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***Institutional Report***

# Wadia Institute of Himalayan Geology

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Wadia Institute of Himalayan Geology (WIHG) is an autonomous Institute of the Department of Science and Technology, Government of India. The mandate of this institution is to

(a) Carry out research towards the development of new concepts and models for the geodynamic evolution of the Himalaya.

(b) Develop exploration strategies and management of the natural reserves like minerals, industrial material, glaciers and water.

(c) Plan and coordinate research towards understanding physical processes causing natural disasters, evaluate their hazard potential and suggest remedial measures.

(d) Serve as national reference center for the database on the Himalayan Geology.

Research, in this institute, is broadly grouped into following thrust areas:

1. Himtransects
2. Climate-Tectonics Interaction
3. Biodiversity-Environment Linkage
4. Sustainable Natural Resources
5. Real Time Geology to Society: Coping with Natural Hazards.

These studies are performed at various platforms. For example, preparation of geological maps, sedimentological and structural mapping of the sequences, collection of data on microseismicity, and GPS studies are performed in field. Microscopic and geochemical chronological studies and data interpretation are done in laboratories. The field and laboratory data are integrated in order to understand various aspects of the evolution of the Himalaya and its active tectonics. Some important thrust areas where the institute has focused during the last five years are highlighted below:

**Himtransects**

The semantic approach towards the Himalaya is the development of geodynamic model of the orogenic belt that can not only explain the archetype of the collision tectonics but can also trace the metamorphic history, constrain processes controlling high rate of erosion and exhumation, extent and nature of crustal shortening, kinematics of the crustal deformation, effects of superposed deformation as well as can provide clues to the space-time distribution of seismicity. The co-ordinated studies are in process along the HIMPROBE (a lithospheric geotransect across the Indian NW Himalaya) project in NW Himalaya. This transect has the advantage over the INDEPTH experiment as one single transect cuts across the entire Himalayan orogen from the Main Frontal Thrust to the Indus Suture Zone and all the essential facilities/expertise are available under one roof. The extended profile encompassing the Siwalik Range will help to trace the effects of post collision superposed deformation in shaping the oblique ramps. A similar integrated geotransect has also been initiated in the Eastern Himalayan Syntaxis region that remained largely unexplored and where the proposed mechanism of perpendicular continent-collision applicable along the Himalayan arc may not hold well because of the observed oblique subduction in the NE Himalaya. The challenge lies in the fact that geotransect in this region would constrain the role of collision, extension as well as shear tectonics. Below mentioned are major results accomplished under this thrust area:

* First ever passive seismology experiment carried out around the Eastern Himalayan Syntaxis shows presence of Moho at a depth of 47 km beneath the Brahmaputra Valley that gradually increases towards east and attains a depth of 62 km at the Suture zone.

* Petrochemical studies of granitoid rocks from the eastern part of Kumaun region suggest that the leading edge of India represented an active arc during the Late Paleoproterozoic time.

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* The intra-crustal low velocity zone (IC-LVZ) beneath Ladakh within a depth range of 15-35 km has been identified. The presence of IC-LVZ and high Poisson's ratio in the crust signifies the presence of partial melt or aqueous fluids or both.

* The crustal growth in the Shyok-Darbuk corridor of NE Ladakh can be explained by two stage melting process involving the generation of orthogneiss with mafic enclaves (pre-collision), and temporal evolution towards increasingly more evolved felsic magmas during reworking processes (post-collision).

* Geochemical volume strain and elemental mobility studies on the mylonitized and extremely deformed phyllonitic quartzite along the MCT in the Bhagirathi Valley predict a very high fluid/rock ratio during development of the MCT zone.

* Minamiite, a Ca-bearing hydrous sulphate mineral, is reported for the first time in India from the Deccan Volcanic Province at Matanumadh (Kachchh, Gujarat). Hydrous sulphates are abundant on the planet Mars but not common on Earth because they form under extreme conditions. Therefore, these can serve as a potential Earth analogue for the Mars and the Martian conditions.

* Orientation patterns of magnetic susceptibility axes from AMS study of soft sediments from a trenched fault zone across the Himalayan Frontal Thrust (HFT), western Himalaya helped to identifying co-seismic structures in the Late Holocene surface sediments.

* Analysis of the geometry and folding pattern within the Chamba Thrust Sheet reveals that regional folds were developed during the southward translation of the Chamba Thrust Sheet. The structural mapping of the area between the Chamba and Tandi synclines further reveals that these synclines are ultimately connected with each other by the two anticlines and with a very open undulating syncline in between. The described structures fit well into asymmetric box fold geometry.

* The preliminary results of Geothermal springs and associated river waters collected from the Main Central Thrust (MCT) zone of the Himalaya show that there is a strong variation from -8.5‰ to +4.0‰ (PDB) indicating the varied sources of their origin.

* The temporal correlation of major suture zones with oceanic geoid anomaly revealed that the increase of geoid anomaly after 90 Ma in the vicinity of the Ninety East Ridge represents a phase of crustal accumulation followed by the formation of Shyok suture.

**Climate-Tectonics Interaction**

Recent researches have shown that tectonic deformation, climate and life interact in ways that are sometimes profound yet not very obvious. This has implications in terms of 1) the development of compressional orogens that is strongly influenced by climate where the extent of erosion determines the short and long term crustal deformation, 2) global geochemical processes and carbon and oxygen cycles that are soundly subjected by tectonics and climate change, and 3) Floral and faunal evolution that has strong bearing with climato-tectonic conditions. Therefore, integration of studies related to a) climate change, b) crustal deformation and its surface manifestations, c) surface processes in terms of geochemical changes, and d) floral and faunal responses to changing global conditions are likely to yield provocative results in climatic, biological, and tectonic interaction research in future.

In the Himalaya, it will be a challenging program to investigate whether the continental scale changes result from a) change in the mode and intensity of tectonic deformation, b) synchronous regional or global change of climate conditions, c) the dynamic evolution of the Himalayan drainage system, or a combination of all these processes. Therefore, most felt need of the contemporary research is to understand that how climate and orogenic organization of Indian subcontinent has responded to 1) continental tectonics at long term time scales of $10^7$-$10^5$ yrs since 60 Ma, 2) Regional crustal deformations at short time scales of $10^2$-$10^5$ yrs. Below are some recent findings under this thrust area:

* Two generations of alluvial fans, younger (23 to 10 ka) in the northwest and older (36 to 29 ka) in the southeast have been identified in the Soan Dun, which record the coupling of climate and tectonics. The uplifted Late Quaternary deposit, similar in age as the top of the older fan sequence, in the hanging wall of the Soan Thrust indicates tectonic activity north of the Himalayan Frontal Thrust (HFT), and suggests out-of-sequence thrusting during the Late Pleistocene.

* The Mio-Pliocene Middle Siwalik Subgroup of the Ranital-Kangra section of the Kangra sub-basin is sandstone dominated succession. It has been observed that at around 100 to 125 ka, it is interceded with a floodplain sequence of 1 to 3 m thick mudstone, which at places has also an abnormal thickness of >30 m. At basin scale, this cyclic pattern is controlled by extrinsic process; however, development of abnormally thick floodplain deposits

is controlled by intrinsic process due to basin tilting along the basin bound transverse fault.

* Sedimentation pattern of the Siwalik succession between 12 to 0.5 Ma, constrained through the reversal magneto-stratigraphy, exhibits two major phases of uplift at ~10 and ~5.5 Ma. The fluvial architecture and isotopic signatures, marking the intensification of the monsoon and accompanying changes in the drainage pattern show unambiguous evidence of climatic change triggered by the tectonic uplift, which was also responsible for re-organization of drainage pattern at ~10 Ma, ~5 Ma and 1.77 Ma in the foreland basin.

* The multi-parameter paleoclimate records of lacustrine sediments underlying the Chandra Peat deposit in Lahul and Spiti area have been precisely documented for the first time, as the Younger Dryas cold event in the NW Himalaya. Pollen data and mineral magnetic record indicating significant wet and warm conditions before 12880 cal yr BP, point towards the Ållerød interstadial climate. This cold/dry climate further intensified until 11640 cal yr BP and terminated with gradual reappearance of local as well as regional flora.

* Mineral magnetic studies from a proglacial lake of Chorabari suggest that variation in magnetic parameters is probably controlled by transportation energy related to the activity of the glacier.

* Patsio paleolake deposit, near the Bara Lacha Pass has revealed that it was developed due to climate-induced landslide and resultant blockade of the Bhaga River ca. 8-7 ka BP. The termination of fluvial sedimentary sequence and sudden onset of the glacial lake deposit marks an abrupt climate shift towards significant warmer conditions around 6.3 ka BP, which correspond to significant Holocene global climatic event.

* The Ganga River system in the NW and Brahmaputra River in the NE Himalaya during the past 40 ka aggraded in two major phases in response of the two phased deglaciation in the Higher Himalaya. The incision of the river valley took place in response to increased monsoon ~11 ka; however, in the foreland the incision took place 3-4 ka later suggesting a time lag in the surfacial responses to particular climatic pulse.

**Biodiversity-Environment Linkage**

Evolution is an innovative science which explains the ways in which the life has advanced, and whose signatures are found well preserved in the fossil records. Numerous lines of evidence reveal that life has changed through time. The biodiversity includes the variability within and between the species and ecosystems. In geological context, it includes diversity within and among fossil taxa, and among paleo-ecosystems. Major geological boundaries are delineated based on distinct biological extinctions and recoveries attributed to ecosystem changes. Detailed understanding about the biodiversity across the major geological boundaries (i.e. PC/C, P/T, K/T, P/E, etc.) in the Himalaya is important for stratigraphic correlation.

Himalaya provides an ideal natural laboratory for testing the evolutionary innovation, diversification, extinction and environmental linkage with various bioevents. The Himalayan sedimentary records grant great opportunity to understand the linkages between biodiversity and environment at different time scales. An integrated multidisciplinary approach involving detailed taxonomy, morphometry, biostratigraphy-sedimentology, stable isotope and sedimentary geochemistry and magneto-stratigraphy is aimed to arrive at meaningful goal on the biodiversity-environmental linkage. Below are the major achievements under this thrust area:

* The oxygen isotope composition ($\delta^{18}O$) of fossilized skeletal elements of vertebrates such as teeth and bones of sharks and other fish and some terrestrial mammals from the sub-Himalayan and western Peninsular Indian successions show strong correspondence with respective animal habitats. The freshwater $\delta^{18}O$ values seem to suggest that monsoon like precipitation may have been active even during the Eocene-Oligocene period.

* Fossils bones and dentitions of rodents, primates, artiodactyls and other land-dwelling mammals recovered from the horizons corresponding to Early Eocene Climatic Optimum (EECO) show a rather close similarity with the contemporaneous fauna from Europe indicating faunal connection with that continent during the Early Eocene (~53 million year ago). This has opened a new debate regarding dispersal of smaller mammals across Europe and the Indian subcontinent.

* Molecular study of fossil resin from the Late Cretaceous Mahadeo Formation of Meghalaya indicates that, the major pyrolysis products and methyl-esterified thermochemolysis products found in the resin are abietane and labdane type diterpenoids, with minor amount of sesquiterpenoids. The exclusive presence of both labdane and abietane diterpenoids and the lack of phenolic terpenoids seem to suggest that, the Cretaceous resin was derived from Pinaceae (pine family) conifers.

* Nannofossils have been recovered from the Upper Bhuban Formation, Mizoram, northeast India, and probably it is for the first time that nannofossils from the Surma basin are recorded. The nannofossil assemblage suggests a hemipelagic depositional setting for the Upper Bhuban Formation of Mizoram.

* The identification and study of ancestral form of the whales (Cetacea) from a huge faunal collection from the Kalakot area, Jammu and Kashmir demonstrates that whales evolved from an aquatic group of mammals living in freshwater bodies rather than on land, necessitating the revisions in the views held so far that whales had land-dwelling ancestors.

* The Muth Formation in Pin valley has yielded an ichnofossil assemblage represented by a variety of ichnogenera, which show intertidal or littoral settings having a soft and sandy substrate and presence of annelid worms indicative of deep marine environment.

* The mineralogical, textural and geochemical characteristics of high-silica rhyolitic tuff breccia at the base of the late Paleocene-Middle Eocene Subathu Formation around Kalakot in Jammu and Kashmir provide a stratigraphic evidence of the earliest collision between the Indian and the Asian plates. The breccia, therefore, represent as an important marker horizon in the foreland stratigraphy.

* The black shales in the early Eocene part of the Subathu Formation in NW Himalaya occur in a relatively carbonate dominant sequence rich in organic matter and poor in carbonates as well as in fauna. They are lithologic expressions of hyperthermal event. An inverse relation between $CaCO_3$ and TOC contents is observed in the black shales. This is likely in response to variations in seawater temperature, dissolved oxygen and/or pH.

* Organic remains from the Dharamsala Group of Kangra Valley indicate that the beginning of orogeny was apparently a key driver for resurgence of life on southern flank of the Himalaya during the early Miocene time. The early Eocene life known from the older sequence of the area was plausibly wiped out by global sea level fall as a precursor to the beginning of Ice Age Earth.

* Evidence of well preserved uvigerinid foraminifera and pteropods in the Tertiary horizons of NE India signifies that the hydrocarbon producing Upper Disang Formation was deposited at a depth of ~500 m, well above the aragonite compensation depth (ACD) in an open marine basin, information crucial in oil exploratory activity in the region.

* Neoproterozoic Organic Walled Microfossils (OWMs) including silicified cyanobacteria and acritarchs have been reported from the Infrakrol and lower Krol formations of outer carbonate belt and Gangolihat Formation of Inner Carbonate belt. Sponge spicules of similar age have also been documented from both outer as well as inner carbonate belts, bringing down their known range.

**Sustainable Natural Resources**

Resources form the backbone of every economy. The very use of resources and their transformation help in building the capital stocks that add to the wealth of present and future generations. In this context, the Himalaya is a special region in the mountain ecosystems of the world. This geodynamically active region is not only important from the viewpoint of climate and as a provider of life, water resource to large part of the subcontinent, but it also houses a variety of flora, fauna, and human communities. Despite the abundance of natural resources, most of its people are living on the edge on subsistence level. A judicious management and study of glaciers, streams, biota and mineral resources in totality is needed for sustained development of economic, ecological and socio-cultural necessities. It is therefore essential to understand the various conditions and processes, which control and affect the occurrence of natural resources particularly, water (glaciers, streams, and groundwater) and mineral. It is therefore proposed to address the aforementioned themes on natural resources, which also have immense societal importance and are essential to accelerate the development activities in our country. Some of the results achieved from this research programme are mentioned below:

* Field evidences, on the basis of loops of lateral and terminal moraines suggest that there were four phases of advances and retreat of the Dokriani-Bamak glacier over the last ~315 years.

* The dates calculated by lichenometry of different loops of deglaciation indicate the influence of climate change on the glaciers and difference in value suggests the effect of orientations of the two glaciers. The north facing Dokriani glacier in the Garhwal Himalaya indicates Little Ice Age maximum during the AD 1692, whereas the south facing Chorabari glacier shows its maximum during the AD 1748.

* Treeline is one of the natural and important climate markers in the high altitude mountain ecosystems. Investigations carried out in the Chorabari and Dokriani glaciers suggest that the treeline has shifted towards higher altitudes at the rate of 10.21m/year in Chorabari and 1.70m/year in Dokriani glacier valleys with in a period of 47 years.

* 'Stannoidite', an unusual sulphide of Cu, Fe, Sn and Zn within the chalcopyrite is reported for the first time from the eastern Kumaun region, which suggest the genesis of polymetallic sulphide mineralization due to cooling of high temperature and sulphur fugacity hydrothermal solution.

* The observed geochemistry of Pinjaur Dun sediment samples probably reflects both the mechanical dispersion/erosion of catchment's host rocks as well as the hydromorphic (aqueous phase) transport and transfer of REE from the aqueous phase to the stream sediments. The high $(La/Yb)_N$ ratios along with the major and trace element chemistry in the samples suggest dominance of a felsic provenance and deposition in an environment dominated by a particulate terrigenous source.

* Geo-accumulation index (I-geo), applied for the purpose of environmental evaluation of heavy metals distribution in Pinjaur Dun area, indicated that leaching of metals from garbage and industrial sewage (effects of anthropogenic activities) has led to enhancement of metal concentration (Pb, Zn and Cu).

* The representative carbon isotope analysis ($\delta^{13}C$) of Almora graphite suggested that the graphite has crystallized from biogenic carbon during the metamorphism of the host sediments.

**Real Time Geology to Society: Coping with Natural Hazards**

The Himalaya is an abode of natural hazards. In addition to the seismic hazard, the mountain belt recurrently witnesses landslides, cloudbursts, flash floods, snow avalanches, glacier lake outburst floods, etc. The frequent occurrences of natural hazards pose a continual threat to the safety of the people inhabiting in and adjacent to this gigantic mountain system. It is therefore essential to enhance our knowledge base on various physical and geodynamic processes causing natural hazards possibly in a real time mode for developing and implementing suitable mitigation measures. This line of fundamental research with serious societal implications forms the central focus of the mission mode project. As a preventive measure to minimize the damage scenario in the event of a large earthquake, microzonation maps depicting dominant frequencies in propagating seismic waves and their amplification by near surface sedimentary column are proposed for major townships and industrial belt, including possible sites of hydro-electric dams. The research programme focusing on landslides, cloud bursts, landslide lake outburst floods and glacial lake outburst floods will establish the kinematic model to identify interactive internal causative factors, which would help in planning of mitigation strategies. The highlights of results under this thrust area are given below:

* A new program combining powerful InSAR and on-going GPS campaign surveys around the reservoir was taken up to constrain better the uplift/subsidence associated with annual loading/unloading of the reservoir. Long term monitoring of GPS, total magnetic field intensity and radon emission are also in progress at 14 stable bench marks established around the Tehri reservoir.

* The recent trench excavation survey carried out across an active fault system in the Quaternary deposits of the Pinjaur Dun demonstrates a 2 meter vertical displacement substantiating our previous reports of large magnitude earthquakes rupturing the frontal Himalaya.

* Continuous radon monitoring in a 68 m deep borehole in the Garhwal Himalaya, and the abnormalities observed in radon emanation and other parameters in the borehole have shown to be precursory signature for the July 23, 2007 Kharsali earthquake of M4.9, that had an epicenter distance of 60 km.

* Seismic hazard analysis of the NW Himalaya carried out using probabilistic technique show high hazard potential zones to be centered around the Kashmir region (0.70g), Kangra region (0.50g), Garhwal region (0.50g) and Darchula region (0.50g) with intervening zones representing the low hazard zones (~0.25g) for 10% probability of exceedance in 50 years.

* A new methodology has been developed based on temporal gravity and solid earth deformation studies to understand the dynamics of alluvial pore space fluid in the Doon Valley, when it was subjected to distant large or great magnitude earthquakes.

* More recently, a moderate (M~6.9) earthquake which occurred in Sikkim, (NE India) on September 18, 2011 is being monitored by the WIHG with the help of eight broadband seismographs installed in and around the epicentral region. The studies are aimed at understanding the size and orientation of the fault plane responsible for the Sikkim Earthquake from the aftershock observations.

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