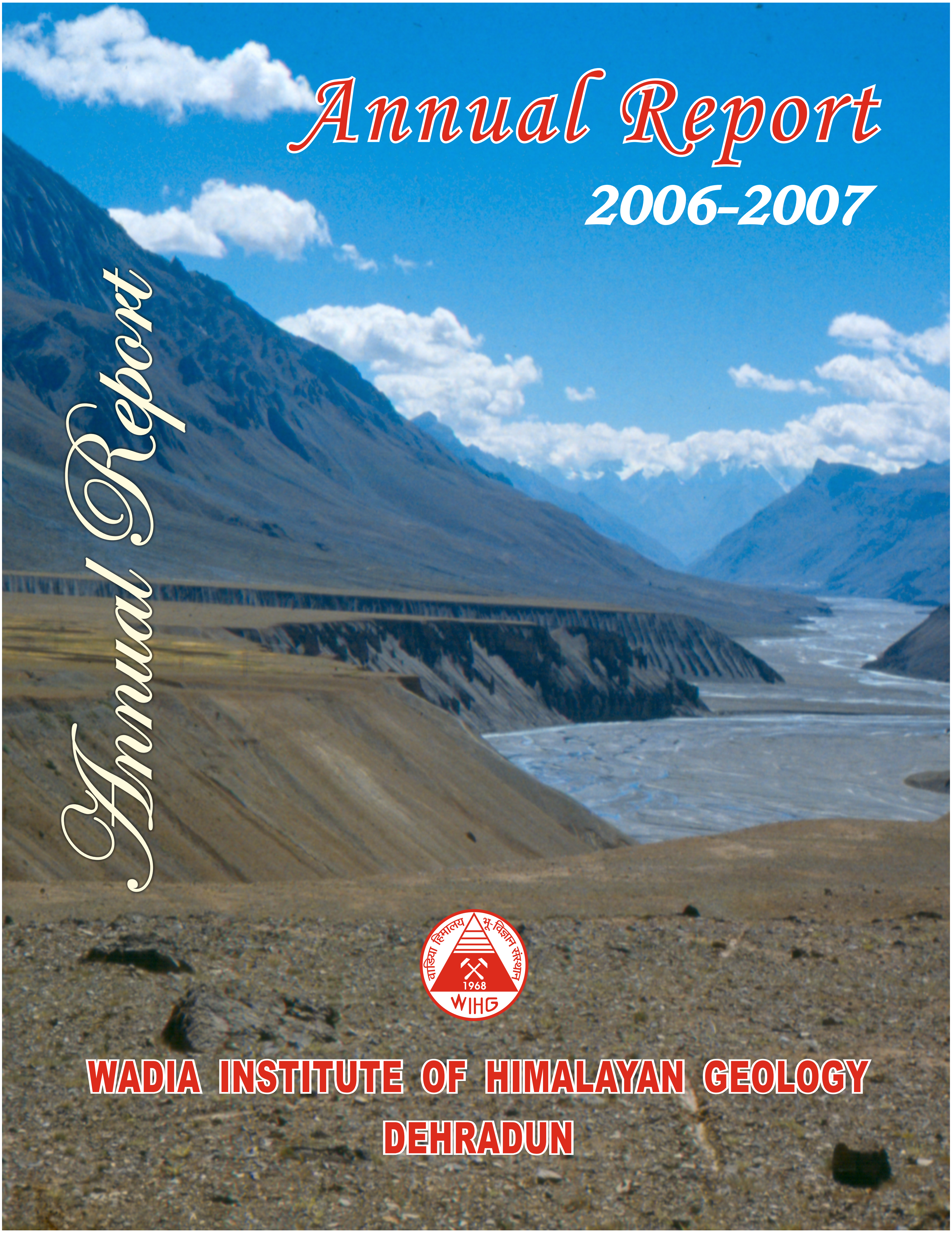
Annual Report

2006-2007



WADIA INSTITUTE OF HIMALAYAN GEOLOGY

DEHRADUN

Credits : R.K. Mazari, K.K. Purohit, D.R. Rao, V.P. Singh and Rambir Kaushik

Cover Photo: View of Spiti valley (H.P.) east of Hal showing development of terrace partly covered by alluvial fan. (Source :

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WADIA INSTITUTE OF HIMALAYAN GEOLOGY

33, General Mahadeo Singh Road, Dehra Dun - 248 001

EPABX : 0135-26227387, 2624806, 2623109

Fax : (91) 0135-2625212 E-mail : director@wihg.res.in

website : http://www.wihg.res.in

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MARCHING FORWARD

Wadia Institute of Himalayan Geology, established in 1968, is an autonomous institute of the Department of Science and Technology, Government of India. The Institute is engaged in geological mapping, structure & tectonic, petrology & geochemistry, geochronology, sedimentology, geomorphology, palaeontology, glaciology, hydrology and geophysical studies to unravel the geological truths related to mountain building for manifold applications in understanding geodynamic processes, impact on climate, natural resources, evolution of life, and assessment and mitigation of natural hazards.

Research activities of the Institute are planned and grouped as a part of Five Year Plan of the Government of India and are implemented through long-term projects and short-term projects, which are supplemented by the sponsored projects focused at various themes within the ambit of the evolution and geodynamics of the Himalaya. Standing at the transition from 10th Five Year Plan to 11th Five Year Plan, the current year was a period of self-introspection and developing vision for the future activities. To promote inter-disciplinary research, the activities under the 10th Plan were grouped into a number of thrust areas.

1. Geodynamics and Crustal Evolution
2. Basin Evolution
3. Natural Hazards
4. Glaciology and Natural Resources
5. Paleoclimate and Environment

Major success stories, milestone achievements during the current year are summarized, whereas the progress of different thrust areas and various projects are detailed out in the subsequent sections. A separate companion volume is brought out reviewing the overall achievements of the Institute during the 10th Five Year Plan and highlighting the basic rationale of research themes planned for 11th Five Year Plan.

The planning of scientific activities for 11th Five Year Plan were greatly facilitated by the comprehensive exercise of developing the vision document of the Institute for the next 10 15 years. Recognizing the continuous growth of analytical and field observation facilities as well as in-house expertise for undertaking integrated geo-scientific research, the major scientific programs during the 11th Five Year Plan are identified to address scientific themes in the form of Mission Mode Projects. The scientific activities during the 11th Five Year Plan are envisaged to be centered around the following Mission Mode Projects:

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

The total programs are being implemented and monitored by the recently reconstituted Governing Body under the steward leadership of Dr. T. Ramasami, Secretary, DST, Government of India, and Research Advisory Committee under the Chairmanship of Dr. M. Ramakrishna, former Sr. Dy. Director General, GSI.

Success Stories

Himalayan Evolution Model: New Insights

To constrain the geodynamic evolution model of the Himalaya, WIHG has recently introduced magnetotelluric technique (MT) to image the deeper structures of the collision zone in terms of electrical resistivity (Fig. 1). Resistivity-depth section shows that Indus suture zone is still preserved as a sub-vertical crustal structure, perhaps a consequence of slower rate of convergence between India and Asia. Further north, evidence of partial melt associated low resistivity mid-crustal layer highlight prevailing high heat flow conditions due to doubling of the crust whereas the resistive Indian lithosphere extends significantly north of the Indus suture at the upper mantle depths. The order of conductance as well as southern limit on the extension of partial melt when compared to Tibet part could be critical in evaluating role of Channel flow model in explaining the inverse metamorphism around Southern Tibet Detachment. Resistivity imaging has also given unequivocal evidence that prior to continent-continent collision a thick ophiolite (oceanic crust) slab was emplaced on the passive Indian continental margin. Subsequent to the collision and during the upwarping of Tso-Morari Dome (TMD) obducted oceanic slab was upthrusted along the Zanskar back thrust. Absorption of fluids, released from the underlying sedimentary sequences, by ultramafic rocks enclosed in the ophiolites led to the serpentinization. Such hydrated ultramafic rocks are exposed and mapped as high conducting zones between Indus-Suture Zone and Tso-Morari Dome. Physical evidence supporting such hypothesis is corroborated by the presence of CH_4 (methane) inclusions in the olivine of ultramafic rocks exposed at Nidar Ophiolitic Complex, Eastern Ladakh Himalaya. The formation of methane inclusion, governed in modern submarine environment, is active pointer of active serpentinization that leads to reduction of CO_2 to CH_4. Such visualization is further consistent with model for supra-subduction zone ophiolites (SSZ) that some serpentinized and buoyant SSZ ophiolites are obducted onto the passive margin shortly after formation and exhumed to the surface without being deeply buried. (*Arora, B.R. et al., Geophys. Res. Lett., 134, L04307, 2007; Sachan, H.K. et al., Earth Planet. Sci. Lett. 257, 47-59, 2007*).

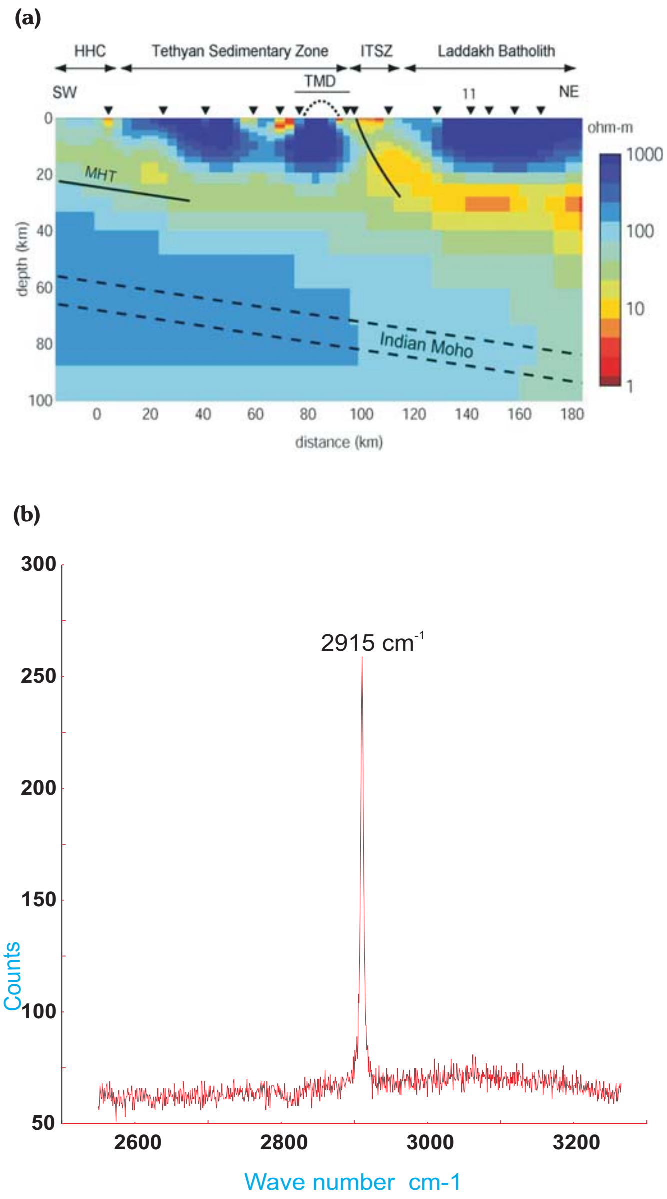

Fig. 1. **(a)** Electrical Resistivity Model across the Indus Suture of the NW Himalaya, obtained by the inversion of long period magnetotelluric data.

(b) Raman spectra showing methane inclusive in olivine mineral of Nidar Ophiolitic complex.

A new litho-chronostratigraphic correlation scheme showing >1 Billion Year Proterozoic hiatus in the Lesser Himalaya, Ganga Basin and the Vindhyan Basin

For last several decades, however, the Inner Carbonate Belt successions were assigned a Mesoproterozoic age (~1400 Ma) mainly based on the "Riphean stromatolites" (organo-sedimentary structures), but discoveries of Vendian - earliest Cambrian multicellular animal microfossils (sponge spicules and protoconodonts) from the Inner Carbonate Belt of the Kumaun Lesser Himalaya have brought out a major chronostratigraphic revolution in the Lesser Himalayan geology. These unprecedented fossil finds have prompted the Institute scientists to propose a major age revision and a new chronostratigraphic correlation scheme that suggests that the two Lesser Himalayan Carbonate Belts, i.e. Inner Shali/Deoban Belt and Outer Krol Belt, are time-equivalents and belong to a single carbonate platform of Vendian to Early Cambrian period (~650-520 Ma). Thus the age and correlation problem that persisted in the Himalayan geology for nearly 150 years is almost resolved.

The new age revelation has also brought out yet another outstanding result that a major hiatus of more than one billion-year exists between the Deoban-Mandhali/Krol-Tal unmetamorphosed sediments (Vendian Early Cambrian, ~650-520 Ma) and the underlying metamorphosed Damtha/Jaunsar Group sediments (Paleoproterozoic); the latter successions have ~1.8 Ga basic volcanics. Regional extent of this long lasting Proterozoic hiatus is discernible even in the Ganga and Vindhyan Basin successions of the Indian Peninsula (Fig. 2).

The above new bio-chronostratigraphic results have paved new ways for understanding the structure and tectonics, and the early evolutionary history of the Himalaya. (*Tiwari, M. et al., 2000, Curr. Sci., 79. 651-654; Azmi, R.J. and Paul, S.K. 2004, Curr. Sci., 86, 1653-1660; Joshi, et al. 2006, Gond. Geol. Magz., 21, 73-82; Azmi et al. 2007, Application in Stratigraphy and Paleoceanography (Narosa New Delhi), 29-62*)

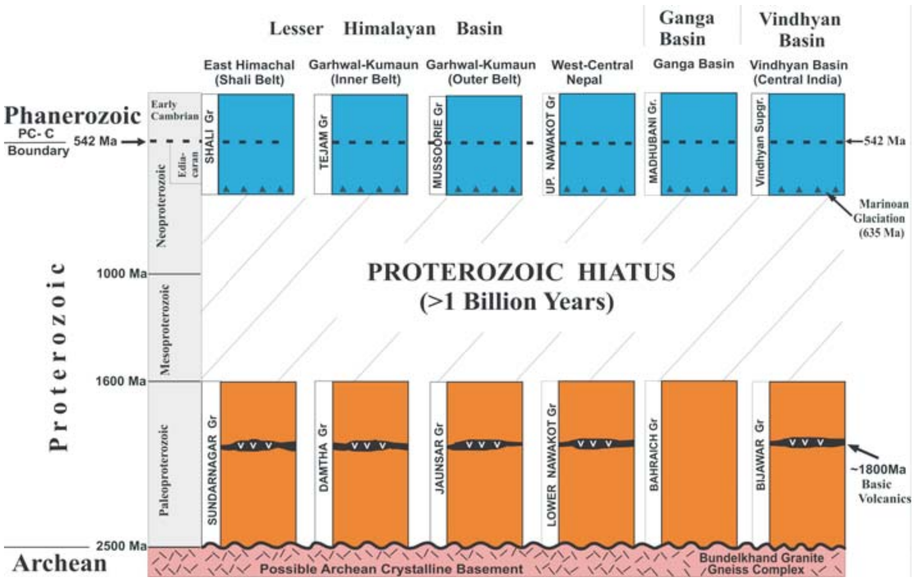

Fig.2. Revised chronostratigraphy of the sedimentary successions showing more than 1 Billion Year hiatus in the Lesser Himalaya - Ganga Basin Vindhyan Basin.

Climate-tectonic interaction and Evolution of Himalaya

The ever rising Himalaya evolved in response to geological processes operating in the deeper part of the earth is common belief. However our recent research have shown that the earth's surface processes have also played important role in shaping the world's highest mountain chain. The major rivers draining the Himalaya respond to the varying Indian monsoon and tectonic conditions archive their resilience in the basins developed in front of the mountain. Therefore sedimentary basins, which are termed as foreland, have been successfully utilized as the laboratories to understand the climate-tectonic interaction vis-à-vis Himalayan evolution through time. Investigations in the sediments of the Siwalik basin located in the Outer Himalaya indicated that this mountain chain achieved the optimum heights, responsible to change the global climatic pattern and setting up of Indian summer monsoon is as old as 10 million years.

The lakes in the Himalaya have smaller catchment therefore they are sensitive indicators of short-

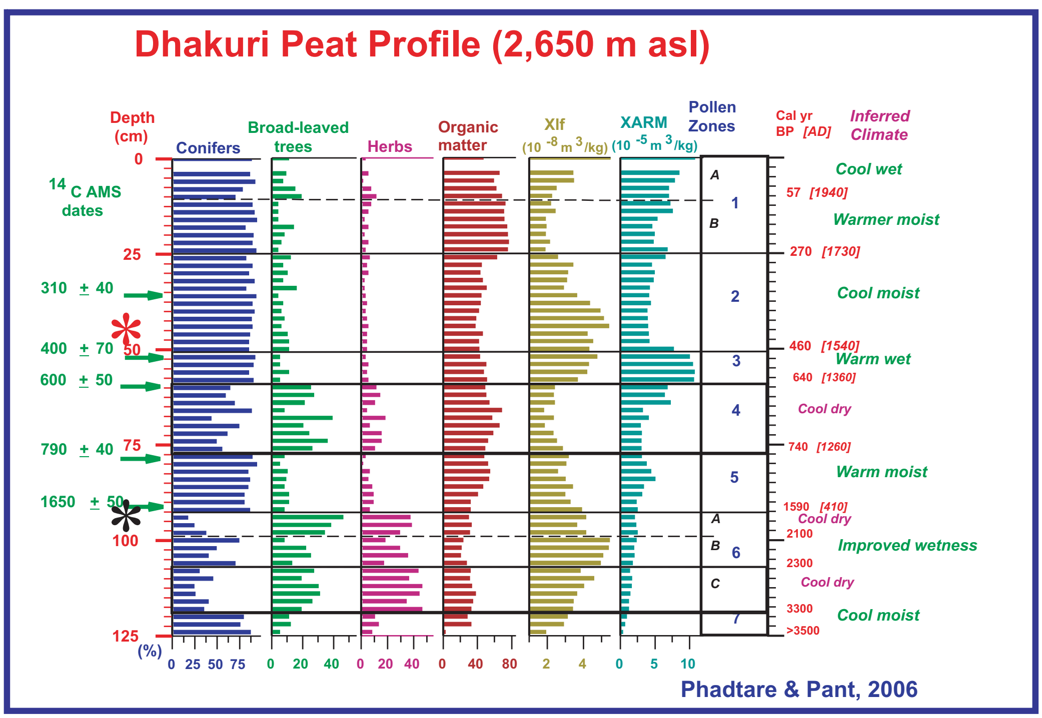

Fig. 3. ✦* A global draught event of ca. 1300 AD is well documented for the Ist time from the Indian subcontinent.

✦ 3200-2900 cal yr BP cold/dry episode of the Himalaya, unexpectedly corresponds with improved monsoon event over the Arabian Sea revealing the complexity of Himalayan climate.

term climatic changes. Understanding the role of high-resolution palaeoclimatic records in the prediction of Indian rainfalls and related socio-economic planning, the lake records in the Himalaya were studied. The study based on pollen stratigraphy, geochemistry and radiometric dating suggested that there are phases of both high and low rainfall conditions. For example the overall cool phase spanning the past 35 centuries was punctuated by drier spells during 3300-2300 and 2100-1600 calendar years before present (Fig. 3). The study has implications in estimating the amount of Himalayan erosion and productivity in the Indian ocean. The studies substantially point out to the fact that the development strategies towards river linking project in the Indian shield should consider the coupled nature of tectonic and climate of Himalaya including the and foreland. *(Phadtare, N.R. & Pant, R.K. 2006, J. Geol. Society India, 68, 495-506; Ruhland, K., Phadtare, N.R & Others 2006, Geophy. Res. Lett., 33, L15709, doi:10.1029/2006 GLO26704).*

Multi Parameter Geophysical Observatory for Earthquake Precursory Research

Multi-Parameter Geophysical Observatory (MPGO) established by the Institute at Ghuttu, Uttranchal Himalaya is India's first integrated attempt for studying earthquake precursors (Fig.4). It is known from dilatancy-diffusion model that impending zone of earthquake goes through characteristics changes in physical properties of rocks during the earthquake cycle. The observatory is equipped with high-precision magnetometer, magnetotelluric, super-conductivity gravimeter, seismometers, GPS, radon, ULF emission and ground water monitoring units for isolating stress-induced changes in magnetization, resistivity, density, elastic failure, deformation, inert gas, electromagnetic emission and water level fluctuation.

The challenge is to isolate these minor signals from the large-scale background variations associated with

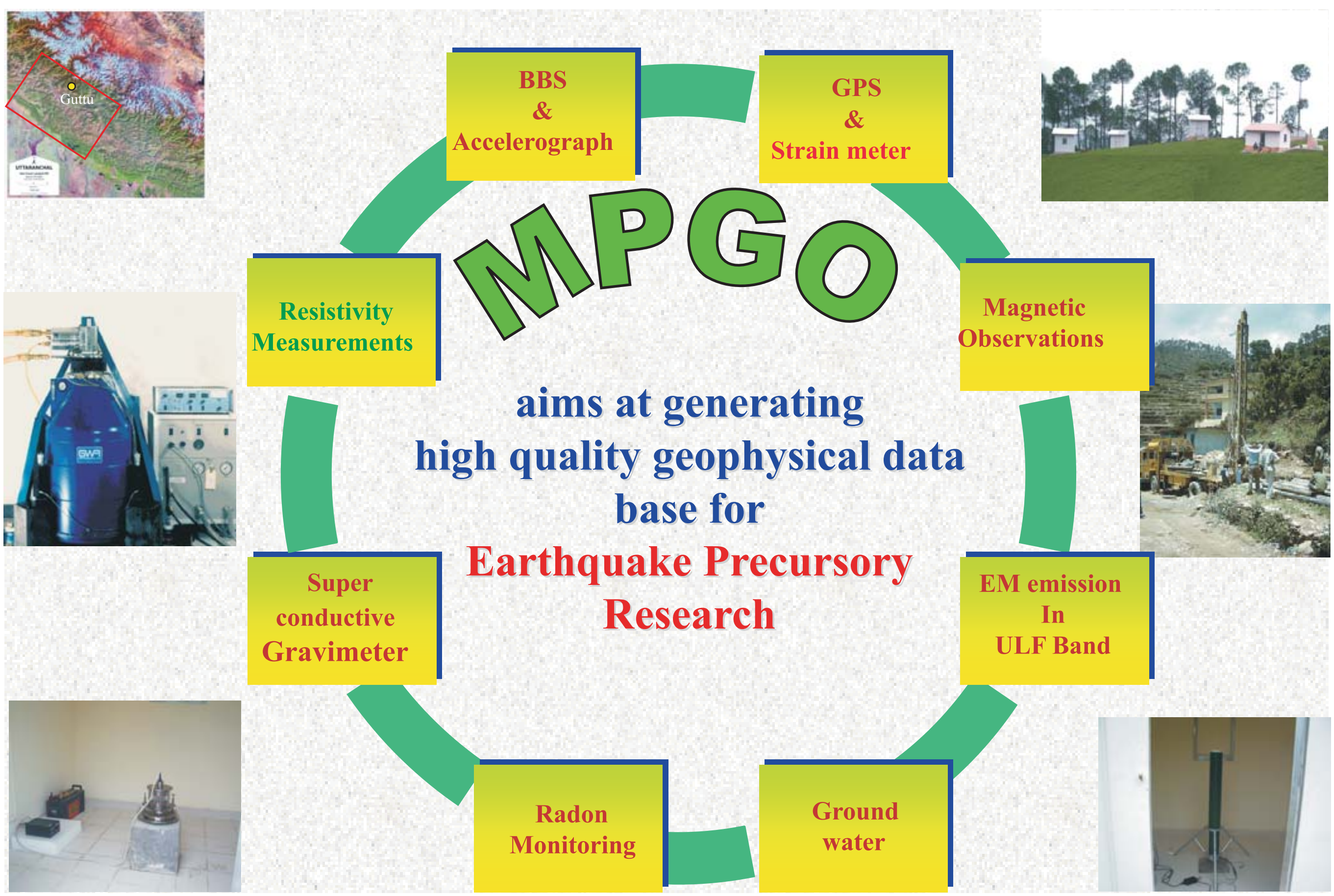

Fig. 4. WIHG's Multiparametric Geophysical Observatory Ghuttu, Uttarakhand.

physical processes other than of tectonic origin. The project aims at detection of these changes to establish their association with earthquake parameters. The MPGO is now fully functional and current focus is on continuous monitoring to characterize the time variability of various geophysical parameters to facilitate detection of earthquake precursory signals.

Milestone Achievements

Geodynamics and Crustal Evolution

- Structural mapping coupled with rock magnetic fabric studies bring out that during the India-Asia collision (65 my ago) the pre-Himalayan normal faults were reactivated as thrust listric faults producing reversal in the sense of relative movement, which highlight the role of inversion tectonics in the Himalayan orogeny (*Dubey and Bhakuni, J. Asian Earth Sci. 29, 424-429, 2007).*
- The geochemistry of eclogites and garnet-amphibolites from Tso-Morari region, Ladakh, has been investigated to characterize their protoliths. The eclogites and garnet-amphibolites have coherent compositions, range from 'depleted' to 'enriched' MORB. Isotopically they have Sr_i ratio (~0.706) similar to some of the Ocean Island Basalt. The enriched components are probably derived by melting of a mantle source with an enriched OIB-type component *(Rao and Rai, Gondwana Research, 9, 512-523, 2006).*
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- The integrated field, petrographic, geochemical and geochronological data of Polokongka La, Rupshu and Nyimaling granites of Ladakh, show high mol. A/CNK values, show presence of normative corundum, and have high Sr_i ratios, suggesting their S-type nature, contrary to the I-type nature described by earlier workers to Ruphsu granite. The Rb-Sr dating of peraluminous granites of Tso-Morari, Ladakh gave an isochron ages of 499 $\pm$ 8 Ma, 487 $\pm$ 23 Ma, 475 $\pm$ 23 Ma, and 456 $\pm$ 16 Ma for Puga gneiss, Polokongka La, Rupshu and Nyimaling granites respectively *(Islam et al., Jour. Geol. Soc. India, 65, 72-86, 2006).*
- Fluid inclusion and geochemical studies on Nagthat Siliciclastics from Tons valley help to assess the provenance during the Proterozoic and recrystallisation during maximum burial to uplift. Chemical signatures and H_2O- CO_2 fluid with 0.9 gm/cm^3 CO_2 density in detrital quartz grains characterise the protolith of the sandstone as granite or granitic gneisses *(Verma and Sharma, Jour. Asian Earth Sci., 29, 440-454, 2007).*
- The seismotectonic model developed for the Kangra-Chamba region attributes the sharp cut-off depth of seismicity to the presence of fluid filled low velocity layer at mid-crustal depths. Space-depth distribution of hypocenters suggests that in the Chamba Nappe the strains resulting from the on-going collision are being consumed by the reverse fault movement on the Chamba Thrust and down dip movement on the Chenab Normal Fault. (*Naresh Kumar et al., Bull.Seism. Soc. Am., Communicated, 2007).*
- For the first time high alumina trondhjemitic rocks have been reported from the western belt of the Lohit complex, which might have formed either by melting of the subducted oceanic crust or newly under-plated basaltic magma beneath the thickened continental arc leaving residual garnet and amphibole. The leucogranites were derived from anatectic melting of a mixture of leucotonalite and metasedimentary rocks, induced by thrust related thickening during collision (*Gururajan & Choudhuri, Geol. Soc of India (next issue), 2007).*
- The structural analysis of thrusts and faults; morphotectonics of river profiles, mountain front sinuosity index, and drainage basin asymmetry vectors indicate that the frontal part of eastern Himalayn syntaxis, Arunachal Pradesh, is characterized by on-going active fault tectonics, and the recent stream migration towards NE and SE directions due to ground tilting (*Khayingshing Luirei, Jour. Geol. Soc., India, 69, 858-861, 2007; Khayingshing Luirei & Bhakuni, Jour. Geol. Soc. India, (accepted), 2006).*

Basin Evolution

- Paleoflow pattern coupled with facies analysis in the Spiti Basin reveal continuity of depositional system between Lesser and Tethyan Himalaya during the Cambrian under prograding river and storm-influenced deltaic paleoenvironment whereas the paleobiological database indicate minimum ~15m.y hiatus at the Cambro-Ordovician unconformity *(Myrow, Parcha and others, Geol. Soc. Am., 118, 491-510, 2006).*
- Sedimentation history of Quaternary succession in the Himalayan foreland demonstrates the variable importance of accommodation space, base-level

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change and relative magnitude of tectonic and climatic forcing as controlling factors on aggradations and entrenchment in Quaternary alluvial fan systems of the Himalayan foreland basin (*Kumar et al., Quaternary International, 159, 620, 2007).*

- Sedimentological studies aided with luminescence chronology in upper the Ganga catchment allow to trace three phase evolution of the terraces: (i) massive erosion and aggradations during last glacial phase (21-11 ka BP), (ii) valley attained its present form after 11 ka due to increased rainfall, and (iii) area near Deoprayag is uplifting @ 1.75 mm/year (*Srivastava et al., Quaternary Research (in press), 2007).*
- Discovery of valcanic ash from the oldest unit of the Himalayan Forel and Basin serve as proxy record of volcanic activity and place canstraint on the timing of Indian-Asian collision during the Late Paleocene-Middle Eocene (*Siddaiah and Kumar, Current Science, 92, 118-125, 2007).*

Natural Hazards

- Integration of GPS data from Himalaya and contiguous regions show that the Indian plate convergence is accommodated within Indian shield by 3-5 mm/yr whereas 14-16mm/yr of crustal shortening is occurring within Lesser Himalaya, largest fraction being absorbed in the Tibetan plateau (*Apel, Banerjee and others, Eos Trans. AGU, 85(52), Fall Meeting supplement, T51B-1524, 2006).*
- New traces of active faults identified in the Kangra valley and Pinjaur Dun of the NW Frontal Himalaya suggest that there have been large magnitude earthquakes visiting the regions in the past to produce sizable and coherent surface faulting, which produced prominent fault scarps (*G. Philip, International Journal of Remote Sensing (in press), 2007. G. Philip and N. S. Virdi, Current Science 92(4) ,532-542, 2007).*
- Based on multichannel analysis of surface waves Dehradun city is divided into 3 microzonation zones: Zone 1 southwestern side of the city as class E (<180m/s), zone II covers mostly the middle part of the city and is classified as D (180-360 m/s), and Zone III covers the northern part of the city and few locations in the southeast and northwest of the city, classified as C (360-760m/s) *(Mahajan, Curr. Sci., 92 (7), 945-955, 2007).*
- The environmental geological studies in Kullu valley show that due to its peculiar geomorphic setting, high relief of peripheral ridges and impact of monsoon rainfall this valley is prone to various natural hazards like cloudbursts, flash floods and landslides. Further unwise human interaction with the geoenvironment of the area account for the losses caused by these phenomena both in terms of life and property (*Sah & Mazari, Jour. Mountain Sci., 4(1), 3-23, 2007).*
- Morpho-structural analysis using remote sensing data (IRS data) along with selected field investigation has helped in delineating a new active fault trace. The fault zone, referred to as the *Singhauli Active Fault (SAF)*, which traverses through the Middle Siwaliks is exposed on the hanging wall of the HFT. The south side up behaviour of this fault is in contrast to the prevalent north side up movement along the HFT. The fault is steeply dipping due NNW/N and has created few sag ponds to the north of the footwall zone (*Philip & Virdi, Curr. Sci., 90(9), 1267-1271, 2007).*

Glaciology, Natural Resources, Paleoclimate and Environment

Glaciology and Geohydrology

- Annual net balance estimated for Dokriani Glacier, over the last decade, indicate continuous degradation at the average rate of (-) 0.32 m. water equivalent per annum, supporting global warming hypothesis. However, uncertainties in the precipitation particularly in winter seems to be the critical factor in sustaining the river run-off during low discharge period of summers (*Dobhal et al., Bulletin of Glaciology (in press), 2007).*
- The size and age relationship of yellow Rhizocarpon geographicum species of lichen reveal that colonization delay and growth rate varies substantially in the four study localities of Himachal Pradesh, namely Sanjoli, Kanlog (both in Shimla), Dharamshala and Dalhousie having colonization delay of 24, 68, 50, 86 years respectively while the respective growth rate have been found to be 0.73, 0.79, 0.56, and 0.54 mm/yr. Colonization period was also confirmed by the absence of lichens on the recent monuments prior to the calculated dates *(Chaujar, Curr. Sci., 90, 11, 2006).*
- 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 last about 315 years. However the histogram of size/frequency distribution of lichens suggests that there were 11 movements. This suggest that the evidences of 7 stages are obliterated due to slides or by the next stage being more powerful and energetic than the previous ones *(Chaujar, Geoscientific Cartography and Information System, Barcelona, Spain, 1, 320-321, 2006).*
- Micro-catchment level investigation of Dingad stream (~77sq.Km) (Dokrani glacier) reveal that Glacier degraded run-off volume varied from 3.5% of the bulk

glacier discharge in 1994 to 7.5% in 1999. This study suggests that the uncertainties in the precipitation characteristics in a changing climate, especially the winter snowfall have pronounced effect on the headwater river run-off variability rather than the run-off variations from a receding glacier *(Renoj et al., Curr. Sci., 92, (3), 376-382, 2007).*

Mineral Resources

- Geochemical landscape of radioactive elements (U, Th, K), in active stream sediments from Bhagirathi-Alaknanda valley shows that U and Th are more enriched (about 2-3 times average upper crustal abundance; AUCA) in Lesser-Himalayan Crystalline (Main Central Thrust Zone; MCTZ) as compared to Proterozoic Metasedimentary Sequence (PMS) rocks with Porphyroids (PH) litho-units showing moderate abundance. REE abundance also shows similar distribution with fractionated LREE and flat HREE pattern. The systematic variation of HFSEs from south to north across the strike are controlled by the lithotectonic units and related to phases of deformation and metamorphism *(Mukherjee et al. Geochemical. Jour., 41, 83-95, 2007).*

- $\delta^{34}S$ values of barite from Tons valley, Lesser Himalaya, and ^{87}Sr / ^{86}Sr ratios in this barite together imply incorporation of sea water sulphate with Ba carrying crustal fluid for the barite formation, with its initial deposition linked to the diagenesis of the host rocks *(Sharma et al., Curr. Sci., 93, 440-443, 2006).*

- In the series of geostandards an amphibolite reference sample (AM-H) from Jeourie Himachal Himalaya has been standardized. Working values have been assigned for all the major oxides, 35 minor and other trace elements including REEs. Notably, the proposed standard has lower concentrations of Ti, alkalies, Ba, Nb, Zn and Zr that are characteristic of deformed metamorphosed basic rocks of Himalayan terrain. Surprisingly, the Cr content is exceptionally high at 690 ppm and hence may be used as high-point calibration standard *(Saini et al., Jour. Geol. Soc. India, 69(4), 799-802, 2007).*

Palaeoclimate and Environment

The Holocene climate and summer monsoon variability in Uttaranchal Himalaya

- The century-scale multi-parameter climate records from the Dhakuri peat sequence of Kumaon Himalaya indicate cold/dry climate during 3300-2300, 2100-1600 and 740-640 cal yr BP, implying the descendance of upper tree-line and corresponding advance of the Pinder Glacier. Significantly warm and wet climate observed between 1600 and 740 cal yr BP reveals the *Medieval Warm Period* whereas the predominantly cold climate prevailed during 460 270 cal yr BP marks the *Little Ice Age* event in Central Himalaya *(Phadtare & Pant, Jour. Geol. Soc. India, 68, 495-506, 2006; Ruhland, Phadtare & others, Geophys. Res. Lett., 33, L15709, doi:10.1029/2006 GL026704, 2006).*

- Late Quaternary deposits in the Pinjaur Dun indicates that the two aggradation phases (96.5+25.3 - 83.7+16.3 ka and 72.4+13.4 - 24.5+4.9 ka) and intervening entrenchment phases (~74 and 20 ka) denote respectively the dominance of climate and tectonic forcing *(Suresh et al., Sedimentology, 2007, In press).*

Academic Pursuits

Under the on-going research programs pursued during the year, the Institute has published 69 research papers both in international and national journals and nearly equal number is in press/communicated. A great satisfying factor has been the numbers of research publications in the SCI journals have continuously grown and the annual impact factor is upswing non-linearly. During the current year the average impact factor per paper has touched the value of 1.12.

In addition to the research publication, the Institute scientists presented 65 papers in international and national seminar/symposia/ workshop of which number of them were invited/keynote review talks. Further five Ph.D. theses have been awarded and two submitted for the award of Ph.D. Degree. Institute research scholars are permitted to register at IIT, Roorkee and more recently the Institute has signed MoU with Kumaon University to enhance academic interactions

To disseminate and share new emerging trends of research in geosciences, the Institute organized three workshops

- Emerging Issues in Uttaranchal for the Development of Water Resources;
- Himalaya Earthquakes: A Fresh Appraisal (HIMEQ-2006);
- Active and Fossil Suture Zones.

In addition the Institute also organized a Discussion Meeting on Tectonic Geomorphology: Landform evolution and Quaternary Tectonic and Third Module of SERC School on Crustal Deformation and

Tectonic Geomorphology (Modern Structural Geology and Tectonics).

The Institute brings out regular Himalayan Geology publications. During the year volumes 27(2) and 28(1) were brought out along with volume 12 of the in-house Hindi magazine Ashmika.

Other Highlights

In keeping with the annual program for the implementation of the official language policy of the Union of India, various steps were taken to promote use of Hindi in routine work as well as in scientific research. Hindi magazine Ashmika included number of original articles related to geological hazards for the benefit of public at large. Hindi noting-drafting and Hindi typing were implemented, also day-to-day work, general circular, notices etc were issued both in Hindi and English. Hindi fortnight was celebrated from September 14-29, 2006, during which various competitions like poetry, essay and debate were organized.

Baldev Raj Arora

Director

PROGRESS IN RESEARCH PROJECTS

1. GEODYNAMICS AND CRUSTAL EVOLUTION

1.1 SUB PROJECT

Crustal evolution in the Trans-Himalayan regions of Tso-Morari, Indus and Shyok Suture Zones

(S.K. Paul, H.K. Sachan and D.R. Rao)

A new fossiliferous site near Shingbuk (35°27' N, 77° 39'E), 12 km NNW of Tsokar within the fore arc basin has yielded about ten plant leaf impressions. Most of them are fragmentary in nature, only two well-preserved palm leaves were considered for the study. This newly discovered fossiliferous locality lies south of the Indus Suture Zone. The molasse horizons in the Indus Suture Zone are divisible into the southern Hemis Member (Middle to Late Eocene) of Indus Formation deposited in fluvial environment and the northern Kargil Formation (Late Oligo-Miocene to Early Pliocene), though there is an apparent lack of consensus on the issue of age range of these formations for want of age diagnostic fossil remains. A few samples of leaf impressions were collected from the Hemis Member of the Indus Formation. The fossil remains are preserved predominantly in the finer part of the siltstone horizons. The identification of the fossil palm was carried out with the help of scientists of the Birbal Sahni Institute of Palaeobotany, Lucknow. The fossil records of palm from the Tertiary of Ladakh are poor. So far only two genera, viz. *Livistona wadiai* and *Trachycarpus ladakhensis* have been described from here. The fossil palm discovered herein is different from all the known species of Palmacites, it is being described here as a new species, *Palmacites tsokarensis* sp. named after the locality Tsokar from where the fossils were collected. The presence of these fossils not only indicates that palms were abundant during the Middle-Late Eocene in the region, but also suggests that the area had not attained as much height as it is today (about 5000 m msl) and that tropical conditions prevailed during their deposition. The NW-SE trending Shergul Ophiolitic Melange and the Hemis Molasse Member of the Indus Formation are cross-cut by N-S trending Tso-Kar Transfer Fault (T-KTF) and its northern edge joins the western side of the WNW-ESE trending Zildat Fault. The ophiolite and ophiolitic mélange were obducted and brought to the surface along the T-KTF and Zildat Fault during later part of the Eocene. These relationships indicate that T-KTF and Zildat Fault, along which the rocks of the Zildat Ophiolitic Melange were obducted, are definitely younger than the middle to late Eocene Hemis Molasse Member of the Indus Formation.

The detailed petrographical study of metamorphic rocks of Pangong Tso metamorphic complex suggests that the rocks belonging to three metamorphic grades are exposed in the complex. The difference is not only in the nature of the index minerals, but also in the grain size. All the varieties are strongly schistose, but the lower grade rocks are more phyllitic in nature. The three metapelites are: biotite grade, garnet-staurolite grade, and sillimanite grade. (i) Biotite grade metapelites rocks contain very unusual amount of carbonate minerals and plagioclase, hence these are all calc-pelites i.e quartz, muscovite, biotite, chlorite, plagioclase, and tourmaline. The matrix is comprised of recrystallised quartz and carbonate. Anhedral plagioclase is present as porphyroblast with numerous quartz inclusions. The plagioclase is also sericitized. (ii) Garnet-staurolite grade metapelites are comprised of quartz, muscovite, biotite, chlorite, plagioclase, garnet and staurolite. The matrix is comprised of recrystallised quartz and plagioclase. The porphyroblast of subhedral garnet and subhedral to anhedral staurolite have quartz inclusions. One garnet porphyroblast shows two-stage growth with core having numerous quartz inclusions which disappear altogether towards the rim. The thin, discontinuous schistosity formed by biotite swerves around garnet and some staurolite with well-developed pressure-shadow. This indicates pre-tectonic activity with respect to schistosity. Staurolite replaces garnet along the grain boundary. The thick schistosity of fine muscovite, biotite and chlorite swerves around plagioclase and clusters of matrix minerals. Muscovite rims staurolite. Discrete haphazard muscovite and biotite flakes form a partial rim around staurolite (retrogressive muscovite and biotite). Quartz is poikiloblastically included in staurolite. In the retrogressive chlorite rich band staurolite is found such that chlorite rims staurolite. Also, chlorite gives an overall appearance of orientation along schistosity (probably pseudomorphing biotite) and it abuts against staurolite. Schistosity of biotite swerves around plagioclase and garnet reveal pre-tectonic plagioclase and garnet. (iii) Sillimanite grade metapelites contain both secondary fibrolite and prograde prismatic sillimanite besides this too contains quartz, carbonate, garnet, biotite, and plagioclase. Quartz and carbonate have fibrolite alterations where some fibrolite has recrystallised into sillimanite needles. Fibrolite shows slight folding which reveales their pre-tectonic nature with respect to phase of deformation. Anhedral garnet with inclusions of quartz and carbonate are observed. Matrix is comprised of granoblastic quartz and carbonate. Discrete random biotite flakes are also present in matrix.

Two types of metabasic rocks also occur in the complex. One variety is with epidote, perhaps actinolite (corresponding to the biotite grade metapelites described above). The other variety is with garnet and hornblende, equivalent to upper amphibolite facies assemblage in pelites. These rocks constitute the mineral assemblage of plagioclase, garnet, hornblende, biotite, chlorite, quartz and carbonate. The matrix is comprised of fine grained recrystallised elongated quartz and plagioclase (plagioclase more in abundance than quartz). There are alternate bands of hornblende rich and biotite rich domains. Schistosity is present in biotite rich domain, flakes of biotite form a narrow discontinuous schistosity swerving around clusters of quartz grains. In hornblende rich domain, discrete grains of hornblende (elongation parallel to schistosity of biotite) enclose quartz grains within them. Hornblende rich domain is not pervasive but patchy in occurrence. Symplectite between quartz and a colourless phase is present. Few porphyroblast of subhedral garnet with biotite are present along fractures in it. Quartz is included in garnet.

Furthermore, the studies on CH_4 inclusions in the serpentinized Nidar Ophiolite show consistency with laboratory results and its observations in modern submarine environments where active serpentinization is occurring. During serpentinization, CO_2 was reduced to CH_4 that was then trapped along fractures in olivine. The lack of aqueous inclusions in association with CH_4 inclusions is consistent with the presence of lizardite in the alteration assemblage. Lizardite (as opposed to chrysotile) forms by hydration of olivine and pyroxene in a rock dominated (low water activity) system at low supersaturation and lizardite is more likely to be preserved (compared to chrysotile) in a non-isotropically stressed environment. The hydration of olivine to produce lizardite is accompanied by volume expansion in the order of 40% to 50%. This expansion serves to decrease permeability in the fractures where lizardite is forming, removing water through the hydration process and prohibiting other fluids from entering the fractures. Preservation of CH_4 inclusions in the Nidar Ophiolite is consistent with models for life cycle of supra-subduction zone ophiolites (SSZ), which suggests that some serpentinized and buoyant SSZ ophiolites are obducted onto the passive margin shortly after formation and exhumed to the surface without being deeply buried. A final important conclusion of this study is that fluid inclusions in at least some altered, buried and exhumed mantle rocks retain the chemical signature of the deep crust and mantle, as others have previously suggested.

The intra-oceanic subduction related arc magmatic rocks amalgamated between the Indian and Eurasia continental margins in the Trans Himalaya of Ladakh were studied. The geochemistry of these pre-collision Andean-type magmatic rocks suggests their fundamental role in the crustal growth and evolution of more evolved felsic magmas. As a part of the study, the geochemical and field relation studies of granitoid rocks from Khardung Granite (KG) and Tirit Granite (TG) from the Shyok tectonic zone, and the Panamik Granite (PG) from along the southern phase of Karakoram plate were taken up during the year. The studies have revealed that re-melting of earlier plutons to produce younger ones seems to have played an important role on the origin of large volumes of granitoids with a strong mantle signature. The melts produced have enhanced concentration of large ion lithophile elements suggesting the involvement of processes like locally coupled crustal assimilation allied with fractional crystallization in zones of thickened crust.

1.2 SUB PROJECT

Mineralisation and metallogeny in space and time in context of diagenesis, magmatism, metamorphism and tectonism: special emphasis on the role of complex fluids in the genesis and evolution of host rocks and ores

(R.S. Rawat, T.N. Jowhar, Rajesh Sharma and D. R. Rao)

The X-ray Diffraction studies were carried out on more than 118 alkali feldspars samples from a variety of granites ranging in space and time, which are of low structural state (intermediate to maximum microcline). The samples were subjected to melt temperature determinations of granites through homogenization quenching experiments in the Experimental Petrological Lab. These samples were run through two different conditions of slow scanning so that the peak separations for 2θ 101 and 2θ 201 are quite contrastingly seen i.e. between the internal standards and the samples so that a proper interpretation is carried out. It was observed in each experiment that prior to homogenization at 1050^0C in 48 hours duration the white alkali feldspar (microcline) changed to flesh coloured (orthoclase), indicating a phase transformation in the feldspar i.e. from low temperature (low structural state) to high temperature (high structural state), from triclinic to monoclinic phase as confirmed through XRD studies. The homogenization experimental studies were carried on 2000, 1800, 1300, 1000, 550, 170 and 20 Ma granites occurring in lithotectonic set up. It is reported that the Malani Igneous Suite rocks were subjected to homogenizationquenching studies as per the techniques of Rawat and Prabha (1998) and Rawat and Nagar (2000) for comparison with the Lesser Himalayan

Granites and this indicated a temperature of more than 700^0 C for the melt of this of suite rocks.

The study of complex fluids vis-à-vis mineralization has revealed that the lithotectonic set up of an area plays a vital role for potential mineralization as observed in the Garhwal Lesser Himalaya between Srinagar and Rudraprayag. Along this traverse, a number of tectonic lineaments are present (NAT and AT). It is observed that the synsedimentary polymetallic sulphides in the parautochtonous Garhwal Group talcose rock (phyllites) are occurring parallel to foliation, while along the NAT the streaks and clots of galena are seen cutting through the foliation of the rocks. Similarly highly altered polymetallic sulphides are seen in deformed and shattered quartzites in the vicinity of NAT, while galena encrustations on quartzite are observed along this thrust at some places. It is also observed that along the NAT the metadoleritic rock (epidiorite) along with hosted sulphides shows alterations, but away from the thrust the pencontemporeneous basic lava flows (now schistose) have a conformable contact with the quartzites. The field study in the Garhwal Group of rocks in Dhari-Devalgarh-Kaliasaur section has clearly revealed that the mineralization is not only controlled by fluids but also by lithotectonic set up of that area. In other words, while searching for mineralization the relationship between the fluids, lithotectonic set up, deformation, magmatism, metamorphism and environment of deposition of minerals is to be known very well in advance based on which a proper model for explorations can be postulated. The mineralizations reported here are based on these considerations.

The samples collected from Bhatwari-Gangotri region were studied for their mineral chemistry and P-T estimates of Higher Himalayan crystallines; and for the petrogenesis of Gangotri granite. The EPMA data on tourmaline, K-feldspar, plagioclase, biotite and muscovite were obtained by utilizing Cameca SX 100 microprobe at WIHG. Mineralogical studies on tourmaline from Gangotri granite reveal that they belong to Alkali Group and are Schorl. These tourmalines are zoned from core to rim. Mg decreases, whereas Fe^{2+}, Ti, Mn and Ca increase. These results show that there was change in physical conditions during crystallization of the leucogranite magma. Thermodynamic modeling of zoned tourmalines is in progress to establish the variation in intensive parameters during crystallization of leucogranite magma. Application of two-feldspar geothermometer gives temperature of subsolidus equilibration of 441^0 to 314^0C and plagioclase-muscovite gives temperature range of 448^0 to 339^0C. P-T estimates were carried out for Higher Himalayan Crystallines in Bhatwari-Gangotri region. These studies reveal increase in both pressure and temperature across the Vaikrita Thrust from the south to the north. Temperature increases from 500^0 to 750 ^{0}C and pressure from 6 to 10 kbar across the MCT zone.

Geochemical and fluid inclusion studies of the granitoid rocks from the Chhiplakot crystallines were carried out. The Chhiplakot crystallines represent a klippe between the root zone rocks and Almora Nappe. The dominant rock type, the granitoid rocks in the Chhiplakot are essentially two-mica gneisses in which there is a considerable variation in the grain size and relative proportion of the constituent minerals. With increasing feldspar content, the gneisses grade into porphyroblastic granite through sub-augen to augen gneiss. The rocks are medium to coarse grained and are exposed as thick and thin bands within metasediments. The gneissosity is defined by alternating quartz-feldspar rich layers and mica-rich layers. The main constituents of the rock are quartz, k-fedspar, perthite, plagioclase, biotite, and muscovite. Small sized garnets and tourmaline crystals are present in the gneisses. Zircon (rounded and sub-rounded), opaques, sphene and apatite occur as accessories. Epidote, chlorite, sericite and calcite occur as products of retrogression. Geochemically, the rocks show small compositional variation in SiO_2 (65-68%), have high Al_2O_3 >16% and high normative corundum > 5, and show peraluminous character with mean mol. A/CNK ratio ~1.81. They have granitic compositions and show elemental scatter on the Harker's variation diagram. Their total REE range between 180-240, and show highly fractionated pattern with distinctive negative Eu anomaly. On the primordial mantle variation diagram the rocks show variable enrichment of the LIL elements, with Rb, Th, and K showing enriched abundances, matching with upper crustal values, and the high field strength elements behaving more like lower crustal rocks, and the rocks also show distinct negative anomalies for Nb, Sr, P and Ti. On the tectonic discrimination diagram of (Y+Nb) vs Rb they plot in the syn-collision granite field, close to the triple boundary point for syn-collision granite, volcanic arc granite and within plate granite fields, and on R1-R2 tectonic discrimination diagram they plot in syn-collision granite field. Fluid inclusion studies of the gneissic rocks from Chhiplakot Crystallines have also been undertaken in order to understand the nature and evolution of fluids with respect to the metamorphism and post-metamorphic recrystallization. Remnants of pre-metamorphic fluid inclusions are present in the form of cavities deformed to the shapes that attribute exceeding internal pressure. Such features are typical to isothermal exhumation. Earliest fluids trapped in inclusions in weakly recrystallized quartz are coexisting near pure carbonic and carbonic-aqueous. The disposition of fluids in random to scattered to various trails and in groups is characteristic of the near metamorphic fluid. The CO_2 homogenization of these inclusions corresponds to a density of about 0.88±0.03 g/cm^3. Melting temperatures suggest up to 8 mol% CH_4 in carbonic fluid that were present during pre-crystallization stage. Hence a record of the fluids participated in evolution history of these gneisses are available. In few grains with incipient annealing texture, migration of the inclusions towards grain boundaries is observed. Such inclusions are monophase carbonic. The late fluid inclusions are filled with an aqueous and low-density CO_2 fluid. A meniscus between liquid carbonic and gas carbonic fluid is seen at room temperature (cf 22°C) in many of them. The envisaged studies will contribute to the discussion on metamorphic and evolution of the crystalline rocks.

Work was also carried out on the exsolution of cubanite and chalcopyrite using X-ray diffractogram and EPM analysis. It helped in thermal assessment of Askot sulphide mineralization. Askot cubanite has low Fe (< 41.34 wt %) and little higher Cu (22.51- 22.63 wt %) than isocubanite, its Zn content (0.001 to 0.023 wt %) is low and shows Se up to 0.063 wt %. The analyses of Askot cubanite reveal slight deviation from the stoichiometric composition of cubanite, with minor Fe enrichment and its Cu (Cu+Fe) is < 0.33. Its x-ray diffraction is closely similar to that of cubanite. The laths of cubanite in chalcopyrite as observed in Askot, are considered as product of subsolidus process wherein isocubanite first formed was transformed to cubanite. Askot cubanite is likely to be a result of natural transformation from isocubanite first formed.

1.3 SUB PROJECT

Study of frontal and oblique ramps in the Western Himalaya

(A.K. Dubey, Keser Singh, and R.J. Perumal)

Structural studies on frontal and oblique ramps were carried out in and around Uttarkashi, Garhwal Inner Lesser Himalaya. The area was chosen for the following reasons:

- a number of oblique thrust ramps are exposed,
- it is closer to the Munsiari rocks, which were earlier thought to have moved along the Munsiari detachment thrust to form the Satengal and Banali klippen in the core of the Mussoorie Syncline (Jayangondaperumal and Dubey, 2001),
- Superposed interference patterns are visible on the geological map,
- An earthquake of moderate magnitude (Mb 6.6, Ms 7.0) with the focal depth of about 10-12 km (Gupta and Gupta, 1995) had occurred in Uttarkashi region on October 20, 1991. No evidence of surface faulting was observed due to this earthquake. However from the distribution of aftershocks, Kayal *et al.* (1995) inferred that displacement along a blind thrust with partial strike-slip component was responsible for the earthquake. The fault trend NW-SE, dip towards north and is located south of the Munsiari Thrust. The isoseismals trend NW-SE parallel to the regional trend of the prominent Himalayan thrusts of the region.

The anisotropy of magnetic susceptibility study was performed to understand the structural evolution of the region. The stress orientations obtained from the magnetic susceptibility axes suggest favorable conditions for initiation of normal faults near surface, whereas the recent seismicity indicated a blind thrust. The variation of stress field in the profile section is explained in terms of a blind thrust, fault propagation fold, and extensional strains at higher topographic levels due to gravity spreading.

The kinematics of late Quaternary deformation associated with evolution of Dehra Dun recess and transverse tectonics were also studied. The studies based on mesoscopic structural analysis, magnetic fabrics, tectonic geomorphology, OSL dating and remote sensing indicate a major tearing off of the Main Boundary Thrust (MBT) during late Quaternary. The distribution of magnetic fabrics (anisotropy of magnetic susceptibility, and anhysteretic remanance) in the Dehra Dun recess with local variation of shortening direction inferred by fracture population, structural configuration and alignment of uplifted solitary Quaternary landforms along a regional transverse zone indicates that the right lateral wrench motion has dominated simple to pure shear deformation. The chronology of the solitary geomorphic landforms indicates that the boundary thrusts (MBT and Himalayan Frontal Thrust, HFT) were reactivated in two phases at <46 ka and <3 ka resulting in the stress transmission along the regional Dehra Dun transverse zone (DTZ) by distributed wrench deformation. The tearing off of the MBT pronounced at around 2 ka forming a detached faulted block that was rotated clockwise near the hanging wall margin due to out of plane deformation forming a triangular basin oblique to the transverse zone. This gave rise to formation of an out of sequence oblique ramp anticline or cross fold due to local change in shortening directions along the strike of the DTZ or oblique ramp boundary.

The studies in the Kishtwar region show that the crystalline rocks of the Himalaya, in general, (Higher Himalayan Crystallines, Central Crystallines etc.) are bounded by the Zanskar Shear Zone/Trans Himadri Fault System at the top and by the Main Central Thrust (MCT) at the base. In the South and tectonically below the MCT lies the Lesser Himalaya comprising the low grade meta-sedimentary succession and the crystallines klippen. In the north and tectonically above the Zanskar Shear Zone lies the sedimentary succession of the Tethys Himalaya. A different geological set up, north of Beas valley, where the Tethyan rocks lying directly in contact with the Lesser Himalayan rocks are observed particularly in areas comprising Chamba and Kashmir in the northwest Himalaya. This geological setting has led a number of workers to define the Main Central Thrust at the junction of the Lesser Himalayan rocks exposed in the Kishtwar Window with the surrounding Higher Himalayan Crystallines. The explanation that the folding of the MCT plane has exposed the Kishtwar Window is too simplistic as the southwestern side of the window is a high angle NE dipping reverse fault. The recognition of tectonic break along the Chenab valley, south of Kishtwar Window, where the Higher Himalayan Crystallines thrust over the Lesser Himalayan rocks is interpreted as the Main Central Thrust. The tectonic evolution of Kishtwar Window indicates that it is a 'fault-bend fold" structure. This antiformal structure has come up because of folding related to the Kishtwar Fault. The KF has breached through the hinterland of the MCT, therefore, it is interpreted as a "break-back thrust". The Kishtwar Fault in the hanging wall of the MCT is the consequence of hinterland propagation deformation. The uplift along the Kishtwar Fault also explains the reoccurrence of concealed portion of the overthrusted Higher Himalayan Crystallines/Lesser Himalayan rocks of the MCT, now exhumed along the Kishtwar Fault as the Kishtwar Window. The overthrust HHC/footwall Lesser Himalayan rocks uplifted as a whole along the Kishtwar Fault, has in fact, again exposed the MCT north of the already exposed MCT. The folding of the Higher Himalayan Crystallines together with the Lesser Himalayan rocks into antiformal structure of the Kishtwar Window is also related with the deformation which has produced the Kishtwar Fault. In other words the Higher Himalayan Crystallines-Lesser Himalaya metsedimentaries contact pre-dates the formation of the Kishtwar Window, suggesting that the MCT was already developed. Based on the structural analysis, a model showing the tectonic evolution of the MCT and the Kishtwar Window has been proposed.

The field studies carried out in the Lahaul region covering the Tethyan rocks (Chamba Thrust Sheet) and the HHC in Chamba, Lahaul and adjoining Kulu regions was undertaken to analyze the deformation pattern and to investigate the relationship between SW and NE vergent folds. Special emphasis was given to establishing whether the observed fold geometry is consistent with the two separate orogenies or is the result of a single event. In this, an attempt was made to analyze the structural elements in conjunction with field evidences to come out with a rational explanation of the opposite vergent folds. In Chamba-Tandi region, three litho-tectonic units are recognized: Lesser Himalayan rocks (LH), Higher Himalayan Crystallines (HHC) and Chamba Thrust Sheet (CTS). The model of thrust wedge propagation above a ductile detachment demonstrates a decrease in the angle of maximum principal stress ($?_1$) with respect to foreland tends producing both foreland and hinterland vergent structures. The experiments (Cotton and Koyi, 2000) using sandbox models from one end to explain the variation in structural development between areas with and without a ductile substrate. The shortening of the sand pack above a ductile substrate develops a box fold bounded by forward and rearward-vergent kinks and flow of the ductile layer into the core of the box fold. The structural styles and geometries of the fold structures of the Chamba Thrust Sheet are analogous to their experiments. Deformation in the Chamba Thrust Sheet is characterized by the development of box fold (Hadsar-Chobia Box Fold) flanked by opposite vergent synclinal structures (Chamba and Tandi Synclines). Lateral ramps bound the extension of the Chamba Thrust Sheet, which have acted as transpressive zones sub-parallel to the migrating ductile front. Fluid inclusion studies of magnesite, dolomite and their occurrence along the thrust zone permitted rapid translation along the Chamba Thrust, and that is why it has translated the far south Tethyan rocks to lie in contact with the Lesser Himalayan rocks. The close correspondence between natural and experimental structures suggests similar boundary conditions for both the Chamba Thrust Sheet and the experiments. The structural evolution of the Chamba Thrust Sheet suggests that out of sequence thrusting has placed younger rocks on to older and the folding has resulted in crustal thickening. Thus, detailed structural investigations of Chamba Thrust Sheet show that opposite vergent folds can develop across a large box fold during a single deformation phase and that a second deformation phase is unnecessary.

The post-2005 Kashmir earthquake studies included mapping of surface ground fractures in Tangdhar, Uri, Rajouri and Punch sections, and liquefaction features in Jammu area lying close to the eastern side of the Line of Control (LOC) in Kashmir, India. The NW trending ground fractures occurring largely in the hanging wall zone of southeastern extension of the causative fault in Tangdhar and Uri sectors resulted principally due to the shear stress deformation. The principle compressive stress deduced from the ground fractures is oriented at N10^0, whereas the causative Tanda fault strikes 330^0. Though fault-plane solution indicates predominantly SW thrusting of the causative fault with secondary component of strike-slip motion, the ground fractures reflect pronounced strike slip component. The occurrence of liquefaction features near Jammu is suggestive of stress transfer to the extent ~ 230 km southeast of the epicenter. Small trenches excavated across the sand blows exhibit signature of two pre-2005 liquefaction events which have been tentatively correlated with 1555 Kashmir and 1905 Kangra earthquakes. The Muzaffarabad-Tanda fault, the Muzaffarabad anticline, the rupture zone of causative fault and the after shocks zone, all are aligned in a ~ 20 km wide belt along the NW-SE trending Himalayan strike in the Kashmir region, suggesting a seismogenic zone that may propagate towards southeast to trigger an earthquake in the Kashmir valley in future.

2. BASIN EVOLUTION

2.1 SUB PROJECT

Evaluation of bio-event stratigraphy in the Cambro-Ordovician succession of Zanskar-Spiti Himalaya and build-up of reproducible palaeontolological database for the Lower Palaeozoic succession of Tethyan Himalayan regions

(S.K. Parcha)

Field work was carried out in the Spiti region of Himachal Himalaya where one section in the Parahio valley was measured and new faunal horizons were marked. Recent work on the Himalayan tectonics indicates that prior to the Cenozoic collision of India and Asia; an enigmatic Cambrian-Ordovician event may have strongly influenced the regional geology of the Himalaya. Stratigraphic and sedimentological analyses of well-preserved Cambrian deposits are critical for understanding the nature of this early tectonic evolution of the Himalaya. The Parahio Formation in the Spiti region in the Tethyan Himalaya contains best-exposed section of the Cambrian strata in the entire Himalaya. This formation consists of >1350m of thick dominantly siliciclastic deltaic deposits. The formation ranges from uppermost Lower Cambrian to middle Middle Cambrian, representing a time span of ~5-10 m.y. Many thin carbonate beds with abundant trilobite fossils directly overlie the fluvial facies and represent the transgressive system tract deposits. An angular unconformity with overlying Ordovician conglomeratic rocks has considerable local relief.

Furthermore, the studies have shown that the Cambrian in the Zanskar valley consists of dominantly siliciclastic marine deposits. The Cambrian succession is caped by a dominantly siliciclastic and upward coarsening unit overlain by a regionally extensive unconformity and overlying conglomerate of early Ordovician. The trilobite-bearing limestone beds represent thin transgressive system tract deposits developed over marine flooding surface. The paleocurrent data for marine and fluvial facies of Parahio Formation in Zanskar and Spiti area indicate the northeast sediment transport. The nature of the Cambrian-Ordovician boundary unconformity is yet unresolved. Lithological observations indicate that the lower units are dominated by sandstone, phyllites, slates and siltstone which in turn are overlain by various dolomitic bands intercalated with silty shale. The early to Middle Cambrian fauna was recovered from shale, siltstone and from dolomite facies. These studies have further revealed that the fauna recovered from the different sections indicate shallow water to deep environment, implying that the Zanskar basin was gradually shallowing during Early and Middle Cambrian.

The present investigation of the Middle Cambrian trilobite fauna identified from the southeastern part of the Zanskar region includes species of polymerid and agnostid genera, the detailed studies are still in progress. It was observed that the faunal similarity between the Zanskar and Spiti basins on the one hand and that of Zanskar and Kashmir basins on the other is striking. However, deep-water forms such as *Oryctocephalus* and *Olenus*, which are the characteristic elements of the Spiti basin, have not been reported so far from the Zanskar and Kashmir basins. On contrary, there are shallow-water forms which are common to both Kashmir and Zanskar basins.

2.2 SUB PROJECT

Biostratigraphic evaluation of selected PC/C (Precambrian/Cambrian) and P/T (Permian/Triassic) boundary sections of NW Himalaya

(R.J. Azmi)

The biostratigraphic investigation of the Inner Carbonate Belt of the Kumaun-Garhwal Lesser Himalaya (Deoban-Gangolihat Belt) and the Shali Belt of the Himachal Lesser Himalaya was carried out. From the Shali Group of Himachal Lesser Himalaya, further recoveries of a fairly good assemblage of SSFs (*Protohertzina, Mongolodus,* cf. *Drepanochites dilatatus, Cambrotubulus,* Hexactinellid sponge-spicules, etc.), magnesitized and silicified clusters and isolated cyanobacteria tubes of *Girvanella* and *Renalcis* along with acanthomorphic acritarchs and vase-shaped organic-walled microfossils (OWMs) clearly strengthen the idea of Azmi and Paul (2004, *Current Science*) that the Shali and Krol Belts are chronostratigraphically equivalent rocks (Vendian-Early Cambrian) in the Lesser Himalaya. This vexed stratigraphic correlation problem, which lasted for several decades in the Himalayan geology is thus likely to be resolved very soon. This would immensely help in re-interpreting the structure and tectonics of the Lesser Himalayan fold-thrust belt and the early evolutionary history of the Himalaya in relation to the Indian Peninsula.

Additionally, a 10 days field work was carried out in the Vindhyan basin with scientists from Swedish Museum of Natural History, Stockholm with a primary aim to establish additional recovery of Cambrian small shelly fossils (SSFs) from the Lower Vindhyan strata and settle down the prevailing contentious issue on the age of the Vindhyan Supergroup. For this purpose, almost all fossiliferous sections covering southern as well as northern flanks of the eastern Vindhyan basin were sampled. The sampling spots were documented through photographs with GPS coordinates. All the samples were split into two parts - one part was brought to the Micropaleontology Lab of the Wadia Institute of Himalayan Geology, Dehra Dun and the other part was sent to the Swedish Museum of Natural History, Stockholm for independent recoveries of microfossils. It is to be noted that the fossil recoveries in both sets of samples have been almost identical (Fig. 5).

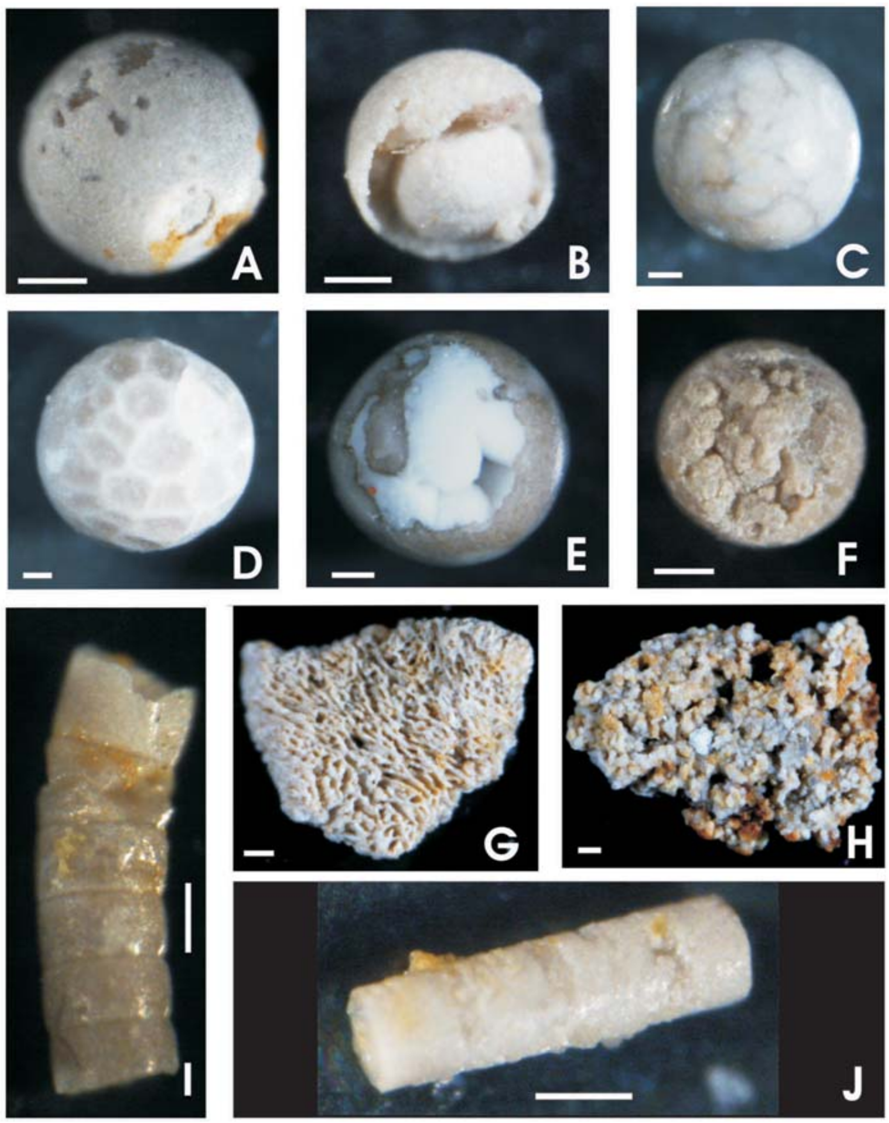

Fig. 5. Light photomicrogaphs illustrating earliest Cambrian small shelly fossils from WIHG sample parts of the Tirohan Dolomite (Lower Vindhyan), Chitrakoot, Madhya Pradesh. **A-F**, phosphatized embryos; **G-H**, calcareous algae, and **I-J**, annulated tubes. Scale bars represent 100 ìm. Note that almost identical forms have been recovered from the Stockholm sample parts by Prof. Stefan Bengtson.

2.3 SUB PROJECT

The Mesoproterozoic and Neoproterozoic microbial carbonate sedimentation and carbon isotope stratigraphy of the Bhagirathi valley, Uttaranchal Lesser Himalaya

(V.C. Tewari)

The Ediacaran (Neoproterozoic)-Lower Cambrian succession in the Garhwal Syncline was studied in detail. The Blaini-Krol-Tal sequence from Rishikesh to Kauriyala and Rikhinikhal to Rathwadhab was systematically measured in sequence stratigraphic order. The Neoproterozoic (Marinoan) Blainian glacial marine sedimentary facies of the Blaini Formation is characterized by the diamictite-tilloid, pebbly beds and interbedded sandy layers (Fig 6). The diamictites are followed by the slaty-silty layers and microbial (stromatolitic) pink (cap) carbonates. The stromatolites are flat laminated, wavy laminated, crenulated laminated and identified as Stratifera and domal forms. The Lower Krol marly shaly layers show the presence of Vendian/Ediacaran Vendotaenid algae and the pink shales are characterized by the microbial mat and Ediacaran facies in the tidal flat environment.

Fig. 6. Diamictite-tillaid, pebbly beds and interbedded sendy layers in the Blaini Formation, Garhwal Himalaya.

Various carbonate sedimentary facies were recognized in both the areas. The main sedimentary facies include cherty, intraclast, oolitic dolomite, zebra dolomite, ministromatolitic carbonate shaly dolomite and silty layer with Ediacaran metazoans. The Krol-Tal contact was studied at Kauriyala where the carbonate facies change into black shale phosphatic and cherty layers of lagoonal facies. The Tal Quartzite (Lower Cambrian), Tal Shell Limestone (Manikot Shell Limestone) of Late Cretaceous age and Subathu Limestone (Eocene) were studied in the Tal valley and Beasi-Kauriyala sections for depositional environment.

The petrographic study of diamictite, quartzites, cherty-oolitic carbonates, stromatolitic dolomite, zebra dolomite, oolitic-oncolitic phosphorites was carried out. The diagenesis and cathodoluminescence study of the Krol dolomite, in particular, was done in detail. It was observed that microbialites are common in the Upper Krol Dolomite and vary from plannar, microbial laminites with desiccation features, laminoid fenestrae, polygonal cracks and intraclasts, to columnar and domal stromatolites. Carbonate grainstones and packstones are common in the Krol and grains are intraclasts, ooids and coated grains, peloids and microbial grains and aggregates of catagraphs and microphytolites. The cathodoluminescence (C.L.) of the ooids invariably showed non-luminescence for the ooid cortex composed of dark micritic microsparitic dolomite. Under the C.L. the darker fibrous crusts are brightly luminescent often with the lamination showing clearly as varying C.L. colours (Fig 7). It was interpreted on the basis of carbonate microfacies, stromatolites, cathodoluminescence and carbon isotope excursions that the Upper Krol Dolomite is a typical Neoproterozoic (Ediacaran) peritidal carbonate platform deposit and of microbial origin.

The Laser Raman Spectroscopic (LSR) chemical analysis and X-ray Diffraction of the Krol carbonate indicate microbial dolomite as a major mineral (primary dolomite). The high resolution carbon and oxygen isotopic analysis is being carried out for isotopic composition and chemo-stratigraphy of Blaini-Krol-Tal succession in the Garhwal Syncline for global comparison.

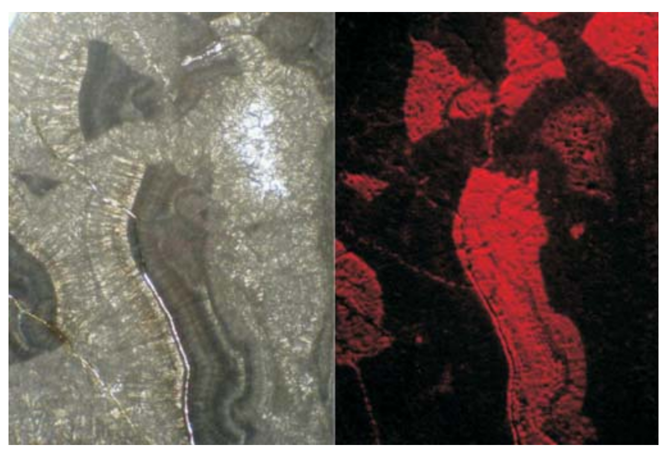

Fig.7. Cathodoluminescence (red)) of the microbial laminations (left) in the upper Krol carbonate, Mussoorie Syncline.

2.4 SUB PROJECT

Late Proterozoic-Early Cambrian Palaeobiology of Lesser Himalayan sequence of Himachal-Uttaranchal Himalaya with reference to evolution of life and its global relevance.

(Meera Tiwari)

A significant assemblage of trace fossils was studied from the lowermost Quartzite member of the Upper Tal Formation, which is in addition to earlier described trace fossils from Himachal Pradesh. The most common trace fossils described here are *Monomorphichnus* isp, *Dimorphichnus* isp., *Dimorphichnus* isp A, *Planolites* isp, *Skolithos* isp, *Merostomichnites* isp, *?Neonerites* isp, along with various scratch marks and burrows. The present assemblage could represent middle to upper part of the Early Cambrian (Tiwari, Meera and Parcha, S.K., 2006).

Further investigation on Proterozoic and Early Paleozoic microbiotic assemblage will lead to increased understanding of microbial taphonomy and paleoecology and to related aspects of modern microbiological communities. New taxonomic approaches will help in recognition of early evolutionary innovation and in a more complete and better documented assessment of prokaryotes-protists diversity through time.

2.5 SUB PROJECT

Geochemical and sedimentological studies of Proterozoic clastic succession of Lesser Himalaya.

(S.K. Ghosh and R. Islam)

Studies were carried out mainly in the inner belt of the Garhwal Lesser Himalaya to measure the litho-sections, study lithofacies distribution, identify types of siliciclastic, and geochemically characterize the siliciclastics. Six litho-sections were measured along Kaliasaur (K), Narkota-Srinagar (NS), Tilwara-Rudraprayag (TR), 8 km south of Lambgaon (L), 3 km of Pratapnagar (P) and Lambgaon-Chaundhar (LC) sections. The siliciclastic packages (SP) of the K,NS,L and P litho-sections represent late Palaeoproterozoic Rautgara Formation of the Damtha Group, and the LC section as also part of crystalline thrust sheet constituted mainly of meta- siliciclastic packages(MSP) belongs to the Berinag Formation. From the petrographic point of view the siliciclastics of this belt can be divided into two types: a) siliciclastic, which has retained the sedimentary texture and suffered the diagenesis, and b) meta-siliciclastic, which has lost the sedimentary petro-texture and suffered metamorphism. Five lithofacies were identified from these sections, namely, Coarse-Grained Siliciclastic (CGS), Medium-Grained Siliciclastic (MGS) and Interbedded Medium and Fine-grained Siliciclastic (IMFS), Fine-Grained Siliciclastic (FGS), and Shale (SH). Out of these five lithofacies, IMFS and FGS are the most abundant lithofacies observed in all the measured litho-sections. Preliminary sedimentological studies suggest a shallow marine shore face type depositional environment. Interestingly, the primary sedimentary structures which are prominent in the Outer Lesser Himalaya are not so common in the Inner Lesser Himalayan domain. From the regional distribution of lithofacies and their features both in the Outer and the Inner Lesser Himalayan belts, collectively point to respective southern and northern shoreline of the Late Palaeoproterozoic shallow sea. Geochemical data shows no significant change in clastic sediments across the Outer and Inner Lesser Himalayan belt in terms of basin deposition and source area. The studies have revealed that both Outer and Inner Lesser Himalayan belts have suffered similar low grade metamorphism and structural deformation. However, the grade of metamorphism is relatively high in the Inner Lesser Himalayan belt. Gradual change from pelitic to arenaceous or siliciclastic dominated sequences with strong volcanic association indicate deposition in a relatively unstable shallowing upward basin. The occurrence of voluminous basaltic volcanism is related to the extensional (rift related) regime. Associated basic volcanic rocks show plume induced signatures. The extension of the basin was most likely due to presence of mantle plume beneath the present day Lesser Himalaya during 2.0 to 1.8 Ga. Non-steady state A-CNK (weathering processes) relations also indicate active tectonism during their deposition.

2.6 SUB PROJECT

Evolution of the Himalayan Foreland Basin.

(Rohtash Kumar, S.K. Ghosh, B.N. Tiwari, Kishor Kumar, N. Siva Siddaiah, R. Islam and S.J. Sangode)

Stratigraphic succession of Subathu-Daghsai formations along Koshaliya River of NW Himalaya reveals an architectural variation from shallow marine to continental setting. This change over is reported at ca. 44 Ma with sharp-based sandstone at the contact and resulted from variation in the base-level (sea level) change in response to major tectonic and/or climate shift. Detrital composition, geochemistry and the rock magnetic change over demonstrate fresh lithologic input by exhumation of new thrust sheet during this period. The lower part of the succession shows rhythmic pattern of limestone-sandstone and shale alternations of about 20 to 35m thick which indicates at least two maximum flooding surfaces (MFS; Fig. 8) marked by nummulitic limestone horizon. The alternations in these sequences represent events of regression and transgression in response to the base-level changes. The stratal intervals between the MFS represent parasequences and shows shallowing upward succession representing single episode of landward progradation of facies due to rise in the relative sea level. The last MFS at ca. 44 Ma (Fig. 8), having shale in the uppermost part shows change in color from grey to purple red with increased carbonate concretion and bioturbation indicate landward side of the basin that became sediment-starved surface in response to the reduced space accommodation that resulted in sub-aerial exposure and oxidation. This surface is truncated by sharp-based sandstone of facies association B (Fig. 8). Widespread occurrence of the sharp-based sandstones throughout the basin and the variation of thickness of the underlying red mudstone facies indicate valley erosion and basin-ward migration of the shoreface facies in response to relative sea level fall forming a subaerial erosional unconformity.

At this turnover of marine to fluvial facies, Najman (2006 at other locality; *J. Asian Earth Sci., 26, 477-487*) based on fission track dating suggest a major unconformity of about 12 Ma. On the other hand Bhatia and Bhargava (2006; *J. Asian Earth Sci., 26, 477-487*) argue for the conformable sequence based on biostratigraphic approach and suggest gradational contact. Rock magnetic and geochemistry reveal fresh water input gradually increased from around 50 m stratigraphic interval (much below from the "passage bed"). This indicates that by this time (ca.44 Ma) drainage system was established to provide detritus to the Subathu sea. Fresh water influx gradually increases up section and marine influence diminished at 82 m (sharp-based sandstone) stratigraphic interval (Fig. 8). Presence of angular detritus hints nearness of the source area. These data reveals a systematic change in basin setup and appearance of new lithologies. Collective studies (sedimentology, petrology, geochemistry and rock magnetism) have inferred that change over was gradual and no unconformity is envisaged. However, presence of sharp-based sandstone reveals major discontinuity surface and reduced space accommodation due to relative sea level fall can be affirmed for the sequence boundary (SB).

This SB is followed by interfluve deposition under coastal floodplain conditions. These deposits show fluvial channels incising the well drained floodplain deposit (mostly soils) which in turn indicates decrease in space accommodation in response to change in base level. Presence of interfluve paleosols above the sharp based sandstone is commonly considered to be the strong evidence for significant base-level fall and the presence of sequence boundary.

In the upsection, absence of marine influence and dominance of fluvial succession also suggests continuous tectonic deformation and retreat of the Subathu sea to the feather edge of the Himalayan foreland basin. Behavior of rock magnetic and geochemical proxies indicate early

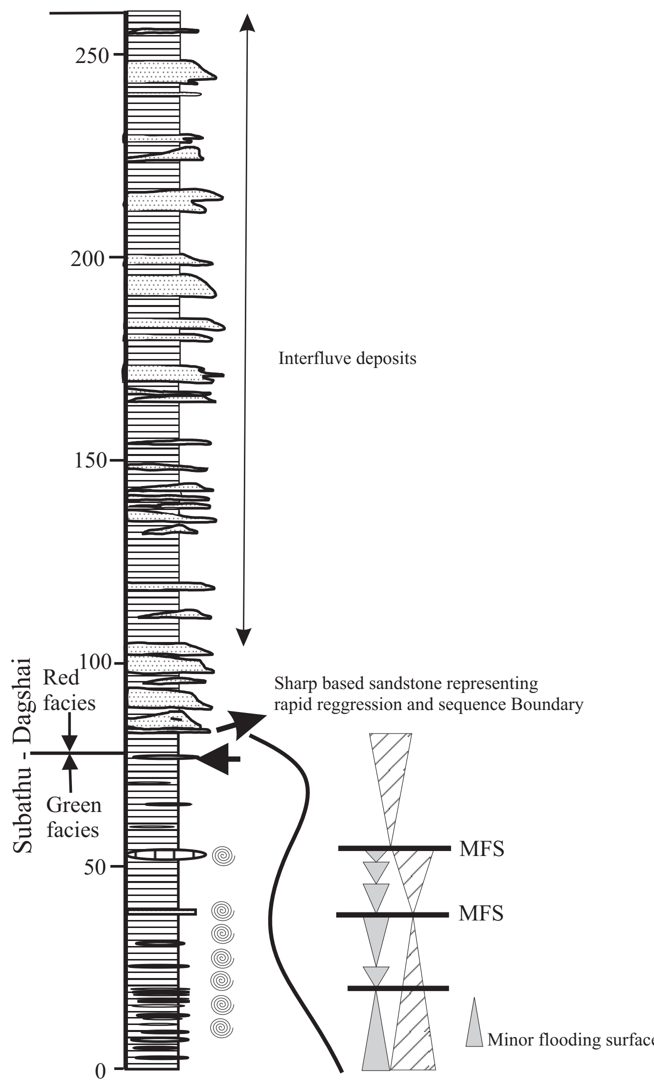

Fig.8. Interpretative section marking the sequence boundary (SB) between Subathu and Dagshai formations. Variation in architecture, rock magnetic behaviour, detrital mineralogy and geochemistry of fine-grain fraction is significant across the SB. The Subathu Formation has two maximum flooding surface representing parasequence boundaries. The marine succession of Subathu Formation is capped by interfluve deposits of Dagshai Formation.

input of the continental detritus into the marine Subathu basin which suggests an uneven basin morphology during the terminal Subathu phase and relatively uniform detrital input afterwards during the Dagshai fluvial regime.

Late Paleocene-Middle Eocene Subathu Formation

The understanding of the timing of collision of Indian plate with Asia and stratigraphic evidence for the same are crucial for correlation of globally significant events, like tectonism, volcanism, and climate. The Late Paleocene-Middle Eocene Subathu Formation, representing the early phase of foreland sedimentation in the northwestern sub-Himalaya, holds the key to get insights into distinct episodes of India-Asia convergence and its consequences. Study of additional samples to establish and document the finding of a volcanic ash horizon associated with coal seams in the basal part of the Subathu Formation was carried on. The stratigraphic position and thickness of the Subathu volcanic ash (Fig. 9) indicate a prominent volcanic event related in all probability to India-Asia collision. The ash beds, besides being time markers, are excellent proxy records of volcanism. In this context, newly discovered tonstein is expected to provide a major impetus to researches on India-Asia collision, penecontemporaneous volcanism and global warming during the Paleocene-Eocene. Some lithic fragments and rare glass shards (Figs. 10 and 11) have now also been observed in the ash. The Subathu volcanic ash will be particularly valuable for high resolution radiometric dating, and has a potential for regional as well as global stratigraphic correlation, so as to enhance our knowledge on India-Asia collision timing, collision related volcanism, Paleocene-Eocene boundary and global warming.

New fossil material studied from the Palaeogene succession comprises marine fish remains including sharks and rays from the Kakara Formation, an insect wing, chapattimyid rodent teeth (representing Middle Eocene taxa Birbalomys), dentition of a hyracodontid perissodactyl (Mammalia) similar to Fostercooperia and several crocodilian teeth (ziphodont as well as others) from the Subathu Formation, and plant remains including charophytes from the Kasauli Formation. New sampled localities include coaly horizons of the Kakara and Subathu formations (Koshaliya River and Subathu town sections) and shaly beds of the Dagshai and Kasauli formations. Work on the lower horizons of the Kakara and Subathu formations is being taken up with the aim of recovering pre-Middle Eocene mammals like in the coeval beds of Pakistan, Rajasthan and Gujarat. From the Kasauli Formation well preserved charophytes (fresh water algae) have been recovered from at least two horizons. One of the charophyte-yielding horizons of the Kasauli Formation also produced fairly well preserved branches of charophyte plants besides the gyrogonites. It may be mentioned here that charophyte plants rarely get preserved because of their delicate nature, and this will be their first report from India. Unfortunately no datable vertebrate fossils have so far been found in the Dagshai Formation. In the current year test samples were taken from most of the shale horizons of the Dagshai Formation. These are being macerated for possible recovery of rodents.

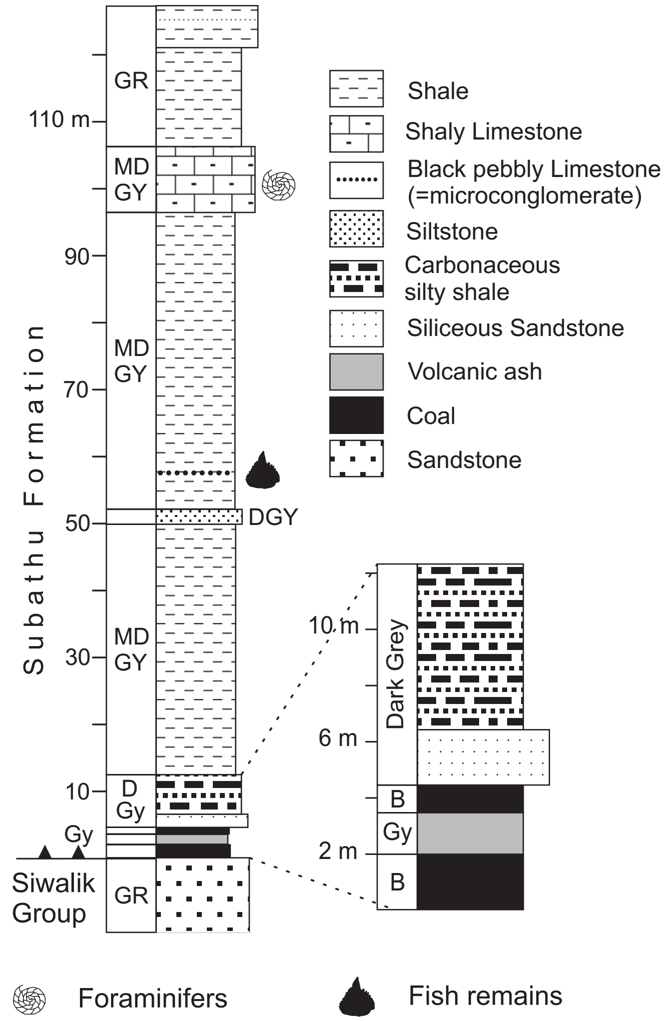

Fig.9. Lithological log of the lower part of the Subathu Formation exposed along the Koshaliya River near Kalka showing stratigraphic position of the volcanic ash and the bounding coal seams. B = black, GY = grey, MDGY = medium grey, DGY = dark grey, and GR = green.

For overall palaeobiogeographic appraisals, the study of Early Palaeogene horizons of Rajasthan and

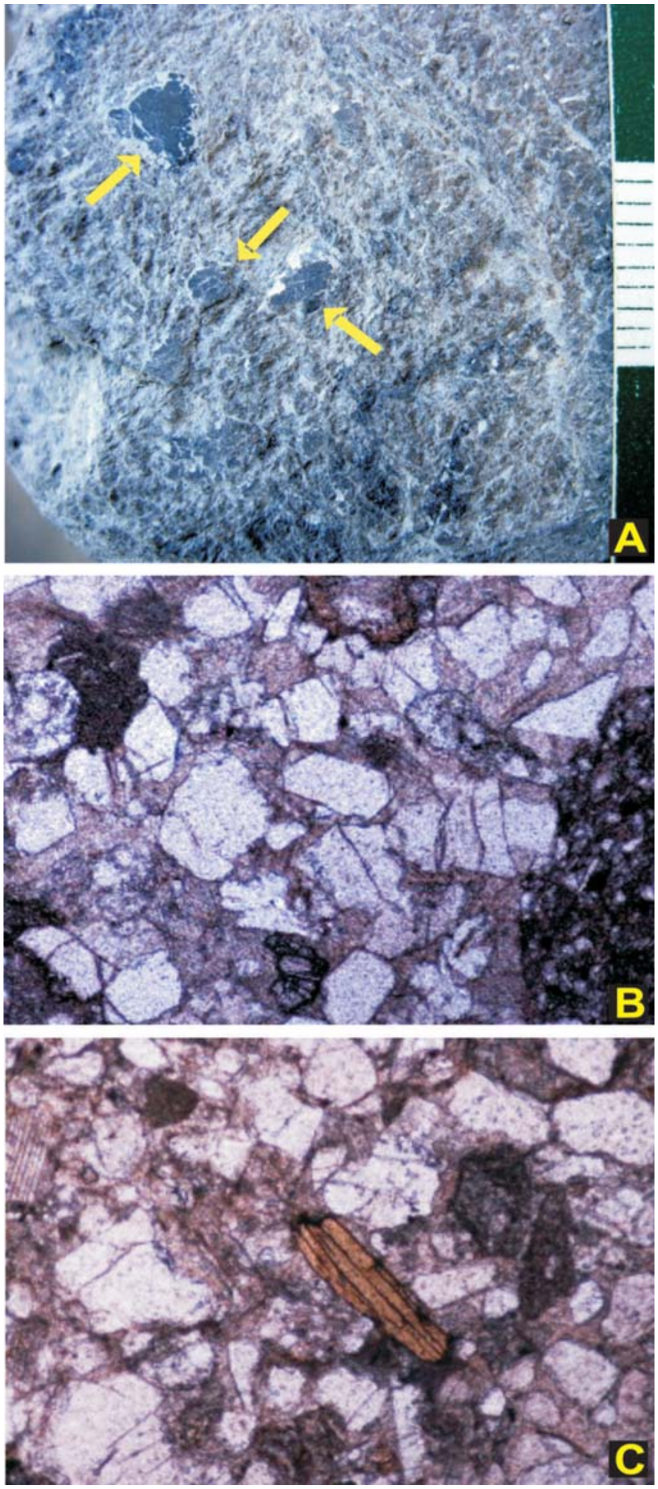

Fig.10 **A**. Photograph of a polished hand specimens of the Subathu ash showing lithic fragments indicated by arrows in clay matrix. Each scale division equals 1 mm. **B**. Photomicrographs of thin sections of the Subathu ash showing clay matrix with euhedral and fractured crystals of quartz in B, and euhedral biotite and quartz in **C.** Plane polarised light, 50X.

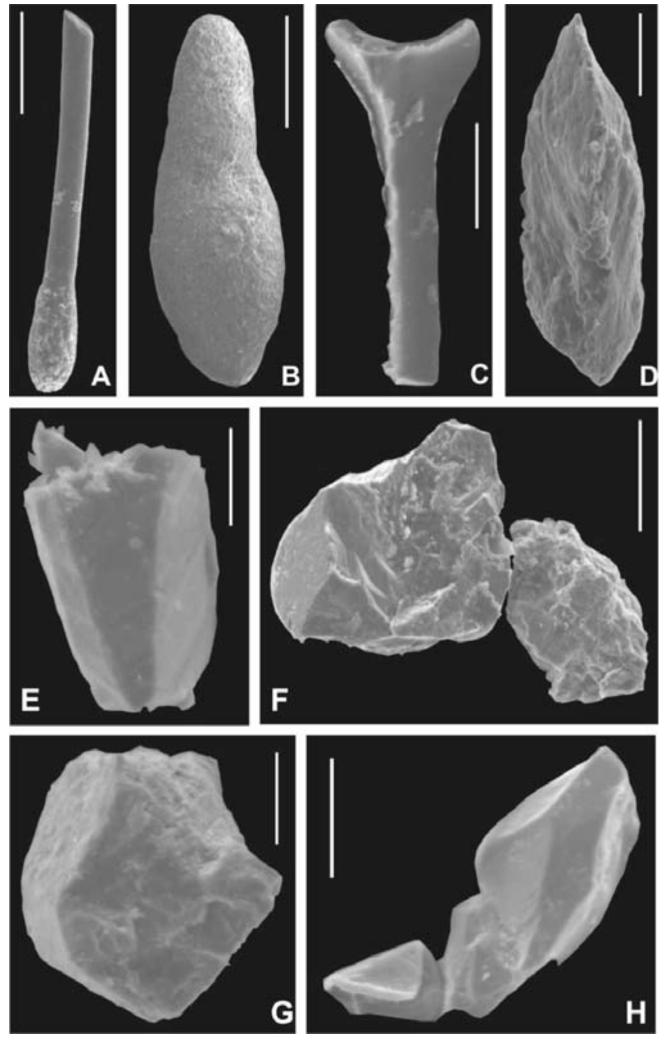

Fig.11. SEM images of glass shards and euhedral and broken quartz crystals from the Subathu ash bed. A. a fragment of Pele's hair with a tear drop, B. Pele's tear, C. Y-shaped shard, D. shard with elongate vesicles, E-H. euhedral and broken quartz crystals. Scale bars equal 300 m in A and B, 100 m in C and D, and 20, 70, 30 and 50 m in E, F, G and H respectively.

Gujarat is also being pursued along side the Sub-Himalayan sequences. Lithologically these beds are very similar to those of the Kakara-Subathu succession of the NW Sub-Himalaya. The study of Palaeocene and Lower Eocene beds of Gujarat and Rajasthan is important because in the NW Himalaya these intervals mostly yield shallow marine fauna. Therefore, information regarding Palaeocene-Lower Eocene land mammal faunas that is coming from Gujarat is not available from the Himalayan records. The Eocene land mammalian material from Gujarat is quite diverse, very well preserved and slightly older than what we get in the Sub-Himalaya. This makes it all the more interesting and significant for understanding the mammalian palaeobiogeography in relation to the India-Asia collision, and origin of modern placental mammals. The mammal groups that have so far been found in Gujarat include Perissodactyla, Artiodactyla, Rodentia, Primates, Chiroptera and Insectivora etc. The fish fauna recovered so far from Gujarat and Rajasthan localities is more or less similar to what we get in the Kakara and Subathu Formations.

Murid lineages in the Siwalik Group depicted in fossil rodent molars from Kangra valley

Murid rodents were subdivided into two lineages as one amongst many basinal bio-events that are inferred from record of the small mammals in the Siwalik Group. Its initiation is manifested in terms of crown morphological polarization rather than the segregation into two groups based on size. Bharil rodents comprising isolated teeth provide empirical evidence in this regard. We have identified host of associated cricetid taxa besides ctenodactylid and sciurid as rarer component of the > 11 ma rodent assemblage conjecturally indicating that niche choice prompted initiation of Karnimata- Rattus and Progonomys- Mus lineages in the milieu of plenty.

New Fossil Localities in the Siwalik Group of Dehra Dun - Haridwar region

Efforts have yielded two fossil-bearing localities in the Siwalik Group in the Doon valley, one is near Mohand and the other is in the city limits of Haridwar. In Mohand locality, a mudstone unit of the Middle Siwalik showing traces of gastropod shells yielded microfossils. Middle Siwalik horizons are exposed in the Mohand Rao and along the Saharanpur-Dehra Dun road cutting approximately across the strike of the succession. The mudstone unit is at ~1100m level in 1800m thick succession of the Middle Siwalik in Mohand Rao and being more prone to denudation provides extended exposed area along its strike for study and sample collection. The fossil assemblage from this section comprises gastropods, ostracods, charophytes, cyprinid fish teeth, crocodile teeth, rodent incisors and an isolated murid rodent molar, in order of declining abundance. The murid rodent molar represents an immigrant murid taxon Parapodemus sp.; it is reported for the first time from the Indian Siwalik Group. While ostracods are represented by five species including a new species Cyclocypris mohandensis Bhandari and Tiwari, chara gyragonites are tentatively referred to Harrisichara, Stephanochara, and Nitellopsis (Tectochara). The Mohand faunule represents a spell of low energy, fresh water environment during Middle Siwalik deposition that was otherwise known to be deposited in high-energy environment by streams. And the record of isolated murid molar Parapodemus suggests 8.1 Ma age to the faunule. In Haridwar locality, a shell-bearing horizon yielded fragmentary vertebrate remains including a crocodile tooth till date though the horizon is extensively exposed in the landslide at 2.5 kms in Mansa Devi Section and holds relatively higher potential than the Mohand locality for vertebrate faunal remains. The work for recovering microfossils is in progress in this locality.

Geochemistry of basal Subathu tonstein

The geochemistry of Tonstein (BST) observed in ash bed has much higher concentrations of rare earth elements (Σ REE =306-800 ppm) and incompatible trace elements such as Zr (515-735 ppm), Nb (36.7-44 ppm), Th (51.6-69 ppm) and Y (50.4-63.3 ppm) than in terrigenous

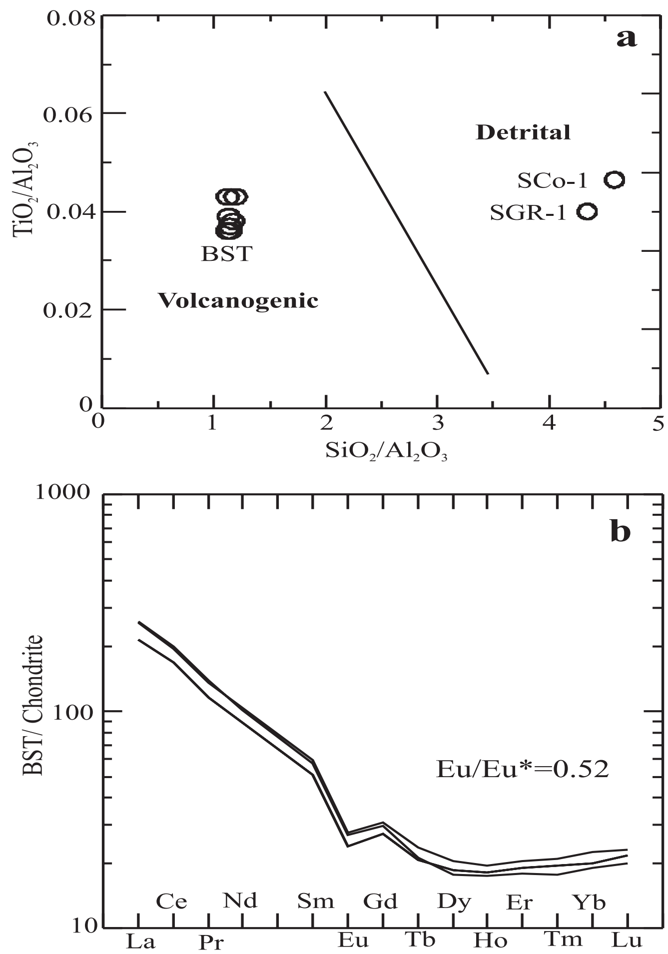

Fig. 12. a. TiO_2/Al_2O_3 vs. SiO_2/Al_2O_3 plot showing discrimination between volcanogenic Basal Subathu Tonstein and detrital shale/mud rocks. For comparison Appalachian Tonstein of volcanic origin, and Cody-shale (SCo-1) and Green River shale (SGR-1) of detrital origin are shown. **b.** Chondrite-normalized REE patterns for the Basal Subathu Tonstein samples.

shale/mudstone. In the BST, light-REEs (LREE) are more abundant than heavy-REEs (HREE). The chondrite-normalized patterns for the BST are LREE-enriched with $(La/Yb)_N$ = 10.64-13.63, show a relatively flat pattern for the HREE and a negative Eu anomaly (Eu/Eu= 0.52-0.6) (Fig. 12). The presence of pyrite suggests that the argillization of the volcanic glass took place in a partially closed system under suboxic to anoxic conditions. The mineralogy and geochemical composition, particularly the immobile trace elements and the rare earth elements of the BST suggest that the volcanic ash was derived from evolved felsic magma. The fine grained nature, purity, and the presence of small quantities of primary crystals in the BST indicate that it is an air-fall deposit from a distant source involving little or no water transport.

3. NATURAL HAZARDS

3.1 SUB PROJECT

Geomorphological studies in the Kullu valley, Himachal Pradesh, with special reference to mass movement and environmental management.

(M.P. Sah and. R.K. Mazari)

During the year the multiple data on geomorphology, geology, landuse and socio-economy was analysed in detail to focus on the environmental status of the Kullu valley and its management. The studies have revealed that the north–south trending Kullu valley between Rohtang in the north and Hansu in the south is a wide and open valley filled with Quaternary sediments along the main course of the Beas river which drains the valley with its tributaries. The tributary channels have deposited large alluvial fans at their mouths (Fig. 13) which form three distinct levels. The development of these fan levels on the left bank is essentially due to the movement of the Beas Fault during late Pleistocene time. The oldest level lies in the relict state having been subjected to intense erosion since the period of deposition, whereas the youngest level is very broad relative to the older two levels. The Beas river has deposited alluvial terraces, which are very distinct towards the lower reaches and form three to four levels. The upper slopes and high altitudinal areas are covered with periglacial and glacial deposits. The evidence of Quaternary glaciation in the Kullu valley is distinctly observed up to Manali and the head valley portions of the side valleys. Mountain variety periglacial imprints are visible at least up to Kullu and little beyond. The terraces, fans and hill slopes have provided an ideal geoenvironment for human activity including agriculture, horticulture, dense settlements and other civilian establishments.

Owing to its typical geomorphic setting, high relief variation, dominant impact of monsoon winds, thick forest cover, presence of glaciers and glacial lakes in the higher reaches, the Kullu valley is prone to various types

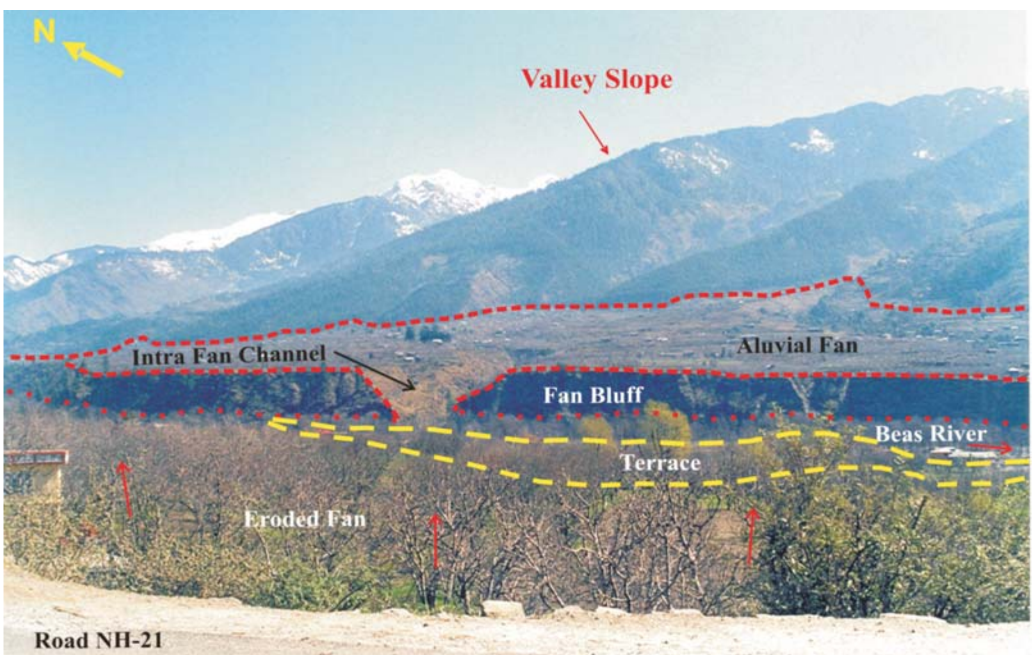

Fig. 13. Panoramic view of a massive alluvial fan near Kullu. The fan is dissected in the middle, whereas the main channel is aligned on the left side of the fan. See the development of river terrace at the toe of the fan descending to the right bank of the river Beas. (Photograph at 1260 m asl facing northeast).

of natural hazards. Annually the damage caused to life and property by cloudbursts, flash floods, forest fires, landslides and mass movement processes in the valley is enormous. The snow avalanches are also common in the higher reaches, but the damage caused by them is generally unnoticed as they occur away from the human habitation. Field studies in the Kullu valley show that the mass movement is mainly restricted to the non-cohesive Quaternary material represented by massive alluvial fans, terraces, etc. confined to the valley bottom. It is observed that mass movement in these landforms usually takes place during the monsoon period when slopes get wet and at saturation point give way for slides and other forms of erosion. River banks in the alluvial fan-terrace tract undergo severe toe erosion during periodic high discharge conditions affected by extremely high rainfall and/or cloudburst events in the catchment. This particular type of mass movement results in severe damage to property and also leads to loss of human lives as a consequence.

It is interesting to note that no major slope failures in the form of landslides are observed on the hill slopes except in the periglacial zone in the upper catchment and high altitude zone elsewhere in the Kullu valley. In the majority of cases even relict periglacial slopes do not show signs of instability partly because of clac cementation and low slope angle. The reasons for the overall hill slope stability in the Kullu valley are not yet clearly understood. However, it is basically the rock type i.e. the crystallines that exhibit strength against the denudational processes to account for minimal amount of slope instability. Moderate soil erosion is in evidence in areas bare of any vegetation. This process is also contributed by massive grazing since there is a considerable cattle population and a traditional practice of economic activity in the region.

Flash floods and cloudbursts are very common in this valley. Forest fires are not uncommon which also contributes to soil erosion during the rainy season. There are 49 glacial lakes associated with the glaciers in the Beas basin and they are categorized into 5 different types. Out of these 22 are major lakes covering an area of more than 0.2 sq km. At least 5 moraine-dammed lakes are found to be potentially dangerous and can burst once they reach the threshold point. Located in the central western and the southeastern parts of the basin, all the 5 potentially dangerous lakes lie close to the retreating glaciers. The number of such lakes is also increasing due to the glacier retreat on account of global warming.

The studies carried out so far indicate that the losses caused by these phenomena both in terms of life and property are mainly due to unwise human interaction with the geoenvironment of the area. For example, altered landuse has substantially led to reduced groundwater conditions on the hill slope which besides causing problems in potable usage is also limiting the small holding irrigation in otherwise globally warming environment. The changed landuse has also considerably affected the forest cover and uncharacteristic usage in terms of horticultural replacing thick vegetation entity, thus exposing large area to soil erosion. In the low lying areas the scarcity of water for both potable and irrigation purposes is widely observed. There is also the tendency for unabated encroachment to the river banks in intrinsically constrained situations. This has already proved fatal in many instances of high discharge flows of the Beas river thereby creating havoc in terms of severe bank erosion and loss of property. In recent years this trend has assumed higher dimension and thus is a perennial threat to the safety of civilian establishments and in some cases the agro-horticultural lands. This is particularly because of rising population, ever-increasing tourist flow, urbanization, infra-structural development and hydropower project activity. The excavated material from the hydropower schemes in the Beas basin has already caused siltation of the Pandoh Barrage in the immediate downstream vicinity. Besides, the 9 km long tunnel with 10 m diameter cutting across the Rohtang Range connecting Beas valley with the Chandra valley will generate about 0.3 million cubic metres of excavated mass which will cause serious environmental problems if not disposed properly within or outside the catchment.

The study shows that there needs to be regulation on organized development of the Kullu valley, lest the situation becomes vulnerable for mitigation in times to come. Already the valley is faced with the rising periodic floating population which causes serious limitation in providing infra-structural facilities in tune with available options and viability. One way of addressing this problem would be resource mapping based on geology, landform types, slope, water resources, existing landuse, etc. to allocate space for various kinds of developmental activities that shall have concurrence of law in force locally or as a matter of policy as the case may be.

3.2 SUB PROJECT

Mass movement and its relationship with the MCT Zone, Uttaranchal Himalaya.

(K.S. Bist and B.S. Rawat)

Detailed mapping for Khanera active landslide zone in the vicinity of MCT, shows that the Khanera slope varying from 37°– 48° is at limiting equilibrium as controlled by the 35° residual angle operating along deep seated joint planes (slip plane of an old landslide) of Garhwal quartzite dipping at 42° due southwest into the valley. The slope is active and the rate of movement increases during rainy season when large quantities of rainwater enter the cracks at the crest. The down slope movement has caused several radial cracks at the crown area making it dangerous to the habitat. The landslide is a multiple and complex slide having combination of rotational, planer and wedge failures. The lithology at the site is mainly quartzite intercalated with metabasics of the Lesser Himalayan sequence. The NEN-SWS trending rocks are highly deformed into mesoscopic open type NWN-SES trending asymmetric folds plunging due west and show variation in dip direction from ESE to WNW at an angle ranging from 32^0 to 48^0. The rocks within the slide zone are highly jointed and fractured and traversed by two N-S trending high angle faults.

3.3 SUB PROJECT

Mapping of active faults using remote sensing techniques.

(G.Philip)

During the year the study has been carried out mainly in the Kangra valley and Soan Duns of the Frontal Himalaya. Morpho-structural analysis using Indian Remote Sensing Satellite data and selected field investigations helped in delineating prominent traces of active fault systems in the area. The two newly recognized active faults in Kangra valley to be referred to as the Naddi Active Fault (NAF) and the Kareri Active Fault (KAF) traverse through the Lower Tertiaries and the Pre-Tertiary rocks of the NW Himalaya respectively. The NAF shows a distinct fault trace, clearly expressed on the Resourcesat (IRS-P6) satellite images and on air photos and is basically a normal fault. It is traceable for over 4 km, striking NW-SE and extends from Naddi village in the northwest to Mcleodganj in the southeast (Fig.14a). The fault dips steeply due NE and has created a prominent sag pond to the north of the footwall zone. The dvelopment of this sag pond, presently known as the Dal Lake, is also partially contributed by subsequent slumping where Naddi fault has restricted its lower extent. The fault scarp is relatively steep in the southeastern part and linear to curvilinear along the fault trace. The northwestern part of the fault scarp beyond Naddi is not so clear on the satellite images because of the decreasing height. On the other hand, the south-eastern part of the fault scarp is larger and also characterized by lineaments, ponded alluvium, and drainages. The scarp observed in this study has a maximum height of 25 m and therefore must have been produced by multiple tectonic offsets. In particular, the south side up behaviour of the fault is in contrast to the north side up movement along the MBT and the Chail Thrust.

The KAF, clearly traceable on Resourcesat (IRS-P6) satellite images and on aerial photographs, has been marked in the upper catchment of Gaj Khad near Kareri village north of the MBT in the Pre-Tertiary group of rocks (Fig. 14b). KAF dips steeply to NE where the fault scarp has been generated in the Quaternary fan deposit and the river terrace. The KAF, which is a sub-parallel fault to the MBT, is predominantly characterized by vertical off-set with locally significant left lateral strike slip of the fan and terrace, which in turn has also laterally shifted few minor streams. The height of the fault scarp trending nearly in a NW-SE varies from 1 to 5 m. The scarp is traceable for a distance of over 3 km. As in the case of NAF, the KAF also shows the south side up behaviour in contrast to the north side up movement along the MBT.

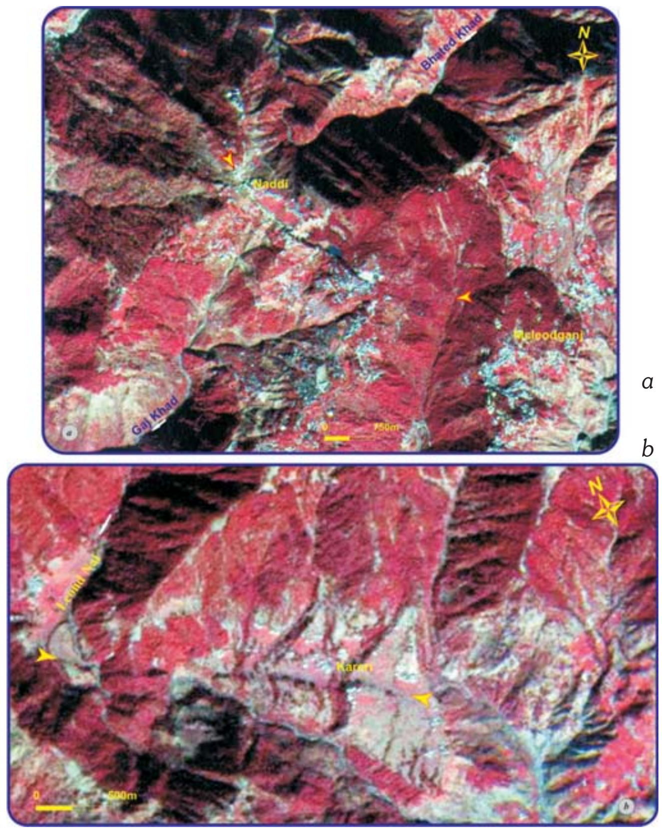

Fig.14. Resourcesat (IRS-P6) false colour image (06 December 2004) showing the expression of (**a**) Naddi and (**b**) Kareri active faults in the Kangra Valley. The yellow arrows show the fault trace.

The two active faults, NAF and KAF, show discrete fault scarps, which are evidently associated with two or more independent large magnitude seismic events in Kangra region. The south side up behaviour of the fault scarps of the two active faults attracts more attention since these indicate extensional conditions and may explain the normal faulting. Furthermore, the NAF and KAF are not only in close proximity of the major structural features of the Himalaya such as the MBT but also obliquely trending to this thrust. While considering the present day observable length of the two fault systems, it is however difficult to infer whether these scarps are the result of a single large magnitude (M>7) earthquake that occurred in the historical past. At the same time, generation of short length scarps due to the secondary effects of the large magnitude earthquakes in the vicinity of the MBT also cannot be ruled out. Since the fault movements are often episodic, the height of a large scarp is usually the aggregate of multiple rupture rather than generated by a single event. In either case the development of fault scarps is clearly indicative of long-term uplift/deformation in the Holocene and cumulative slips along these faults. This however needs further in-depth investigation. This study is also aimed at putting new constraints on rates of movement and geometry of individual faults in the northwestern part of the Kangra valley. Tectonic landforms indicating a major active fault system has also been recognized in Soan Dun. The deformation in the Quaternary deposits corroborate that the Frontal Himalayan region has repeatedly ruptured in the recent past.

3.4 SUB PROJECT

Monitoring and analysis of seismicity in NW Himalaya.

(Sushil Kumar, V. Sriram, A.K. Mundepi, Ravinder Singh, H.C. Pandey, R.M. Sharma and S.K. Chabak)

Digital (short period and broadband) and analog (short period) data from seismic stations on 500 earthquakes (local, regional and teleseismic) in Himachal Pradesh and Uttarakhand were fed to computer for further analysis. Out of these, about 34 local earthquakes during October-November 2005 (Fig. 15) were rechecked and analyzed. The depth of these local earthquakes extends from about 4 to 21 km with r.m.s. ranging less than 1. The earthquakes lie within the network having less ERZ and ERH, whereas earthquakes outside the network are having higher ERZ and ERH. The seismic activity is generally concentrated north of the Dhauladhar region.

In the monitoring of seismicity in the NW Himalaya, WIHG gradually switched from digital to analog this year. There are 25 digital seismographs running in Uttarakhand under HIMSELP (Himalayan School Earthquake Laboratory Program DST Mission Mode Program on seismology; WIHG is the nodal agency for implementing this project in NW Himalaya). 4 digital instruments under Tehri Reservoir Array (Garhwal Sector) and 10 digital seismographs under WIHG Seismological

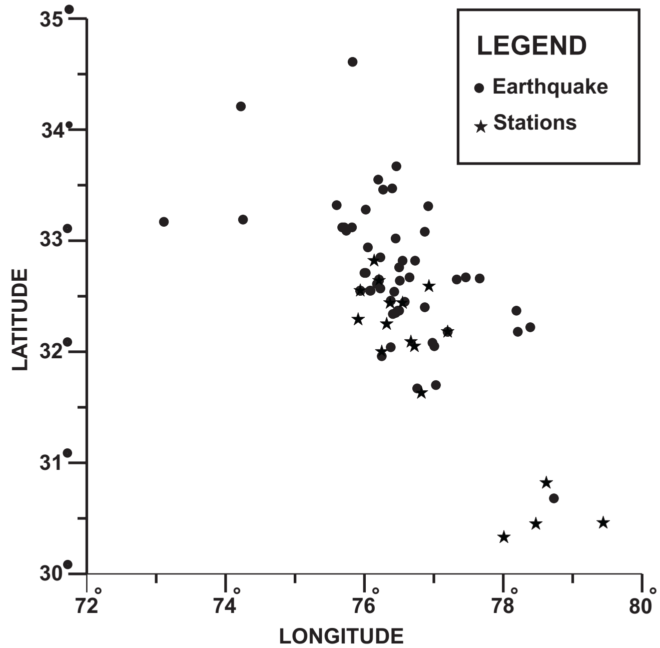

Fig.15. Epicentral plot of earthquake for the period of Oct. 2005 to Nov. 2005.

Network are running in Himachal and Garhwal-Kumaon region. Analysis of digital data of March-June 2006 pertaining to 239 earthquakes (local, regional and teleseismic) was done, whereas data of 68 local earthquakes was processed. The distribution of the epicenters has been shown in figure 16. The estimated focal depth of these earthquakes lies between 8 and 35

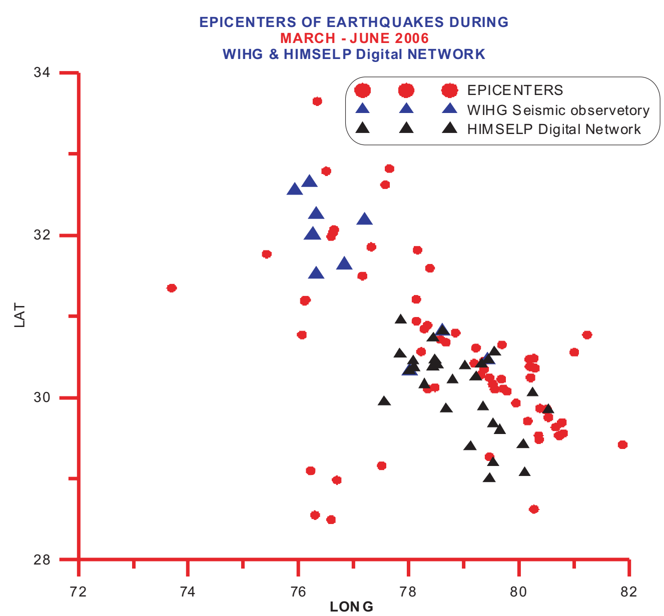

Fig.16. Epicentral plot of earthquake for the period of March, 2006 to June, 2006.

km. Here only those earthquakes were selected whose r.m.s. error range is <1.

Work on broadband and short period seismic noise analysis of the NW Himalayan Seismic Experiment was conducted to quantify and characterize the seismic noise levels at sites. Power spectral densities of background noise for each broadband and short period seismometer deployed in NW Himalaya were calculated and compared with the high-noise model and low-noise Model of Peterson (1993). All segments from day and night local time windows were included in the calculation without parsing out earthquakes. Noise levels were considerably higher for some stations, in particular, in the high frequencies. Power spectral density estimates show moderate noise levels with all stations falling within the high and low bounds of Peterson (1993), except for two stations, which were built on alluvium ground and exceed the high-noise model at frequencies >1.0 Hz.

3.5 SUB PROJECT

Site response studies in major population centres in NW Himalaya.

(A.K. Mundepi)

Site Response Studies in Chandigarh City

The present study has applied the H/V ambient noise methodology to estimate the soft sediment amplification (primarily the resonance frequency) for the city of Chandigarh. The Chandigarh city is underlain by a significant fill of sediments of Siwalik Formation, which lies north of the study area. Some of these sediments were soft soil, but exact distribution and thickness were unknown. The H/V ratios of microseism noise were used to determine the distribution of these soils as well as their thickness. We have used the resonance frequency to obtain an estimate of sediment thickness without disturbing the ground.

The Nakamura technique is widely used for determination of predominant frequencies of geological sites, and a fairly large area could be surveyed in a relatively short time with limited resource spending. In the absence of a high resolution subsurface model for Chandigarh, the herein established model for soil thickness and resonance frequencies (Fig.17) may serve as basic inputs for earthquake mitigation actions as well as a basis for more detailed investigations. No estimate of non-linear behaviour of the soils under strong shaking can be given by the Nakamura method. The H/V technique is recognized as a fast and inexpensive way to estimate the fundamental frequency of resonance of soil sites but we have refrained from using the amplification factors beyond being indicative of a resonance frequency. The interpolation of these results has allowed us to draw up a map, which reflects the spatial distribution of soft sediment in the study area, including the frequency of resonance and thickness. The H/V method may be easily applied in subsequent detailed studies and future investigation in this direction would greatly benefit from more geotechnical information that will allow for establishing or rejecting correlation with results from the H/V technique.

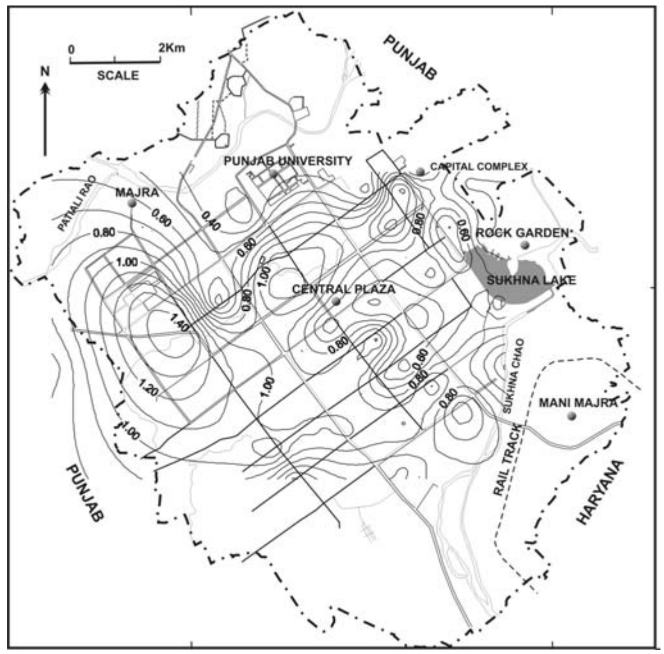

Fig.17. Contour map of resonance frequency of Chandigarh City.

Six stations in Uttaranchal and Himachal Himalaya were deployed for regular monitoring of seismic activity of the region. Nakamura technique (H/V ratio) applied on earthquakes and micro tremor recorded at Bhatwari, Garurganga, Banikhet, Bharmour, Chhatrari and Tissa observatories, to examine differences of empirical site characteristics among coda wave of earthquakes and micro tremors. Two set of earthquakes (near and distant) used in the study for comparison of amplification. The near and distant earthquakes having the epicentral distance 10 - 15 Km and 100 - 150 Km respectively. The H/V ratio obtained by using GEOPSY software, the resonance frequencies and amplitude of each site were calculated (Table-1) and graphic plot as shown in figure 18.

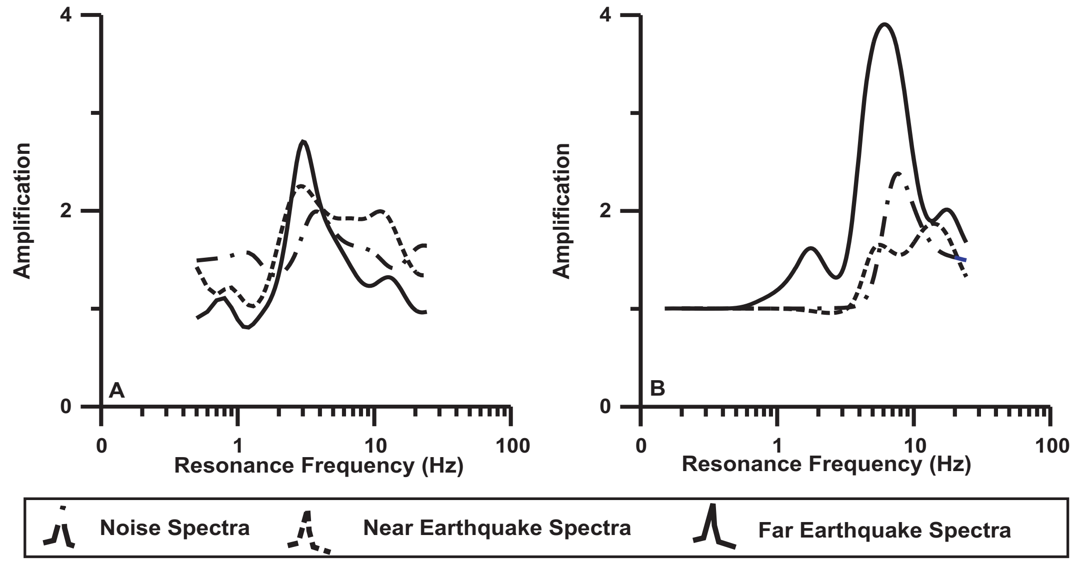

Fig. 18. Spectra at different observation sites: **A**. Bharmour **B**. Garurganga.

Table 1. *Showing the resonance frequency and amplification of near, distant earthquake and noise.*

S. No	STATION	NEAR EARTHQUAKE		DISTANT EARTHQUAKE		NOISE	
		Frequency	Amplification	Frequency	Amplification	Frequency	Amplification
1.	Bhatwari	2.5 Hz	3.80	2.3 Hz	4.75	2.0Hz	1.80
2.	Garurganga	5.5 Hz	1.60	6.0 Hz	3.90	6.0 Hz	1.75
3.	Banikhet	0.35 Hz	1.65	0.4 Hz	3.00	-	-
4.	Bharmour	3.0 Hz	2.5	3.0 Hz	3.5	3.5 Hz	2.0
5.	Chhatrari	1.1, 3.5 Hz	1.55, 1.8	1.75-3.5	1.25	5.0 Hz	1.5
6.	Tissa	2.5 Hz	2.25	0.8,2.5Hz	1.5, 1.75	4.5 Hz	1.5

Ground motion generated by moderate to small earthquake and micro tremor were used to estimate the amplification due to geological and topographical effect. It revealed that degree of compactness of the rock types and presence of sediment thickness play a significant role in site amplification but the resonance frequency was almost same in the earthquakes and micro tremors. It was also concluded that amplification can be more during the earthquake in comparison to micro tremor.

3.6 SUB PROJECT

Seismicity, seismotectonics and seismic hazard assessment of NW Himalaya.

(V.Sriram)

Suits of accelerograms have been generated from hypothetical moderate size earthquakes (M 5.5 & 6.0) in the National Capital Region to estimate the seismic hazard and risk from such events. A basic fault plane solution is assumed for this purpose. The ranges of the different parameters like depth of focus, stress drop values have been used in order to examine the effect of these parameters on hazard. The accelerograms have been synthesized using two basic velocity models, one representing a hard site (1m low velocity cover) and the other a site with a significant low velocity sediment (100m) cover. The decay of peak ground acceleration (pga) values with distance is relatively fast in the case of low velocity surface layer of 100 m as compared to that of 1 m. Also, the decay of pga with distance becomes slower if we increase the depth of focus from 10 km to 20 km. The dependence of pga on stress drop has also been estimated. We find that the site amplifications for the low velocity cover model with respect to the hard site model do not occur uniformly at all the epicentral distances, rather it is dependent on the angle of incidence of energy into the layers. The pga values are generally amplified by more than a factor of 2 with increase in stress drop from 100 bars to 400 bars. The seismic exposure and risk of the population in the National Capitol region has been presented. The results presented in this study may serve as important input to the earthquake hazard mitigation plans of the National Capital Region

3.7 SUB PROJECT

Local earthquake tomography for crustal and upper mantle structure of the NW Himalaya.

(a) Seismotectonic model of the Kangra-Chamba sector of NW Himalaya

(Naresh Kumar, Jyoti Sharma, B.R. Arora and Sagarika Mukhopadhyaya (IITR)

The space-time distribution of micro-seismicity in the Himalaya displays large lateral variability along the Himalayan arc with well-defined segments of intense/low seismicity, seismic gaps or tectonically stable zones. Kangra-Chamba region of NW Himalaya that formed the seat of devastating 1905 Kangra earthquake (M 8.0) has persistently been a zone of intense seismicity as reveled by the clustering of epicenters. To generate area specific seismic velocity models and to improve the locations of the seismic events for better understanding of the seismicity and seismotectonics of the Kangra-Chamba segment of the NW Himalaya, a special experiment with an array of closely spaced seismometers was launched in April 2004. Taking advantage of close station spacing of 21 station array, the joint hypocenter determination formulation coupled with inversion of travel times of 172 local seismic events recorded during the first 2

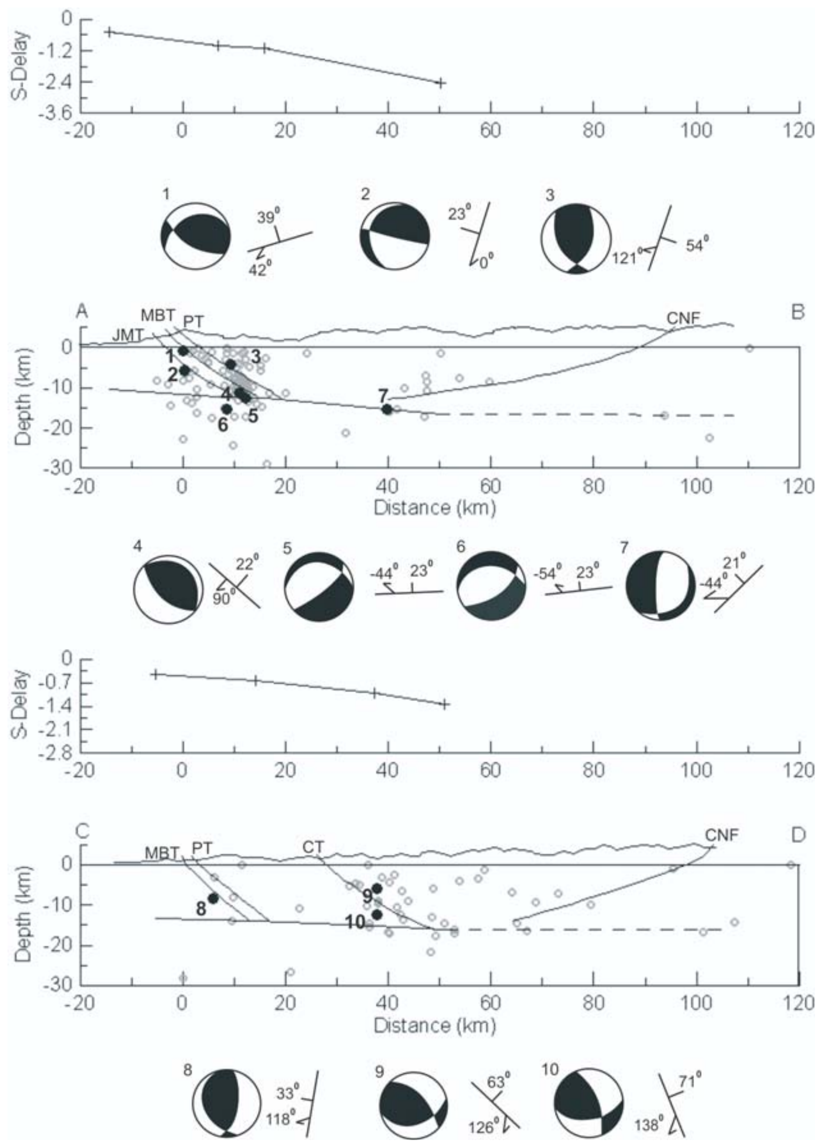

Fig.19. The depth distribution of hypocenters along profiles AB (Kangra) and CD (Chamba Nappe). The alignments of hypocenters trace the subsurface extensions of the major thrust zones. The FPSs of ten events, numbered and marked by solid circles, are also shown. The top panels show the trend in stations correction along each profile that is transformed to approximate the geometry of the upper surface of the mapped low velocity layer (dashed line) that tends to define the lower cut-off crustal seismicity.

years of array operation were carried out to obtain earthquake location parameters as well as 1-D velocity structure. Further, the fault-plane solutions of some 10 earthquakes are used to elucidate the complex tectonics and seismotectonics of the Kangra-Chamba region (Fig.19).

The minimum 1-D velocity model divides the average 45 km thick crust into four layers sitting over a half space. The most conspicuous feature of the velocity structure is the layer in the depth range of 15-18 km that is characterized by low S-wave velocity and high Vp/Vs ratio, signifying increased saturation. Allowing for the station corrections, obtained as a by-product of joint hypocenter determination, permits to view this fluid-filled anomalous layer as a gentle NE dipping detachment plane that defines the lower limit of the crustal seismicity in the frontal part of the Himalaya. Above this plane, the improved location of epicenters show close cluster of seismic events immediately northeast of the Kangra town, while away from this zone the seismicity in the Chamba sector has more even distribution. In the later sector, space-depth distribution of hypocenters suggests that the strains resulting from the on-going collision of the Indian plate with Asia are being consumed by the reverse fault movement on the Chamba Thrust and down dip movement on the Chenab Normal Fault, defining respectively the southern and northern boundary of the Chamba Nappe. The weakly metamorphosed sedimentary sequence of the Chamba Nappe (CN) that extensively covers the study area is mapped as a 10 km thick layer with P-wave velocity of 5.23 km/s, much lower than the typical velocity of upper continental crust. The clustered seismicity in the Kangra sector has three distinct source regions and mechanisms: The southward displacement of the thick Chamba nappe sheet over the Panjal imbricate zone along the Panjal thrust account for the seismicity at shallow depth of less than 7 km whereas the nucleation of strains near the junction where northeast dipping MBT merges with the detachment plane produce focused seismicity above the plane of detachment. The seismicity in a small pocket below the plane of detachment appears to be consequence of the stresses generated at the base of the NE dipping detachment plane by the transverse structure, the presence of such a structure is consistent with nodal plane of earthquakes in this depth range as well as with structural discontinuity indicated by linear zone of positive station corrections.

b) Attenuation Studies of the Kashmir Earthquake

(Sushil Kumar)

Estimated the Crustal Q_β in the Himalaya in Kashmir syntax region using teleseismic Broadband SH waveforms for the October 8, 2005 Kashmir earthquake. The average value of the intrinsic shear wave quality factor Q_β, for the upper 15 km of crustal thickness in the Himalaya in the Kashmir syntax region has been estimated first time. For this teleseismic Broad Band SH and $_{S}$SH waveforms, of the October 8, 2005 Kashmir earthquake (Mw 7.6), from 28 GSN stations of NEIC have been used. The frequency independent average value of Q estimated in the range of 0.2-1.5 Hz is found to be 610±127. This is half of the value estimated in the Garhwal Himalaya. Low attenuation indicates that the rock mass in the top 15 km around the source region is compact and having capability of accumulating high stress and releasing in the form of major earthquakes. However, in the Garhwal Himalaya the value obtained by Dinesh et al. 2005, indicates that in this region rock mass is not very compact that is why we are getting earthquakes of magnitude range 6.0 to 6.8 only.

3.8 SUB PROJECT

Seismic Hazard and sub-surface studies using Engineering Seismograph

(A.K. Mahajan)

Shear wave velocity fields from surface wave to detect anomalies in the subsurface using Multichannel Analysis of Surface wave (MASW) method

Determination of nature and location of dissolution features especially within the upper 30 meters soil column can be an essential component for any land use planning. The Multi-channel Analysis of Surface Waves (MASW) helps to identify lateral and vertical variability in the near surface layers in and around any anomaly related to any paleochannels, cavities, or signatures of erosion/subsidence. This method can also help in delineating the hydrological characteristics in terms of clustering of fractures and or unmapped streams channel. Engineers practitioners generally needs to know the shear strength and shear modulus of the soil column where they like to build a structure. Surface waves appearing on multichannel seismic data designed to image environmental, engineering and ground water targets, although these waves have traditionally been viewed as noise. A recent development of incorporating concepts of spectral analysis of surface waves (SASW) developed by civil engineers' applications with multitrace seismic reflection method show great potential for detecting and in some cases delineating anomalous subsurface material. Continuous acquisition of Multichannel surface wave data along linear transect has recently shown great promise in detecting paleochannels shallow voids and tunnels, mapping of bedrock surface, delineating fractures/faults system etc. The shear wave profile generated in this manner contains information about the horizontal and vertical continuity of material as shallow as few meters down to a depth of more than 30 meters in some settings. This information will be of great use for the town and country planning, land use planning and future sustainable development of any city. Under this work shear wave velocity profiles have been generated for maximum sites in Dehra Dun city delineating features of paleochannels, cavities, phase of erosion and subsidence along with shear wave velocity with depth.

A shallow surface wave survey using Multi-channel Analysis of Surface Waves (MASW) technique was also conducted across the Himalayan Frontal Thrust at a number of sites in an attempt to determine the existence of fault which has been identified at very shallow depth (3-4 meters) during paleo-seismological investigations by different authors. The basic idea of this survey was to identify shallow faults near the Himalayan Frontal Thrust (HFT) and to appraise the resolving power of the MASW technique in the Himalayan region. Two to three reflection profiles were acquired at each site using an 8kg sledge hammer energy source and 24 channels engineering seismograph using roll along technique. The field parameters were designed to optimize the recording of subsurface structures and geological units in the 30-40 meters depth range. Further to strengthen our data three different geophysical techniques were applied in one of the sites near Panchkula where active faults have been identified using paleo-seismological method. To achieve the goal, a multidisciplinary approach, a joint experiment was designed using Seismic reflection (MASW Method), Electrical Resistivity and Time Domain Method on the same profile trending across the hidden fault. The profile was taken along the trench portion to identify the faults reported by paleo-seismological evidences. The geophysical results were then compared to geologically documented trench measuring 40 m in length and 5 m in depth east of the geophysical line with a NE-SW orientation. The trench intercepted an active fault zone. The geological study determined that the intercepted fault had slipped 3 m and possibly related to the imbrications of HFT. The geophysical survey carried out along three lines in the area trend NE-SW and N-S intercepted two faults at different depth level. One of the fault recognized through trench correlated well with the geologically recognized fault trending NNW-SSE dipping NE.

The same experiment was performed at Ganeshpur, south of Mohand hill to identify the trace of HFT which had already been reported by Shivaji et al. 1996. The feature was identified by HERT as well as MASW technique, thus supporting the evolutionary model of the Mohand Siwalik basin given by Shivaji et al. 1996. These two methods i.e. MASW and Electrical resistivity methods proved to be more successful in identifying shallow subsurface features and any discontinuities in the subsurface.

Seismic Microzonation and Shallow Shear Wave Velocity studies in Delhi

The National Capital Region having a population of over 16 million is situated in a highly earthquake prone belt (Zone IV, IS 1893-1984). Evidence of this is already found in minor to major cracks in buildings due to earthquakes triggered in Garhwal Himalaya or in Kuchchh region. The repeated alarm from 1991 Uttarkashi earthquake (mb 6.4), 1999 Chamoli earthquake (mb 6.8) and 2001 Kuchchh earthquake (M 7.7) necessitated to ponder on the factor that contributed to the damage pattern of buildings in the National Capital Region(NCR). One simple way of accounting for site conditions in calculating seismic hazard is to use the shear wave velocity in the shallow subsurface to classify materials as shear wave velocity is one of the key parameters to represent the stiffness of the subsurface layers. Considering this, ten representative sites have been selected by Earthquake Risk Evaluation Centre (EREC), India Metrological Department, and New Delhi. The shear wave velocity investigations were carried out using MASW seismic reflection approach. The sites selected have been distributed on Alwar quartzite (JNU site, Asola site) of Delhi Supergroup, along the left bank of Yamuna river (Akshar Dham site), and near lakes(Najafgarh lake site, Bhalsawa lake site) and at locations with thick sediment covers (Bavana, Suhalpur, Ghazipur, Kirbi Cantt., etc). The analysis revealed that the sites located on Alwar quartzites of Delhi Super Group shows a shear wave velocity (Vs) of 770m/s at the surface to 2800 m/s at a depth of 50 meters. The sites located near the lake sediments (i.e. Nazafgarh and Bhalsawa) and Yamuna bank (Akshar Dham) showed shear wave velocity of <180 m/sec at the surface up to a depth of 7-8 meters, whereas others sites located on thick sediments (mostly clay with varying hardness) showed Vs of 180m/s to 250m/s. According to the NEHRP classification the sites covered can be classified under three categories i.e. Class 'A' (hard rock) having Vs > 1500m/s (JNU site and, Asola site), class E (soft soil) having Vs>180m/sec-360 (Bavana, Suhalpur, Gahzipur and Kirbi cantt. sites), and class F located near lake sediments and along the Yamuna river bank. It is pertinent to note that the sites classified under class F need site specific evaluation. The shear wave velocity investigations thus enables us to take an immediate stock of the soil stiffness parameters which if combined with other inputs like borehole data, strong motion earthquake data and dynamic properties of each soil layer, can help in taking up studies on site response modeling nd amplification function of each site (Fig.20).

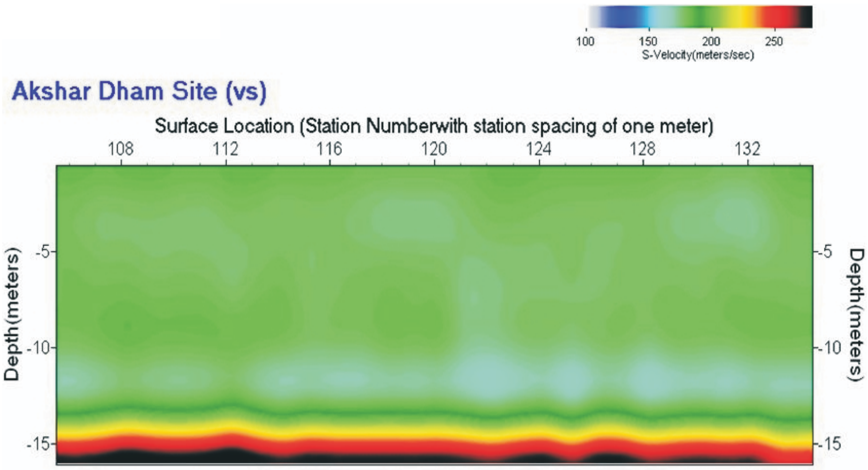

Fig. 20. 2D shear wave velcoity profile of Akshar Dham site, New Delhi.Top 10 m soil layers shows shear wave velocity of the order of 180m/s.The existance of low shear wave velocity indicates

3.9 SUB PROJECT

Kinematics of the India-Asia convergence process as manifest in NW Himalaya from GPS measurements.

(P. Banerjee)

GPS Field measurements were carried out in Ladakh, Himachal Pradesh and Kashmir during 2006. In October 2005, two permanent GPS stations were installed at Uri and Keran (Kashmir) immediately after the October 8, 2005 Kashmir earthquake. The Uri station was withdrawn because of instrument problem. In Ladakh, repeat measurements were carried out at Sarchu, Pangong Tso, Panamik, Nyoma, Shakti and Leh. In Spiti, GPS measurement was carried out at Kaza. In Himachal Pradesh, GPS measurements were carried out at Dalhousie, Jispa, Nurpur, Rewalsar and Una.

GPS data from entire Asia and surrounding continents were processed to study the post-seismic deformation of the 2004 Sumatra Earthquake. Data from more than 2400 GPS stations were integrated to produce a mega-regional deformation map of India and surrounding continents, centred round Himalaya. In collaboration with California University, Berkeley, the interactions between different tectonic plates at the plate boundaries were studied. Data was procured from Kashmir region from our own GPS stations and also in collaboration with IIGM, Bombay to study the 2005 Kashmir earthquake. To study the internal deformation of the India plate routinely processed all GPS station data that were generated from our own Permanent GPS stations as well as collected from SOI National Data centre.

Sumatra Earthquake

Static off-sets produced by the December 26, 2004 M _9 Sumatra Andaman earthquake as measured by Global Positioning System (GPS) revealed a large amount of slip along the entire 1300 km long rupture. Most seismic slip inversions place little slip on the Andaman segment, whereas both near-field and far-field GPS offsets demand large slip on the Andaman segment. Available data sets of the static offset were compiled to render a more detailed picture of the static-slip distribution. Geodetic offsets were constructed in a manner such that post-earthquake positions of continuous GPS sites were reckoned to a time 1 day after the earthquake and campaign GPS sites were similarly corrected for post-seismic motions. The newly revised slip distribution (Mw 9.22) revealed substantial segmentation of slip along the Andaman Islands, with the southern quarter slipping _15 m in unison with the adjacent Nicobar and northern Sumatran segments of length _700 km. A small excess of geodetic moment relative to the seismic moment is inferred. A similar compilation of GPS off-sets from the March 28, 2005 Nias earthquake is well explained with dip slip averaging several meters (Mw _ 8.66) distributed primarily at depths greater than 20 km.

Using GPS data collected over the last one decade in various parts of India, we have quantitatively studied the strain pattern within the Indian shield zone. The effect of the 2004 Great Sumatra earthquake is being studied from the post-seismic GPS data. The role of long-term visco-elastic deformation in the asthenosphere is being studied. The role of Indian plate collision with Eurasia and its impact on other plate boundaries are also being studied in a much broader spatial and temporal scale.

GPS data collected from Uri, Keran and Gulmarg is being used to study the kinematics of the 2005 Kashmir earthquake.

3.10 SUB PROJECT

Geological controls on radon emanation and its role in environmental pollution assessment and earthquake studies.

(V.M. Choubey and S.K. Bartarya)

Radon concentration was measured in soil gas and water of Bhillangana valley of Garhwal Himalaya. The exposed rocks in the Lesser Himalayan section are predominantly consist of quartzite and metabasic with intercalation of phyllite and chlorite schist. Several radon measurements in both soil (9.3 to 32.3 kBq/m^3) and water (5.1 to 6.6 Bq/l) were made in this formation. Higher radon concentration recorded from this locality in both soil (59.3 kBq/m^3) and water (168.2 Bq/l) was possibly related with subsurface radioactive mineralization, which would facilitate enhanced radon production. The occurrence of uranium has been reported from these rocks and is associated with sheared biotite gneisses close to the Bhatwari-Ramgarh Thrust. The various fractures associated with thrust plane have provided the easy pathways for escape of gases from the deeper sources.

The Central Crystalline rocks in the Higher Himalaya consist of sheared granitic gneisses, porphyritic gneiss, talc schist, mica schist, mylonites and quartzo-feldspathic schist. Overall, high concentration of radon i.e. 3.6 to 84.2 kBq/m^3 in soil and 6.1 to 168.2 Bq/l in groundwater have been recorded from these crystalline rocks. Observations of low radon concentration in colluvial springs suggest high porosity leading to natural de-emanation and relatively high values in fracture-joint and fault related springs and hand pumps is possibly due to increased ratio of rock surface area to water volume and uranium mineralization in close vicinity in case of later. The radon values were recorded highest in the springs draining through gneiss, granite, mylonite etc. Radon concentrations have been related with four spring types viz. fracture-joint related spring, fault-lineament related spring, fluvial related spring and colluvial related spring, showing geohydrological characteristics of the rocks through which they are emanating. The high radon concentration in fracture-joint and fault-lineament spring is related to increased ratio of rock surface area to water volume and uranium mineralisation in the shear zones present in the close vicinity of fault and thrust. The low concentration of radon in fluvial and colluvial springs is possibly because of high transmissivity and turbulent flow within such deposits leading to natural de-emanation of gases.

3.11 SUB PROJECT

Geological, geomorphological and geotechnical investigation of Pawari and Nathpa slide zone and upgradation of existing landslide inventory of Sutlej valley, Himachal Pradesh

(Vikram Gupta and M.P. Sah)

The active and paleo-landslide mapping in the Satluj valley has indicated that the river was blocked and breached at many places like Khab, Dubling, Spilo, Morang, Akpa, Ribba, Pawari, Karchham, Kilba, Tapri and Wangtu during the Quaternary period. This was further corroborated by the occurrence of Landslide Lake Outbursts Flood (LLOF) in 2000 and 2005 which caused a colossal damage in the area.

It was observed that both anthropogenic and natural factors are responsible for the increased spatial distribution of landslides in the area. Among the anthropogenic factors, excavation of hill slopes, change in landuse pattern and faulty land management practices are responsible for the increased occurrence of landslides and related mass movement activities in the area. The area under investigation has witnessed a lot of developmental activities during the last fifteen years. Two hydroelectric power projects namely 1500 MW Nathpa Jakhri Hydroelectric Project and 300 MW Baspa Stage II Hydroelectric Project have come up. Nathpa Jakhri Hydroelectric Project has the longest hydropower tunnel in the world measuring 27.394 m and has also 982 m long tail race tunnel. The project stretches for a length of about 50 km from the dam site to the power house and involved the excavation of 3.5 million m^3 of material which was dumped all along the river.

The change in landuse pattern in the area has also been observed. The sharp increase in area under agricultural practices from 3707 to 9111 hectares during 1990-2003 and horticultural practices from 5205 to 9432 hectares during 1997-2004 clearly depict that the area is highly under anthropogenic pressure.

It has further been reported that in the recent years, there is a shift in the climatic pattern in the area under investigation. The area upstream of Morang, falling in the semi-arid to arid temperate zone, receives considerable amount of precipitation in the form of rainfall in the present day climatic set up. This has been evidenced by the six years average rainfall data recorded at Pooh. The average annual rainfall recorded during each year is > 100 mm except during 2003 where it is zero. It is inferred that the shift in the climatic pattern more area will fall in the rainfall cover and increase the vulnerability of the hill slopes in terms of landslides and related mass movement activities.

In addition, geo-mechanical characterization of rocks exposed all along the National Highway (NH-22), using Schmidt Hammer Rebound (SHR), measured. Analysis of data is underway.

3.12 SUB PROJECT

Monitoring of Geophysical and Hydrologial changes due to impounding water

(B.R. Arora, V.M.Choubey, S.K.Bartarya, A.K.Mundepi, Gautam Rawat and Rajesh S)

Seismic studies

Total seven digital stations are installed in the region, to monitor the seismicity during the impounding of reservoir. During the year 2006 2007 about 600 earthquakes (local, regional and teleseismic) were recorded in the network. The earthquakes lying within the network have less ERZ and ERH, whereas earthquakes outside the network have higher ERZ and ERH. The seismic activity generally concentrated north of the MCT. The depth of these local earthquakes ranges from about 4 to 24 Km. Data of 165 earthquakes are analysed to show alignment and migratory trends (Fig. 21).

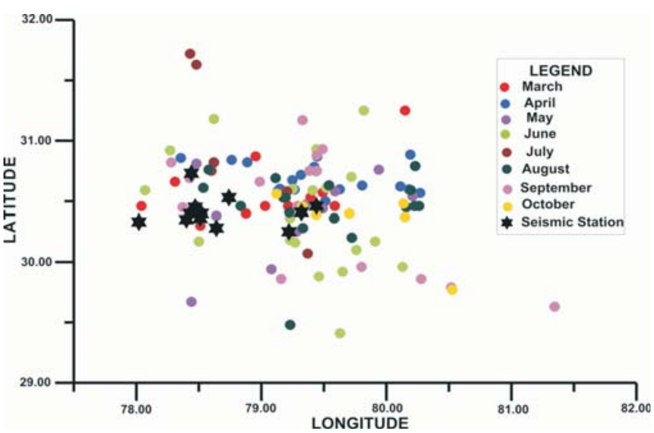

Fig. 21. Epicenteral plot of earthquakes in Garhwal Region.

GPS Studies

As the part of this project fourteen benchmark points were established around the Tehri reservoir and two campaign sets of GPS data were collected. During the first phase the collected data were used to identify the precise GPS locations of the benchmark points for further re-occupation. However, some points were changed due to logistical and technical reasons. The second phase of the campaign was completed in November 2006, and on most of the benchmark locations the data were collected for more than four days. Preliminary analysis of the data showed that in most locations signal reception were good and consequently good S/N level of the recorded data.

Magnetic Field Component

Total magnetic field as observed in different bench marks established around Tehri reservoir was compared with MPGO Ghuttu. The data recorded at Ghuttu was used to estimate and eliminate the magnetic field variation of ionospheric and magnetospheric origin. The day time and night time data were analysed separately as night time data are having high signal to noise ratio. Correlations of magnetic field variations with reservoir loading and unloading can be established only with availability of high precision noise free magnetic data from number of campgain data.

Radon Studies

Two repeat soil radon measurements were carried out, first during the months of May-June 2006, and second during the months of October-November 2006. A total of 18 bench marks were selected for the study around the Tehri dam reservoir. The radon value varied from 6803 Bq/m3 to 24966 Bq/m3 during May-June 2006 and 3763 Bq/m3 to 24966 Bq/m3 during October-November 2006. Slight increases in radon concentration were observed during the second measurement period (October-November). Atmospheric temperature and pressure were also recorded on the same locations. Besides, repeat measurements of radon for three months were also recorded in Badshahi Thaul University Campus. To understand the radon changes related to water level fluctuation in Tehri dam more repeat measurements are required.

4. GLACIOLOGY AND NATURAL RESOURCES

4.1 SUB PROJECT

Geohydrological investigations and water quality assessment in headward region of Kumaun and Garhwal Himalaya with emphasis on identification of hill aquifers.

(S.K. Bartarya and P.P. Khanna)

The geohydrological studies in the headwater region of the Kali, Ramganga and Pindar rivers in Champawat, Pithoragarh and Bageshwar area of Kumaun Himalaya were undertaken. The objectives were to understand the geohydrological characteristics of the aquifers, identification of hill aquifers and spring zones, water quality assessment and for formulating strategies for recharge of springs based on watershed conditions.

Geohyhydrological characterstics

The study area falls in the subtropical Lesser Himalayan belt in eastern part of the Kumaun Himalaya. In general, the rocks are characterized by multiple deformations resulting in superimposed folding and repeated faulting and thrusting. The rocks exposed in the area, from south to north belong to Saryu Formation of Almora Group (sericite-chlorite schist, amphibolite, mylonitized granite gneiss, augen gneiss, garnetiferous mica schist, micaceous weathered quartzite, granodiorite in Champawat area), Rautgara Formation (quartzite, slate), Deoban Formation (dolomitic limestone, slate, phyllite), Mandhali Formation (pyretic slates, argillaceous and dolomitic limestone), and Berinag Formation (quartzite with metamorphosed basalt and tuffites).

Three types of water-bearing formations can be recognized in the study area.

- Fractured hard rocks
- Fluvial and colluvial deposits,
- Karst aquifers

Faults, fractures, joints, slope characteristics, landforms, lineaments and karstic features control the formation of springs. Genetically, therefore, the springs can be classified as: i) lineament-fault controlled springs, ii) colluvial related springs, iii) fluvial related springs, iv) Fracture-joint related spring, and v) karst related springs. Each type has different discharges. A number of water table springs were identified along wide U shaped valleys in Champawat- Lohaghat-Pithoragarh area.

The aquifers in the Pithoragarh area consist of valley fill deposits in the central part and fractured and jointed limestone along the valley sides. In Champawat area fractured and weathered granite, gneisses and schists having secondary porosity and permeability forms the aquifer. Several localized small aquifers of limited yield are present in Champawat area. The static water level in these aquifers varies from 6 to 67 m b.g.l. in Champawat area and 12 to 91 m b.g.l. in Pithoragarh district.

Identification of hill aquifers

Besides the combination of physiographic, lithological, structural, geomorphological, and hydrological characteristics the following features helped in the identification of potential aquifers in the hill region: i) presence of an amphitheater shaped geomorphology, ii) presence of springs and seepages in the upslope and down slope area, iii) a relative relief of more that 100 m, iv) large recharge area drained by 1^{st} and 2^{nd} order stream or presence of ephemeral streams, v) presence of quaternary sediments in the form of old valley fill, river terraces, alluvial fans and colluvial deposits, vi) presence of lineaments and lineament controlled streams, and vii) highly fractured and jointed weathered bed rock. A number of sites were identified for drilling in the aquifer. A limited water discharge of 25 to 100 LPM is available from these wells.

Hydrochemistry

The studies have shown that water chemistry is consistent with local lithology. The relative abundance of predominant cations and anions in the groundwaters of the Kumaun region is as: Ca > Mg > Na > K and HCO_3 > SO_4 >Cl >NO_3. The chemical composition is controlled predominantly by rock weathering. Mostly congruent weathering of carbonate and incongruent weathering of silicate lithology control the concentration of major elements in groundwater. The low concentration of major elements in groundwaters/subsurface waters of Kumaun region, compared with groundwater of the peninsular region, in the majority of the samples signifies rapid infiltration and quick outflow of the rainwater, and thus low residence time of water which would permit interaction with the rock, because of the steep slopes in the Himalayan region. This is in contrast to conditions for most waters present in the Peninsular region. However, the relatively high concentration of elements in waters of springs and hand pumps (groundwater) compared with streams is due to i) biological activity which produces relatively high soil pCO_2 values, ii) relatively higher temperature, and iii) relatively high depth of circulation of water resulting in longer water residence time in thick regolith and rock.

Diminishing discharges of springs and their recharge

In recent years, attention has been drawn on the declining discharge of the springs in the Himalayan region which ranges from 10 to 75 % in the last 50 years or so. The main causes for the declining trend appear to be changing landuse, increased surface runoff due to deforestation, reduction in net recharge area due to urbanization, natural and induced seismicity due to uncontrolled blasting for road construction and vehicular traffic in the recharge area of springs etc. These have locally upset the pattern of groundwater flow and lowered the peizometric surface, thus resulting in gradual decrease in the discharge of springs. The recharge strategies are therefore directed towards the treatment of catchment area around the water resource and spring for water conservation through vegetative measures particularly in the recharge area. It has been observed that integrated measures and particularly vegetative measures play a significance role in modifying the infiltration rate by reducing the surface runoff. Based on field observations, the strategies needed to mitigate the problem of declining discharge of springs includes the following: i) rejuvenate diminishing natural springs through integrated measures approach but more emphasis should be on vegetative measures, ii) develop water resources by introducing proper measures of reducing surface runoff and through improving groundwater conditions, iii) improve quality of drinking water by protecting catchment area of springs from contamination. The other components of the conservation and development strategy includes: i) improve water yield of springs by protecting the recharge areas, ii) develop spring sanctuaries in order to induce and augment infiltration of rain water, iii) conserve rainwater (roof-top harvesting and infiltration tank) and surface water flowing in streams by constructing conservation tanks and development of an efficiently organized system of water distribution with participation of the beneficiaries themselves. It is expected that all the towns in the Himalayan region will be under pressure of urbanization. With growing urbanization and ever increasing demand and as the water supply problems expected to grow in future, there is an urgent need to prepare a comprehensive water management plan of ground and surface water resources for their judicious utilization and new sustainable water supply scheme for the urban centers.

4.2 SUB PROJECT

Glaciological studies of Dokriani Glacier and Chorabari Glacier, Garhwal Himalaya.

(J.T Gergan, R.K. Chaujar, D.P. Dobhal and P.S. Negi)

Chorabari glacier

The work deals with the glaciological studies of the Chorabari glacier in the Garhwal Himalaya. Also, using the lichenometric technique and landform associations cycles of advance and retreat of this glacier have been attempted. The first measurement of about 2000 lichens in the region was carried out in the last week of October 2003. Some of the prominent lichens were well marked in the field for future reference. These lichens were measured again during the first weak of November 2004, 2005 and 2006 and a growth of 1 mm was recorded in all these lichens. So a growth rate of 1 mm per year has been established in the area. In addition, the lichenometric studies have revealed that the Dokriani glacier started retreating from its maximum advance (4500 m from the present snout) due to global warming some 315 years ago. This age was calculated on dating the largest lichen developed on the loop of lateral and terminal moraines of the first stage of the glacial advance. This confirms that the recession rate of the glacier was at 14.3 m/year.

Lichenometric studies were also conducted to date surface-exposure due to glacier melting in Chorabari glacier. To explore lesser known lichens for sampling, two species, i.e., Lecanora (Fig. 22a) of yellow color and Lobaria (Fig. 22 b) of gray color were identified due to their uniform growth pattern and spatial distribution. The largest, i.e., 274.32 mm thallus of Lobaria (Fig.22 c) was searched out and efforts are being made to date the exposed surface after incorporation of colonization delay and aspect factor prevalent in the study area. The influence of aspect on growth of Lecanora species has been determined and it is revealed that highest (0.56 mm/year) growth was from the southern aspect which experiences most adverse climatic scenario, i.e., maximum solar radiation and rainfall. The lowest growth (0.39 mm/year) was observed in the northern aspect which encounters least solar radiation and therefore bears good moisture content. The eastern (0.46 mm/year) and western (0.42 mm/year) aspects have shown relatively low variation in growth. It is evident from above investigation that aspect factor has a profound influence on lichen growth and needs to be considered for accurate dating. It is widely accepted especially in the context of Himalaya that refine knowledge of lichen ecology is likely to improve accuracy and reliability of technique and study of lichen growth in relation to the aspects is one such endeavor.

The annual net balance of the Chorabari glacier investigated for the period 2005-2006 showed continuous negative balance of (-) 4.78 x 10^6 m^3. Mean glacier degradation during the study period between 2002/03 and 2005/06 was found to be - 0.76m w.e.a^{-1}. The study of mass balance pattern shows that the annual mean ablation rate ranges between -2.0 and -3.0m w.e. a^1, while annual mean accumulation rate was 0.55-0.60m.w e. a^{-1} during the study period. It is also observed that the melting is more in the upper ablation area than the lower ablation area. This may be due to the extensive debris covered glacier surface of the Chorabari glacier. In order to evaluate the influence of surface debris cover on surface melting, three stakes located within the range of 500 m^2 area at different places of thick debris cover (20-50cm), thin debris (1-2cm) cover and debris free surface were monitored for the period June 10 to June 30, 2006. These stakes were measured daily and air temperature,

PROGRESS IN RESEARCH PROJECTS

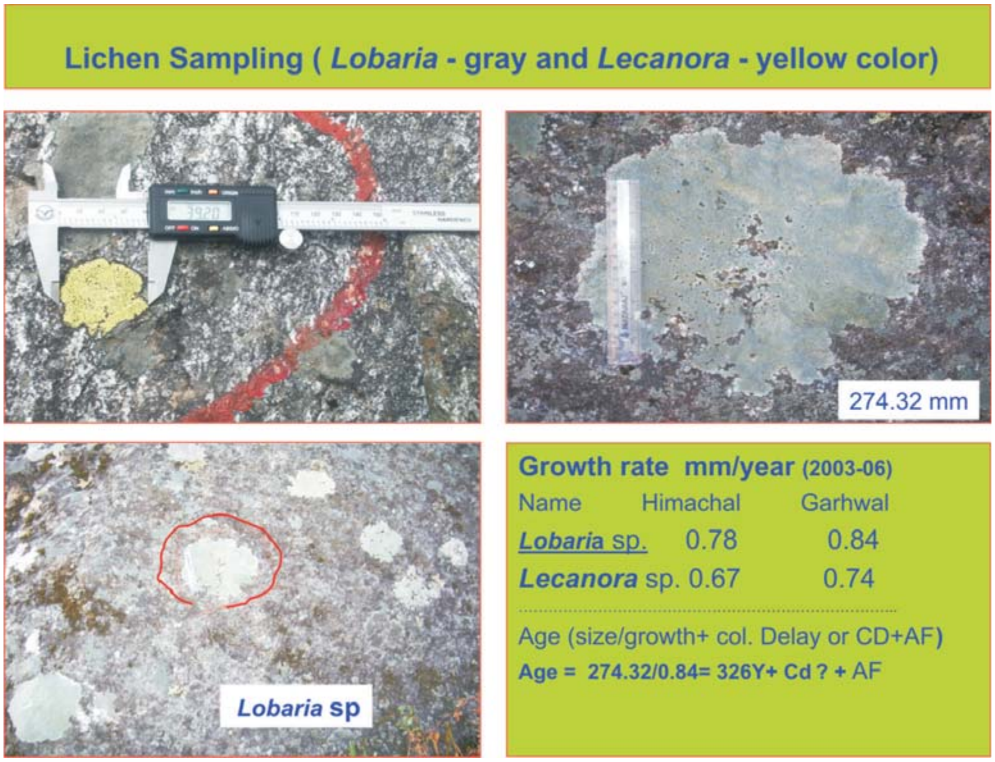

Fig. 22. Lichenometry for glacier recession.

precipitation and wind velocity/direction were also recorded. Results show significant difference in melting over the debris layer (Fig.23). The melting obtained for a thick debris-covered surface was 1.2 cm/day w.e. smaller than those obtained for debris free surfaces and thin debris covered 4.5-5.5 cm/day w.e. Thus, it is observed that the debris-covered surface has substantial lower melting. The total melting in the ablation zone during the entire ablation period is larger in the upper ablation area where the glacier surface is thin debris covered or debris free. It is postulated that the presence of supraglacial debris strongly influences glacier ablation in similar climatic setting. Such type of study will be continued for further analysis of melting pattern in debris covered glacier.

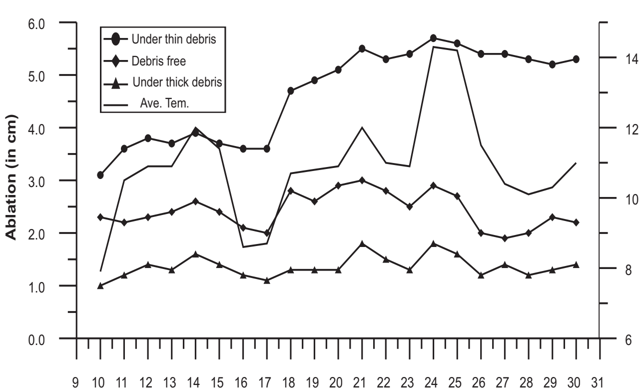

Fig. 23. Relationship between debris-cover thickness and ablation.

The snout and Equilibrium Line Altitude (ELA) fluctuation study shows that the snout of the glacier has receded about 10 m and vacated an area of 640m^2. The ELA also ascended about 160 m from its position at an altitude of 4900 in 2005.

Discharge measurement and meteorological data have been collected for a period of one month. These data were analysed and interpreted. The total discharge for the observation period was 6.55 x 10^6 m^3 with an average of 0.28 x 10^6m^3/d. The maximum and minimum temperature recorded during the period was 12^{0}C and 3.1^{0}C respectively. During the period a net of 252 mm rainfall was recorded which includes 2 mm snowfall on 13 June 2006.

In bioengineering study, Alnus neplensis (Fig. 24) has been used as precursor taxa for the identification of hill slope instability, vis-à-vis landslides in the Garhwal Himalaya. The habitat, spatial distribution and floristic dynamics of these taxa are veritably helpful in the identification of areas of potential hill slope movement through ecological manifestation. In order to develop temporal affinity with instability/landslide along any slope, the annual growth rate of Alnus neplensi is determined 145 cm after the measurement of 102 saplings for four years at three experimental sites. In essence Alnus neplensis provides natural information on slope conditions and therefore this technique is eco-friendly, cost effective and involves local resource as a scientific tool for this study. In fact it may be adopted as a bioengineering technique for landslide hazard mitigation in the Himalaya. Local, national and global importance of this technique is evident considering broad range of phyto-geographical distribution of these precursor taxa in the

PROGRESS IN RESEARCH PROJECTS

Fig.24. *Alanus nepalensis* A slope instability precursor in Central Himalaya.

entire central Himalaya from Himachal to Meghalaya. The data for habitat ecology and spatial distribution is derived from the study of about 50 floras of respective locality, region and country and depicted in figure 25. The global relevance is recognized due to its natural distribution in south-east Asia (200-2800 m), especially in

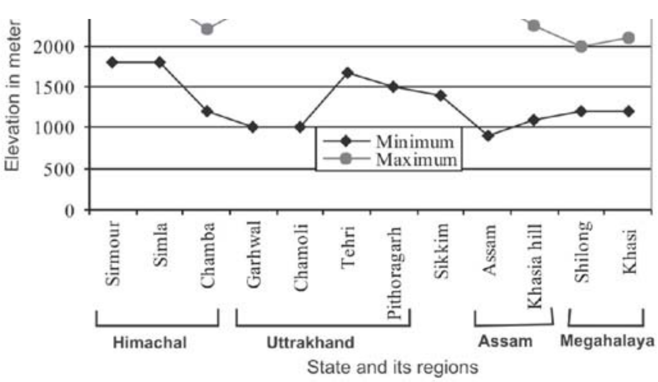

Fig.25. Spatial distribution of *Alanus nepalensis* in Indian Himalaya.

countries like Nepal, Tibet, Bhutan, China, Myanmar (Burma), Bangladesh and other similar geographical regions of the world (Fig. 26).

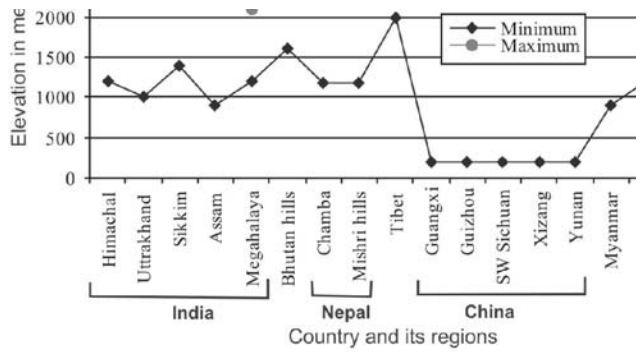

Fig.26. Global (South-east Asia) distribution of *Alanus nepalensis.*

4.3 SUB PROJECT

Geochemical investigations of active stream sediments and preparation of reference rock standards from Himalayan orogenic belt.

(P.P. Khanna, N.K. Saini, K.K. Purohit, and P.K. Mukherjee)

About 75 stream sediment samples collected from Pithoragarh and Champawat region, along river Kali and its tributaries Dhauli and Gauri, were analysed for major and trace elemental abundance. Baseline values were estimated for each element catchmentwise as well for the whole area. Apart from this an attempt was made to know the geochemical dispersion pattern of elements in the study area.

Geochemical survey based on low order active stream sediments as media were conducted in the Garhwal region of Uttarakhand Himalaya. Highly mobile and relatively less mobile elements revealed contrasting geochemical landscape. In particular, the distribution of less mobile HFSEs like U, Th, REEs and LILEs like Rb, Sr were found to be relatively enriched in MCTZ whereas Fe, Ti, Ni, and Cu are notably depleted. Although these signatures are largely controlled by the lithological variations, however, the influence of relative degree of deformations is also apparent. There is a systematic variation of median values of some elements in major litho-tectonic units from south to north. Ni and Cu being extremely mobile, the fluid removed this phase in highly sheared and deformed terrain of MCTZ. The HFSEs (U, Th, Ti and REEs) being relatively less soluble have been largely enriched in more intensely deformed ductile shear

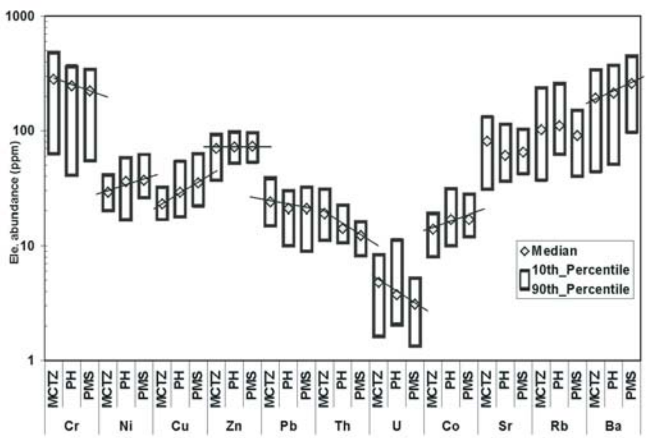

Fig. 27. Median values as baselines for selected trace elements in the three lithotectonic areas. The range of concentration of the trace element is in the respective lithotectonic areas are represented by the Bar delimited by Maximum (90th percentile) and Minimum (10th percentile) values. The increasing or decreasing trend lines of individual trace element are drawn through the median values (open diamond symbol) from N to S (left-right in the diagram) MCTZ, PH and PMS.

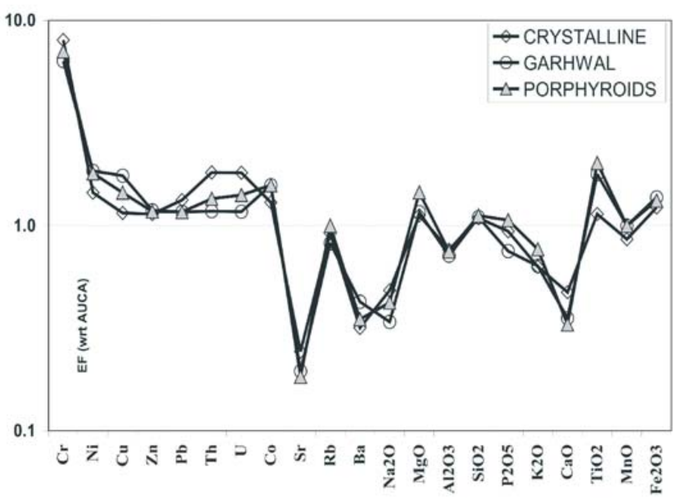

Fig. 28. Average upper crustal abundance (AUCA) normalized multi-element diagram illustrating the Enrichment Factors (EF, w.r.t. AUCA) for selected\ trace and major elements.

zone (MCTZ) and the excluded more mobile transition elements were probably emplaced at upper levels within met sedimentary sequences. Remobilization probably led to occurrences of sulphide mineralization that are generally found restricted within the Lesser Himalayan sedimentary sequence. As a whole, the entire Lesser Himalayan belt is characteristically enriched in HFSEs with respect to average upper crustal abundance (AUCA), whereas the LILEs are mostly depleted (Fig.27 & 28). Interestingly, the median value of Cr is found to be exceptionally high as much as 6-8 times the AUCA. The high value of Cr seems to be a result of residual enrichment due to repeated recycling of the Proterozoic metasedimentaries. On the other hand, Sr shows extreme depletion of about 4-5 times AUCA, which requires a rational explanation involving large-scale process.

Himalayan geoanalytical reference standards

Preliminary information values were assigned for the ultra mafic reference geostandard UM-H from Nyoma in Ladakh Himalaya. Range of major, minor and trace elements are given below. UM-H (Ultra-Mafic Reference Geo-Standard from Nyoma-Ladakh, Himalaya).

Major Elements	(Wt. %) Trace	(ppm) Elements	
SiO_2	43-45	Ba	20-30
Al_2O_3	1-3	Cr	1700-2100
Fe_2O_3	7-10	Co	70-100
MnO	0.15-0.2	Cu	25-50
MgO	30-32	Ni	400-600
CaO	10-11	Rb	0.5-2.0
Na_2O	0.01-0.03	Sr	5-8
P_2O_5	0.02-0.04	Sc	30-35
TiO_2	0.01-0.03	Y	0.8-2.0
K_2O	0.01-0.02	Th	<1
		<1	U

5. PALAEOCLIMATE AND ENVIRONMENT

5.1 SUB PROJECT

Late Quaternary vegetation history and climate changes with respect to SW monsoon in Garhwal Himalaya.

(N.R. Phadtare)

Dayara peat deposit, Bhagirathi valley, Garhwal Himalaya

This peat deposit documents past 6000-year climate record of the Gangotri glacier area. The multi-proxy centennial-scale climate data (pollen, organic matter and magnetic susceptibility) reveal two major dry-shifts (around 5900 and 2400 cal yr BP) suggesting the depleted monsoon and temperature rise in the region. Around these times, the probabilities of decrease in melt and hence the advance (or at least relatively decreased retreat) of Gangotri and associated glaciers is envisaged. The wet-shifts observed around 5200, 3600 and 1000 cal yr BP, however, indicate improved temperatures as well as monsoon, suggesting enhanced glacial retreats in the region.

Bedni peat deposit, Nanda Devi Bioreserve

Samples collected from peat deposits and lake sediments of the Bedni meadow (ca. 3600 m altitude) are being processed for various proxy records. The AMS ^{14}C date obtained for one of the peat profiles (3635-m altitude) indicates that, this site documents past 2500-year climate history of the region. The organic matter contents (LOI) and magnetic susceptibility data are generated; while laboratory processing of samples for pollen analysis is in progress.

5.2 SUB PROJECT

Geo-Database for Uttaranchal : an information system for environmental management and monitoring of Himalayan Geo-Resources.

(B.P.Sharma and A.K.L. Asthana)

Under the geodatabase project work was carried out on the geomorphology of Mandakini basin in the Lesser Himalaya of Garhwal Himalaya. Towards this, drainage morphometry was analyzed in terms of run-off, infiltration and susceptibility to erosion in the Mandakini basin. An attempt was also made to correlate drainage morphometry with slope and also altitude using topographical maps and satellite data. The hill slopes of the basin are characterized by stepped profile which represents phases of lateral erosion by the main river, vis-à-vis neotectonic activity. The satellite data analyses indicate that the present day valleyside slopes are shaped by the ongoing large scale mass wasting. The study was carried out in a GIS environment using the ARC/INFO GIS software.

Geomorphologically, the Mandakini basin is a complex terrain with two types of landforms - glacial and fluvial. The horn peaks, serrated ridges, cirques, and snow-clad slopes, hanging valleys, cascades, rapids and gigantic escarpments comprise the gorgeous glacial landscape of the Mandakini basin. Interlocking spurs, incised meanders, summit, rock benches and structural terraces represent the features of the fluvial regime of the basin. In the process of rejuvenation Mandakini basin stage shows several geomorphic changes. The gradient from the valley bottom to the mountain uplands varies from 640 m (Rudraprayag confluence of Mandakini and Alaknanda rivers) to 6940 m (snow-clad peaks in Kedarnath-Chaukhambha in the northern part). The various altitudinal zones comprised by the Mandakini basin and their characteristics are shown in Table 2.

Fluvial terraces are the most prevalent landform in the Mandakini basin. These are extensively developed around Guptkashi, Kalimath and Ghagali and most of them are paired. These terraces are presently occupied by thick forests of Oak and located 25 m above the present day river bed. The matrix is composed of gneissic and quartzitic rocks. Big boulders, pebbles and cobbles with fine material mainly derived from crystallines are also observed in the terrace deposits. The clasts are generally rounded indicating fluvial transport. A terrace has also developed along the road from Kalimath to Kotimaand appears to be older in the sequence of the terraces mentioned above. It is located about 10 to 15 m from the river bed.

In the fluvial terraces at Bainswara, Siyalsaur, Chandrapuri and Tilwara catchment processes related to climatic variations are discernible and could be between

Table 2. *Altitudinal zones of the Mandakini basin.*

Altitudinal Regions	Altitudinal Zones	Area in sq km	% of the area
Riverine Tracts	Less than 1000m	130.500	5.80
Mandakini hill Tracts	1000m-2000m	309.150	13.74
Hill Top Slopes	2000m-3000m	761.850	33.86
Mountain slopes	3000m-4000m	784.125	34.85
High Mountain Slopes	More than 4000m	264.375	11.75

cold and warm at different stages in time (Fig.29). In these terraces, a sequence of boulder deposits followed by fine clay deposits could be observed. At Siyalsaur and Chandrapuri three levels of terraces i.e. T_1 to T_3 (numbering from bottom to top) are observed. T_1 terrace is at 5 m, T_2 at 20 m and T_3 is at 40 m above from the present river bed.

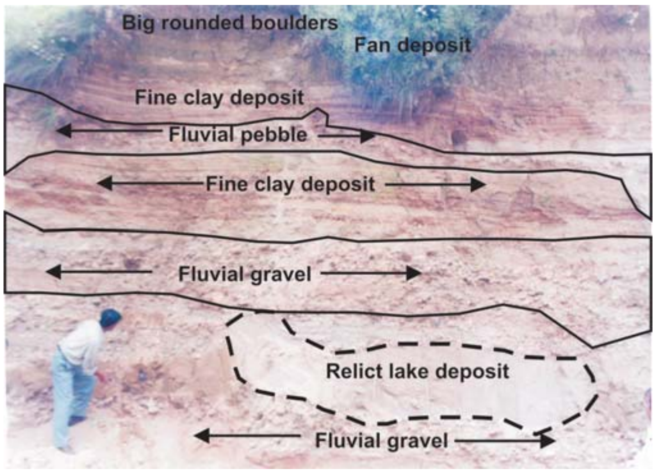

Fig.29. The climatic fluctuations in the quaternary deposits at Tilwara village in Mandakini basin.

Besides landform study morphometric drainage analysis of the Mandakini basin was also carried out.

5.3 SUB PROJECT

Tectono-climatic studies in Alakhnanda Valley near Deoprayag

(Pradeep Srivastava and R. Islam)

Alaknanda and Bhagirathi Rivers in NW Himalaya were studied to ascertain the aggradational and incision processes in different climato-tectonic setting. Observations in Alaknanda valley on the landslide dammed lake deposits at Srinagar indicated that these were located in the vicinity of the E-W and NW-SE trending south dipping North Almora Thrust (NAT) in the Alaknanda basin around Srinagar Garhwal. Preliminary observations suggest that activation of crumpled and unstable phyllite dominated slopes led to temporary damming of 2nd and 3rd order tributaries of Alaknanda River. Sedimentary styles of the succession indicate deposition under the transient lacustrine environment, with seasonality. Luminescence chronology suggests that the lakes were formed after the Last Glacial Maximum (LGM) and probably continued till the mid-Holocene time. Lake formation is attributed to sliding of phylite-dominated slopes following the reestablishment of the southwest monsoon after LGM. Presence of contorted laminas is interpreted as episodic events of seismic activity. The lakes eventually disappeared due to breaching of debris dams around mid-Holocene.

The Bhagirathi river at Dharasu was studied to understand the incision and aggradational dynamics of the river. Samples for geochemical analysis, Optically Stimulated Luminescence (OSL) dating and sedimentological studies were collected. The preliminary investigations and chronological results indicated that the river in the time spans of ~10 ka between 15-5 ka, formed four levels of terraces and it incised ~70 m in 9 ka at the rate of 7.8 mm/year.

5.4 SUB PROJECT

Evolution of Late Quaternary deposits in the NW Himalaya

(N. Suresh and Rohtash Kumar)

Preliminary studies were carried out in the Soan Dun to document the late Quaternary stratigraphic succession and associated lithofacies assemblage to understand the role of tectonics and climate in their development. The Soan Dun, a structural valley in the sub-Himalaya, is bordered by Soan Thrust in the north and detached Siwalik hills in the south. The Middle and Upper Siwalik formations are exposed in the hanging wall of the Soan Thrust. The Soan river and Sohan Nadi are the two axial rivers in the valley, originating in the hanging wall mountains in the north and flowing towards SE and NW direction respectively with the drainage divide falling in the western part of the Dun. The late Quaternary deposits in the Soan Dun show drastically different lithofacies as compared to adjoining Pinjaur Dun. The Soan Dun dominantly has predominant sand and mud alterations, whereas gravel dominates succession in the Pinjaur Dun.

The late Quaternary deposition in the Soan Dun is in the form of alluvial fan and fluvial deposits; fluvial deposits are dominant along the axis of the valley, whereas alluvial fans, which show interfingering with fluvial deposit, occur on both the flanks of the valley. Based on preliminary field survey, the exposed successions are 10 to 25 m thick and dominated by sand-mud litho-units with rare occurrence of gravel. The gravel units are common towards the top of the sections and have erosional contact with the underlain units. Few vertical profiles were measured between Daulatpur in the west and Una in the east. Apart from sedimentological observation, samples were also collected for luminescence dating, grain-size analysis and clay mineralogy. In this study, three prominent lithofacies association were observed which are

Fig. 30. (**a**) Vertical succession of late Quaternary deposit in the Soan Dun showing dominance of sand-mud facies (**b**) Thickly bedded, multistory grey sand having sheet geometry.

arranged vertically (Fig.30a). Facies association A comprises alternation of sand and silt-clay. The sand is fine-grained and grey to brownish grey coloured. The silt to clay grade mud is buff in colour and shows pedogenic alteration. Facies association B is characterised by thick, multistory, fine- to coarse-grained grey sand having sheet geometry with occasional pebbly sand in between (Fig. 30b). It shows development of calcretes along the bedding plane. Facies association C is similar to facies association A, but less pedogenic. This vertical variation suggests that drainage pattern changed through time. The facies association B reflects large braided stream deposit, whereas facies association A and C show meandering river pattern with well developed flood plains. This suggests either aridity increase from facies association A to B with humid phase further up section, or change in space accommodation. The late Quaternary sedimentary succession of Soan Dun is over-thrust by Middle Siwalik Formation along the Soan Thrust which probably resulted in the cessation of deposition in the Dun. Presently, the sedimentary pile is incised by the piedmont streams, originating from the hanging wall of the Soan Thrust as well as from the detached Siwalik hills.

6. NORTHEAST HIMALAYA

6.1 SUB PROJECT

Kinematic history of the thrust sheets and metamorphic evolution of the crystallines of Western Arunachal Pradesh.

(N.S. Gururajan and B.K. Choudhuri)

In Bhareli-Tenga valley sections referred to as Kameng sector in western Arunachal adjacent to Bhutan, the Lesser Himalayan Sequence (LHS) is bounded by MBT in the south and MCT in the north. The LHS consists of a narrow belt of Gondwana Group of sediments, occurring above the MBT at the base, is tectonically overlain by the Lesser Himalayan Buxa-Miri Group of sediments of Terminal Neo-Proterozoic to Lower Cambrian age, which in turn thrusted over by the Bomdila or Lesser Himalayan Crystallines. The MCT separates the footwall Bomdila crystalline of low to medium grade metamorphism from the hanging wall high grade Sela or the Higher Himalayan Crystallines. The Buxa-Miri sequence occur as a linear northeast trending belt between Tenga in the west and Daparizo in Subansiri sections in the east and also occur as a tectonic window around Rupa in this sector. The Buxa-Miri sediments composed of limestone, quartzites interleaved with slaty phyllites and basic volcanics occur at different tectonic levels within the LHC. These sediments are also known as Tenga and Dedza Formations and were included under the Bomdila Crystallines by earlier workers. The quartzite-limestone sequence exposed around Rupa in Tenga valley is redefined as Buxa-Miri Group, based on petrography and recently published work on sedimentology, palaeobiology, stable isotope and chemostratigraphic data by WIHG. The quartzite is deformed and foliated and thin elongated flakes of muscovite and minor chlorite define the foliation. The quartz grains are highly elongated forming ribbons that also define the foliation. Small recrystallised quartz grains ornament the margins of the ribbons. This microstructure in quartz aggregates suggests deformation at mid green schist facies conditions. A narrow belt of quartzites that overlies the Gondwanas in Kameng section is part of the Bomdila Crystallines. They are biotite rich micaceous quartzites, highly deformed and recrystallised and intimately associated with gneissic rocks. This band can be discontinuously traced towards the east and well exposed in Siyom valley section between Kaying and Bille.

The Bomdila or Lesser Himalayan Crystallines (LHC) that are well exposed in western Arunachal Pradesh in Kameng sector are bounded at the base by the Bomdila Thrust and at the top by the MCT. The LHC can be divided into lower and upper units. The lower unit consists of quartzites and phyllites with minor marble and basic rocks, tectonically interleaved with tabular bodies of granitic gneisses. The schist layers interleaved within the gneisses contain small, often rounded garnet crystals. The matrix consists of quartz, reddish-brown biotite, muscovite, minor plagioclase and opaques. The upper unit locally known as Dirang Formation that immediately lies below the MCT consists of garnetiferous mica schist (+staurolite,+kyanite)micaceous quartzites, calcsilicates, marble and boudins of amphibolites. This unit is about 5000 m in thickness and well exposed in Kameng valley of western Arunachal Pradesh adjacent to eastern Bhutan, which can be correlated with the Jaishidanda Formation that lies below the MCT in Bhutan (Dasgupta,1995). The lower unit can be correlated with the Shumar Formation (Dasgupta, 1995) or Daling-Shumar Group (Gansser, 1983) that lies below the Jaishdanda Formation in Bhutan.

The gneissic bodies mostly associated with the lower unit represent Proterozoic intrusive granites that were later deformed during India-Asia collision. The gneisses are dominantly represented by mylonitic augen gneisses and minor finegrained gneiss. A small body of deformed hornblende bearing granodiorite is exposed at salari having intrusive relationship with the surrounding gneisses and associated metasediments. The gneisses contain a well developed foliation (S_2) and a strong stretching mineral lineation and made up of quartz, K-feldspar, plagioclase, biotite and muscovite with secondary chlorite, epidote and Fe-oxides. The foliation (S2) is sub-parallel to the MCT and various kinematic indicators such as the S-C fabrics, asymmetric porphyroclasts, shear folds ctc., indicate top to south shearing under simple shear regime. The dynamic recrystallisation of feldspars and the occurrence of myrmykite around the feldspars indicate that the temperature of deformation (>400^{0}C) occurred under upper green schist or lower amphibolite facies conditions and the deformation continued under low temperature conditions.

Deformation microstructural analysis of the gneisses has been carried out in terms of polyphase aggregates which shows three end member types microstructural and mechanical behavior proposed by Handy(1996), based on natural tectonites and experimental deformation. As the Bomdila gneisses occur in the form of thrust sheet and pervasively deformed, undeformed portions are rarely exposed. The deformation microstructures in weakly deformed gneissic portion having higher amount of interconnected feldspar framework (with small volume propotion of weak minerals such as quartz and micas), has been deformed and disintegrated leading to the development of foliation. The foliation is generally parallel to the thrust boundary representing the shear plane. During continued deformation the strain was accommodated along the interconnected weak minerals and comprising dynamically recrystallised quartz. The micas aligned parallel to foliation induce geometrical softening. These observations suggest that the strain was partitioned from the initial feldspar supported to matrix supported rheology, thereby decreasing the overall strength of the deforming gneisses.

Major, trace and rare earth element analyses indicate that the gneisses are peraluminous, with S-type granite characteristics that must have derived from metasedimentary dominated sources, whereas the granodiorite is metaluminous, with I-type signatures. The granodiorite associated with minor precursor basic rocks is a rare occurrence in the whole of the Lesser Himalayan Crystallines that suggests its evolution from I-type source with involvement of mantle in their petrogenesis. Whether or not these acid intrusives are related to an orogenic event (Kameng Orogeny), but definitely during this period the northern continental margin of the Indian shield witnessed a regional thermal event involving both sedimentary and mantle materials.

6.2 SUB PROJECT

Lithotectonic terranes and neotectonic features between the valley of Kameng and Siang rivers, Arunachal Pradesh.

(D.K. Misra and Pradeep Srivastava)

Field and lab studies coupled with interpretation of topographic maps in the western Arunachal Pradesh reveal that the Kameng River cuts through the rising Siwaliks and forms four levels of tectonically uplifted alluvial terraces along a major 10 km long NW-SE trending transverse active fault namely the Bhalukpong Fault. The older terrace T_1 (240 m), the T_2 (220 m), the T_3 (200 m) and T_4 (150 m) above mean sea level have been observed along the western footwall side of the fault which in contrast to only one T_4 (150 m) present on the eastern side. This indicates that the western (Bhalukpong side) block across the fault has lifted up 90 m more in three pulses. The OSL dates of the sand samples collected from the alluvial cover of the T_1 and T_4 terrace are 13.9 ± 3.1 ka BP and 7.3 ± 1.0 ka BP respectively (Pradeep Srivastava, personal communication). This indicates that the alluvial aggradations on terrace T_1 started before 13.9 ka and incision is younger than 13.9 ka BP. The younger age of 7.3 ka from T_4 terrace indicate that the river experienced three episodic movements of tectonic uplift between 13.9 and 7.3 ka. Therefore, total uplift of ~90m occurred along the fault in 6.6 ka (13.9 - 7.3 ka). East of Bhalukpong, in the central part of the Subansiri valley, the 16 km long NW-SE trending Joram Fault lies within the Bomdila Group. Movements in the geologically recent time on this fault have caused blockade of the river Kale and resulted in the formation of a lake at Ziro. The lake is now vanished due to the neotectonic activity. The NNW-SSE trending Ziro paleolake deposits of 50 m thickness are exposed at an altitude of 1600 m above the m.s.l. The lacustrine deposits consist of thick carbonaceous layers towards the top underlain by alternation of sand, silt and clay with boulder bed at the bottom. The deposits extend for nearly 15 km and have a width of about 5 km. The peat associated with the carbonaceous layer capping the lake sediments has given ^{14}C age of 40,000 years (Kar et al. 1997). The OSL dating of alluvial terraces at Bhalukpong and ^{14}C date from lacustrine deposits at Ziro (Kar et al. 1997) suggest that the faults were neotectonically active during the Late Pleistocene-Holocene time.

The Kameng river in NE India was studied to compare the incision rates in NW and NE Himalaya, cuts through the rising Siwaliks, the frontal ranges of the Himalaya and forms four levels of alluvial terraces (Fig. 31). The geomorphic configuration and overlying alluvial

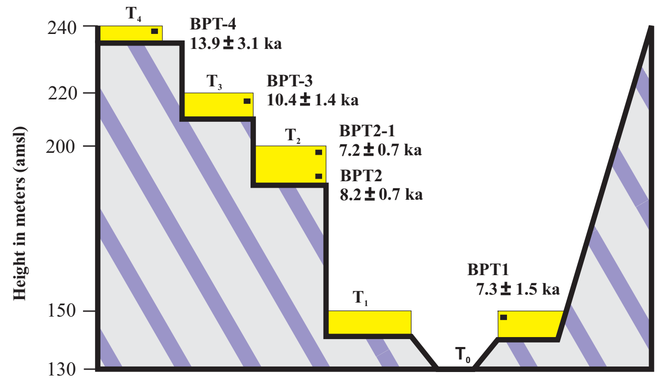

Fig.31. Terraces system of Kameg river, Bhalukpang, NE Himalaya

cover of each terrace was studied to decipher the uplift history of the Himalayan front and varying sedimentation style of the river.

The ratio of the thicknesses of alluvial cover and strath bedrock formed subsequent to incision phase was used as a measure of geomorphic instability (GI) and GI-Index was calculated for each incision and aggradation phase. It is suggested that the area was geomorphologically most unstable when the Kameng river incised terrace T_2-T_1. The luminescence chronology constrained this phase at ~7 ka. The older incision phases i.e. from T_4-T_3 and T_3-T_1 occurred at ~14 and ~10 ka respectively. The alluvial cover of the terraces is composed of four major lithofacies i.e. i) matrix-supported boulders, ii) clast-supported boulders, iii) parallel laminated medium sand, and iv) bioturbated fine sand. The vertical variation of the lithofacies indicated that the river flowed under braided conditions during the wet climatic conditions.

The study further suggested that Siwaliks in the area were uplifted 105 m during the last 14 ka at the rate of 7.5 mm/year. Considering the channel incision of 95 m from terrace T_4 to T_2 that occurred in the time span of ~8 ka between 14 and 6 ka suggested the uplift rate of 11.9 mm/year. Therefore, we suggest that the uplift rate of Siwaliks in the NE Himalaya may have been between 7.5 to 11.9 mm/year. The studies well corroborate with the published incision rates from the central Himalaya in Nepal.

6.3 SUB PROJECT

The terminal Proterozoic-Lower Palaeozoic sedimentation, palaeo-biological and carbon isotope events in the NE Lesser Himalaya.

(V.C. Tewari)

Field work was done in the Rangit valley, Sikkim Lesser Himalaya and the Seppa- Bhalukpong areas of East and

West Kameng districts in the Arunachal Himalaya. The Buxa-Lower Gondwana succession is well exposed around Namchi in south Sikkim and Rangit river in south and west Sikkim. The Buxa-Gondwana relationship was studied and it is established that the Buxa Dolomite is a Meso-Neoproterozoic carbonate succession with typical Riphean- Vendian stromatolites, microbiota and acritarchs (Fig.32). The Miri Quartzite is not exposed here and a probable continuous Lower Cambrian or PrecambrianCambrian boundary is missing as found in the Arunachal Himalaya. The Lower Permian Gondwana (Rangit/Tattapani Boulder Beds) are well exposed near Tattapani village. This sequence is also developed in Namchi- Maniram road section and Jorethang/melli section.

In the East Kameng district between Seppa and Palizi the Miri Quartzite is well developed. The thick marine section (tidalite) was studied with special reference to sedimentary facies variations and depositional environment. The purple-pink Miri Quartzite shows well preserved ripple marks, cross bedding, wavy bedding and skolithos burrows. The base of the Miri Quartzitze is exposed near a stream on Bana-Palizi section. The Lower Miri is made up of Lower Cambrian diamictite-tilloid beds of glacial origin and white quartzite of marine environment. Various sedimentary facies recognized are shaly facies (100 m), diamictite siliciclastic facies (600 m) with large scale cross lamination and ripple bedding, sandy facies (350 m) and pebbly-sandy facies (350 m) of fluvial-marine environment. The Miri Group is not the part of the Gondwana sequence exposed between Khuppi and road to Bhalukpong. The Gondwana black shales/coal beds within sandy layers contain plant fossils *Glossopteris* and *Gangamopteris.*

The siliciclastic marine facies of the Miri Group is suitable for the preservation of the trace fossils and a detailed investigation is required. The Miri Quartzite of the East Kameng, Subansiri (Kamla valley) and Siang (Nikte Quartzite) are identical in age, petrography, sedimentary facies and depositional environment. The Lower Cambrian sea was widespread in the Arunachal Lesser Himalaya. The Miri Quartzite is correlated with the Tal Quartzite (Lower Cambrian) of the Uttarakhand Lesser Himalaya. The more metamorphosed quartzite and volcanic sequence exposed in Siang valley near Panging is Lower Proterozoic in age (1800 Ma) and may be equivalent of the Berinag-Rampur Quartzite cycle. It should not be included in the Miri Group. Glacial palaeoclimate was dominant during the sedimentation of the Miri Group in the eastern Lesser Himalaya.

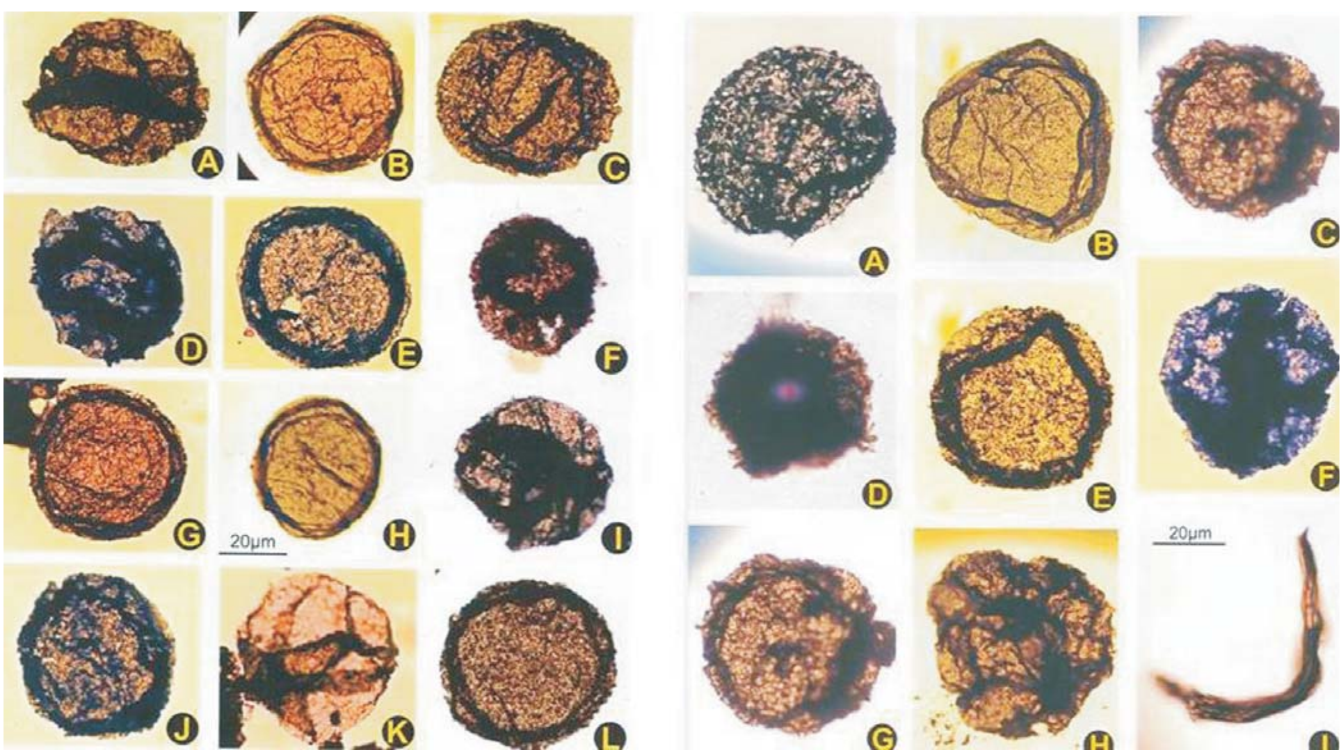

Fig.32. The diversified microbiota and acritarchs from the Buxa Dolomite, Ranjit Window, Sokkim Lesser Himalaya.

Detailed petrography was done on the Buxa Dolomite, (cherty oolitic dolomite and microbiota Fig. 32). The diamictites, orthoquartzite, quartz greywacke, quartzarenite of the Miri Group and diamictites, pebbly beds, sandstones of the Lower Gondwana were studied for the petrographic and diagenetic characters.

6.4 SUB PROJECT

Geochemical characterization and petrogenetic studies of Abor volcanics in Arunachal Himalaya.

(A. Krishnakanta Singh)

The continental flood basalt affinity of the Abor volcanic rocks cropping out extensively in the Siang window of the Eastern Himalayan Syntaxial Bend comprises predominantly tholeiitic basalt with minor alkaline basalt. The Abor volcanics are mainly composed of phyric and aphyric types with several agglomeratic flows. The pillows are predominantly associated with the basal parts of the basaltic flows (Fig 33a). The pyroclastics present a range varying from coarse agglomerates to volcanic bombs, lapillies and coarse ash (Fig. 33 b&c). The presence of spherical bombs and lapillies indicate that the liquid bled are sufficiently fluid when the molten lava was ejected. Alkaline basalt of the Abor volcanics of Arunachal Himalaya are characterized by the presence of alkali feldspar phenocrysts and absence of plagioclase phenocrysts; the groundmass is composed of clinopyroxene, microlite, alkali amphibole, apatite, titanite, feldspar, epidote, magnetite, ilmenite, exhibiting intergranular to intersertal textures with occasionally sub-ophiolitic texture. It shows significantly high values of TiO_2 (4.17-5.13 wt.%) P_2O_5 (1.27-2.34 wt.%), K_2O (1.72-5.06 wt.%), Rb (23.62-81.00 ppm), Sr (1226-2082 ppm), Ba (1289-2132 ppm), Zr (359-1049 ppm), Th (7.03-16.30 ppm); and depletion in SiO_2 (41.95-47.73 wt. %) Na_2O (1.42-2.20 wt. %), Al_2O_3 (10.25-12.84 wt. %) and Fe_2O_3 (9.99-11.43 wt.%), and therefore these are identified as high-Ti basalts with Ti/Y (>500). It has extremely enriched REE [?REE (515-719.83)] with strongly fractionated REE abundances [(La/Yb_N) = 26.34-44.10] and insignificant Eu anomaly (Eu/Eu* = 0.97-1.36). In the [Mg]-[Fe] plot these rocks show a gentle decrease of [Mg] with a steep increase of [Fe], a trend which implies that the rocks are related to one another by the extent of melting of the source or fractionation crystallization of olivine and clinopyroxene in a trend sub-parallel to [Fe] axis. Mantle metasomatism is considered as the main process for such enrichment of

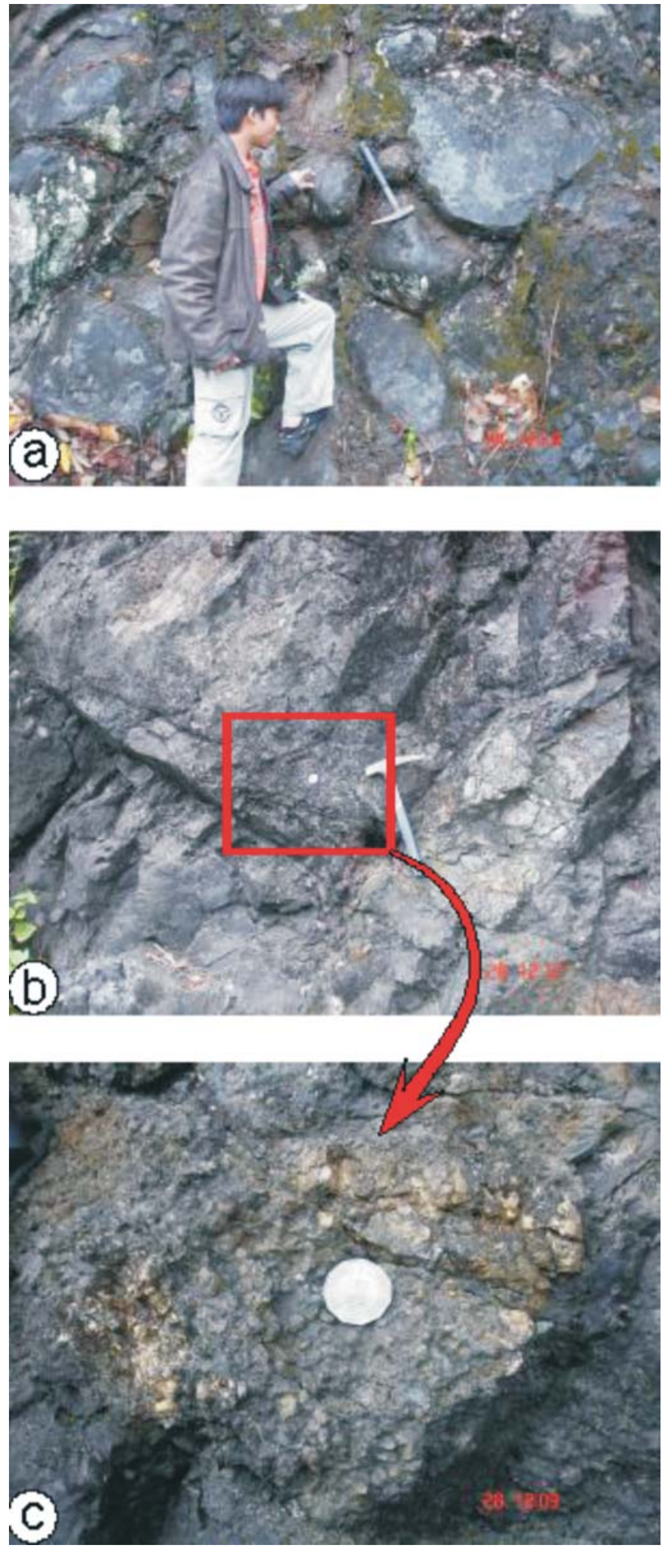

Fig.33. Field photographs showing (**a**) Pillow basalts (**b**) Lapillies (**c**) Close view of lapillies in Abor volcanics of Arunachal Himalaya.

source either by addition of melt or fluid phase. Geochemical and petrogenetic studies suggest that these rocks were probably derived from the non garnet-lherzolite/pyrolite metasomatised enriched mantle.

The Abor volcanics are traversed discordantly by acid dykes and numerous basic dykes trending N-S, NW-SE, NNE-SSW and are cutting across basaltic flows, quartzite, dolomitic-limestone. The acid dykes exhibit porphyritic and granophyric textures with quartz, alkali feldspar and alkali amphibole as essential minerals. Chemically, they range from dacite to rhyolite showing high SiO_2, Fe_2O_3, Na_2O+K_2O, Zr, Th, U, Nb, Y, Zr/Rb values and low in CaO, MgO, Ba, Sc values which suggest their crustal origin. The U (1.1-2.3) and Th (17.7-25.3) contents in these acid dykes and their ratios of Th/U (8.17-18.91) are higher than the upper continental crust. The dykes show high values of radioelement concentration (Ur = 15.5.-26.09) and high heat production (HP = 1.87-2.89 μWm^{-3}). The average total heat generation value of 5.33 HGU for these rocks is higher than the average value of 3.8 HGU for the continental crust; however, these values are lower than the value of 8.3 HGU obtained for the Peninsular India. The petrogenetic studies have inferred low degree partial melting of a crustal source rock for the generation of these acid dykes. Mafic dykes intruded within the Miri/Buxa formation of Arunachal Himalaya are basaltic in composition. They are aphyric and show intergranular, intersertal and predominantly consist of plagioclase, pyroxene, Fe-Ti oxides. They are subalkaline and tholeiites and characterized by depleted high field strength elements (HFSE) and Nb, P, Ti with low values of TiO_2 (1.59-2.82), Ti/Y (< 500), Zr (104-244), Zr/Y (3.92-9.03). The parental magma appears to have been derived from a subcontinental lithospheric mantle source with Fe/Mg ratio exceeding that of model pyrolite. On the basis of HFSE discrimination diagrams, it is suggested they were emplaced in the 'within plate' tectonic setting.

6.5 SUB PROJECT

Foraminiferal Biostratigraphy and Paleoecology of the Tertiary sediments of parts of Nagaland, Mizoram and Arunachal Pradesh.

(Kapesa Lokho)

Studies on foraminiferal biostratigraphy and paleoenvironment on the Bhubhans of Mizoram waere initiated. Except for few reports, no previous workers have worked in detail on the foraminiferal biostratigraphy and paleoenvironment of the Bhubhans. The present investigation revealed the presence of seven species, grouped under six genera belonging to planktic and benthic foraminifera. The assemblage contains Ammonia umbonata (Le Roy), Baggina sp., Clavatorella sturanii Giannelli and Salvatorini, Lagena sp., Orbulina bilobata (d'Orbigny), Praeorbulina glomerosa circularis Blow and Praeorbulina transitoria Blow.

Different views have existed on the age and paleoenvironment of the Bhubhan Formation of Mizoram. The present foraminiferal age markers belonging to planktic foraminiferal Zone N9 suggest Langhian (early part of Middle Miocene) for this part of the Upper Bhubhans of Mizoram. The concurrent ranges of Orbulina (spans from base N9 to Recent) and Praeorbulina glomerosa circularis (spans from base N8 to middle N9) suggest a confined age of Zone N9 (14.2-14.8 Ma) of Langhian, (Gradstein *et al.*, 2004). Earlier views on the depositional environments were of inner-neritic to shallow marine based on bivalves. The present work has set this with a relatively deeper paleobathymetry. The present recorded foraminiferal assemblage suggests a paleobathymetry of 60-80m (part of middle shelf) for this part of Upper Bhubhan Formation of Mizoram. The high percentage of planktic foraminifera (4:1) with benthic foraminifera suggests subanoxic/anoxic conditions of deposition for part of the upper Bhubhan Formation. Sediments deposited in subanoxic/anoxic conditions are considered as good source rock for hydrocarbon formation.

The foraminiferal assemblage described above is the first report from the Bhubhan Formation of Mizoram.

6.6 SUB PROJECT

Neotectonic investigation of a part of Arunachal Himalaya between MBT and HFF in East and West Siang Districts, Arunachal Pradesh

(S.S. Bhakuni and Khayingshing Luirei)

In the frontal part of the Eastern Syntaxial Bend (ESB) or the Siang Antiform, Arunachal Pradesh, the folded Main Boundary Thrust (MBT) and the Himalayan Frontal Thrust (HFT) system show recent tectonic activities. The NW-SE tending major ESB is a transverse structure with respect to the eastern Himalayan orographic trend of NE-SW. From the Quaternary times the Siang Antiform has been under SW-NE compression. The NW-SE trending Mishmi Thrust

(MT) has attenuated the eastern limb of the antiform. Merged with the MBT, the MT has thrust the Lesser Himalayan rocks over the recent sediments. The epicentre of the great 1950 Assam earthquake falls in the hanging wall (HW) of the MT.

Much of the shortening of the Lesser Himalayan rocks is accommodated near the base of HW of the high-angle MBT in the form of isoclinal folding and imbricate thrusting. Intense internal deformation is confined in a narrow belt along the base of HW. The Gondwana rocks occurring at the base of the hanging wall of the MBT have accommodated much of the deformation related to the movement along the MBT. Active hanging wall and footwall imbricate structures of the MBT have repeated the lithounits in space forming the tectonic horses. The active intraformational thrusts and faults within the Sub-Himalaya form part of the footwall imbricate zone of the MBT.

Along the segmented active HFT the Siwalik rocks have thrust over the Quaternary sediments. The Sub-Himalayan fault propagation folds show their curved hinges due to differential amounts of tectonic transport of hanging walls along the HFT thrust system. The straight ENE-WSW trending active dextral strike-slip Sompa Fault has shifted the major Siang river laterally. Normal faults are syn- to late-tectonic structures developed during late tectonic transportation of rocks along the MBT and HFT. Along active normal faults the loose cover material has been sagged down along the base of HW. The frontal neotectonic activity seems to be associated with the recent uplift of the Namche Barwa Syntaxis or crustal scale antiform, which has brought up the high-grade Indian basement rocks occurring in its core.

In the eastern Himalayan region, Arunachal Pradesh, the Siang river is also influenced by active lineaments. The sudden deflection in flow direction from NW-SE to almost E-W of the Siang river is noticeable south of Rengging village along a strike-slip dextral Sompa Fault. Paleochannel reconstruction suggests a gradual eastward lateral migration of the river, which shows a swing in its flow direction from N-S to present NW-SE. Drainage basin asymmetry vectors (T), calculated from transverse topographic profiles of Ledum-Pasighat transect, suggest southwestward ground tilting. T values range from 0.0 to 0.80 with mean vector 0.30 and bearing of 183°. The data are concentrated in the southwest quadrant. The successive eastward migration of the major river is due to normal faulting along the NW-SE trending Ranaghat Fault, including due to other relatively smaller discontinuous faults recognized in the field. These broadly eastern steeply dipping normal faults show their footwalls downthrown towards ENE. The Ranaghat Fault was active during the deposition of T_3 and T_2 fluvial terraces while at present it is passive as indicated by the development of T_1 terrace on either side of the Siang river.

Various types of soft sediment deformation structures were recognized in the fluvial deposit in Rotung, Siang river valley. The structures include folds, convolute beddings, water escape structures (pillar and dish) and up-warped beds, which are confined between two undeformed layers (Fig. 34 a&b). Sedimentary sequence consisting of laminated silts and sands have been disrupted due to liquefaction. These structures, formed during or shortly after deposition, may provide an insight to the recent past tectonic activity and its intensity. The structures are interpreted as seismic in origin on the basis of their morphology and pattern of occurrence.

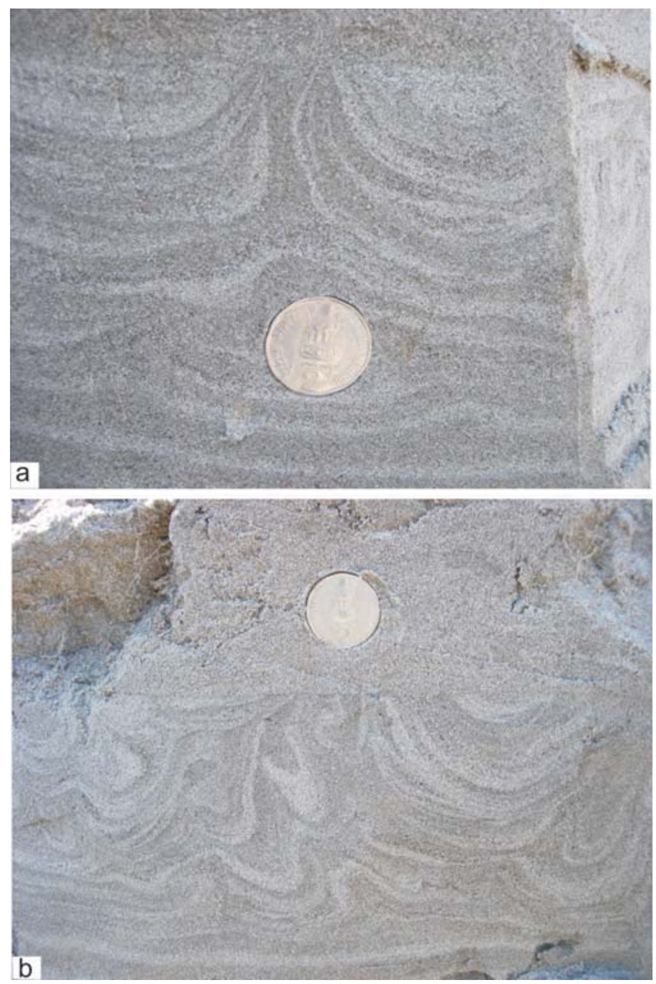

Fig.34. a&b Various soft sediment deformational structures developed in the Quaternary deposit, Rotung.

SPONSORED PROJECTS

PROJECT

Physics of Earthquake Process and Comprehensive Analyses of Multiparameter Observations for Precursory Research.

(Indo-Russian collaborative program under ILTP Scheme)

Indian Team:

(B.R. Arora, Naresh Kumar, S.K. Chabak, P.R. Baidya (IMD))

Russian Team:

(G. Sobolev, A. Ponomarev, A.D. Zevyalov, A. Lybushin, M. Gokhberg, V. Gitis, V. Smirnov, Schmidt Institute of Physics, RAS, Moscow, Russia)

The project aims to develop and apply a problem-domain oriented information technology for earthquake source characterization for better understanding on Earthquake preparation processes. The spatial-temporal analysis of multiparameter observations by new approaches and technology is envisaged to identify short-term earthquake precursory phenomena. As a first step, the seismic catalogue for NW Himalaya has been compiled and tested for completeness using the 'MagUnif' software. The results show the catalogue has been uniform for earthquakes of magnitude 4.3 in the post-1963 period. With the introduction of eight seismic stations by WIHG in the year 1984, this minimum detection threshold has reduced to 3.8. In the post-1999 Chamoli Earthquake, threshold was further lowered to 2.0 as some of the stations introduced for aftershock studies continue to function. The applications of developed geo-information technology and their retrospective interpretation have helped to draw-up the following conclusion:

- Space distribution of these data has helped to identify seismic regimes in western Himalaya with intense zones centered around Kangra, Rampur-Kinnaur, Garhwal and Kali River sectors.

- Geo-informatic technology has been used for complex spatial-temporal analysis of Earthquake occurrences. Earthquake of magnitude six and above are concentrated in a narrow belt, commonly referred to as Himalayan seismic belt that is marked by rough topography where RMS of elevation changes range ~ 550 meters. In seismo-tectonic models, this zone is viewed as a ramp structures in the detachment zone separating Indian plate and overriding Himalayan wedge. GPS measurements help to view this belt as a locked section where strains are accumulating continuously.

- The test applications of RTL algorithm have indicated a strong precursory signature of 1999-Chamoli Earthquake of M 6.6. Similarly the time variation of b-value in the Guttenberg Richter relations indicates reduction before the 1999-Chamoli Earthquake (Fig. 35).

- Space-time distribution also reveal well-defined period of quiescence before the 1991 Uttarkashi and 1999 Chamoli Earthquake (Fig.36). Analysis of time frequency spectrum structure of main shock has been applied for deducting hidden periodicity. Statistical significant increase of periodic component has been identified within the moving time window of the length 4 years before the 1991- Uttarkashi and 1999 -

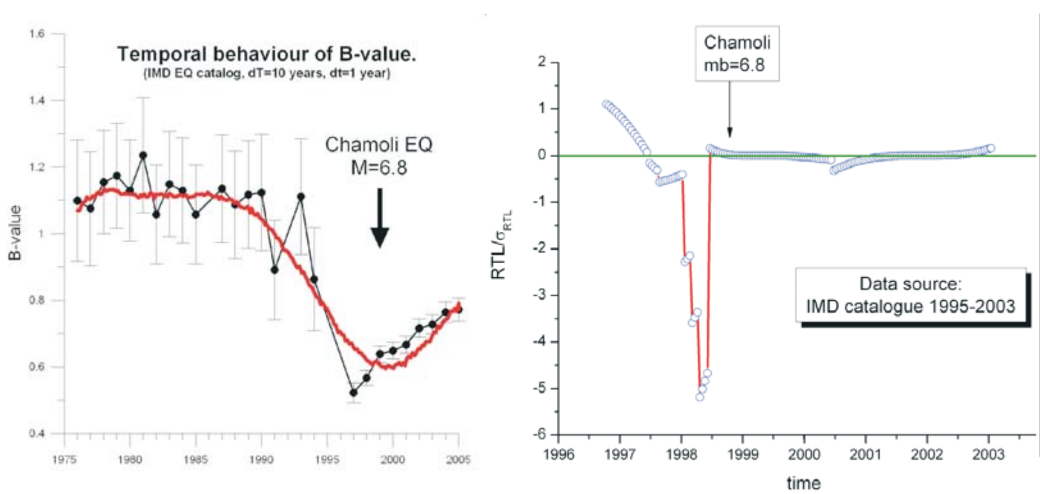

Fig. 35. Precursory signals of Chamoli Earthquake using B-value and RTL algorithm.

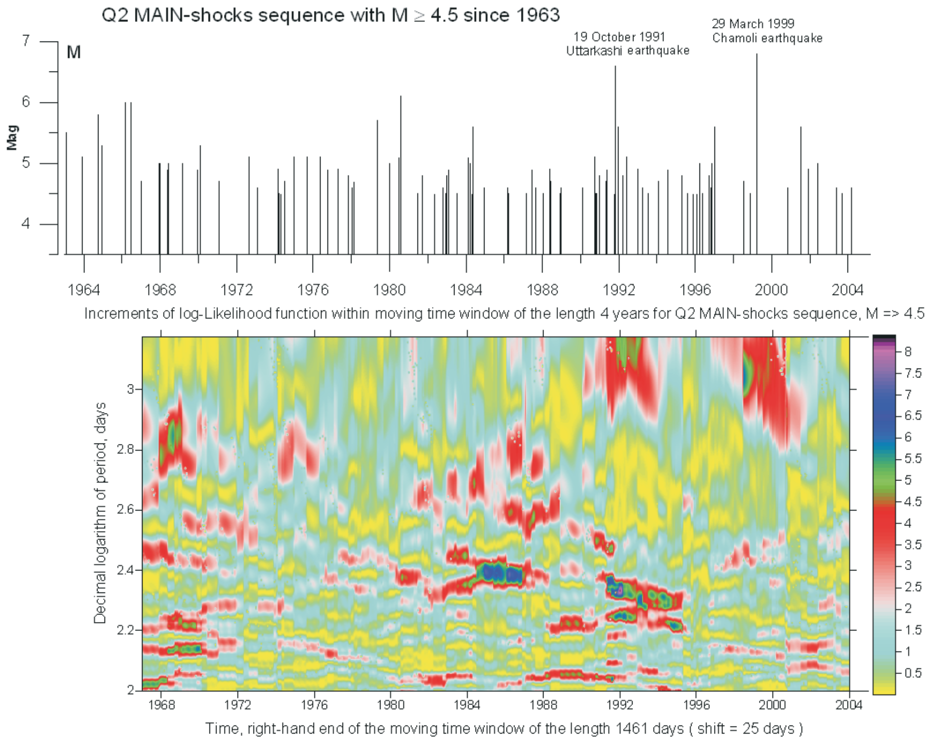

Fig. 36. Time frequency spectrum analysis of Seismic events for Precursory studies.

Chamoli Earthquakes.

- Wavelet Analysis has been applied on the digital date of three components for 199 events to characterize the dominant waveforms, which help to characterize the different source mechanisms of earthquakes of NW Himalaya.

PROJECT

Electrical Conductivity Imaging of Uttaranchal Himalaya

(DST sponsored project under the Seismicity program)

(B.R. Arora and Gautam Rawat)

With the objective of mapping deep subsurface in terms of electrical resistivity and define the subsurface geometry of known tectonic boundaries in Uttaranchal Himalaya, Magnetotelluric data was collected at 18 stations with inter-station spacing of 10-15 kms along Bijnaur to Mallari profile. The stability of frequency dependent impedance tensor, calculated from measured electric and magnetic fields, is known to be function of natural electromagnetic source fields. Since the period of survey scanned the solar minimum, these natural EM fields were very weak and thus necessitated longer occupancy. Five-day occupancy at each site ensured improvement in the estimation of impedance tensor at periods greater than 500 sec at most of the stations. However, at few stations electric field recordings were very noisy perhaps due to unbalanced power network of the region. This reflects in larger error bars in estimated impedance tensors.

Initial data analysis for few stations indicates the validity of 2-D approximation with N45W as regional geoelectric strike. The TM mode inversion of five stations impedances, on the southern part of the profile, using Nonlinear Conjugate algorithm of Randie and Mackie, allowed to image the resistivity-depth distribution as shown in figure 37. Very remarkable feature in this model is a dipping conductive layer at a depth of 20-30 km beneath the sites. This is perhaps the detachment plane separating the down going Indian plate from the overriding Himalayan wedge. The high conductivity is due to fluids released by dehydration reactions and squeezed from down going sediments in the compression regime. The high conductivity perhaps simulates the brittle-ductile transition and, thus, explains the confinement of crustal seismicity to the brittle part above. Another important feature of resistivity-depth distribution is that it helps to trace the geometry of HFT, MBT and MCT in the depth section. The on-going dimensionality analysis of the data of all 18 stations and more recently acquired data from another profile from Pilibhit-Malpa along the Kali-river

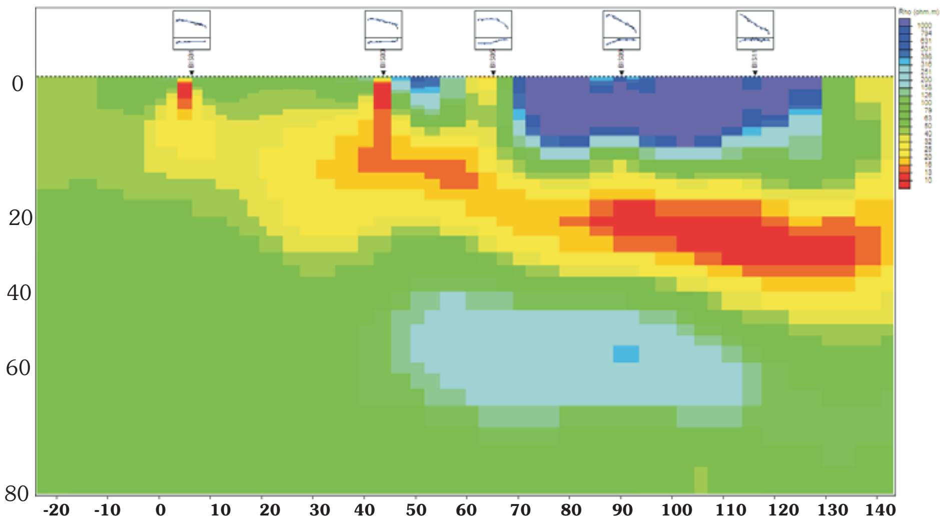

Fig.37. The electrical resistivity-depth distribution along the southern part of the Bijnaur-Mallari profile. The low-resistivity zone defines the detachment plane separating the down going Indian plate from the overriding Himalayan wedge.

valley will permit to map the generalized tectonic setting of collision zone.

PROJECT

Multiple Geophysical Investigation around Eastern Himalayan Syntaxes

(DST Sponsored Project under DCS program

(B.R. Arora, Gautam Rawat, V. Sriram and Dilip Yadav)

With the objective to probe deep subsurface in terms of electrical resistivity and velocity structure around Eastern Himalayan Syntax region, a multidisciplinary program with the sponsorship of DST under "Deep Continental Studies in India" has been started.

Although limited in spatial extent, the syntaxial region provide distinctive setting to understand the various tectonic processes associated with plate collision, particularly the extensional and shear tectonics related to the indenter corner. The operational activities of the project involve magnetotelluric surveys and passive seismology experiment. The program is launched by the deployment of 12 Broad Band Seismometers as well as MT measurements along the Lohit valley transect (Fig. 38). Due to steep slopes, dense and thick forest cover and limited spatial extent, the selection of sites has been a challenging task. However, the deployment phase of the program is successfully accomplished and nature of data recorded is satisfactory. Magnetotelluric data acquisition at

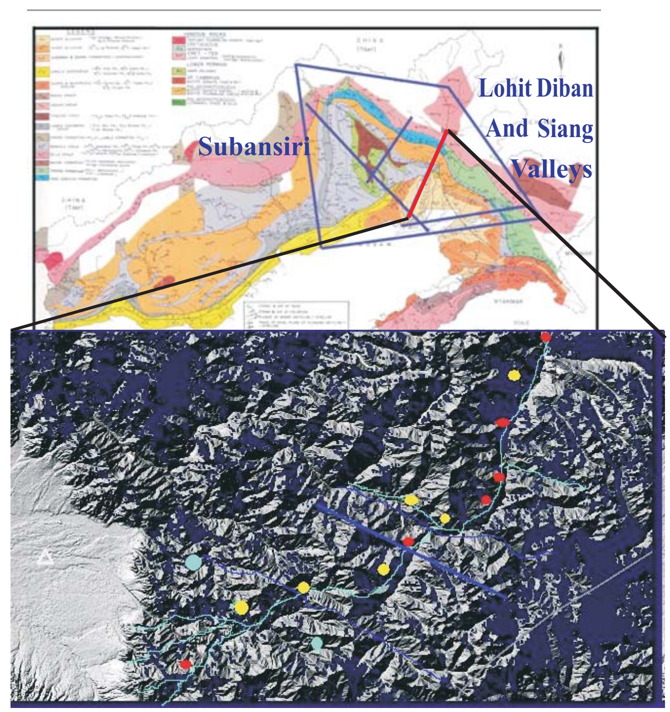

Fig.38. Magnetotelluric and broadband sesismometry investigation along the NE systaxes of Arunachal Pradesh.

11-sites were measured with 3-day occupancy at each site from Teju to Walang along the Lohit Valley Profile. Initial observations of MT time series indicate strongly polarized current channeling in one direction and weak signal in other direction.

PROJECT

Multiparameteric Geophysical Observatory for Earthquake precursor studies

(DST Sponsored Project under Seismicity Program)

(B.R. Arora, V.M. Choubey, Ajay Paul, Rajesh S., Gautam Rawat and Naresh Kumar)

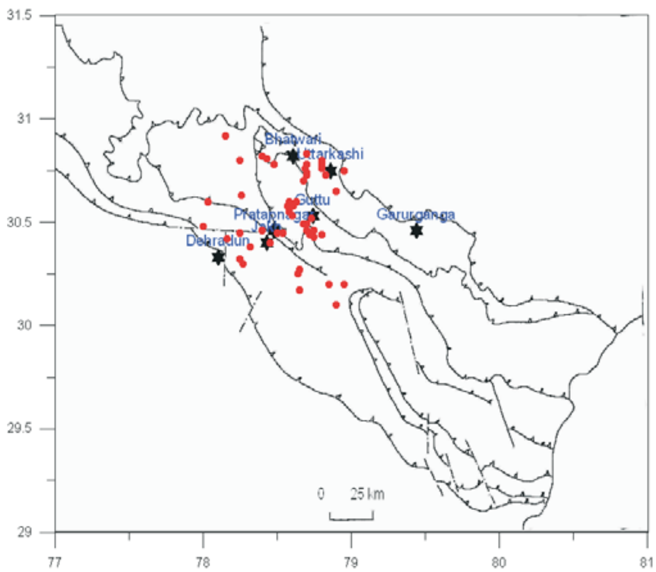

Fig. 39. Seismicity around Ghuttu MPGO Observatory.

Establishment of Multiparameteric Geophysical Observatory in Ghuttu region for studying earthquake precursors in integrated maaner is India's first attempt in this direction. Laboratory studies have shown that impending zone of seismicity goes through characteristics changes in the physical properties of rocks during the earthquake cycle. These changes are revealed in perturbation of physical properties of rocks. The project aims in the detection of these changes and studying their correlation with associated earthquakes if any. The MPGO observatory is equipped GPS, BBS, Accelerograph, Radon data loggers, water fluctuation, atmospheric temperature and pressure monitoring, rain gauges, Digital fluxgate magnetometer, Overhauser magnetometer, ULF band Induction coil magnetometer, Declination and Inclination magnetometer and Super conductive Gravimeter. All the instruments are installed, tested and functioning continuously.

Seismic Activity

Figure 39 shows the seismicity plot for the duration of Aug 2006- Dec 2007 as per events recorded in MPGO Ghuttu. However for location of earthquakes, other station data was also incorporated. It is clear that choice of the site for precursory studies is quit suitable, as area is seismically active. Space-time distribution of micro-seismicity can prove effective in identifying zones of quiescence whereas temporal changes in Vp/Vs ratio could be effective way to ascertain nature of stress accumulation beneath the observing site.

Crustal deformation studies

The GPS unit is currently functioning in dual supply power mode with sufficient battery backup and has squarely prevented the instrument from going off. One set of campaign survey was carried out with all rover GPS units along with the CORS-GPS in the observatory campus. This was done mainly to check the signal reception quality, multipath effect, antenna visibility, visual identification of various satellites in the Antenna sky plot etc. Processing of acquired data is currently in progress by utilizing the existing facilities.

Crustal magnetization and resistivity changes

All the components of magnetic fields are being monitored since Aug 16, 2006 to decipher stress induced changes in the magnetization of rocks whereas the transfer function summarizing the relationship between vertical and horizontal time varying magnetic field components would serve as useful guide to monitor temporal changes in resistivity. Magnetometer data is being analyzed with reference to campaign mode and continuous mode of observation along Tehri reservoir to remove the variations due to external origin. Analysis of ULF band magnetometer data shows the clear evidence of Schumann resonance in MPGO site indicating the good quality of data. Daily spectrograms are calculated and data is filtered in various bands for studying any abnormal changes. It was observed most of the signal is below 5 Hz. Recently azimuth of reference pillars were established by survey of India. These Pillars will be used as a reference mark in calculating Declination and Inclination at the site twice a day.

Radon and ground water fluctuations

Two bore holes one 68m deep and other 12 m deep were drilled at Kopardhar to monitor continuous radon and water level fluctuations beside that other probes to measure atmospheric temperature & pressure, water temperature and rain gauge were also installed at the same site. Presently, radon is monitored using three radon probes at Ghuttu observatory. The first radon probe is installed at 50 meter depth (submerged in water) the second probe is placed at 10 m depth in the same bore hole and the third probe is placed at 10m depth in12m deep borehole. All the parameters are recorded at 15-minute interval. In order to simplify the data processing the primary radon time series with measurement at a 15-minute resolution is decimated (averaged) to 1-hour and 1-day resolution. Radon time series contain cyclic diurnal variations. These were investigated by using the FFT spectra from one time series representing different intervals. Cyclic constituents are clearly observed at 1 and 2 cycles per day (diurnal = 24 hours and semidiurnal = 12 hours). A 24-hour cyclic variation and higher harmonics are known in various time series of earth and planetary science phenomena. In order to draw any conclusion based on the time series spectrum of radon and other parameters more data is needed**.**

During this year the project passes from the phase of construction of housing as per the specific requirement of each geophysical parameter and performance testing to the real time monitoring phase.

PROJECT

Telemetered Seismic Monitoring of Garhwal for developing hazard scenario in Uttranchal

(DST sponsored project under the Seismicity program)

(Ajay Paul and B.R. Arora)

Himalaya is one of the seismically most active regions of the world. Accumulating seismic data indicates large lateral variability along the length of the Himalayan arc with numbers of well defined zones of high seismicity. Garhwal Himalaya, particularly the Uttranchal part, is presently active and has experienced 2 earthquakes of magnitude greater than 6 in recent years, 1991-Utarkashi and 1999-Chamoli Earthquakes. The area also lies in the seismic gap and GPS data exhibit that region is critically stressed. The region was being monitored only by regional network. Recognizing that space-time distribution of microseismicity provides important clues on the reactivation of the faults, dense seismic network has been the need of the hour. Further, a proper azimuthal coverage is basic perquisite for reliable estimates of earthquakes parameters, a key to search and establish linkage of seismicity with tectonic features. With an objective to provide adequate instrumental coverage to the critical stressed areas of Uttranchal to delineate vulnerable seismic source zones and active fault zone for proper seismic hazard assessment, a 10-station VSAT linked network of Broad Band Seismometer has been established under the DST sponsored project. The locations of the sites in the background of tectonic

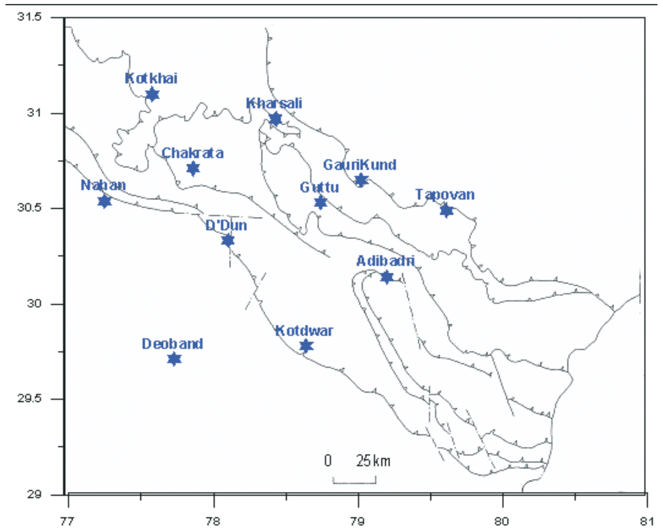

Fig. 40. VSAT Linked BBS Seismic Network.

elements are shown in figure 40. Aperture and sites are selected to provide regional coverage and with couple of sites located to remote locations, north of the narrow Himalayan seismic belt, should ensure reliable estimation of the earthquake location parameters, particularly the depth of hypocenters. Almost all sites satisfy the noise levels to the USGS prescribed limits. A recent 4.9 M Kharsali earthquake of July 23, 2007 has provided the testing ground for this telemetered seismic network. Given the real time availability of data, earthquake parameters were calculated in short time of 30 minutes. More significant is that the epicenter was located to an accuracy of better than 3 km and hypocenter better than 5 km, an improvement by a factor of 3. The source mechanism from a first fault plane solution shows a reverse fault mechanism with a significant strike slip contribution. It is expected that introduction of this real time monitoring system will greatly enhance our understanding of the seismotectonic of the region and will help to meet the societal needs by providing timely information to disaster and mitigation managers.

PROJECT

Neotectonic-Active tectonics of 1905 Kangra earthquake meizoseismal region I Kangra and Soan Dun in Himachal Pradesh, NW

(DST-Seismicity Programme)

(V.C. Thakur)

To understand the morphogenic nature of large to great earthquakes, like 1905 Kangra earthquake, Quaternary geological mapping was carried out in Kangra area in hinterland and Una Dun in foreland of the Sub-Himalaya of Himachal Pradesh. In the hinterland, the Jawlamukhi

Thrust (JT), which brings lower Siwalik over the Middle and Upper Siwaliks, trends NW-SE and of regional dimension. Banganga river flowing NE-SW across Kangra, Jawalamukhi ridge and Guler show the development of 2 levels of terraces. The strath terraces on the hanging wall side are at a higher level than on the footwall of the Jawalamukhi Thrust. Can this thrust (JT) be the causative fault for the 1905 Kangra earthquake? Detailed mapping and dating of terraces will be undertaken to determine the slip-rate and uplift-rate. A NW-SE trending active fault was identified south of the MBT. A trench along the active fault will be excavated to find the occurrence of paleoearthquake and signature of 1905 Kangra earthquake.

In the foreland, Quaternary geological mapping was done in the Una Dun. Structural data were collected across the Frontal Siwalik Range (FSR) to analyse the geometry of Janauri Anticline (JA). The Quaternary mapping included mapping of terraces, drainage pattern, paleo-river channel and flood plain deposits. A Digital Elevation Model (DEM) of the Una Dun and adjoining areas was generated using Indian CARTOSAT-1 stereo pair satellite data. From this data the morphometric indices are being extracted using GIS softwares for identifying active tectonic structures. 12 samples of post-Siwalik Soan Dun sediments were collected for OSL dating. One trenching site along the HFT was identified for paleoseismological study.

PROJECT

Active Faults and Neotectonic Activity (with reference to Seismic Hazards) in Parts of the Frontal Himalaya and the Piedmont Zone Between Satluj and Yamuna (AFNAH)

(DST-Seismicity Programme)

(N.S. Virdi and G. Philip)

Studies carried out on the morphotectonic evolution of the Soan, Sirsa, Bata, Markanda and Giri river valleys to establish the active tectonics and its influence on the tectonic tilting of the basins. The data on morphotectonic parameters such as basin asymmetry factor (AF), transverse topographic symmetry factor (T) and ratio of valley floor to valley height (VF) was calculated and earlier results confirmed with more readings using 1:50,000 scale base maps. The new data corroborate the data reported earlier. More parameters are also being applied to work out the active and tilted nature of the basins.

The data on Parduni basin is now being refined and OSL data are being analysed for material from some fans and terraces affected by Bata Fault, Panchbhaya Thrust and the N-S bounding faults in the basin.

The Jalmuse fan which blocked the channel of Vedic Saraswati resulting into Uttamawala -Katasan High and creation of Bata and Markanda as separate basins was dated at about 25 ka using OSL method on fan material. This and few earlier published C^{14} dates (20-28 ka) revealed that Kiarda Dun segment of the Dun valley experienced major faulting activity around 20-25 ka ago which continued up to 10 to 12 ka B.P. These data clearly call for re-evaluation of the timing of the drying up of the Saraswati, shifting of drainage of Markanda and Bata and opening of the Yamuna tear to provide exit for the Yamuna river approximately 5000 years ago as proposed by some workers. We feel that these events could have initiated around 10 ka ago and culminated around 5 ka.

PROJECT

Petrogenesis and Tectonic Significance of Igneous Rocks Associated with Permian Argillites of southeast Karakoram.

(DST-Deep Continental Studies)

(H.Rai and D.R. Rao)

The Karakoram micro-plate is the southern most sector of the Central Asian micro-plate mosaic which was separated by narrow rift basin. A major rifting phase, however, started during Permian time which drifted not only Karakoram but whole of the Eurasian (Asian) Plate from the Gondwana land. This was the time when a huge thickness of black argillites occupied most part of the Karakoram Tethys basin. Geodynamic setting for this sequence may be interpreted as the evolution of a passive margin affected by extensional activities. The extensional activity is evident in the form of the extrusion of basalts and komatiitic rocks in the region.

Detailed geochemical studies of komatiites and basalts of the Chhongtash, southeast Karakoram were carried out during the year. It was found that the basaltic and komatiitic (ultrabasic) flows are petrologically and geochemically distinct, yet they display a close spatial and temporal association, and related with each other through olivine and clinopyroxene fractionation. The chemical characteristic of ultrabasic to basic magmatism in the region is consistent with formation above a mantle plume that impinged on the continental lithosphere. Hence, a model of partial melting in a mantle plume and fractional crystallization in a deep-seated magma chamber is envisaged to explain the evolution history of these volcanic rocks. The komatiite melts are interpreted to have been derived by high degree partial melting of mantle plumes in the tail region, while the basalts were interpreted to be the result of interaction of source plume with cool mantle through which the plume head passes. The studies carried out are first of its kind to suggest rift related nature in the Chhongtash, southeast Karakoram, that represents the initial stage of Mesozoic rifting along the southern margin of the Eurasia when the Gondwana land started drifting away from the Eurasia.

PROJECT

Evolution and Radiation and Extinction of Cambrian Trilobites from the Zanskar and Spiti Himalaya: Morphometric and Statistical approach

(DST-SERC Studies)

(S.K. Parcha, Shivani Pandey and S. V. Sabnis, (IIT, Bombay))

Field was carried out in different sections in the Spiti valley. One section in the Spiti valley was measured and detailed sampling carried out. Observation on sedimentary structures was also documented. The material was scanned and one trilobite genus was selected for detailed morphometric/biometric analysis. The details analysis of the fauna is underway. The image analysis software was installed and a total of thirtytwo cranidial variables were measured for the specimens in order to create multi-parametric data for statistical analysis. Besides, detailed analysis of the fauna in the lithostratigraphic column is also underway.

PROJECT

Integrated Stratigraphic and Paleontologic Study of the Trilobite bearing Cambrian Tethyan Himalaya

(NSF-National Science Foundation, USA)

(Paul Myrow, Nigel Hughes, S.K. Parcha and Sanchi Peng)

Field was carried out in the Kumaon and Dehra Dun in Uttarakhand for understanding the biostratigraphic evolution of the region. Our work in the Kumaon did not yield any Cambrian trilobites, despite documentation of a trilobite from the early 20th century from the same location. The metamorphic grade was slightly too high for abundant preservation. The section in this region is the along-strike equivalent of those in other parts of northern India that we have worked previously, and although we were not able to measure a bed-by-bed section, we were able to work out the basic stratigraphy. We managed to collect a variety of Ordovician macrofossils, including trilobites, and also collected a suite of samples that will be analyzed for detrital zircon ages. We spent several weeks working on the Gopichand ka Mahal section near Dehra Dun. We measured a considerable part of section in two quartz sandstone formations of the Tal Group. As inferred by us (Myrow et al., 2003) that these were the near shore equivalents of the Tethyan Himalayan Cambrian deposits was subsequently confirmed by our sedimentological analysis of these units which indicates that they are primarily fluvial lithofacies. Drafting of sections and plotting of paleocurrent data are in progress. We processed a sample of possible bentonite at Sam Bowring's lab at MIT and it appears that it contains mostly detrital zircons.

PROJECT

Mineralogical and Geochemical Studies of Sediments from the Kakara-Subathu Succession (Paleocene to Middle Eocene), NW Himalayan Foothills.

(DST-SERC-Earth Sciences)

(N. Siva Siddaiah)

Geochemistry of Dogadda ooidal ironstone from late Paleocenemiddle Eocene Subathu Formation, NW Himalaya was studied. The ooidal ironstone is iron rich (36.3-59.6 wt %) and silica (13.2-33 wt %) poor. It has high abundance of Zr, (201-716 ppm), Nb (11-42 ppm) and REE (REE 236-340 ppm). The LREE/HREE ratio expressed as $(La/Yb)_N$ varies from 6.83 to 20.92. Chondrite-normalised REE patterns indicate that despite variations in contents, the samples studied have similarities in REE patterns. They show a steep LREE slope and a rather flat HREE trend. The $(La/Sm)_N$ ratio, indicating the fractionation of light REE, is fairly uniform for all samples, ranging from 2.51 to 4.44. Heavy REE are much less fractionated as is indicated by low ratios of $(Gd/Yb)_N$ varying from 0.98 to 2.39. The most distinct feature recorded in the chondrite-normalised REE patterns is the negative Eu anomaly (Eu/Eu = 0.6-0.87). The REE features of the Dogadda ooidal ironstone are in good correspondence with the REE patterns reported for Phanerozoic oolitic ironstones and also are similar to the REE patterns reported for volcanic ash fall deposit from similar stratigraphic level elsewhere in the basin. The rare earth patterns with respect to North American Shale Composite are shown in Figure 41. In the shale-normalised REE patterns, detrital beds will have a broadly horizontal profile, while samples with volcanic component (ooidal ironstones) display more variable profiles. Similarity of the REE patterns and the incompatible trace element contents of the Dogadda ironstone with those of volcanogenic tonstein present at similar stratigraphic positions in the basin strongly suggest that they share a similar source. Volcanic ash by

SPONSORED PROJECT

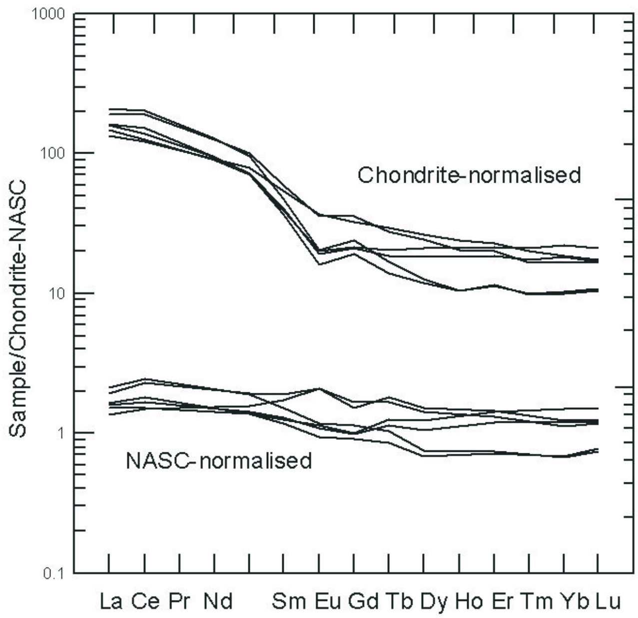

Fig.41. CI-Chondrite- and NASC-normalized REE patterns for the Dogaddaooidal ironstone samples.

direct fallout and/or fluvial reworking was an important source of Fe, Al and Si required for berthierine formation. These sources promoted the authigenic or early diagenetic formation of berthierine in the Subathu Formation indicating a link between volcanic activity and ooidal ironstone formation.

PROJECT

Himalayan School Earthquake Laboratory Programme (HIMSELP)

(DST-Seismicity Programme)

(A.K. Mahajan)

The Department of Science & Technology, Government of India, has initiated a project on Himalayan School Earthquake Laboratory Programme (HIMSELP) under Mission Mode Project on Seismology for Northwest Himalaya and Northeast Himalaya regions. The Wadia Institute of Himalayan Geology has been the nodal agency for implementing this project in NW Himalaya and Delhi area. Under this programme, 58 schools have been covered with the installation of seismographs. The training of teachers had been provided in 2005 and the data are flowing in regularly from all these schools. Among the 58 schools, 25 schools each have been working with these instruments in Himachal and Uttarakhand, three schools in Leh region and five schools in National Capital Region. Five schools selected from NCR are: DPS, R.K. Puram.; DPS, Dwarka; Tagore International, Vasant Vihar; Hill Wood Academy, Preet Vihar and Heritage School, Rohini. This programme has provided an opportunity to school teachers and children above Class X onwards to understand some basics of earthquake processes and measurement of earthquakes using seismographs. Thus, we have been able to achieve the target of public awareness and to inculcate the culture of measurement among school students in earthquake prone areas. Different exhibitions and stalls have been displayed in different schools for awareness among school children on earthquake processes and recording of earthquake.

On the eve of April 4, 1905 Kangra Earthquake centenary, Wadia Institute installed a stall for exhibiting seismographs along with poster of earthquake processes at Shimla organized by district administration for participatory and interactive learning and an opportunity to students and teachers in attaining higher levels of conceptual development in earthquake science.

PROJECT

Rock Properties Laboratory -A NationalFacility

(DST- Earth Science)

(Vikram Gupta)

The project titled "Rock Properties Laboratory - A National Facility" was initiated with the aim of creating standard facility for: i) the measurement of P and S wave velocities in the rock samples under the laboratory condition, ii) to train students and researchers in the measurement and interpretation of rock properties, and iii) to eventually develop a database on rock properties and make it available on a public domain.

During the year fabrication of seismic velocity measuring unit by procuring various technical components viz. Transducer, Pulsar, Receiver, Oscilloscope, BNC cables and connectors, Sample holders, PC, etc. was carried out. Concurrently, granite samples from different segments of the Himalaya were collected and analyzed for magnetic, physical and chemical properties. Based on available geochemical data, these granites have seen classified into four categories i.e. i) granites associated with subduction magmatism, ii) granites associated with continental magmatism, iii) Proterozoic granites of lower crustal origin, and iv) granites associated with Pan African thermal event.

The magnetic rock properties, density and seismic velocity measurements were carried out to investigate whether the four different varieties had distinctive properties that could help to isolate source magmatism for these granites. The work is still continuing.

PROJECT

Petromineralogical and Geochemical characterization of the Ophiolite suite in Manipur, North Eastern India

(DST- SERC, Fast Track Young Scientists Scheme)

(A. Krishnakanta Singh)

The Manipur Ophiolite Complex (MOC) is a discontinuous and allochthonous body with NNE-SSW trend parallel to the Indo-Burmese Orogenic Belt (IBOB). The Complex consists predominantly of well-preserved mantle sequence of tectonised peridotites and cumulate ultramafics (harzburgite, lherzolite, wehrlite, dunite, sepentinite) with mafic intrusive (gabbro, dolerite), volcanic rocks (basalt, spilite) and pelagic sediments (cherts, cherty quartzite, limestone). At places, Podiform and layered with minor massive types of chromite occur and mostly associated with serpentinite and serpentinised peridotite. Harzburgite is the dominant variety while wehrlite is a rare variety which is greenish black to blackish in colour with hard and compact medium grains. Harzburgite shows interlocking grains of olivine, orthopyroxene and some opaque minerals. Olivine is highly fractured and transformed to antigorite and alteration is seen along the fractures and boundaries of the grains which are replaced by serpentine. Subhedral form of bronzite is the main constituent mineral of the rock. Schillerization in the rocks is due to the presence of iron inclusions in the mineral. Enstatite is a dominating mineral in orthopyroxene. Opaque minerals are differentiated into chromite and magnetite through ore microscopy studies. Lherzolite essentially composed of olivine, orthopyroxene and clinopyroxene and opaque minerals as accessory and shows hypidiomorphic granular texture. At places, tabular grains of orthopyroxene (enstatite or bronzite) shows corroded margins within the larger grains of clinopyroxene. This feature suggests that the sequence of crystallization was olivine-orthopyroxene-clinopyroxene. In wehrlite, olivine and clinopyroxene are abundant where clinopyroxene is represented by diopside and augite. Most of the clinopyroxene grains are fractured which may be an indication of high degree of shearing. Orthopyroxene is represented by few grains of enstatite and bronzite which exhibit strain by the presence of lamellae and extinction of undulose. In dunite, xenoblastic granular texture is interlocked to show diffused grain boundaries. At places, dunite exhibits mesh texture and sheared dunite shows high degree of alteration to serpentines and release of opaque granules. Granules of magnetite and chromite are found arranged in linear fashion along the border and fracture networks of olivine grains.

The ultramafic rocks exhibit a restricted range of chemical composition, with usually low SiO_2 (40.49 - 48. 21 wt. %), TiO_2 (0.02-0.12 wt. %), Na_2O (0.46-0.50 wt.%), K_2O (trace to 0.01 wt.%), P_2O_5 (0.02 wt.%), Nb (1.2 -1.8 ppm), Y (0.4-3.7 ppm), Zr (1-3 ppm) with high content of MgO (32.11-39.17 wt.%) and compatible trace elements like Sc (4-15 ppm), V (25-244 ppm), Cr (2697-3907 ppm), Co (73-156 ppm) and Ni (1909-3583 ppm). The elements such as Th, U and Pb, generally associated with continental crust, are very low in concentration. The CaO/Al_2O_3 relation in the ultramafics indicates their CaO-enriched nature, with Al_2O_3/CaO ratio of <1. They range from sub-alkaline (Nb/Y = 1.07-4.66) to alkaline (Nb/Y = 0.35- 0.93) affinity of abyssal peridotites. All the samples have high loss on ignition (LOI), reflecting extensive serpentinisation of olivine and orthopyroxene. The high Mg # with enrichment of Cr, Ni, Co and strongly depleted Ti suggest that the rocks were refractory residual fragments separated from mantle derived magma.

Pillow basalts have been reported from the MOC (Fig. 42 a,b,c&d). The pillows are closely packed together or individualistic and they vary from 5.0 cm to 0.5 m in diameter, and undeformed spheroid to flattened ellipsoids in shape. The presence of pillow structures indicates sub-aqueous nature of volcanism. The pillow basalts are ranging from silica under saturated to silica saturated with respect to SiO_2, with high concentration of Al_2O_3, Ni, Cr and low concentration of TiO_2 and P_2O_5. Their chemistry suggests that these basic volcanic rocks are sub-alkaline and tholeiitic in composition. Petrographical and geochemical data indicate that pillow basalts of MOC are derived from a common source at higher degree of

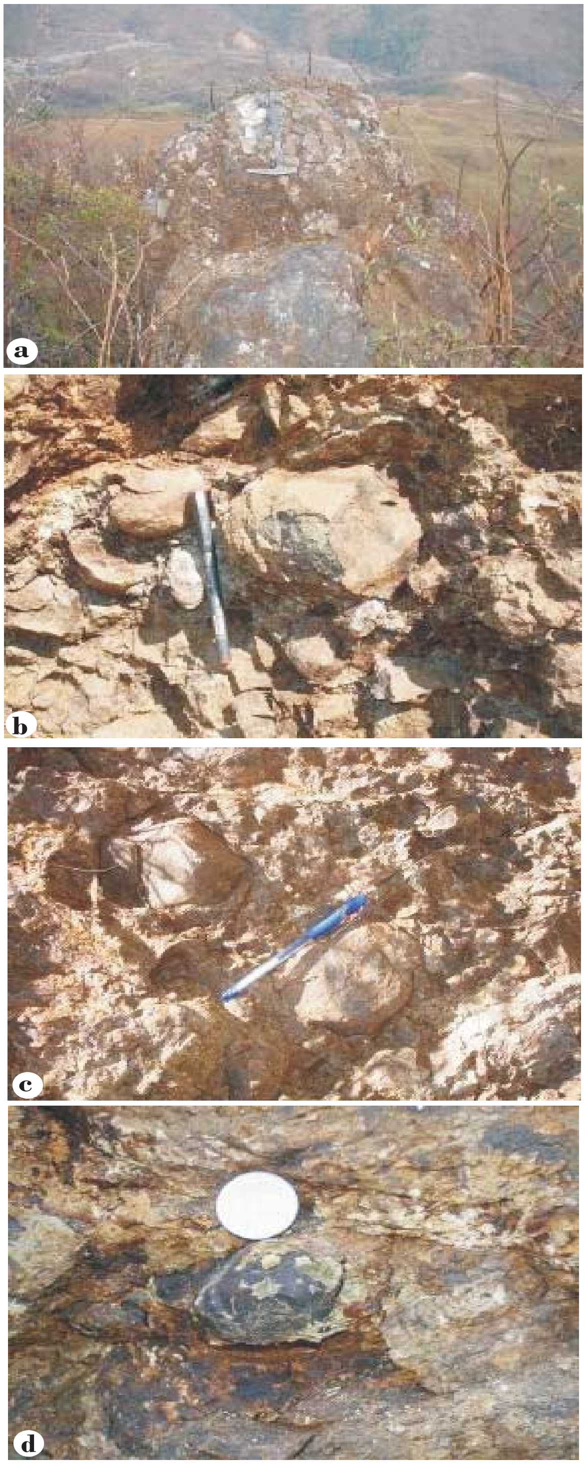

Fig.42. Field photographs showing (**a**) highly fracture Pillow basalts (Lat. 28°05' N & Long. 95°22' E); (**b**), (**c**) and (**d**) show Pillow basalts are closely packed together and separated from each other (Lat. 28°07' N & Long. 95°26' E) in Manipur Opholitic Complex, Northeast India.

partial melting and possibly emplaced in a plate margin environment which could be in back arc basin of an oceanic environment.

PROJECT

Development of district database center for Champawat District, Uttaranchal

(DST- NRDMS)

(Bhagawat Sharma , A.K.L.Asthana and Suman Lata Rawat)

Using Geographical Information System (GIS) the four blocks of Champawat district, namely, Pati, Barakot, Lohaghat and Champawat were studied for optimizing the present utilization of natural resource, forest distribution, landuse, slope stability, infrastructure distribution and socio-economic status. IRS TM data were used to cross examine the district blocks that have contrastingly different setup and presently undergoing deforestation due to unsustainable human activities. ARC/INFO was used for generating thematic maps and these were superimposed on different combinations for delineating the final output. The thematic maps are used for decision support and planning of the district. One of the thematic maps for the target area, where soil erosion and consequent slope instability vulnerability exists, soil conserving plants species have been recommended. The high rate of gully erosion and active river network was attributed to local geological conditions that host highly fractured and weak lithology type. The morphometric analysis was also done to determine the role of external forces on the landforms. The maximum drainage density was observed near streams actively engaged in gully erosion. Based on above data (thematic maps) appropriate remedial measures have been suggested to ensure sustainable development of the district without altering the present agricultural and irrigation pattern.

Under the socio-economic theme the demography, occupational pattern, land holdings, developmental activity, education, health, communication, transport, general amenities, electricity, drinking water, landuse and irrigation and cropping pattern parameters were covered. The relevant data have been collected from various agencies during field work and compiled on prescribed computer compatible format to facilitate desired computerization retrieval and dissemination to users.

PROJECT

Neotectonic with special reference to delineation of active faults in the foothills of Papumare district in Arunachal Pradesh.

(DST- SERC, Fast Track Young Scientists Scheme)

(R.K Mrinalinee Devi)

Lineament analysis of the study area was conducted by using satellite imagery. It was observed that major trends are found to be along the ENE-WSW, NE-SW and NNE-SSW occupying 34.04%, 21.92% and 11.30% respectively, while the minor per cent trends are E-W, WNW-ESE, N-S, NW-SE and NNW-SSE occupying 9.5%. 8.3%, 5.8%, 5.14% and 3.95% respectively. The analysis has shown the regional structural trend of the study area. The newer trends i.e. NW-SE. N-S and E-W have now started developing along the present day lower order streams indicating neotectonic activity.

Relative relief map (Fig. 43) using Smith's (1935) method of slope analysis shows seven classes of the relative relief in the study area. These are: i) <100 m, ii) 100 m 300 m, iii) 300 m 500 m, iv) 500 m 700 m, v) 700 m 900 m, vi) 900 m 1100 m, and vii) >1100 m occupying 3.04%, 33.73%, 23.36%, 20.97%, 13.08%, 4.76% and 1.06% respectively.

Transverse topographic basin symmetry map (Fig. 44) based on Cox's (1994) method was prepared to obtain a quick look on identifying possible tilting elements in neotectonic regions using only topographic map. The study revealed that the asymmetry vectors are randomly distributed signifying well disturbed nature of the study area. The accumulation of stream migration is directed mostly towards the northeast and southeast direction being controlled by the regional structural deformation

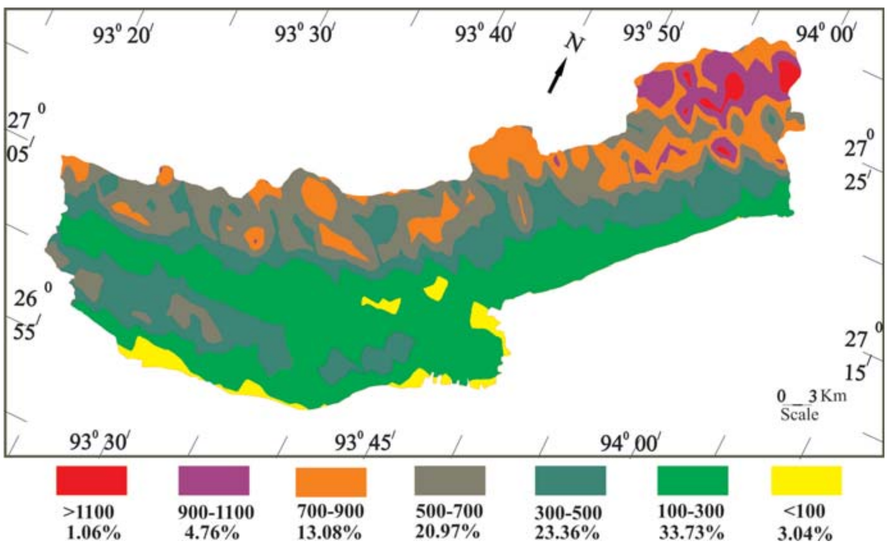

Fig.43. Relative Relief of the foothill region of the Papumpare district, Arunachal

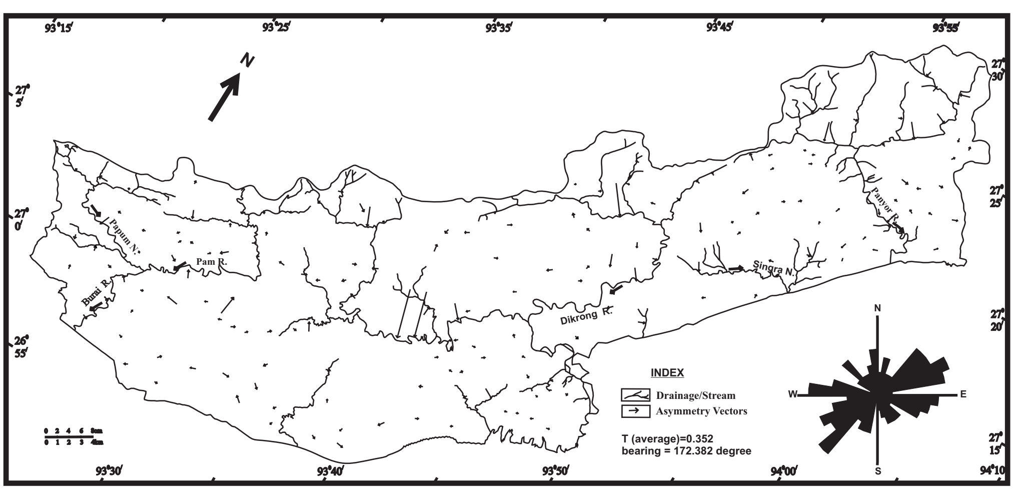

Fig.44. Transverse topographic basin symmetry of the foothill region of the Papumpare district, Arunachal Himalaya with rose diagram.

along the ENE-WSW to NE-SW. This is contributing mostly to the higher order streams, while the average mean vector magnitude and bearing of the whole basin shows the preferred direction towards the southeast. This shows the accumulation of the lower order streams migrating toward the newer deformational trend of NW-SE giving rise to the average asymmetry vector towards SE.

The average asymmetry vector T is 0.352, 172° directed towards southeast as observed by taking 183 numbers of active meander midline segments of 2 km and 5 km each. T value ranges from 0.33 to 1 indicating varying degree of asymmetry of the study area. Average T value along the frontal margin of the study area ranging from 0.359 to 0.390 also indicates the asymmetric nature of the frontal margin. The average asymmetric vector was also found along the southeast direction as followed by the present day streams draining out from the mountainous region indicating deformational trend of NW-SE direction.

Mountain front sinuosity

This reflects the balance between erosion that tends to produce irregular or sinuous fronts and tectonic forces and create a straight mountain front coincident with an active range bounding fault.

In the study area, the Smf value was found to be 2.17 signifying active nature of the mountain fronts. The frontal part of the study area has been divided into three segments viz., i) Panyor R. to Dikrong R. (Smf=2.46), ii) Rangajan N. to Balijan N. (Smf=1.75), and iii) Segmented part of the Burai R (Smf=2.14). The Smf values indicate the activeness of the mountain front region. However, the higher value of the Smf in segment 1 could be attributed to the fast eroding unconsolidated nature of the lithology of the frontal region.

Active Faults

Most of the active fault trends are found to be aligned along NE-SW, NW-SE and E-W to ESE-WNW direction in the foothill region of the Papumpare district. In Kimin section along the NW-SE trending fault scarps the pebble and sandstone beds are found to be dipping in SE direction in the frontal margin, whereas within the Siwaliks the sandstone beds are found to be dipping towards the north, and in-between streams are found to be deflecting to E-W to ESE-WNW direction for some extent before resuming their southward flow. This suggests the stressed conditions being followed by the streams. The NW-SE trending faults uplifting the Quaternary deposits are representing the active faults. Middle Siwalik

Fig. 45. A right lateral fault displacing Middle Siwalik sandstone bedding for 30 cm in a N-S movement near the frontal part of the study area.

sandstone bed displaced by 30 cm by a right lateral fault in N-S movement is also observed near the frontal part of the foothill region (Fig. 45).

PROJECT

Hazard Zonation and Risk Assessment of the Landslide Affected Areas between Banderdewa-Gohpur in Itanagar Capital Complex, Arunachal Pradesh, using GIS and Remote Sensing Techniques.

(DST-SERC Project)

(Trilochan Singh)

Detailed geological map of Itanagar Capital Complex was prepared. The geological investigations suggest that the area is highly fragile and geodynamically active mainly because it is sandwitched between three tectonically active boundary thrusts, viz., Bomdila Thrust (BT) in the north, and Main Boundary Thrust (MBT) and Himalayan Frontal Fault (HFF) in the south. In fact, the MBT is concealed here by the Bomdila Thrust sheet. These thrusts have contributed significantly in the development of the landforms. In addition, uplifted terraces, triangular facets, fault scarps, discordant drainage pattern and active landslides, which are present in the Capital Complex, are some of the evidences suggesting neotectonic activity in the area. The tectonic factor and landform setting together contribute to the landslide problem in the area. In such terrain, particularly with rugged and immature topography traversed by faults and thrusts, the sediments have become fractured and pulverised, which in turn are highly susceptible to slope failure. Further, various features, such as geomorphological attributes, prolonged rainfall, unconsolidated nature of soft sediments, rapid erosion (both by surface run-off and toe cutting by active river action), fast weathering and hill slopes act in a combined manner to render the area prone to the landslides.

Risk assessment shows that most of the Itanagar urban area falls under the Low Hazard to Moderate Hazard category, and a few under High to Very High Hazard category. So far as NH-52A is concerned, its Banderdewa-Itanagar sector falls under Low to Moderate Hazard category, and its Chimpu-Solangi sector falls under High to Very High Hazard category. Efforts were made to highlight the landslides hazard problem in the Workshops and Conferences organized in this region.

PROJECT

Ultrahigh-Pressure Metamorphism in Tso-Morari Region, Ladakh Himalaya: Implications for Deep Crustal Processes in Himalaya.

(DST-Deep Continental Studies)

(H.K.Sachan)

The chemistry of eclogite reveals SiO_2 abundances vary little between ~45 and 48 wt% displaying basaltic composition. Although these rocks show alkaline to sub-alkaline nature based on TAS classification, they are strictly sub-alkaline based on Nb/Y ratios which varies between 0 .14 and 0.51; majority of these are <0.20. Their TiO_2 and FeO (t) indicate high Ti-Fe basalt characteristics. Rare earth and multi-element patterns display enriched characteristics similar to OIB-E-MORB but with negative Nb and Sr anomalies, and erratic behavior of Rb, Ba and K. The whole rock $^{87}Sr/^{86}Sr$ ratios vary widely between 0.70884 and 0.73721 probably indicating variable interaction with the host granitoid with $^{87}Sr/^{86}Sr$ ratio of 0.92547. The LILE and Sr ratios appear to have been perturbed by post-crystallization processes. Whole rock $^{143}Nd/^{144}Nd$ ratio varies from 0.512136 to 0.513063 with e_{Nd} (t=0) values varying between +3.3 and +8.3, indicating their derivation from depleted sources. These are similar to the adjoining N-MORB (~+9) and OIB (~+3) of the Zildat Ophiolitic Melange of the Indus Suture Zone. On the other hand they are very different from those of the Phe volcanics (eastern extension of the Permian Panjal volcanics) with e_{Nd} (t=0) values of 2.73 and 8.68 but with similar trace elements and Sr ratios.

Seven zircon grains were studied from diamond bearing eclogite and gneisses of ultrahigh-pressure rock unit in Tso Morari Crystalline Complex, Himalaya. Zircons were separated and mounted in epoxy resins. It is ~ 40-120 µm in diameter having extremely variable internal and external structure. The eclogite zircons are small and sub-rounded to irregular while gneissic zircons are wavy in outline. It exhibit relatively patchy core and oscillatory zoning in the rim. The rim portion is having progressive occurrences of mineral inclusions from biotite to cpx-omphacite. It is observed that the zircon has inherited core having Th/U ratio >0.5 of typical magmatic type. On the contrary the outer part reflected by the re-crystallized zircon domains have low Th/U ratio as low as <0.1, which is typical of metamorphic growth zircon indicative of pre- and post-eclogitic phases. It was also noticed that the textural relationship between zircon blob around megacryst rutile in omphacite convincingly clues for metasomatism at or near peak metamorphism i.e. P>39 kbar, T>750^{0}C, as is well supported by the prior observation of microdiamond from the Himalaya. The close association of ompdol as indicative of UHP and the presence of biotite may perhaps be the source for new zircon. Moreover, the study showed that the leading edge of the Indian plate may have suffered thermal event at the diamond forming depth.

PROJECT

Biostratigraphical study of the Upper Palaeozoic-Mesozoic Succession of the Eastern Karakoram and its Correlation with Adjacent Regions

(DST-SERC-Earth Sciences)

(K.P. Juyal)

The following conclusions have been drawn from the biostratrigraphic studies carried out on the Upper Palaeozoic-Mesozoic succession of the eastern Karakoram and its correlation with adjacent regions:

- The lower and upper Shyok areas in Late Mesozoic were represented by the two different basins that evolved in different times and were occupying areas to the south and to the north of Karakoram Batholith.
- The uppermost marine sedimentary units in the lower Shyok area were deposited during early late Cretaceous time (Aptian-Albian) in a transgressive and regressive cycle. The final regression of sea from the area occurred at the end of Albian owing to India-Asia collision.
- The lowermost Member-1 of Burtsa Formation was deposited in upper Triassic followed by Member-2 in Jurassic to lower Cretaceous. The uppermost i.e. Member-1 of the Burtsa Formation was deposited in ? Lower Cretaceous. The sea withdrew from the area in ? post early Cretaceous (? end of Barremian) time.
- The sea was closed earlier in the upper Shyok area than the lower Shyok area as suggested by the present

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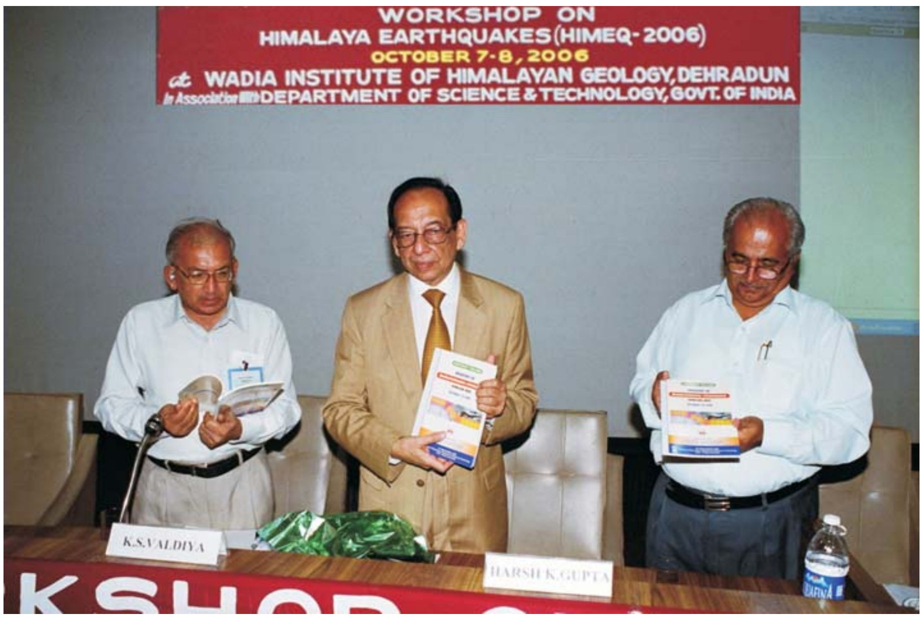
SEMINAR/SYMPOSIA/WORKSHOP ORGANISED

(a) Workshop on Himalaya Earthquakes (HIMEQ-2006)

Wadia Institute of Himalayan Geology organized Workshop on Himalayan Earthquakes: A Fresh Appraisal on October 7-8, 2006. The workshop was inaugurated by Dr H.K. Gupta, Raja Ramanna Fellow, who also gave an overview of the Muzaffarabad earthquake. The main aim of the workshop was to provide platform to take stock of our current understanding of geodynamic processes causing devastating earthquakes in the Himalayan collision zone and to identify strategies for filling the knowledge gap, need for up-gradation of monitoring systems and evaluating hazard potential to suggest mitigation measures.

The technical sessions of the workshop covered forty two research presentations, including overview lectures by eminent scientists. About 65 participants from various organizatios like, Wadia Institute of Himalayan Geology, National Geophysical Research Institute, Survey of India, Indian Institute of Geomagnetism, RRL Jorhat, Kashmir University, Garhwal University, Banaras Hindu University etc. participated in this workshop.



Chief Guest Dr. H.K. Gupta releasing Abstract volume during HIMEQ 2006.

(b) National Seminar on Active and Fossil Suture Zones and the Annual General Meeting-2006 of the Geological Society of India

Wadia Institute of Himalayan Geology organized 'National Seminar on Active and Fossil Suture Zones' and the Annual General Meeting-2006 of the Geological Society of India, on November 22-24, 2006. Dr Harsh K. Gupta, Raja Ramanna Fellow, National Geophysical Research Institute and General President of Indian Science Congress-2007 was the chief guest and inaugurated the seminar. Prof C. Leelanandam, F.N.A., delivered a special key note address on Suture Zones.

The Seminar included two days technical discussions on the Suture Zones followed by one day proceedings of the Annual General Meeting of the Geological Society of India. The technical sessions of Suture Zones covered about ninety research presentations including invited talks by eminent earth scientists and thirty-nine oral presentations. About one hundred participants from various organizations like IIT'S, Wadia Institute of Himalayan Geology, Geological Society of India, Geological Survey of India, NGRI, Indian Institute of Geomagnetism, India Statistical Institute, Rajasthan University, Osmania University, Mysore University, Bundelkhand University, Kumaun Unversity, Allahabad University and BHU participated in this event. One day proceedings of the Annual General Meeting of Geological Society of India included invited talks both by eminent earth scientists and young researchers. One day field excursion was also organized to the Krol-Tal succession of the Mussoorie Syncline.

Chief Guest Dr. H.K. Gupta along with Prof. C. Leelanandam and Prof. B.R. Arora sharing the dias during the inaugural function of seminar on Active and Fossil Suture Zone -2006.

(c) Discussion Meeting on Tectonic Geomorphology: Landform Evolution and Quaternary Tectonics

A Discussion Meeting on Tectonic Geomorphology: Landform Evolution and Quaternary Tectonics" was organized by Wadia Institute of Himalayan Geology on November 10-11, 2006. The objective of this meeting was to evolve a research programme on Tectonic Geomorphology which has become an emerging area of research both at national and international scene. Tectonic Geomorphology involves an integrated and interactive research of several disciplines, like structural geology, tectonics, geomorphology, geochronology and sedimentology. It has direct relevance for better understanding the causes and processes of natural hazards and environmental change. In inaugural session of the meeting, Dr. B.R. Arora, Director, WIHG welcomed the participants, and Dr. V.C. Thakur gave an introduction to the meeting. Dr. M. Prithiviraj, DST, in his remarks described the DST perspective and Prof. S.K. Tandon, Chairman, PAC, presided over the meeting.

The meeting was attended by 25 participants from different organizations like IIT, Kanpur; CMMAC, Bangalore; GSI, Lucknow; M.S. University, Baroda; Jammu University; BSIR Jaipur; RRL College Bhuj; IIRS, Dehra Dun and Wadia Institute of Himalayan Geology Dehra Dun. The Discussion Meeting was conducted in four technical sessions. In Technical Session-I, presentations were made on individual proposals under three heads, namely, the Western India Tectonic Province, the Northwest Himalaya Tectonic Province, and the Northeast-Himalaya/Region Tectonic Province. After the presentations, discussion followed in Technical SessionII to identify the major/principal areas of researches/projects and research teams. It was decided to have the principal projects and their sub-projects on the following topics: i) Himalayan Front, ii) Himalayan Hinterland, iii) Kachch basin, and iv) Shillong Plateau and Arunachal Himalaya Front.

(d) Third Module of SERC School on Crustal Deformation and Tectonic Geomorphology (Modern Structural Geology and Tectonics)

The Earth System Science Division of the Department of Science & Technology, Government of India is conducting a five year cycle of the SERC School Programme on "Crustal Deformation and Tectonic Geomorphology". The third module under this was organized at Wadia Institute of Himalayan Geology, Dehra Dun on February 6 to February 20, 2007. The theme of the Course was, "Modern Structural Geology and Tectonics with Special Reference to the Himalaya". The Course was inaugurated in a modest function by Dr. B. R. Arora, Director, Wadia Institute of Himalayan Geology. An overview of the third module was presented by Dr A. K. Dubey.

A total of 30 candidates from various universities, IIT'S and research organizatins attended this programme. During the Training Programme, a large number of resource persons lectured and interacted with the participants. The faculty consisted of renowned scientists from various universities and institutions including Wadia Institute of Himalayan Geology. Three days field work along the Main Boundary Thrust and the Himalayan Frontal Fault was organized for the participants. The field training included structural mapping, terrace mapping through EDM (total station mapping), identification of tectonic scarps and suitable sites for GPR survey, sampling for OSL dating and anisotropy of magnetic susceptibility studies. The GPR profiles ran through an earlier identified hidden tectonic scarp that was also picked-up by the participants.

Group photograph of participants of Third Module of SERC School Course on Crustal Deformation and Tectonic Geomorphology.

(e) Summer Training-cum-Research for postgraduate Students in Earth sciences

Wadia Institute of Himalayan Geology is engaged in a number of programmes towards basic research in Himalayan geology in addition to the recently launched projects on the applied aspects of geosciences concerning societal implications in the Himalaya. To generate interest in some of the specialized branches of applied geosciences in the Himalaya and stimulate research acumen and aptitude, a short term training was organized from 14 May to 15 July 2006 for the postgraduate students in earth sciences. During the reporting year the training was aimed on the recently launched research programme on "Multiparameter Geological Studies in Western Uttaranchal Himalaya: Biharigarh-Uttarkashi Corridor". 11 postgraduate students with meritorious academic background were selected from different universities and institutions such as Poona University, Kurukshetra University, Garhwal University, Aligarh Muslim University, Indian Institute of Technology-Kharagpur and Delhi University. The training was initiated with basic lectures and field work in Himalaya. Thereafter the students were attached with scientists of WIHG to work in the corresponding area of their interest for a period of 8-10 weeks. The training has also offered an opportunity to the students towards accomplishment of their PG Dissertation by making use of the data generated during this programme.

VISITS ABROAD

- Dr. T. Singh Visited 16 countries, viz., Iran, Turkey, Syria, Jordan, Israel, Egypt, Sudan, Ethiopia, Kenya, Tanzania, Malawi, Zambia, Zimbabwe, Mozambique, Swaziland and South Africa, in an expedition named as the Gondwanaland Expedition, from 24th March to 28th June 2006.
- Rajesh Sharma visited Nanjing University, Nanjing, and Huangshan, in China to participate in the 'Asian Current Research on Fluid Inclusions', from 24- 31, May 2006.
- Dr. N.R. Phadtare visited Environmental Change Research Centre (ECRC), University College London, UK, as an invited participant in International conference on Holocene Climate Variability "HOLIVAR-2006" from 12-15 June 2006.
- Sh. Naresh Kumar (Project Scientist) and Dr. S.K. Chabak (SLT) visited Moscow, Russia to participate in the ILTP project training progrmme, June 20- July 10, 2006.
- Dr. R.J.G. Perumal visited Taiwan and Singapore to participate in National Programme for Training Scientists and Technologist in Government Sector from June 25 to July 5 2006.
- Dr. M.P. Sah visited Kathmandu, Nepal to participate in the ICIMOD workshop from August 8-9, 2006.
- Sh. Gautam Rawat visited University of Alberta, Edmonton, Canada for research work from August 13-28, 2006.
- Sh. Gautam Rawat and Sh. D.D. Khandelwal visited Metronix, Branschweig, Germany for training programme from September 1-10, 2006.
- Dr. B.R. Arora visit Laboratoire de Geologie de l' Ecole Normale Superieure at Paris, and on a visit to active centers involved in Glaciology at the University of Zurich, Switzerland from September 7-17, 2006.
- Dr. B.R. Arora visited Moscow to attend the Indo-Russian joint workshop as a part of DST delegation at I.P.E., Moscow from October 16-19, 2006.
- Dr. Sushil Kumar and Dr. A.K. Mahajan visited Nepal to attend International workshop on Seismology and Seismotectonics, organized by Dept. of Geology and Mines, Kathmandu, Nepal from 28-29 November, 2006,
- Dr. Sushil Kumar Visited Germany to attend the symposium on 'Earth surface processes in the Indian-African monsoonal realm' from January 7 -16, January 2007.

AWARDS AND HONOURS

- Dr. Rohtash Kumar, Dr. S. K.Ghosh and Dr. S. J. Sangode were honoured with National Mineral Award for the year 2005, conferred by Ministry of Steel and Mines, Govt. of India for the significant achievements in the understanding of the Himalayan Foreland Basin.
- Dr. Rajesh Sharma was honoured with Smt. Ketharaju Venkata Subbamma- Sri Subba Rao Medal for the year 2006, conferred by Indian Society of Applied Geochemist for his contribution to geochemical and fluid inclusion studies of Ore-minerals.
- Sh.V. Sriram was given best research paper award for his paper entitled "The 1986 Dharamasala earthquake of Himachal Himalaya- estimates of source parameters, average intrinsic attenuation and site amplification functions" for the year 2006.

Ph.D. THESES

Name	Supervisor/s	Title of the Thesis	University	Awarded/ Submitted
Subhajit Sinha	Dr.Rohtash Kumar Dr. S.K. Ghosh	Magnetostratigraphy and Sedimentology of the Neogene succession in the Himalayan Foreland Basin, Ravi Re-entrant.	HNB Garhwal University, Srinagar Garhwal	Awarded
B. P. Singh	Dr. S.K. Parcha	Paleontology and biostratigraphy of the Cambrian Successions in the Zanskar region of the Ladakh Himalaya.	HNB Garhwal University, Srinagar Garhwal	Awarded
Ajay Kumar	Dr.Rajesh Sharma Dr. Pankaj Srivastava	Genesis of magnesite deposit in Panthal, district Udhampur, Jammu and Kashmir (India).	Geology Dept. Jammu University, Jammu	Awarded
Hishmi Jamil Husain	Dr. A.K. Raina Dr. R.J.Azmi	Lithology and Soil Characteristics in Relation to Forest Vegetation of Garhwal Himalaya.	F.R.I.Deemed University, Dehra Dun.	Awarded
Tejpal Singh	Dr. N.S.Virdi Dr.Ravinder Kumar	Structure and Morphotectonics of a part of Himalayan foot hills in the Morni hills of Northern Himalaya and adjoining territories of Himachal Pardesh and Chandigarh.	Panjab University	Awarded
Yogesh Prasad	Dr. R.C. Ramola Dr. V.M. Choubey	Occurrence of radon in soil and water in relation to lithology and seismic activity.	HNB Garhwal University, Srinagar Garhwal	Submitted
Dirghayu Prasad	Dr. B.L. Dhar Dr. R.K. Mazari	Landform-soil-forest relationship in the Kiarda Dun, District University Sirmour (Himachal Pradesh)	FRI	Submitted

MEMBERSHIP OF NATIONAL/INTERNATIONAL COMMITTEES

Name	Status	Prestigious Committee/s Outside WIHG
B.R. Arora	Member	Governing Body of the Birbal Sahni Institute of Palaeobotany, Lucknow
	Member	Centre of Advance Study in Geology, Chandigarh
R.K.Mazari	*Co-opted Member*	Task Force on Mountain Ecosystems (Environment & Forest Sector), 11th Five Year Plan (2007-2012). Planning Commission, Government of India
V.C.Tewari	Member	Section of Earth System Sciences for 2007-08 (95th session of the Indian Science Congress, Association Kolkata to be held in Visakhapatnam in 2008
Rajesh Sharma	i) Member	Scientific Committee- Asian Current Research on Fluid inclusions (International)
	ii) Convener	National Seminar on Active and Fossil Suture Zones and the Annual General Meeting of the Geological Society of India, November
R. Islam	Member	National Working Group IGCP-427
S.K. Parcha	Member	Cambrian Working Group
	Member	International Trilobite workers Union
	Member	International Iconological workers Union
Vikram Gupta	Principal Member	Hill Area Development Engineering Sectional Committee constituted by the Bureau of Indian Standards (BIS), New Delhi

PARTICIPATION IN SEMINAR/SYMPOSIA/ WORKSHOP/ TRAINING COURSES

Seminar/Symposia/Workshop

- National Workshop on Role of Geodesy in Surveying Practices, April 10-11, 2006.
  Participant: A.K. Mahajan
- Brain Storming Workshop on Himalayan Glacier Inventory, organized by Geological Survey of India, Lucknow and DST, at Lucknow, May 3-4, 2006.
  Participants: G. Philip and D.P. Dobhal
- Workshop on Promotion of Rural Technology for Agriculture Development in Dehra Dun Valley at D.B.S.PG College, Dehra Dun, May 14-15, 2006.
  Participant: A.K.L. Asthana
- Workshop on Asian Current Research on Fluid Inclusions, Nanjing, China, May 26-28, 2005.
  Participant: Rajesh Sharma
- Workshop of IGCP Project 493 in Gangtok and the Rangit Valley, Sikkim, June 2006.
  Participant: V.C.Tewari
- Open Science Meeting on Natural Climate Variability and Global Warming, UCL, London, June 12-15, 2006.
  Participant: N.R.Phadtare
- Application of ICP-MS in Earth System Sciences, organized at NGRI, Hyderabad, June 26, 2006.
  Participant: P.K. Mukherjee
- Workshop on Dimensions of Nanotechnology: Science, Technology & Society, sponsored by NIAS-DST, Bangalore, June 26 to July 1, 2006.
  Participants: R.K. Mazari
- Workshop on Emerging Issues in Uttaranchal for the Development of Water Resources, June 29, 2006
  Participants: V.M. Choubey, S.K.Bartarya, V. Gupta and P.S. Negi
- Himalayan Science Workshop, Dehra Dun, organised by IIT Roorkee and University of Beverley, USA, June 28, 2006
  Participants: M.P. Sah
- Field Workshop Meeting on the Tectonics of Ladakh and Karakoram held at Delhi University, July 5, 2006.
  Participant: B.R. Arora
- First Meeting of the Expert Committee on Glaciers in Disaster Mitigation and Management Centre, Uttaranchal, held at Secretariat, Uttaranchal Government, Uttaranchal, July 18, 2006.
  Participant: B.R. Arora
- 17th Mid-Year Meeting of Indian Academy of Sciences, Bangalore held at Bangalore, July 14, 2006.
  Participant: B. R. Arora
- Workshop on Disaster Preparedness Plan for Natural Hazards, ICIMOD, Kathmandu, August 7-9, 2006.
  Participant: M.P. Sah
- National Seminar on Precambrian Life: Indian Scenario, Durgapur Government College, Durgapur, August 23-24, 2006.
  Participant: R.J.Azmi, V.C.Tewari
- Brain Storming Session on Disasters Associated with Glaciers in Uttaranchal: Their Potential and Societal Perspectives, Disaster Mitigation and Management Centre, Uttaranchal Secretariat, September 4, 2006.

Participants: B.R.Arora, M.P. Sah, G.Philip, V. Gupta, D.P.Dobhal

- Seminar on Disaster Management in Arunachal Pradesh, September 9, 2006.
  Participant: T. Singh

- International Brain Storming Session on Geochemical Precursors for Earthquakes, Saha Institute of Nuclear Physics, Calcutta, September 11-13, 2006.
  Participant: V.M. Choubey

- Workshop on Science and Open Economy in the Perspective of Uttaranchal. Organized by WIHG and UCOST, Dehra Dun, September 14-15, 2006.
  Participant: P.S. Negi

- Workshop on Disaster Management, Assam Administrative Staff College, Guwahati. Organized by TERI in association with Disaster Risk Management Cell, Government of Assam, September 19-20, 2006.
  Participant: T. Singh

- Conference on Geo-information Technologies, organized by Coordinates in association with IIT-Guwahati, NERIWALM, NE-Space Application Centre, Survey of India, DST, September 21-22 , 2006.
  Participant: T. Singh

- 'First Science Meet' of Heads of all the Institutes funded by DST with Secretary DST held at Jawaharalal Nehru Centre for Advanced Scientific Research, Bangalore (meeting was called for providing inputs for presentation in the Planning Commission), September 23-24, 2006.
  Participants: B.R. Arora , A.K. Dubey, N.S. Gururajan and Dr. Pradeep Srivastava

- International Symposium On Geospatial databases for Sustainable development, Goa India, 27-30 September, 2006.
  Participant: A.K.Mahajan

- Field Meeting of the IGCP Project 493, organized in collaboration with GSI in the Mussoorie and Garhwal Synclines, October 2006.
  Participant : V.C.Tewari

- Governing Body meeting of Uttaranchal Sapce Application Centre (U-SAC) held at Chief Secretary's office, Dehradun, October 5, 2006.
  Participant : B.R. Arora

- Workshop on Himalayan Earthquakes: A Fresh Appraisal, WIHG, Dehra Dun, October 7- 8, 2006.
  Participants: B.R. Arora, A.K. Dubey, R.K.Mazari, R.S. Rawat, M.P.Sah , G.Philip, Sushil Kumar, P. Banerjee, A.K.Mahajan,A.K.Mundepi and S. Chabak

- Brain Storming Session on Palaeontological Research in India- Future Directions, Jammu University, Jammu, October 9-10, 2006.
  Participant: S.K. Parcha

- National Symposium on Plant Biotechnology , FRI, Dehradun, October12-14, 2006.
  Participant: V.C.Tewari

- Workshop on Disaster Management in Arunachal Pradesh: Towards a Pragmatic Strategy, Itanagar, organized by Arunachal Pradesh State Disaster Management Authority, October13, 2006.
  Participant: T. Singh

- Environment Health & Safety (EHS) and Water Technology, organized by Sawn Environmental Pvt. Ltd., Dehra Dun, October 13, 2006.
  Participant: S.K.Bartarya

- Workshop on Indo-German Collaborative, INSA, New Delhi, October 24-27, 2006.
  Participants: N.R. Phadtare and P.Srivastava

- 31st Annual Convention and Third International Seminar and Exhibition on Exploration Geophysics, Hyderabad International Convention Centre, Hyderabad, November 6-12, 2006.
  Participant: P. Banerjee

- First Uttaranchal State Science Congress, Dehra Dun, November 10-11, 2006.
  Participants: M.P. Sah, G. Philip, V. Gupta and D.P. Dobhal

- Discussion Meeting on Tectonic Geomorphology: Landform Evolution and Quaternary Tectonics, Sponsored by DST, WIHG, November 10-11, 2006.
  Participant: R.K. Mazari

- Discussion meeting on Tectonic Geomorphology: Landform Evolution and Quaternary Tectonics, WIHG, Dehra Dun, November 10-11, 2006.
  Participants: R.K. Mazari, G.Philip and V.Gupta

- National Seminar on Energy and its Alternatives, , ONGC, Dehra Dun, November 14-15, 2006.
  Participants: B.N.Tiwari

- Diamond Jubilee International Conference, Birbal Sahni Institute of Palaeobotany, Lucknow, November15-17, 2006.
  Participants: V.C.Tewari, B.N.Tiwari and Kapesa Lokho

- National Seminar on Active and Fossil Suture Zones, WIHG, Dehra Dun, November 22-24, 2006.
  Participants: B.R. Arora, A.K. Dubey, R.K. Mazari, N.S. Gururajan,, B.K. Choudhri, Rohtash Kumar, P.P. Khanna, S.K. Ghosh, Kesar Singh, S.K. Paul, T.N. Jowhar, Rajesh Sharma, R. Islam, G. Philip, D.R. Rao, S.J. Sangode and A.K. Singh

- Symposium on New Innovations in Science and Technology, INSA, New Delhi, November 27, 2006.
  Participant: P. Srivastava

- International Workshop on Seismology and Seismotectonics, organized by Department of Geology and Mines, Kathmandu, Nepal, November 28-29, 2006.
  Participants: Sushil Kumar A.K.Mahajan

- First India Disaster Management Congress (IDMC) organized by the National Institute of Disaster Management, Vigyan Bhawan, New Delhi, November 29-30, 2006.
  Participant: V. Gupta

- Glaciology Meeting of Uttaranchal Government, held at DMCC, Dehra Dun, December 7, 2006.
  Participant: B.R. Arora

- Seminar on Intellectual Property and Innovation Management in Knowledge Era, organized by National Research Development Corporation, Government of India, Dehra Dun, December 21, 2006.
  Participant: P.S. Negi

- Seminar on Advances in Biotechnical Research in India During Last Decade (1996-2006), organized by University of Bikaner and M.N. Institute of Applied Sciences, Bikaner, Rajasthan, December 26-28, 2006.
  Participant: P.S. Negi

- National Conference on Himalaya to Indian Ocean: Geomorphic Processes and Landscape Change, organized by RCFORHG, University of Jammu, December 26-28, 2006.
  Participant: D.P. Dobhal

- Indian Science Congress Association (94th Session), Annamalai University, January 3-6, 2007.
  Participants: B.R.Arora, V.C.Tewari, B.N.Tiwari and T.N. Jowhar

- Symposium on Earth Surface Processes in the Indian-African Monsoonal Realm, University of Potsdam,Germany, January 7-16, 2007.
  Participant: Sushil Kumar

- Course on Microwave Remote Sensing Applications, IIRS, Dehra Dun, February 2-16, 2007.
  Participant: G.Philip

- 3rd Module of the SERC School on Crustal Deformation and Tectonic Geomorphology: Modern Geology and Tectonics, WIHG, Dehra Dun, February 6-20, 2007.
  Participant: R.K. Mazari, V. Gupta

- 3rd International Groundwater Conference (IGC-2007) on Water, Environment and Agriculture: Present Problems and Future Challenges, organised by Tamil Nadu, Agricultural University, Coimbatore, February 7-10, 2007.
  Participant: S.K. Bartarya

- International Workshop on Geology and Natural Hazards of the Eastern Himalaya Syntaxis, Indo-Burmese Arc and Adjoining Regions, Itanagar, February 9-11, 2007.
  Participant: R.K. Mrinalinee Devi

- Training Course on Application of GPS in Atmospheric and Ionospheric Studies, IIT Mumbai, February 27, 2007.
  Participant: S.Rajesh

- National Seminar and Annual Convention of the Indian Society of Applied Geochemists, Jaipur, Feb. 14-15, 2007.
  Participant: Rajesh Sharma

LECTURES BY VISITING SCIENTISTS

Name and Address	Date	Topic
Prof. Ragnar Stefansson University of Akureyri Iceland	8.4.06	Measurements of Low Magnitude Earthquake
Dr. Reynir Bodvarsson Director Swedish National Seismic Network Sweden	8.4.06	Successes of Earthquake prediction research in Iceland and Implications for the Science of Seismology for other earthquake-prone areas
Dr. S.R. Shetye Director NIO, Goa	10.4.06	Source Region of the 26th December, 2006 Tsunami and Indian Tide
Prof. Maurice E. Tucker Durham University, UK	12.4.06	Carbonate sequence stratigraphy and hydrocarbon geology features
Prof. Maurice E. Tucker Durham University, UK	13.4.06	Limestone Cycles and Cycles: The answer lies in the Sun
Dr. Manika Prasad Dept. of Earth Sciences IIT, Powai, Mumbai	17.4.06	Applications of Rock physics Experiments for Tectonic Understanding of Rocks
Dr. S.K. Gupta Hydrological Physical Research Laboratory Ahmedabad	11.5.06	Studying Patterns, Processes and Functions of Cycle Components through water Isotopes
Prof. Mary Leech Dept. of Geosciences San Francisco State University California, U.S.A	28.6.06	Himalayan gneiss domes: Examples of two contrasting types -The Tso Morari and Leo Pargil domes
Prof. V. Rajamani School of Environmental Sciences J.N.U., New Delhi	29.6.06	Emerging issues in Uttaranchal for the development of water resources
Prof. Stefan Bengtson Dy. Chairman, Dept. of Paleozology Swedish Museum of Natural History Sweden	16.11.06	Multicellular Organisms in the history of Life
Prof. J.W. Schopf University of California Los Angeles, U.S.A.	20.11.06	The earliest history of life: Solution to Darwins Dilemma
Dr. Onkar S. Chauhan NIO, Goa	12.1.07	Climate reconstruction since the Last Glaciation
Prof. Martin Pickford College de' France, Paris France	15.1.07	The Expanding Earth Hypothesis: a“Challenge to Plate Tectonics

Name and Address	Date	Topic
Drs. V. Smirnov & A. Ponomarev Institute of Physics of the Earth Russian Academy of Sciences Moscow	1.2.07	Physics of the Failure and statistics of *Seismicity: Progress and Problems*
Prof. Mathew J. Kohn University of South Corolina U.S.A	14.3.07	From Monazite to Mountains: P-T history of the Central Nepal Himalya
Dr. MVMS Rao Emeritus Scientist NGRI, Hyderabad	22.3.07	Current Use of Acousting Methods in the Laboratory Study of Rock Fracture
Prof. M. Gokhberg Institute of Physics of the Earth Moscow		I. Geochemical problem forCaliforni a cluster II. New Approaches of the monitoring of porosity, permeability, shear and Bulk viscosity of the modulus and dynamic pore fluid in vicinity of seismo-active fault Zone III. Tsunami detection by bottom electro- magnetic-station
Dr. R.P. Singh Central Ground Water Board Dehradun	28.2.07	More Crop Per Drop
Dr. Anand K. Sharma Indian Meteorological Department Dehradun	28.2.07	Water Harvesting

LECTURES BY INSTITUTE SCIENTISTS

Name	Venue	Date	*Topic*
T. Singh	Gondwana Expedition 2006 (delivered series of Lectures enroute	11.04.06 to 20.06-06	(i) *An introduction to the Himalaya* (ii) *Geodynamic Evolution of the Himalaya* (iii) *Drifting Gondwana Continents* (iv) *Geologic features en route Gondwanaland Expedition*
A.K. Dubey	Geological Survey of India, Dehradun	22.04.06	*(i) Noncylindrical fold interference patterns* *(ii) Deveopment of thrusts in the Himalaya*
Vikram Gupta	Kendriya Vidalaya FRI, Dehradun	25.05.06	*Natural and man made disasters in the Himalaya*
T. Singh	Dept. of Geology & Mining Govt. of Arunachal Pradesh	28.08.06	*Earthquake Disaster in Arunachal: Awareness and personal protection*
Rajesh Sharma	Jammu University, Jammu	20.9.06	*Fluid Inclusions Studies I: Principles and Practice*
Rajesh Sharma	Jammu University, Jammu	20.9.06	*Fluid Inclusion Studies II: Microthermometry and Modeling*
Rajesh Sharma	Jammu University Jammu	21.9.06	*Modeling of Sulphides in Himalaya*
A.K. Mahajan	ITBP Academy Mussoorie	12.10.06	*Methodology of seismic Microzonation*
G. Philip	D.B.S. College, Dehradun	18.10.06	*Active tectonics in seismic hazard assessment*
S.K.Bartarya	WRDMC, IIT, Roorkee	11.10.06	*Basic Hydrogeology*
T. Singh	Dept. of Earthquake Eng. IIT, Roorkee	01.11.06	*Earthquake awareness with reference to Seismo-tectonics of Arunachal Himalaya*
S.K. Parcha	Dept. of Geology, DBS College, Dehradun		*Lower Paleozoic successions of the Tethyan Himalayan regions*
Vikram Gupta	Indo-Tibetan Border Police ITBP, Dehradun	13.12.06	*Natural disasters with and their management in the Himalaya*
G. Philip	Dept. of Geology Govt. College, Kottayam Kerala	03.11.06	*Tectonic geomorphology and active faults*
T.N. Jowhar	Geology Department Delhi University, Delhi	12-15.2.07	*Application of computers and mathematics in Geology*
A.K. Mahajan	ITBP, Mussoorie	21.02.07	*Disaster Management*
S. Rajesh	IIT, Mumbai	03.03.07	*Space based gravimetric techniques*
R.K. Mazari	Geosciences Division IIRS, Dehradun	09.03.07	*Tectonic geomorphology of Trans Himalayan Lahaul-Spiti valley, Himachal Pradesh*
S.K.Bartarya	IIRS, Dehradun	23.03.07	*Hydrogeology of mountainous terrain with special reference to Himalaya*

TECHNICAL SERVICES

Analytical Services

Central Facility Laboratories

During this year a total number of three thousand five hundred fifty eight (3558) samples were analyzed for different elements using XRF, XRD, SEM and ICPMS/AAS. The SEM unit was out of order for most of the time. During this year a new instrument SEM with EDAX was added to the CFL, which has been installed and standardized.

Samples Analysed from April 2006 to March 2007

LABORATORY	WIHG USERS	OUTSIDE USRS	TOTAL
XRF	647	804	1451
XRD	410	470	880
SEM	245	45	290
ICP-MS/AAS	509	428	937
TOTAL SAMPLES ANALYSED			**3558**

Enhancement / New addition of SEM-EDAX Facility

New Scanning Electron Microscope (Zeiss EVO-40 EP) with most advanced EDAX facility (Bruker LN2 free X-Flash 4010 SDD x-ray detector) was installed in the Central Facility replacing the old Philips' Microscope (PSEM-515). The new system is fully functional with improved resolution of 3nm and digital image processing and storage capabilities. Multiple imaging modes are available even at a pressure up to 3000 Pa using SE and BSE signals. The state-of-the-art EDX facility will satisfy the long standing need of users, providing them qualitative and quantitative compositional analysis of different phases, grains and selected points of the sample including elemental mapping of the selected area.

Photography Section

During the reporting year around 45 rolls of colour negative films were exposed, 1600 colour prints made and 20 CD's burnt for the photographic coverage of various functions, including seminars/symposia organized in the Institute. Apart from this around 20 films were exposed and their developing and processing arranged with around 875 prints of assorted sizes for Institute scientists.

Drawing Section

The drawing section catered to the cartographic needs of the scientists of the Institute including the sponsored projects. During the year, the Drawing Section drafted 60 geological/geo-morphological maps to the scientists of the Institute. The staff of the Drawing Section also prepared posters/charts 8; identity cards, 129; addition and alteration in maps/diagrams, 17; litho-logs, geochemical graphs and geological cross sections, 55 and writing work in photo-plates, 14.

Sample Processing Lab.

The Sample Processing Lab provided thin/polished sections to the requirements of the Institute scientists. During the year the laboratory provided 2349 thin and polished sections to various users for carrying out microscopic, fluid inclusion and EPMA studies. 968 rock samples were powdered for carrying out mineral identification, major, trace and REE analysis by XRD, XRF and ICPMS.

S.P. NAUTIYAL MUSEUM

Museum, the educative wing of the Institute had a large number of student visitors from different universities, local schools and general public and as usual remained the main centre of attraction for the national and international visitors. Students in large groups from different schools, universities, colleges and from other institutions visited the Museum and guided tours were provided to them. A relief model of the Himalaya and paintings depicting the impact of human activities on the environment displayed in the Museum remained a point of attraction for the visitors. During the year, a new 3-dimensional painting depicting the panoramic view of the Bhagirathi valley was prepared and exhibited for the general public. Also, during the year, visitors from USA, Austria, U.K, Ukraine, Thailand, Australia, England, Japan, Nepal, France, Russia, Moscow, Israel and Canada visited the Museum.

Museum observed Open days on National Technology Day (May 11, 2006), Foundation Day (June 29, 2006), Founders Day (October 23, 2006) and National Science Day (February 28, 2007). Like the previous years enormous number of students and general public visited the Museum on these occasions. On the eve of Science Day Week, science quiz and essay competition were organized for students of the Doon valley. Students from various schools of the Doon valley as well as from surrounding schools participated in the quiz competition. Prizes were also distributed to the outstanding students, who stood first, second and third in order of merit in both quiz and essay competition.

LIBRARY

The Library of Wadia Institute of Himalayan Geology is one of the best libraries in the field of earth sciences in the northern part of the country. It is a medium size specialized library consisting of books, monographs, journals and seminar/conference proceedings on Earth Sciences with special reference to Himalayan Geology. The Library not only serves to the scientific, technical and administrative staff of the Institute but also caters to the needs of outside scientists and researchers from the sister organizations and various research institutions, universities and NGO's.

A large number of national and international scientific core journals in the field of earth sciences are subscribed in the Library which is not available in any other Library in the region. The Library subscribes to 132 journals, out of which 52 are Indian and 76 are foreign. The Library received 12 titles of journals as gratis. The Library has full text online access to 47 journals, out of the 76 titles subscribed. Also, it has online access to these journals through Science@direct web editions, Blackwell-synergy, Springer-link, Informa-world and ingentaconnect.

During the year, the Library acquired a total number of 281 books. Out of these 92 books/reference books were purchased while 9 books were received as gratis. In addition 133 books in Hindi were purchased for the Hindi collection. The catalog of CD-ROMs, available in the Library has been updated. The reprint collection of the Library was reorganized. A total number of 538 bibliographic records of reprints available in the reprint collection of the Library were added to the reprint database. This database is available on intranet through the web interfacing software GenIsis. The Himalayan Geology Database (HIMGEO) was updated by adding 226 records

The Library incorporates a reprographic cell which serves as a central facility for photocopying and cyclostyling. A large number of photocopies of articles from journals/monographs were provided to the scientists and research scholars of the Institute. The photocopying and cyclostyling facility was also provided to the

PUBLICATION & DOCUMENTATION

The Publication and Documentation Section is involved in bringing out the regular journal of Himalayan Geology and publishing Hindi magazine Ashmika, Annual Report in Hindi and English. During the year, the Section published Himalayan Geology vols. 27(2) 2006 and 28(1) 2007, Hindi magazine Ashmika volume 12 and Annual Report of the Institute for the year 2005-06 both in Hindi and English. Abstract volumes for the seminars on Emerging Issues in Uttaranchal for the Development of Water Resources, Himalaya Earthquakes: A Fresh Appraisal (HIMEQ-2006) and Active and Fossil Suture Zones were also brought out during the year. Apart from this, various jobs such as printing of the S.P. Nautiyal Memorial Lecture, Circular for the above-mentioned seminars, invitation cards for the seminars/workshops, certificates for celebration of Foundation Day and National Science Day were also brought out by the Section. Additionally, services for scanning and color printing of maps, diagrams and figures as requisitioned by the Institute scientists were provided by the Section.

Dr. T. Ramasami, Secretary, Dept. of Science & Technology, Govt. of India, in discussion with the Scientists on his I[st] visit to the Institute.

FOUNDATION DAY CELEBRATIONS

The Foundation Day of the Institute was celebrated on 29 June 2006. His Excellency Shri Sudershan Agarwal, Hon'ble Governor, Uttarakhand State was the Chief Guest. His Excellency also inaugurated the Foundation Day Seminar on Emerging Issues in Uttarakhand for the development of Water Resources. Prof. V. Rajamani, Jawahar Lal Nehru University, New Delhi delivered the Foundation Day Lecture on "*Water Technology Proposes: Science Disposes*". On this occasion, His Excellency, distributed award for the best research paper published during the year. The award was given to Sh.V. Sriram for research paper entitled "The 1986 Dharamasala earthquake of Himachal Himalaya: estimates of source parameters, average intrinsic attenuation and site amplification functions", published in Journal of Seismology. The best worker awards were given to Sh. Rambir Kaushik, Technical Assistant; Sh.S.S. Bhandari, Technical Assistant; Sh. B.K. Juyal, Assistant; Sh. O.P. Anand, Assistant; Sh. Shiv Singh Negi, L.D.C.; Sh. R.S. Yadav, Driver and Sh. Girish Chander Singh, Cook-cum-Guest House Attendant for the good work carried out by them during the year 2005-2006.

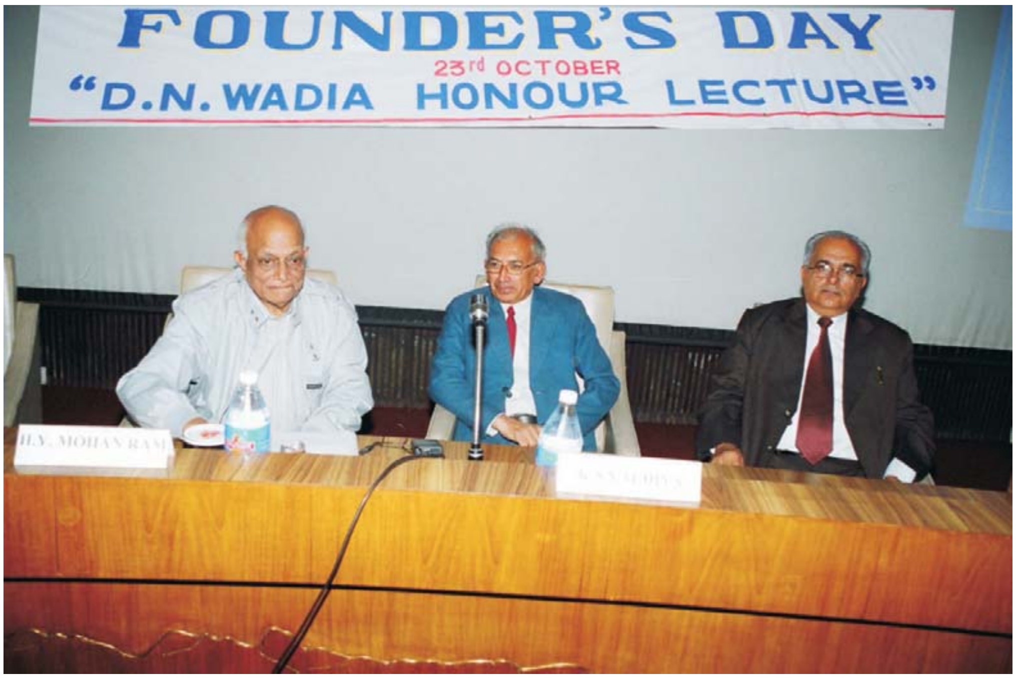
His Excellency Shri Sudershan Agarwal, Hon'ble Governor, Uttarakhand presiding over the function of Foundation Day celebration.

NATIONAL TECHNOLOGY DAY

The Eighth National Technology Day was celebrated by the Institute on May 11, 2006. On this occasion, an Open Day was observed by keeping Museum and other laboratories of the Institute open for the general public and for the school and college children. A large number of students and people visited the Institute Museum and other laboratories. A Lecture was delivered by Dr. S.K. Gupta, Senior Scientist of Physical Research Laboratory, Ahmedabad, on Studying Patterns, Processes and Functions of Hydrological Cycle Components through Water Isotopes.

FOUNDER'S DAY

The Institute celebrated its Founder's Day on 23rd October 2006. In the Honour of Prof. D.N. Wadia, generally a lecture by some eminent person is organized. The Chief Guest, Prof. H.Y. Mohan Ram, Ex- Professor, Dept. of Botany, University of Delhi, delivered the D.N. Wadia Honour Lecture on “Life strategies of flowering plants”. The lecture was well attended by scientists from different organizations from Doon Valley and was well covered by the media.



Prof. K.S. Valdiya introducing the Chief Guest Prof. H.Y. Mohan Ram during the Founder's Day “ D.N. Wadia Honour Lecture”

NATIONAL SCIENCE DAY CELEBRATIONS- 2007

The National Science Day week was celebrated by the Institute by organizing Science Quiz and Hindi Essay Competition for the educational institutions of the Doon valley from 22 to 28 February 2007. In total 21 educational institutions participated in the quiz competition. Even the students from far off places like Mussoorie, and Vikasnagar also participated in the quiz competition. For Hindi Essay competition, the topic was Jal Hi Jeevan Hai, where 20 educational institutions participated. In addition to these activities some of the scientists delivered lectures in various schools in and around the Doon valley. The theme of this year's Science Week celebration was 'More Crop Per Drop'

On February 28, 2007, an open day was observed. On this day various laboratories were opened for students and general public. Students from far off places like Doiwala, Mussoorie, Sailakui, Raiwala and Rishikesh participated. In total nearly 29 educational institutions with more than 2,500 school children and a large number of general public visited the Institute Museum and laboratories. The scientists of the Institute attended the quarries of the inquisitive students. The functioning and the uses of the various scientific instruments were explained to the students and general public. This year a special exhibit was put up, depicting view of the Bhagirathi valley with its glaciers and water resources, which became a point of attraction to the students and general public.

Two special science lectures were delivered by Dr. R.P. Singh, Central Ground Water Board, Dehradun and Dr. Anand K Sharma, Scientist, Indian Meteorological Department, Dehradun on 'More Crop Per Drop' and 'Water Harvesting', respectively. A large crowd of students and general public attended the lectures. The prizes and certificates were also given to the winners of the Science Quiz and Hindi Essay Competitions.

Students from various schools of Doon Valley visiting the Institute Museum during the National Science Day celebration.

DISTINGUISHED VISITORS TO THE INSTITUTE

- His Excellency, Shri Sudershan Agarwal, Governor, Uttaranchal
- Brig. Manail, National Defence College
- Maj. Gen. D. Mukherjee National Defence College
- Prof. H.Y. Mohan Ram, INSA Hony. Scientist
- Dr. V. Smirnov and Dr. A. Ponomarev, Institute of Physics of the Earth, RAS, Moscow
- Prof. M. Gokhberg (Academician, RANS), Institute of Physics of the Earth, RAS, Moscow
- Prof. Martin Pickford, College de' France, Paris, France
- Professor J.W. Schopf, University of California, Los Angeles, USA
- Prof. Stefan Bengtson, Dept. of Paleozology, Swedish Museum of Natural History, SWEDEN
- Prof. Mary Leech, Dept. of Geosciences, San Francisco State University, California, USA
- Dr. Manika Prasad, Dept. of Earth Sciences, IIT, Powai, Mumbai
- Prof. Maurice E. Tucker, Durham University, UK
- Dr. S.R. Shetye, Director, National Institute of Oceanography, Goa
- Dr. Reynir Bodvarsson, Director, Swedish National Seismic Network
- Prof. V.S. Ramamurthy, Ex-Secretary, DST, New Delhi

His Excellency Shri Sudershan Agarwal, Hon'ble Governor, Uttarakhand being welcomed by Prof. B.R. Arora during his visit to Institute on Foundation Day 2006.

Dr. T. Ramasami, Secretary, DST inaugurating the Store/ logistic building of the Institute.

STATUS OF IMPLEMENTATION OF HINDI

During the year under report, efforts for progressive use of Hindi were continued. The scientists and staff of the Institute were time and again apprised with the various orders and constitutional provisions of official Language Act to increase awareness for progressive use of Hindi in day-to-day work. Various incentive schemes for encouraging progressive use of Hindi were implemented. General orders, circulars and notices were issued in Hindi as well as in English.

On the occasion of the Foundation Day of the Institute on 29 June 2006, the Hindi magazine Ashmika volume 12 was released.

Hindi fortnight was celebrated from 14 September 2006 to 29 September 2006, during which various competitions like poetry, essay and debate were organized. Dr. L.M.S. Palni, Senior Advisor & Project Director, Pantnagar (Uttarakhand) delivered an invited lecture entitled "Khuli Arthbyawastha Ke Paripekhsa main Jaiv Vividhta Sanrakshan Kee Aniwarya Awashyakta" on 14.09.2006 to inspire the staff for progressive use of Hindi in their work.

The Annual Report of the Institute for the year 2005-2006 was translated in Hindi and published in bilingual form.

On the occasion of the National Science Day week, a Hindi Essay competition was organized for the students of various schools of Dehra dun. The title of the Hindi Essay was "Jal Hi Jeevan Hai".

His Excellency Shri Sudershan Agarwal, Hon'ble Governor, Uttarakhand releasing the Hindi magazine 'Ashmika' during the Foundation Day 2006.

MISCELLANEOUS ITEMS

1. Reservations / Concessions for SC/ST employees

Government orders on reservations for SC/ST/OBC's are followed in recruitment to posts in various categories.

2. Monitoring of personnel matters

Monitoring of personnel matters relating to employees of the Institute are done through various committees appointed by the Director/Governing Body from time to time.

3. Mechanism for redressal of employee's grievances

There is a Grievance Committee consisting of four Senior Scientist/Officers for redressal of employee's grievances. To look into the grievances of women employees in the Institute, a separate Committee has also been constituted. The Committee consists of six members. Chairman and two other members of the Committee are female Officers, which include one officer from Geological Survey of India.

4. Welfare measures

The Institute has various welfare measures for the benefit of its employees. Various advances like House Building Advance, Conveyance Advance, Festival Advance etc. are given to the employees. There is a salary Earner's Cooperative Society run by the Institute employees which provides loans to its members as and when required. The Institute also runs a canteen for the welfare of the employees. As a welfare measure Institute is providing recreational facilities to its employees.

5. Sanctioned Staff-strength (category-wise)

[A] NON-PLAN :

Group/ Category	Scien-tific	Techni-cal	Adminis-trative	Ancill-ary	Total
A	61	-	2	-	63
B	-	2	5	-	7
C	-	35	30	13	78
D	-	28	-	25	53
Total	**61**	**65**	**37**	**38**	**201**

[B] PLAN :

Group/ Category	Scien-tific	Techni-cal	Adminis-trative	Ancill-ary	Total
A	2	-	-	-	2
B	-	-	1	-	1
C	-	2	-	1	3
D	-	-	-	1	1
Total	**2**	**2**	1	**2**	**7**

6. Approved budget grant for the year 2006-2007

Plan : Rs. 1050.00 Lakhs

Non-Plan : Rs. 114.00 Lakhs

Total : Rs. 1050.00 + 114.00 = 1164.00 Lakhs

7. Xth Plan approved outlay

Plan : Rs. 3000.00 Lakhs

Released : Rs. 4055.00 Lakhs

Sl. No.	F. Year	Amount Released (Rupees in Lakhs)
1.	2002-2003	575.00
2.	2003-2004	630.00
3.	2004-2005	750.00
4.	2005-2006	1000.00
5.	2006-2007	1100.00
		4055.00 Lakhs

STAFF OF THE INSTITUTE AS ON 31.3.2007

(A) Scientific Staff

1.	Prof. B.R. Arora	Director
2.	Dr. A.K. Dubey	Scientist 'G'
3.	Dr. Trilochan Singh	Scientist 'F'
4.	Dr. R.K. Mazari	Scientist 'F'
5.	Dr. R.J. Azmi	Scientist 'F'
6.	Dr. J.T. Gergan	Scientist 'F'
7.	Dr. N.S. Gururajan	Scientist 'F'
8.	Dr. V.C. Tiwari	Scientist 'F'
9.	Dr. B.K. Choudhary	Scientist 'F'
10.	Dr. V.M. Choubey	Scientist 'F'
11.	Dr. P.P. Khanna	Scientist 'F'
12.	Dr. Rohtash Kumar	Scientist 'F'
13.	Dr. (Mrs.)Meera Tiwari	Scientist 'F'
14.	Dr. S.K. Ghosh	Scientist 'F'
15.	Dr. R.S. Rawat	Scientist 'E'
16.	Dr. K.S. Bist	Scientist 'E'
17.	Dr. D.K. Misra	Scientist 'E'
18.	Dr. R.K. Choujar	Scientist 'E'
19.	Dr. N.R. Phadtare	Scientist 'E'
20.	Dr. Keser Singh	Scientist 'E'
21.	Dr. M.P. Sah	Scientist 'E'
22.	Dr. N.K. Saini	Scientist 'E'
23.	Dr. S.K. Paul	Scientist 'E'
24.	Dr. K.K. Purohit	Scientist 'E'
25.	Dr. T.N. Jowhar	Scientist 'E'
26.	Dr. Kishor Kumar	Scientist 'E'
27.	Dr. N.Siva Siddaiah	Scientist 'E'
28.	Dr. Rajesh Sharma	Scientist 'E'
29.	Dr. G. Philip	Scientist 'E'
30.	Dr. Rafikul Islam	Scientist 'E'
31.	Dr. B.N. Tiwari	Scientist 'E'
32.	Dr. D. Rameshwar Rao	Scientist 'E'
33.	Dr. S.K. Bartarya	Scientist 'E'
34.	Dr. P.K. Mukharjee	Scientist 'E'
35.	Dr. S.J. Sangode	Scientist 'D' (on lien)
36	Dr. Sushil Kumar	Scientist 'D'
37.	Dr. P. Banerjee	Scientist 'D'
38.	Dr. S.K. Parcha	Scientist 'D'
39.	Dr. H.K. Sachan	Scientist 'D'
40.	Sh. B.S. Rawat	Scientist 'C'
41.	Dr. A.K. Mahajan	Scientist 'C'
42.	Dr. D.P. Dobhal	Scientist 'C'
43.	Dr. Vikram Gupta	Scientist 'C'
44.	Dr. S.S. Bhakuni	Scientist 'C'
45.	Dr. Suresh N.	Scientist 'C'
46.	Sh. V. Sriram	Scientist 'C'
47.	Dr. A.K. Mundepi	Scientist 'C'
48.	Dr. Pradeep Srivastava	Scientist 'C'
49.	Dr. Ajay Paul	Scientist 'C'
50.	Dr. B.P. Sharma	Scientist 'B'
51.	Dr. P.S. Negi	Scientist 'B'
52.	Dr. A.K.L Asthana	Scientist 'B'
53.	Dr. Kapesa Lokho	Scientist 'B'
54.	Dr. A.K.Singh	Scientist 'B'
55.	Dr. R. Jayangondaperumal	Scientist 'B'
56.	Dr. Khaying Shing Luirei	Scientist 'B'
57	Dr. Rajesh S.	Scientist 'B'
58	Sh. Gautam Rawat	Scientist 'B'
59.	Dr. B.K. Mukherjee	Scientist 'B'
60.	Sh. Naresh Kumar	Scientist 'B'
61.	Sh. Narendra Kumar Meena	Scientist 'B'
62.	Dr. Dilip Kumar Yadav	Scientist 'B' (Lien Vacancy)
63.	Dr.(Miss)Swapnamita Choudhuri	Scientsit 'B'

(B) Technical Staff

1.	Sh. V.P. Singh	Sr.Pub.&Doc.Officer Gr.III(5)
2.	Sh. Saeed Ahmad	Sr.Librarian Gr.III(5)
3.	Sh. J.J. Sharma	Sr.Tech.Officer Gr.III(5)
4.	Sh. M.M.S. Rawat	Tech.Officer Gr.III(4)
5.	Sh. B.B. Sharma	Tech.Officer Gr.III(4)
6.	Sh. A.K.Pandit	Artist-cum-Modellor Gr.III(4)
7.	Sh. Sanjeev Dabral	Jr.Tech.Officer Gr.III(4)
8.	Dr. R.K. Sehgal	Jr.Tech.Officer Gr.III(4)
9.	Sh. Chandra Shekhar	Jr.Tech.Officer Gr.III(3)
10.	Sh. V.P. Gupta	Jr.Tech.Officer Gr.III(3)
11.	Sh. Samay Singh	Jr.Tech.Officer Gr.III(3)
12.	Sh. Vishnu Shreshtha	Sr.Lab.Asstt. Gr.II(5)
13.	Sh. S.C. Kothiyal	Lab.Asstt. Gr.II(5)
14.	Sh. Rakesh Kumar	Sr.Tech.Asstt. Gr.III(2)
15.	Sh. N.K. Juyal	Sr.Tech.Asstt. Gr.III(2)
16.	Sh. T.K. Ahuja	Sr.Tech.Asstt. Gr.III(2)
17.	Sh. C.B. Sharma	Junior Engineer Gr.III(1)
18.	Sh. S.S. Bhandari	Tech.Asstt. Gr.III(1)
19.	Sh. Rambir Kaushik	Tech.Asstt. Gr.III(1)
20.	Dr. Jitendra Bhatt	Tech.Asstt. (EDP) Gr.III(1)
21.	Sh. Bharat Singh Rana	Tech.Asstt. Gr.III(1)
22.	Sh. Pankaj Chauhan	Tech.Asstt. Gr.III(1)
23.	Sh. V.K. Kala	Draftsman Gr.II (5)
24.	Sh. G.S. Khattri	Draftsman Gr.II (5)
25.	Sh. Navneet Kumar	Draftsman Gr.II (5)
26.	Sh. B.B. Saran	Draftsman Gr.II (3)
27.	Sh. Chandra Pal	Section Cutter Gr.II(5)
28.	Sh. Shekhranandan	Section Cutter Gr.II(5)
29.	Sh. Pushkar Singh	Section Cutter Gr.II(5)
30.	Sh. Satya Prakash	Section Cutter Gr.II(5)
31.	Sh. Santu Das	Section Cutter Gr.II(3)
32.	Sh. Nand Ram	Elect-cum-Pump Optr.Gr.II(5)
33.	Sh. Ravindra Singh	Sr.Tech. Assistant
34.	Sh. H.C. Pandey	Sr.Tech. Assistant
35.	Sh. Lokeshwar Vashistha	S.L.T.
36.	Dr. S.K. Chabak	S.L.T.
37.	Sh. R.M. Sharma	S.L.T.
38.	Sh. C.P. Dabral	S.L.T.
39.	Sh. Satish Pd. Bahuguna	Lab. Asstt.Gr.II(3)
40.	Sh. S.K. Thapliyal	Lab. Asstt.Gr.II(3)
41.	Sh. Shiv Pd. Bahuguna	Lab. Asstt.Gr.II(3)
42.	Sh. Sashidhar Pd.Balodi	Lab. Asstt.Gr.II(3)
43.	Sh. Rajendra Prakash	Lab. Asstt.Gr.II(3)
44.	Sh. A.K. Gupta	Lab. Asstt.Gr.II(3)
45.	Sh. Tirath Raj	Lab. Asstt.Gr.II(3)
46.	Sh. Balram Singh	Elect-cum-Pump Optr.Gr.II(3)

47.	Sh. Anoop Singh	F.C.L.A. Gr.I(4)
48.	Sh. Pratap Singh	F.C.L.A. Gr.I(4)
49.	Sh. Ram Kishor	F.C.L.A. Gr.I(3)
50.	Sh. Ansuya Prasad	F.C.L.A. Gr.I(3)
51.	Sh. Puran Singh	F.C.L.A. Gr.I(3)
52.	Sh. Ram Khilawan	F.C.L.A. Gr.I(3)
53.	Sh. Madhu Sudan	F.C.L.A. Gr.I(3)
54.	Sh. Hari Singh	F.C.L.A. Gr.I(3)
55.	Sh. Ravi Lal	F.C.L.A. Gr.I(3)
56.	Sh. Preetam Singh	F.C.L.A. Gr.I(2)
57.	Sh. Vivekanand Khanduri	F.C.L.A. Gr.I(1)
58.	Sh. Subodh Barthwal	Lab. Assistant
59.	Sh. Nain Das	Lab. Assistant
60.	Mrs. Rama Pant	Field Attendent
61.	Sh. R.S. Negi	Field Attendent
62.	Sh. Ramesh Chandra	Field Attendent
63.	Sh. Khusi Ram	Field Attendent
64.	Sh. Tikam Singh	Field Attendent
65.	Sh. Bharosa Nand	Field Attendent
66.	Sh. B.B. Panthri	Field Attendent
67.	Sh. M.S. Rawat	Field Attendent

(C) Administrative Staff

1.	Sh. Dinesh Chandra	Registrar
2.	Sh. Harish Chandra	Fin. & Accounts Officer
3.	Sh. R.K. Matah	Administrative Officer
4.	Sh. G.S. Negi	Asstt. Fin. & Acc. Officer
5.	Sh. Manas Kumar Biswas	Store & Purchase Officer
6.	Sh. Tapan Banerjee	Sr. Personal Assistant
7.	Sh. U.S. Tikkha	Accountant
8.	Mrs. Manju Pant	Office Superintendent
9.	Mrs. Shamlata Kaushik	Assistant (Hindi)
10.	Mrs. Nirmal Rattan	Assistant
11.	Sh. O.P. Anand	Assistant
12.	Sh. N.B. Tewari	Assistant
13.	Sh. B.K. Juyal	Assistant
14.	Sh. D.P. Chaudary	Stenographer Grade -II
15.	Sh. P.P. Dhasmana	Stenographer Grade -II
16.	Smt. Rajvinder Kaur Nagpal	Stenographer Grade III
17.	Sh. Hukam Singh	U.D.C (Assistant Adhoc)
18.	Sh. D.S. Rawat	U.D.C
19.	Sh. S.S. Bisht	U.D.C.
20.	Mrs. Sarojini Rai	U.D.C.
21.	Mrs. Sharda Sehgal	U.D.C.
22.	Sh. M.M. Barthwal	U.D.C.
23.	Sh. M.C. Sharma	U.D.C.
24.	Sh. A.S. Negi	U.D.C.
25.	Sh. S.K. Chettri	U.D.C.
26.	Sh. Vinod Singh Rawat	U.D.C.
27.	Sh. S.K. Srivastava	L.D.C.(UDC Adhoc)
28.	Mrs. Prabha Kharbanda	L.D.C.
29.	Sh. R.C. Arya	L.D.C.
30.	Mrs. Kalpana Chandel	L.D.C.
31.	Mrs. Anita Chaudhary	L.D.C.
32.	Sh. Shiv Singh Negi	L.D.C.
33.	Mrs. Neelam Chabak	L.D.C.
34.	Mrs. Seema Juyal	L.D.C.
35.	Mrs. Suman Nanda	L.D.C.
36.	Sh. Kulwant Singh Manral	L.D.C.
37.	Sh. Rahul Sharma	L.D.C.

(D) Ancillary Staff

1.	Sh. Puran Singh	Driver
2.	Sh. Dewan Singh	Driver
3.	Sh. Sohan Singh	Driver
4.	Sh. Ganga Ram	Driver
5.	Sh. Chander Pal	Driver
6.	Sh. Naresh Kumar	Driver
7.	Sh. Shyam Singh	Driver
8.	Sh. M.K. Tamang	Driver
9.	Sh. R.S. Yadav	Driver
10.	Sh. Surjan Singh	Driver
11.	Sh. Girish Chander Singh	Guest House Attend. cum-Cook
12.	Sh. Dinesh Parsad Saklani	Guest House Attend. cum-Cook
13.	Sh. Bhagat Singh	Bearer
14.	Mrs. Kamla Devi	Bearer
15.	Mrs. Deveshawari Rawat	Bearer
16.	Sh. Shyam Lal	Bearer
17.	Sh. S.K. Gupta	Bearer
18.	Sh. Chait Ram	Bearer
19.	Mrs. Omwati	Bearer
20.	Sh. Jeevan Lal	Bearer
21.	Sh. Surendra Singh	Bearer
22.	Sh. Vijai Ram Bhatt	Bearer
23.	Sh. Lal Bahadur	Chowkidar
24.	Sh. Har Prasad	Chowkidar
25.	Sh. Mahendra Singh	Chowkidar
26.	Sh. Rohlu Ram	Chowkidar
27.	Sh. H.S. Manral	Chowkidar
28.	Sh. G.D. Sharma	Chowkidar
29.	Sh. Swaroop Singh	Mali
30.	Sh. Ashok Kumar	Mali
31.	Sh. Satya Narayan	Mali
32.	Mrs. Dukhni Devi	Mali
33.	Sh. Ramesh	Safaiwala
34.	Sh. Hari Kishan	Safaiwala

(E) Security Staff (on Contract)

1.	Sh. Om Prakash Thapa	Security Guard
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	(b) Dr. B. Hari Gopal (Nominee of Secretary, DST)	Scientist 'F' & Adviser (AI) Dept. of Science & Technology Technology Bhavan, New Mehrauli Road New Delhi - 110 016	Member (1.2.2006 onwards)
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Finance Committee
w.e.f. 01.12.2006)

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(upto 30.11.2006)

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Building Committee
(w.e.f. 1.12.2006)

Sl. No.	Name	Address	Status
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2.	Joint Secretary & Financial Adviser or his outhorized representative	Dept. of Science & Technology Technology Bhavan, New Mehrauli Road New Delhi 110016	Member
3.	Dr. A.K. Dubey	Scientist 'G' Wadia Institute of Himalayan Geology Dehradun 248 001	Member
4.	Shri Rajesh Agarwal	Chief Engineer (Civil) Dept. of Civil Engineering, Oil and Natural Gas Corporation Shed No. 32, Dehradun 248 001	Member
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7.	Shri Dinesh Chandra	Registrar Wadia Institute of Himalayan Geology Dehradun 248 001	Member Secretary

STATEMENT OF ACCOUNTS

CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS

21/2 Pleasant Valley,
Rajpur Road, Rajpur P.O., Dehradun-248 009
Phone : (0135) 2724622, 2735974
E-mail-chandrabhangoel@yahoo.com

AUDITORS REPORT

We have examined the attached Balance Sheet of **Wadia Institute of Himalayan Geology, Dehradun,** as at 31st March 2007 and the annexed Income & Expenditure Account and Receipt and Payment Account for the year ended on that date. These Financial statements are the responsibility of the Institute's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We have conducted our audit in accordance with the accounting standards generally accepted in India. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatements. An audit includes examining on test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles and significant estimates made by the management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis of our opinion.

In our opinion and to the best of our information and according to the explanations given to us the said accounts give a true and fair view: -

1) In the case of the Balance Sheet of the state of affairs as at 31st March 2007.

2) In the case of Income & Expenditure Account of the deficit for the year ended on 31st March 2007.

3) In the case of Receipt & Payment Account of the receipts and payments for the year ended on 31st March 2007.

For **CHANDRA BHAN GOEL & CO.,**
CHARTERED ACCOUNTANTS

Sd/
(CHANDRA BHAN GOEL)
FCA PARTNER

DATED: 31.07.07
PLACE: DEHRADUN

CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS

21/2 Pleasant Valley,
Rajpur Road, Rajpur P.O., Dehradun-248 009
Phone : (0135) 2724622, 2735974
E-mail-chandrabhangoel@yahoo.com

SIGNIFICANT ACCOUNTING POLICIES AND NOTES TO ACCOUNTS FOR THE YEAR ENDING 31.03.2007

SIGNIFICANT ACCOUNTING POLICIES

A. ACCOUNTING CONVENTION:

The accounts have been prepared on cash basis with income recognized and expenses accounted for on actual receipt/payment basis except the following:

i) Expenses Payable

B. FIXED ASSETS

i) Fixed Assets are stated at cost of acquisition or cost of construction plus the related expenditure. As per the decision of management from the current year depreciation has been charged on the Fixed Assets at the rates specified in the Income Tax Act.

ii) Full depreciation has been charged on the additions to all Fixed Assets made during the year.

iii) Vehicle purchases prior to 01.04.98 have been debited to Equipment account.

C. CLASSIFICATION

The previous year figures have been regrouped and rearranged wherever found necessary in order to confirm to this year classification. Further, the current years figures have been rounded off to the nearest Rupee.

CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS

21/2 Pleasant Valley,
Rajpur Road, Rajpur P.O., Dehradun-248 009
Phone : (0135) 2724622, 2735974
E-mail-chandrabhangoel@yahoo.com

NOTES TO ACCOUNTS

A. ` MAIN ACCOUNT OF WIHG:

i) Schedule '1' to '11' forms part of the Balance Sheet, '12' to '36' forms part of the Income & Expenditure and Receipts & Payments Account as on 31.03.07.

ii) Balance of Debtors and Creditors as on 31.03.07 subject to confirmation.

iii) Separate Balance Sheet have been prepared for :

- Contributory Provident Fund/ General Provident Fund and New Pension Scheme.
- Pension Fund.
- Projects.

iv) In Schedule 11: Current Assets, Loans & Advances an amount of Rs. 4300000.00 (Rupees Forty Three Lakhs only) has been shown under the head Income Tax paid represent the demand paid to the Income Tax Department during the year but as the appeal is pending so it is shown as a Current Asset.

For CHANDRA BHAN GOEL & CO
CHARTERED ACCOUNTANTS

Sd/
(CHANDRA BHAN GOEL)
F.C.A.

DATED : 31.07.07
PLACE : DEHRADUN

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN
BALANCE SHEET
(AS ON 31ST MARCH 2007)

(AMOUNT IN RUPEES)

PARTICULARS	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES		
Corpus/ Capital Fund	301,859,409	298,551,165
Reserves and Surplus	-	-
Earmaked/ Endowment Fund	567,048	1,967,401
Secured Loans & Borrowings	-	-
Unsecured Loans & Borrowings	-	-
Deferred Credit Liabilities	-	-
Current Liabilities & Provisions	658,070	3,086,338
TOTAL	**303,084,527**	**303,604,904**
ASSETS		
Fixed Assets	254,490,224	244,353,715
Investment from Earmaked/ Endowment Fund	21,177	19,255
Investment- others	-	-
Current Assets Loans & Advances	48,573,126	59,231,934
TOTAL	**303,084,527**	**303,604,904**

AUDITOR'S REPORT

"As per our separate report of even date"

Significant Accounting Policies and Notes on Accounts as per Annexure

For CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS

Sd/

CHANDRA BHAN GOEL
(F.C.A)

Sd/	Sd/	Sd/
(HARISH CHANDRA)	**(DINESH CHANDRA)**	**(B.R. ARORA)**
FINANCE & ACCOUNTS OFFICER	REGISTRAR	DIRECTOR

DATED : 31.07.2007
PLACE : DEHRADUN

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN
INCOME & EXPENDITURE A/C
(FOR THE PERIOD ENDED 31ST MARCH 2007)

(AMOUNT IN RUPEES)

S.N.	PARTICULARS	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**		
	Income from sales/ services	-	-
	Grants/ Subsidies	65,400,000	82,000,000
	Fees/Subscription	63,254	16,000
	Income from Investments (Income on Invest from Earmarked/ Endowment - Fund)	208,000	217,896
	Income from Royalty, Publication etc.	52,797	81,266
	Interest earned	1,810,035	3,452,272
	Other Income	1,822,090	2,677,942
	Increase/ Decrease in stock of Finished goods & WIP& Stock of Publication	(45,602)	-
	Rounding Off	1	
TOTAL (A)		**69,310,575**	**88,445,376**
B	**EXPENDITURE**		
	Establishment Expenses	56,740,222	58,587,288
	Other Research & Administrative Expenses	19,635,989	15,205,379
	Expenditure on Grant/ Subsidies etc.	-	-
	Interest/ Bank Charges	19,570	9,794
	Depreciation Account	42,003,471	
	TOTAL (B)	**118,399,252**	**73,802,461**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)	(49,088,677)	14,642,915
	Transfer to Special Reserve (Specify each)	-	-
	Transfer to / from General Reserve	-	-
	GRAND TOTAL	**69,310,575**	**88,445,376**

AUDITOR'S REPORT

"As per our separate report of even date"

Significant Accounting Policies and Notes on Accounts as per Annexure

For CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS

Sd/

CHANDRA BHAN GOEL
(F.C.A)

Sd/	Sd/	Sd/
(HARISH CHANDRA)	**(DINESH CHANDRA)**	**(B.R. ARORA)**
FINANCE & ACCOUNTS OFFICER	REGISTRAR	DIRECTOR

DATED : 31.07.2007
PLACE : DEHRADUN

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN
RECEIPTS & PAYMENTS A/C
(FOR THE YEAR ENDED 31st MARCH 2007)

PARTICULARS	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS		
Opening Balance	12,062,252	22,246,227
Grants - in - Aids	116,400,000	142,000,000
Grants - in - Aids (Ear Marked)	1,880,531	5,449,400
Loan & Advances	24,855,065	16,724,578
Loan & Advances (Ear Marked)	782,451	-
Fees/Subscription	63,254	16,000
Income from Investments	208,000	217,897
Income from Royalty, Publication etc.	52,797	81,266
Interest earned on Loan to Staff	1,810,035	3,452,272
Other Income	1,607,929	2,677,942
Investment	38,100,000	9,500,000
Decrease in stock (publications)	-	-
	197,822,314	**202,365,582**
PAYMENTS		
Establishment Expenses	56,740,222	58,467,788
Other Administrative Expenses	19,635,989	15,205,379
Interest/ Bank Charges	19,570	9,794
Loans & Advances	33,954,329	12,883,309
Loans & Advances (Ear Marked)	775,424	-
Investments	19,350,000	38,100,000
Fixed Assets	50,743,058	59,400,414
Ear Marked Fund Expenses	2,956,752	5,500,948
Grant - in - Aid (Ear Marked) Refunded	118,920	735,698
Closing Balance	13,528,050	12,062,252
Increase in value of closing Stock (Publications)	**197,822,314**	**202,365,582**

AUDITOR'S REPORT

"As per our separate report of even date"

Significant Accounting Policies and Notes on Accounts as per Annexure

For CHANDRA BHAN GOEL & CO.
CHARTERED ACCOUNTANTS
Sd/

CHANDRA BHAN GOEL
(F.C.A)

Sd/	Sd/	Sd/
(HARISH CHANDRA)	**(DINESH CHANDRA)**	**(B.R. ARORA)**
FINANCE & ACCOUNTS OFFICER	REGISTRAR	DIRECTOR

DATED : 31.07.2007
PLACE : DEHRADUN

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