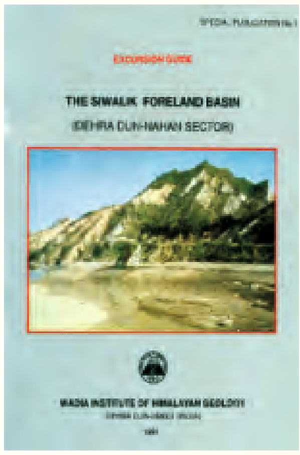

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