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ABSTRACT VOLUME

Third Nepal Geological Congress

26–28 September 2001

Kathmandu, Nepal

THIRD NEPAL GEOLOGICAL CONGRESS
26–28 September 2001

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NEPAL GEOLOGICAL SOCIETY

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Hydrographic nets as reconnaissance models for aerial photo interpretation

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It is known that the integration of the drainage channels of the waters spatially determines a model known as drainage net. This type of net has a great importance in geomorphology and photo interpretation. The net characteristics may reveal the landform behaviour and they may be equally useful in the reconnaissance survey carried out by the help of aerial photographs. Such nets may be of integrated or unintegrated and convergent or divergent types. In the aerial photographs and in the field, it is also possible to recognise ancient nets or palaeomodels formed in conditions different form those at present. Finally, there are other nets that are buried by sediments or that are in the subsurface. The main net types and their possible interpretation are summarised below.

Dendritic net: It is characterised by a steady increase in the number of tributaries from the mouth to the source area, usually following a seriate pattern as regards the number of courses of different order. The dominant factor in the genesis of this model is homogeneity of surface material. Horizontal to sub-horizontal sedimentary rocks with clay, silt, and sand offer the best conditions for the development of this model.

Pinnate net: The essential characteristic that differentiates it from the dendritic net is the very acute angle that the affluents make. It may also present a seriate model. It frequently appears on the rear side of the hogback relief and also where there exist inclined planes that determine a regional slope.

Orthogonal net: It is frequently the result of a strong structural control due to joints and conjugate faults that meet at a right angle. It is common on some igneous and metamorphic massifs.

Trellis net: It is characterised by a very long main and some subsequent courses while the affluents are short, meet at a right angle, and have an obsequent or consequent nature. It generally responds to a strong structural control caused by inclined and even vertical strata corresponding to monoclinal structures and limbs of folds. The main course follows the strike whereas the affluent courses of greater length follow the dip direction. The alternation of strata of different resistance to erosion causes a marked surface anisotropy that controls the dominant direction of the net.

Radial net: In this case, the main courses are arranged as the spokes of a wheel and may lithologically be convergent or divergent. They respond to both structural control and morphological conditions. The net generally originates from a dome-like structure or circular depression.

Annular net: It is often associated with morphological or structural models similar to those mentioned for the radial net, but it requires that the streams be arranged in a concentric pattern. It can result from circular or concentric faults, dome or basin structure, or annular metamorphic zoning.

Parallel net: This type of net neither converges nor diverges. It may be controlled by lineaments, parallel faults, or joints.

Geomorphology and neotectonics of the mid-northern part of Bangladesh based on remote sensing

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Bangladesh lies in a tectonically complex and active region that is expressed by frequent occurrence of earthquakes in its northeastern and eastern sides. Studies show that the Dauki Fault, an important tectonic element present in the northern part, is still active. It is considered that the geomorphology of adjacent areas is affected by the fault. The study of geomorphology and neotectonics of the mid-northern part of the country was carried out using Landsat MSS (bands 5 and 7) and TM FCC, SPOT imageries, and aerial photographs with limited fieldwork. In the study area, the following six landforms were identified: northern hills, Madhupur tract, Mymensingh surface, alluvial fan, floodplains, and depressions. The northern hills are composed of Late Tertiary sedimentary rocks, the Madhupur tract is composed of Pleistocene residual soil, and the other landforms contain Holocene sediments. Some neotectonic activity is marked by the development of a small fan on an old fan, differential soil development on an alluvial fan, stream offset at the foothills, local abnormalities in the drainage pattern, short-length meandering of streams, two terrace levels along the riverbank, spatial variation in fan development, poorly-developed natural levee, and the presence of buried wood fragments in the sediment.

Sedimentary record of the geodynamic evolution of the Himalaya

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The Himalayan Range was formed as a result of a complex geodynamic evolution characterised by the opening of the Tethyan oceanic realm, then by the closing of the Tethyan oceanic basin, and finally by a complex suturing, including inversion of the Tethyan structures (Fig. 1 and 2).

Pre-rifting (Precambrian to Early Palaeozoic–Late Carboniferous, before 290 Ma)

Pre-rifting sequences are well documented in the Himalaya. Precambrian to Early Palaeozoic sequences are developed in the Lesser and Higher Himalayas. Late Pan-African to Early Caledonian granites are widespread either in the Higher or in the Lesser Himalaya (Tso Morari, Manserah, Kathmandu nappe). Early Palaeozoic to Early Carboniferous platform deposits are exposed north of the South Tibetan Detachment, and they characterise a Gondwana marine platform.

Rifting (Late Carboniferous–Permian, 290–245 Ma)

Rifting occurred during the Late Carboniferous to Permian Period. The Late Palaeozoic sequences are exposed north of the South Tibetan Detachment (Tethyan Himalaya), and they show strong variations in thickness (either at a local scale or as revealed by comparison with the South Zanskar and Lahul–Spiti sequences). However, the old extensional structures are generally not preserved because they were strongly inverted during the Himalayan collision. The Late Palaeozoic Gondwana sequences are locally present in the Lesser Himalaya.

Oceanic accretion and Indian margin evolution (Late Permian–Cretaceous, 245–65 Ma)

The Tethyan oceanic lithosphere is preserved in the Indus Ophiolite (Spongtang klippe, Nidar ophiolitic nappe, Amlang La nappe, Xigaze ophiolite, Lohit nappe etc); Tethyan oceanic sediments also form small tectonic slices within the Indus Suture Zone; both document the Cretaceous history of the Tethys Ocean. Early stages of oceanic evolution are rare; some are preserved in the Drakar Po unit, where the Late Permian lava characterises an oceanic island environment. Even if strongly removed by inversion, the evolution of the Indian margin can be reconstructed; the sequences of the Lamayuru nappe and its equivalents are characteristic of slope deposits; the so-called Tethys Himalaya (Zanskar nappe, Spiti belt, ‘ Tibetan’ sequences of Nepal) represents the Indian platform.

Oceanic subduction (Late Jurassic–Palaeocene, 150–52 Ma)

The Tethyan oceanic lithosphere was subducted at the northern margin of the Tethys Ocean. Evidences in the Ladakh Himalaya are the Dras arc sequences (Late Jurassic–Albian), the Nindham flysch (Barremian–Palaeocene) and part of the Ladakh batholith (Cenomanian–Eocene) including the Khardung La volcanics. The Dras–Kohistan sequence characterises an intra-oceanic arc environment, and the sequence collided with the Asian margin at 100 Ma; the Nindham flysch, Ladakh and Kangdese batholiths, and Khardung La and Lingzizong volcanics represent the Asian margin of Andean type. This episode is characterised on the Indian margin by wild flysches and melanges of Upper Cretaceous–Palaeocene age.

Continental subduction (Palaeocene–Early/Middle Eocene, 52–44 Ma)

The thinnest part of the Indian margin suffered subduction, as documented by the eclogitic metamorphism dated 55 Ma in the Tso Morari unit. During the Early/Middle Eocene times, marine sedimentation ceased contemporaneously on both the Indus Basin and the Indian platform (Zanskar, Tingri, Kampa Dzong), indicating that the

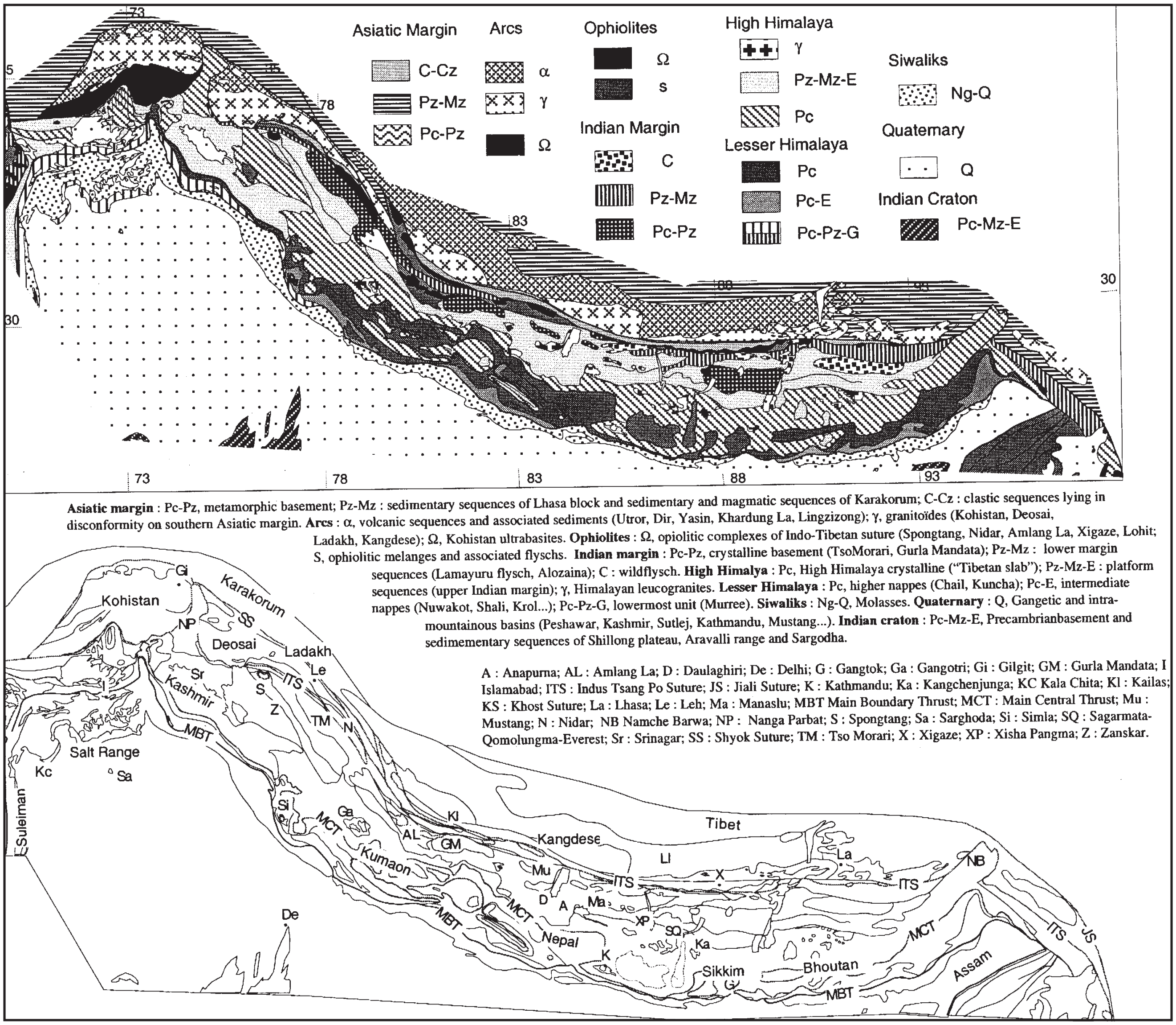

Fig. 1: Structural map of the Himalaya

crust of the area recovered for the first time a normal thickness. The occurrence of a Late Palaeocene–Middle Eocene marine basin south of the area (Subathu Basin) suggests further that the lithosphere was even thicker than normal giving birth to a first mountainous relief. The erosion of the Himalayan relief is documented by the increasing clastic content of the Palaeocene–Eocene sequences either in the Indus Basin, or in the Zanskar and Subathu basins. Emplacement of granitic bodies continued in the Ladakh batholith.

Continental collision (Middle/Late Eocene–Oligocene/Early Miocene, 44–23 Ma)

This episode is characterised mainly by the deformation (shortening) of the Indian marginal sequences, which resulted, with the emplacement of nappes, in the growing of mountain range and thickening of crust. It is registered within the two sedimentary basins: the Murree–Darhamsala Basin in the South, and the Indus Basin in the North. The Murree–Darhamsala Basin represents a flexural foreland basin at the front of a growing mountain range. The Indus Basin became a residual intramontane episutural basin; it shows a succession of continental formations, which are separated by unconformities and they become increasingly clastic in their upper part. Their deformation is multiphase; the oldest sequences were first affected by south-vergent ductile structures, then by north-vergent ones, and lastly by brittle ones; the younger sequences show north-vergent ductile and brittle structures, and the youngest sequences were affected only by north-vergent brittle structures (thrusts and strike slip faults).

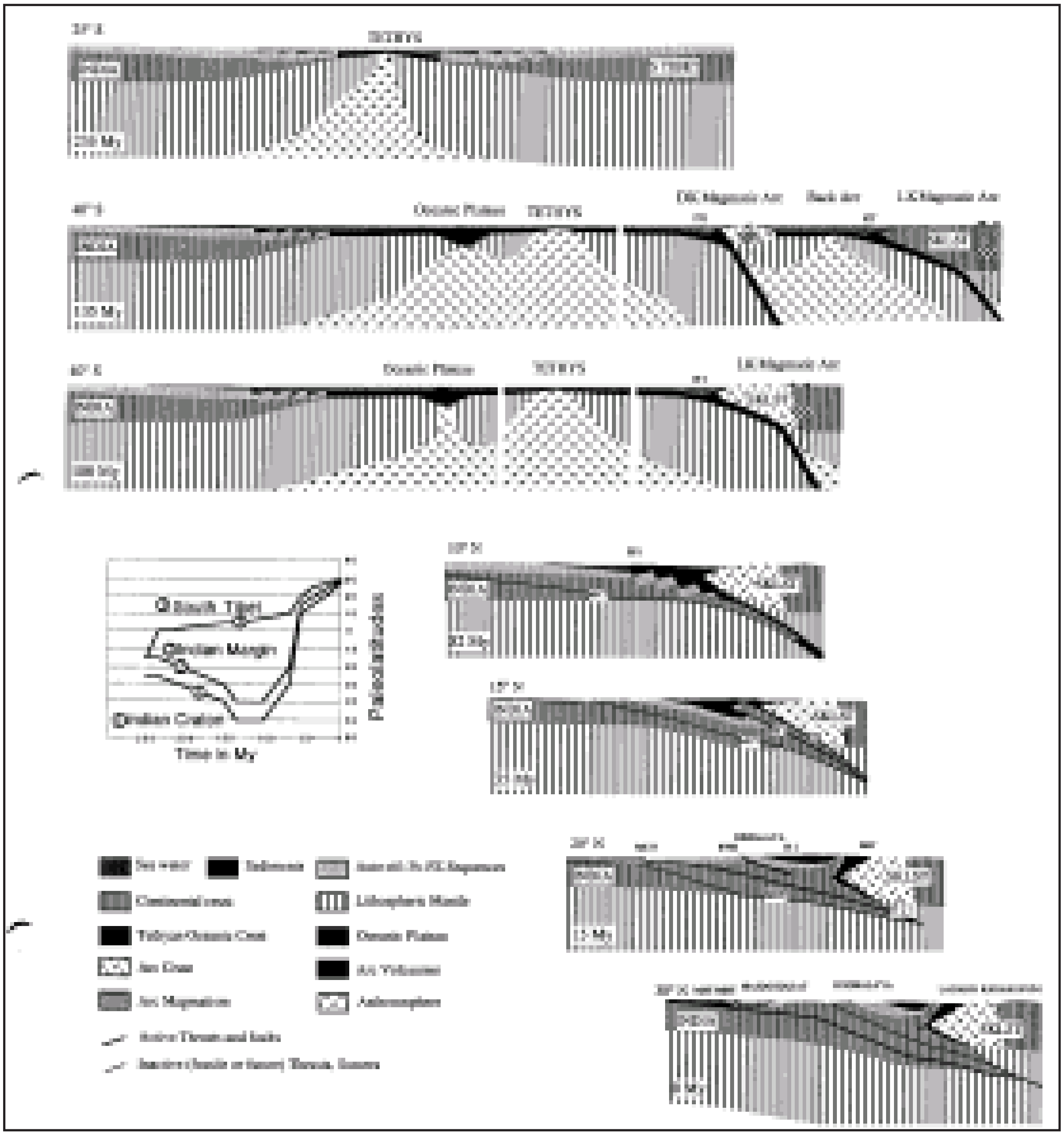

Fig. 2: Geodynamic evolution of the Himalaya. IT1 and IT2: Indus Thrusts; IRT: Indus Reto Thrust; KT: Karakorum Thrust; MBT: Main Boundary Thrust; MCT: Main Central Thrust; MST: Main Siwalik or Frontal Thrust; FNH: North Himalayan Detachment; DK: Dras–Kohistan Arc; LK: Ladakh–Kangdese Arc; SKLST: South Karakorum–Ladakh–South Tibet Block

Continental duplication (Miocene, 23–6 Ma)

The deformation migrated southwards and was located in the old Indian crust; the MCT zone was the active structure, which resulted from the classic inverted metamorphism, the emplacement of leucogranites, and the growing of a mountainous relief; the sedimentary cover (south Zanskar, Annapurnas, North Sagarmatha) underwent extensional tectonic regime (South Tibetan Detachment). To the south of the mountain front, the Indian crust became flexured, which formed the Siwalik molassic basin. The Ladakh Himalaya was affected by local tectonic readjustment (Karghil Basin, Pashkyum Thrust).

Continental triplication (Pliocene–Quaternary, 6–0 My)

The deformation migrates still southwards up to the MBT zone. The whole Himalayan Range represents a tectonic prism under the verge of failure. The deformation that is undergoing locally is strongly correlated with the tectonic readjustment and the rate of erosion. The Northern Himalaya is locally affected by extensional structures (Tso Morari graben, Thakkhola graben etc).

Estimating streaming potentials associated with geothermal circulation at the MCT in Central Nepal

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Streaming potential coefficient and sample conductivity were measured in the laboratory as a function of KCl electrolyte conductivity for six crushed rock samples collected at the MCT zone near the Tatopani-Kodari hot spring in Central Nepal. Surface conductivity values range from 0.11±0.07 to 1.19±0.13 mS/m and values of inferred z potential vary from -16.3±0.2 mV to -41.2±1.0 mV. These experimental measurements were used to model the streaming potential coefficient and the rock resistivity as a function of permeability. The electric potential generated on surface by the geothermal circulation at the MCT zone was then derived using a simple two-dimensional analytical calculation. The maximum expected anomaly depends on the values of poorly known parameters such as the permeability of the MCT, but can be expected to vary from 200 mV to values as small of 20 mV. Although such anomalies may be difficult to detect, they may exhibit some sensitivity to variations of crustal parameters associated with stress accumulation, and may therefore open an interesting possibility in the search for earthquake precursors.

Geology of Sausar Group (Proterozoic) of Kamptee–Koradi sector of Nagpur District, Central India: field and petrographic features

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This paper describes the geology of the Kamptee and Koradi areas respectively situated in the Kanhan and Kolar valleys. The paper forms one of a series that records the findings of the team of research workers from the University Department of Geology, Nagpur, and from a few other institutes in India and abroad (Gwalani et al. 1997, 1999, 2001).

In this paper, the mapped region is referred to as the Kamptee–Koradi sector, which lies on the northern periphery of the city of Nagpur (Maharashtra State) in Central India (Fig. 1). The sector is almost a flat region into which a few broad valleys like that of Kanhan and Kolar have been cut. The terrain towards the east shows a rugged topography marked by the range of Suradevi Hills almost aligned east–west. The sector comprises a complex zone of metasedimentary and metabasic rocks closely associated with a large number of pegmatite and granite intrusions. These Proterozoic rocks (the Sausar Group) form a narrow belt intervening the two major faults, and as such, the northern and southern boundaries of the belt appear nearly straight lines (Fig. 1). The Lower Gondwana rocks (shale, sandstone, and coal), which at places in the southern part of the mapped area are overlain by the Deccan basalts, occur on either side of the Sausar belt.

In the Kamptee–Koradi sector, the Sausar Group, which is also referred to as the Proterozoic Sausar Orogeny (Sarkar et al. 1981; Kumar 1992), is represented by the upper three formations of the Sausar sequence, namely Bichua, Junewani, and Chorbaoli Formations comprising a wide variety of metasedimentary rocks (i.e., quarzites, schists, and marbles). These rocks and associated intrusives (i.e., amphibolites, granites/orthogneisses, and pegmatites) are the oldest rocks in the sector. They are exposed mainly in the river and stream cuttings and on the Suradevi Range.

Field relations, overall geological and structural set-up, and petrography of these rocks (including the intrusives) are described in this paper.

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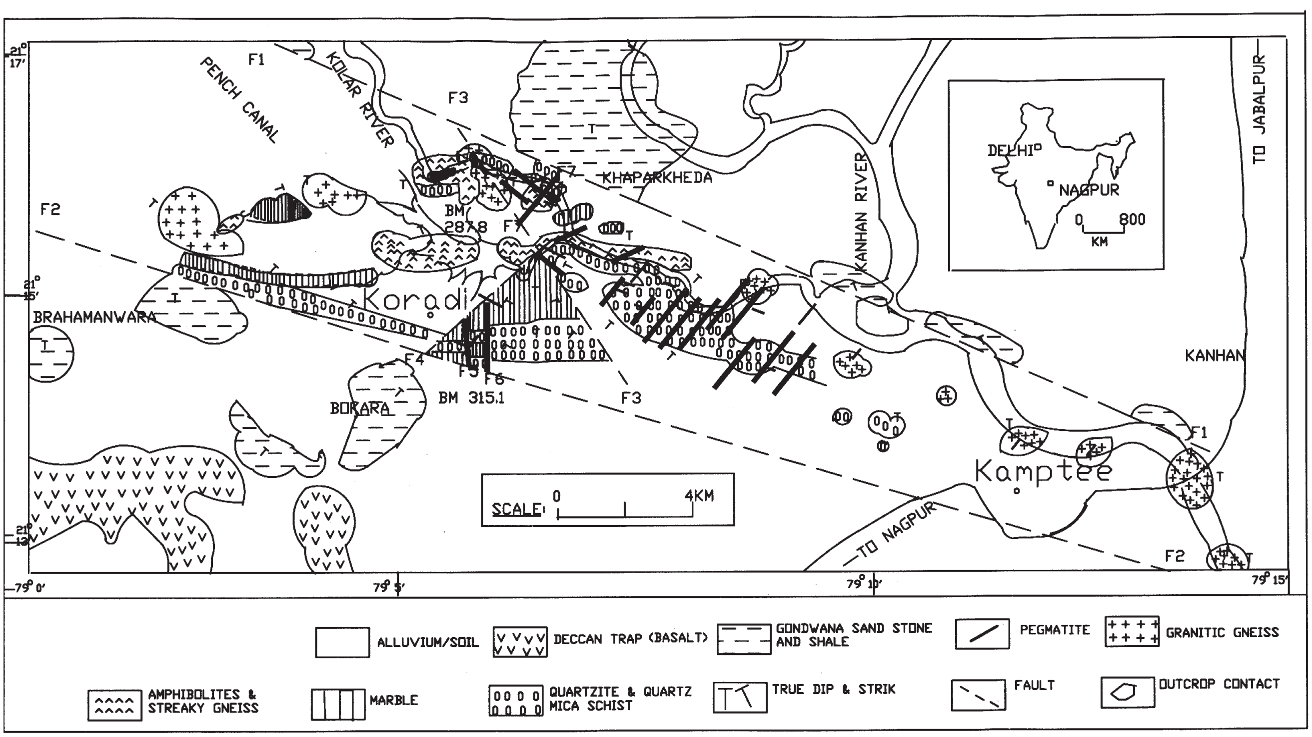

Fig. 1: Geological map of the Kamptee–Koradi sector, Nagpur District, Central India

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Amphibolites and pegmatites of the Koradi–Suradevi sector, Nagpur District, Central India: geology, mineralogy, and petrography

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In the Koradi–Suradevi sector of the Kolar Valley on the northern outskirts of the city of Nagpur in Central India, Proterozoic metasedimentary rocks of the upper Sausar Group comprising (in order of increasing age) Bichua marbles, Junewani micaschists, and Chorbaoli quartzites are intruded by amphibolites (metabasics), granites, and pegmatites. The first geological map together with a descriptive paper containing new data on the granitic pegmatites of the Koradi area was published by Gwalani et al. (1999). The terrain characteristics, geology, stratigraphy, and petrography of the Sausar rocks of this sector and its contiguous Kamptee area are presented in the companion paper (Dhote et al. 2001). In this paper, we present a detailed description of the geology of the intrusive rocks of Koradi-Suradevi sector comprising major and minor intrusions of closely associated metabasic (amphibolites) and pegmatites, which are not confined to any particular formation of the Sausar Group. The metabasic intrusions are represented by amphibolites, whereas acid intrusions comprise granite (orthogneiss) and pegmatite.

The Sausar metasedimentary and sedimentary formations as well as amphibolites form the host rocks. They are crosscut by the swarms (with almost N–S and E–W trends) of pegmatite dykes, which at many places branch out into sill units localised along weak planes of schistocity, joints, and fractures. The pegmatite dykes dominate the geology in the east Suradevi and Kolar valleys. Significant textural variation is present within both acid and basic intrusions. Large sheet-like intrusions of pegmatite and massive granite plutons generally appear fresh and pinkish in colour and they show from medium- to very coarse-grained texture. Massive bodies of amphibolites are dark green to almost black in colour and they are often well foliated showing medium- to coarse-grained schistose texture. On the other hand, migmatised amphibolites (streaky gneiss) appear banded due to the presence of leucocratic aplite layers of variable thickness (less than a cm to about a few cm). The pegmatites are classified into two types: (i) simple pegmatite consisting of quartz, feldspar, biotite and apatite, and (ii) complex pegmatite containing in addition muscovite, tourmaline, and epidote. Both the varieties contain small books of mica of no commercial value.

In thin sections, the minerological and textural characteristics of amphibolites and pegmatites are very distinctive. The dominant mineral assemblage in amphibolites includes amphiboles (27.24 to 26.04%), quartz (4.07 to 39.98%), plagioclase (4.92 to 9.09%) and epidote (17.16 to 2.262%). Tourmaline, sphene, biotite, apatite, zircon, garnet, and opaques occur as common accessory minerals.

Both amphibolites and pegmatites have igneous parentage. The amphibolites represent metamorphosed basic intrusives and they predate the emplacement of pegmatite dykes. The chemical study of amphibolites has indicated their affinity to tholeiitic basalts, which probably represent basic magmatism of pre- to syntectonic type in the Sausar orogeny. They are enriched in Fe and Mg, and show komatiitic affinity. The pegmatites may be genetically related to the associated granitic rocks, which are also tourmaline-bearing and almost devoid of biotite. They are mostly potassic in composition and represent post-folding phenomena.

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Gondwanic India from break-up to continental collision: a tectono-sedimentation overview of parts of the Himalayas

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After being dismembered from the Gondwana assembly during the Late Jurassic, the Indian Plate drifted on the Neo-Tethys Ocean northwards with counter clockwise rotation. It passed over a mantle plume hotspot during the Maastrichtian/Early Palaeocene time and drifted further until it collided with the Eurasian Plate in the Eocene time. This process gave rise to the Himalayan Chain in a compressive tectonic domain and also profoundly influenced the tectonic evolution of Central Asia. The border area of the Himalayan mountains with the Tibetan Plateau is composed of a series of microplates accreted to Asia before India–Eurasia collision. Since initial collision with the Lhasa block ca. 50 Ma ago at a convergence rate of 50 mm/year, India has moved northwards further to ca. 2,000 km resulting in a compression that uplifted the 5 km-high Tibetan Plateau with a thickened from 50 to more than 70 km crust. Crustal shortening occurred by continued indentation of India into Asia by homogeneous thickening of the Tibetan lithosphere, partial underthrusting of the Indian Plate beneath Tibet, intracontinental thrusting and internal deformation and lateral eastward extrusion of Tibet and Southeast Asia along major strike-slip faults. The far-field compressive stresses generated by the India–Eurasia collision and convergence are thought to have influenced Baikal rifting and passive rifting of the Red Sea.

The Indus Suture (Yarlung–Zangbo) marks the subduction zone in the process of continental collision where there lie the obducted remnants of Neo-Tethyan crust and deep marine sediments (Triassic–Eocene). Lithological spectrum on the collisional front includes turbidites, ophiolitic melanges, calc-alkaline volcanics, granite batholith, and post-orogenic molasse sedimentary deposits. The Ophiolitic Melange Zone represents dismembered parts of the Neo-Tethyan ocean crust on which there existed seamounts/oceanic islands. This zone is thought to be the relict of an ancient convergent zone/trench between the Indian and Eurasian plates.

Apparently, the upper part of the Indian crust near the suture in the Lhasa side is detached from the lower part and has been thrust upward and northward relative to the Gangdese plutonic belt. The Ladakh–Gangdese plutonic complex represents a magmatic arc. The lower part of the crust may have been subducted (= delaminated) beneath the Gangdese belt after initial collision marking the first intracontinental underthrusting zone. The second zone of intracontinental underthrusting is possibly associated with the leucogranite belts of the High Himalayas. There may be widespread development of a mechanically weak mid-crustal partially melt layer north of the Yarlung–Zangbo Suture.

In the Western Himalayas, the Kohistan–Dras/Ladakh island arc collided with the approaching Indian Plate. Final collision of island arc-accreted northern margin of India with Eurasia took place along the Shyok Suture in the Early Oligocene time. The island arc complex was considerably thickened by voluminous generation of calc-alkaline magma before the collision. Strong compressive force has resulted in the obduction of Spongtang Ophiolite coeval with the India–Eurasia collision.

There was oblique convergence/collision in Late Oligocene between the Indo-Burma–Andaman Block (IBA) and the Indian Plate. The northeastern prolongation of the Indian landmass collided against the northern end of IBA during Mio-Pliocene.

Apart from flysch and molasse, and related sedimentary complex in the collisional suture zone, there was Palaeozoic and Mesozoic sedimentation in the southern Tethyan passive margin of India in several sub-basins of the High Tethyan Himalayas. Mesozoic was marked by carbonate platform development. Shallow to deep marine sedimentation occurred. Parts of the marine passive margin sedimentation in the northwestern Himalayas may compare with marine sedimentary cycles of Karakoram region. Exemplary passive margin sedimentation may be glimpsed in the megasequences of the most complete sections of the Zanskar Range in the Tethys Himalayas. The sedimentary sections in the Tethyan Himalaya in southern Tibet (Central Himalayas) suggest evolution of the Neo-Tethyan Basin from a wide ocean to a narrow remnant trench basin. Olistostromes, chaotic deposits, associated turbidites, pelagic radiolarites, hemipelagic marls, and volcaniclastics are remarkable sedimentary associations in the Cretaceous sequence in the northern deep-water facies belt.

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First mineralogical indicator of ultra-high-pressure rock from Indian Himalaya

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The discovery of coesite, an ultra-high-pressure (UHP) mineral, within garnet was made by optical microscopy and confirmed by Raman Spectroscopy is reported for the first time from the Tso-Morari Crystalline Complex (TMC), eastern Ladakh, India.

The TMC is located between the Indus Suture Zone and Zanskar Tetheyan sediments. The TMC stretches for 50 km NE–SW and 100 km NW–SE, and is bounded by two detachment faults. It has three principal tectono-stratigraphic units: the Puga Formation, Taglang La Formation, and Polokangla and Rupshu granitoids.

The eclogite occurs in the form of lenses, boudins, and irregular masses within the Puga Gneiss of sillimanite-kyanite grade. These eclogites can macroscopically be subdivided into dark- and light- coloured types. The dark coloured eclogites are more massive and fine-grained than light coloured ones. The eclogite is composed essentially of euhedral, inclusion-rich garnet with well-developed crystal face and 100 to 500 mm in size, omphacite, sodic amphibole (glaucophane), quartz, and coarse flakes of phengite. Accessory phase of eclogite are rutile, chlorite, apatite etc.

The garnet porphyroblasts invariably display intense radial and concentric fracturing with well-developed major element zoning with increasing Mg and decreasing Ca and Fe/Mg from core to rim. This is interpreted as evidence for increasing temperature during crystallisation. It has inclusions of omphacite, phengite, glaucophane, and rutile in varying size with monominerallic and bimineralic quartz and coesite. Coesite is a high-pressure polymorph of SiO_2 characterised by 30–80 mm size, high relief, and lower birefringence compared with quartz. It displaced the principal Raman band by 523.1 cm^{-1}.

The textural relationship, rim-to-rim mapping of porphyroblastic garnet and the coesite stability field within mechanically strong garnet, must have crystallised near peak P–T conditions with >28 kbar and >700^o C . It is inferred that the return of UHP rock to the earth's surface took place from a depth of >90 km, without suffering significant transformation of coesite to quartz. It has also represented mantle fragment with lithospheric and asthenospheric imprints. The presence of such a UHP mineral in the Indian continental crust reveals that the Indian plate subducted to >90 km depth making a very steep angle and then it exhumed very rapidly.

Upper Siwalik mammalian faunas of India and Nepal

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Tatrot and Pinjor mammalian faunas occurring in the Upper Siwalik succession are well known from India and Nepal. The Upper Siwalik successions exposed at Chandigarh and Jammu in India are very rich as compared to those at Surai Khola and Ratu Khola in Nepal. In Nepal, the Tatrot Fauna is known by only four marker taxa, viz., *Stegodon bombifrons, Hippohyus tatroti, Giraffa punjabiensis* and *Proamphibos* cf. *P. lachrymans*. The marker taxa of the Pinjor Fauna in Nepal include *Equus sivalensis, Potamochoerus* cf. *P. theobaldi* and *Cervus* sp. In India, 25 marker taxa of the Tatrot and 49 of the Pinjor Fauna are recorded in Chandigarh alone. In India and Pakistan, Tatrot–Pinjor faunal boundary coincides with Gauss–Matuyama magnetic boundary (Chron C2An–C2r) at 2.58 Ma. However, the upper limit of extinction or migration of the Pinjor Fauna is variable in different sections of Chandigarh and Jammu, and ranges from 1.72 Ma to 0.6 Ma. The Upper Siwalik faunas are very well known from the areas west of the Yamuna River and no record is found between the Yamuna River and Nepal border. The Upper Siwalik succession in this area is represented mainly by conglomeratic beds. The faunas reappear at the Surai Khola in Nepal. It is possible that due to the intensification of the Himalayan orogeny, as indicated by thick deposits of conglomerates, the route of migration shifted to the south and its evidence may be concealed under the Indo–Gangetic alluvium. Two biostratigraphic interval zones, *Elephas planifrons* Interval Zone (3.6 to 2.6 Ma) and *Equus sivalensis* Interval Zone (2.6 to 0.6 Ma), recognised in India are yet to be demarcated in Nepal. More magnetostratigraphic data and vertebrate collection from fossiliferous sections are required for Nepal.

Tide-storm-dominated shelf sequence of the Neoproterozoic Blaini Formation and its implications on the sedimentation history of the Krol Belt, Kumaun Lesser Himalaya, India

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The diamictite-bearing Neoproterozoic Blaini Formation has direct implications on the genetic evolution of the Krol Belt. Detailed lithofacies and palaeocurrent analysis of the Blaini Formation suggests that the sediments belong to the following two distinct facies associations: storm-dominated and tide-dominated. The storm-dominated facies association overlies the transgressive lag deposit facies and comprises offshore, offshore transitional, and subtidal facies. The tide-dominated facies association, on the other hand, comprises intertidal to supratidal facies.

The transgression at the base of the Blaini Formation was related to intrabasinal tectonic adjustments and changed the barrier island system of the Nagthat time into the shelf system during the Blaini time. High-energy tides–storm conditions of sedimentation in the Blaini Basin gradually changed into moderate to low energy conditions, wherein, diamictites were emplaced through downslope re-sedimentation of cohesive debris flows. The debris owes its origin to intermixing of extrabasinal and intrabasinal class with hinterland sediments, which were eroded in response to some tectonic adjustments during the end stage of the Blaini sedimentation. Afterwards, the tectonic conditions in the basin became stable giving rise to the deposition of a thick succession of Krol carbonates. Thus, the Krol Belt evolved through at least three distinct cycles of sedimentation, which may be called as the Jaunsar–Simla, Blaini, and Krol cycles, respectively.

Significance of trace fossils in the stratigraphic set-up of the Cambrian successions in the Tethyan Zone of Garhwal Himalaya, India, and its problems

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The Garhwal region is represented by the Late Precambrian to Mesozoic succession of rocks along the Dhauli Ganga and Girthi Ganga valleys, which are resting on the basement rock of the Central Crystalline Group. It has been observed that the Palaeozoic–Mesozoic successions in this region are well exposed in the Malari–Belchadura sections. However, the present paper reveals an account of observations along with some faunal studies and their stratigraphic significance in the Cambrian succession of this region.

The Cambrian succession of the Garhwal Tethyan Himalaya is deformed and devoid of any vegetation. The

area dealt in this region lies in the Chamoli District of Uttaranchal Pradesh. It constitutes the northeastern part of the Chamoli District (longitudes: 79° 45' and 80° 50' E; latitudes: 30° 40' and 30° 46' N). The average altitude of the region ranges between 3,000 and 5,816 m. The stratigraphy of the Garhwal–Kumaun Tethyan Zone in general has been discussed by a number of workers. Kumar et al. (1970, 1977) gave a lithostratigraphic account of the Malla Johar (Garhwal–Kumaun) area. Later on, Shah and Sinha (1974) studied the area and its fauna. They also superimposed the biostratigraphic data on the formal stratigraphic units of the entire region of Garhwal Himalaya and proposed various new faunal horizons. Parcha (1999), and Sudan and Kumar (2000) studied the trace fossil horizons of the area.

Stratigraphically, the Lower Palaeozoic succession of the Garhwal Himalaya is divided into the Martoli, Ralam, Garbyang, Shiala, and Young Limestone, and Variegated formations. These formations are resting on the proven metamorphic Central Crystalline Group. The Martoli Formation contains high-grade metasedimentary rocks in the basal part and low-grade phyllites and quartzites in its upper part. The Martoli Formation is unconformably overlain by the purple quartzite intercalated with the lenticular conglomerates in the basal part, constituting the Relam Formation, which in turn is overlain by the Garbyang Formation. Tandon and Bhatia (1978) divided the Garbyang Formation into three units. The lower unit consists of an alteration of limestone, calcareous shale, and siltstone; the middle unit is represented by oölitic limestone and red dolomite; and the upper unit is of compact, laminated, grey quartzite, graded siltstone, arenaceous limestone, and brown-green shale. The Garbyang Formation is the most extensively developed unit of the Lower Palaeozoic succession of the Garhwal Tethyan Himalaya; it is conformably overlain by the Shiala Formation.

Parcha (1998) recorded a rich and diversified assemblage of trace fossils from the middle unit of the Garbyang Formation. The trace fossil assemblage present in this unit is represented by *Phycodes, Planolites, Cruziana, Isopodichnus, Chondirites*, and some burrowing traces. The present assemblage of trace fossils is very much significant because no body fossils of Early Cambrian age are reported so far from the Garbyang or underlying formation. The only body fossil doubtfully identified so far is from the Milam Formation (Kakakar and Srivastava 1996). The Milam Formation is considered the equivalent of the Martoli Formation, which itself makes the fixation of boundary a problematic one. Based on presently identified trace fossil fauna and the fauna identified by the earlier workers, a trace fossil assemblage is marked in this succession. Based on this trace fossil faunal assemblage, it is assumed that the Precambrian–Cambrian boundary lies somewhere in the Martoli Formation.

The trace fossil assemblage reported during the present study from the Garbyang Formation of the Garhwal region can be correlated with the assemblage of other Early Cambrian Tethyan successions of Zanskar, Spiti and Kashmir, and with the Tal Formation of the Lesser Himalaya. However, so far not a single trilobite have been reported from the Garbyang Formation in the present studies. The trace fossil studies indicate an Early Cambrian age to the middle unit of the Garbyang Formation. The assemblage of trace fossils identified from this formation is more or less cosmopolitan in nature.

In the absence of body fossils (particularly, the trilobite fauna), the trace fossil assemblage has great biostratigraphic significance in order to fix the boundaries between the Precambrian–Cambrian successions of the Garhwal Tethyan Himalaya. The typical Early Cambrian trace fossil *Phycodes pedum*, which is considered as a boundary marker world over, has not been reported so far from this succession. The trace fossil data indicate that the bulk of the Garbyang Formation is of Cambrian age, but due to the lack of fauna, its upper and lower limits could not be defined.

Lithofacies variations and depositional environment of Barail pay sands in the Lakwa oilfield, Assam, India

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The Lakwa oilfield is the largest oil-bearing structure of upper Assam, giving commercial production of oil and gas since 1968. The main pay sands in the oilfield are mostly within the Tipam Group. Commercial exploitation of oil from the Tipam reservoirs has resulted in a depleted production over the years. This has brought the focus of hydrocarbon exploration on the deeper prospective horizons notably the Barails (Oligocene) and the Basal Sandstone (Eocene). The Barail Group of rocks conformably overlie the Jaintia Group deposited under shallow/open marine environment and is unconformably overlain by the fluvial Tipam Group (Miocene). The lower part of the Barail sequence is dominantly arenaceous and massive without significant development of carbonaceous facies. The upper part of the sequence is characterised by a dominantly argillaceous facies with the development of subordinate coal-bearing horizons as well as a few intervening sand bodies. In the present study, six mappable lithounits (I–VI) have been identified from electrical logs within the coal–shale sequence of the Barail Group. The sand bodies are thin and laterally discontinuous. Log responses for the bottommost pay zone (Lithounit I) show a unique coarsening-upward trend typical of the delta front environment. The subsequent sand bodies (Lithounits II–VI) are mostly characterised by either blocky or bell-shaped SP log profiles indicating a uniform grain gradation or a fining-upward trend, respectively. Granulometric studies also corroborate this observation. The Lithounit I is presumed to represent a transitional facies between the marginal marine and deltaic environment, while the succeeding lithounits were deposited by the distributary channels in a delta plain environment.

Stepwise anatexis of Akpa Granite, Higher Himachal Himalaya, India

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The Palaeozoic Akpa Granite in the Kinnaur District of Himachal Pradesh, India, is intruded into the Higher Himalayan Precambrian metamorphics (Central Crystallines). The Akpa Granite in the Kinnaur area is occurring in the alumosilicate-bearing gneisses, migmatites, calc-silicates and psammitic gneisses, besides staurolite-bearing schists, and meta-quartzites. This granite body shows locally discordant contact, but on regional scale shows a concordant contact with the host rocks and enclosing structures. In the field, four distinct phases of granitic activity crosscutting each other are seen in this granite body. The granitic activity is followed by beryl- (aquamarine) bearing pegmatitic activity. The size and shape of the grains, mineral inclusions, nature of xenoliths, and their shape and size in the granite body in addition to the host and mineral chemistry have been used to interpret the petrogenesis of this granite. This body is basically two-mica-bearing granite showing four distinct phases due to stepwise anatexis of the metasedimentary rocks (crustal anatexis producing a S-type peraluminous melt due to continent–continent collision) during the Caledonian Orogeny–Pan African Orogeny. The anatexis was further enhanced by the breakdown of micas at a depth of greater than 17 km and at temperatures higher than 700 ^{o}C, although the last phase of the granite was formed at 650 ^{o}C and about 4–5 kbar pressure under fluid-rich conditions. The temperature of more than 700 ^{o}C is supported by the homogenisation studies on feldspars and 650 ^{o}C is further supported by the two-mica thermometry (Lal 1991). This granite, after deformation and metamorphism, is also crosscut by three types of pegmatite vein consisting of tourmaline as well as beryl, and rarely garnet and fluorite. Three distinct phases of pegmatite activity are observed in this area (Rawat et al. 2001). The assimilation of the xenoliths of country rocks in the ascending magma depended on the temperature of rising magma to yield different types of granite.

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Homogenisation studies of alkali feldspars from some selected granitoids in space and time: a preliminary account

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Homogenisation (quenching) experiments were carried out with the alkali feldspars from the Precambrian (1,880±40 Ma) Amritpur Granite (Varadarajan 1978; Trivedi and Pande 1993), Naini Granite (1,000±10 Ma: Varadarajan and Rawat 1981), Dhauladhar Range Granite (545±12 Ma: Mehta 1979) and Tertiary Badrinath Granite (20±2 Ma: Scaillet et al. 1990). These granites are intruded into the metamorphosed sedimentary and igneous rocks, and contain xenoliths of host rock. The homogenisation of alkali feldspars was carried out at a high temperature (1,050±2 °C) and surface pressure for a minimum duration of 48 hours. The experimental time less than this had resulted into incomplete homogenisation and erroneous results. This method of granite-melt temperature determination has been perfected by Rawat and Prabha (1998), and Rawat and Nagar (2000). The technique is very simple, and at the same time, natural pure alkali feldspars can be used directly and hence the results are very near to the actual values. The preliminary homogenisation studies on the alkali feldspar from these granite bodies had shown the melt temperature of 705 to 750 °C for the Amritpur Granite, 720 to 818 °C for the Naini Granite, 725 to 835 °C for the Dhauladhar Range Granites, and 720 to 750 °C for the Badrinath Granites. It seems that the melt temperature variation in space and time was influenced by the nature of the source rocks as well as the fluids present in the melt at a constant pressure. The Amritpur and Badrinath Granites do not show much variation in melt temperatures (705 to 750 °C), while the Naini and Dhauladhar Range Granites show a wider variation in melt temperatures (720 to 835 °C) due to larger size of the bodies as well as source material, particularly in case of the Dhauladhar (Rawat and Nagar 2000). It is noticed that perthitic alkali feldspars had crystallised at a lower temperature than pure K-feldspars (Rawat 1978; Rawat and Nagar 2000).

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Tectonic significance of Kangra re-entrant, NW Himalaya

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Geological study in the field as well as the study of anisotropy of magnetic susceptibility (using Kappabridge KLY3) was carried out in the Punjab re-entrant of the NW Himalaya. At the same time, finite strain analysis and model deformation studies were also conducted. Shortening rates derived from the balancing of the cross-section across the re-entrants were found to be unreliable. A uniform pattern of finite strain in the Lesser Himalayan formations and magnetic susceptibility ellipsoid patterns in the foreland foothill region across the Main Boundary Thrust suggest a primary curvature of the Punjab re-entrant. The model deformation studies explain the structural framework of the area.

This study reveals that the re-entrant was formed as a normal fault oblique ramp structure during an earlier tensional phase in the region and later reactivated as a thrust fault with a combination of simple shear and later shortening during the Himalayan orogeny.

Field association, sedimentological attributes, and depositional environment of clastic shelf sediments in the South Jaintia Hills, Meghalaya, India

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The South Jaintia Hills forming part of the Meghalaya shelf consist of a thick pile of alternating clastic and carbonate sediments (Eocene) abutting against the Precambrian rocks of the Shillong Plateau in the north and the Neogene clastics in the south. Field study shows that the thick sequence of sediments is characterised by three mappable sandstone units alternating with three limestone units. The bottommost unit shows the development of thin carbonaceous bands, the middle unit is having at least three workable coal seams, while the topmost unit is totally devoid of carbonaceous shale or coal beds. The sandstones are well bedded having variable hardness and lithification. The grain size varies between 0.36 and 2.05 ϕ and standard deviation between 0.51 and 1.18 ϕ. Though all the three log normal subpopulations are found, the saltation population forms the dominant group. Petrographic study shows that the sandstones are quartz arenite type with dominating nonundulose monocrystalline quartz forming the framework. Both textural and mineralogical maturity is indicated by the petrographic characteristics. The textural and mineralogical attributes of the sandstones together with the characteristic planar cross-stratifications particularly well developed in the middle sandstone unit are indicative of the fluvial depositional environment.

Channel migration and bank erosion in Mukalmua–Howlighat area, Assam: mitigation measures based on GIS and remote sensing

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The Mukalmua–Howlighat area downstream of Gauhati constitutes a sector in the trunk valley of the Brahmaputra River where the menace of bank erosion and floods consequent to the northward migration has assumed critical proportion and has drawn the attention of governmental agencies to adopt effective mitigation measures. A study to this effect was carried out with the aid of visual remote sensing products to generate inputs in the form of the present-day status of the landforms and processes, which in combination with hydrological parameters help in formulating anti-erosion measures, particularly the long-term ones. Subsequently, the integration of multi-dated data (derived from remote sensing and field maps) using AutoCAD software would help to formulate more precise and effective mitigation measures. Utilisation of multi-dated FCCs, TMs, aerial photos, and topographic maps coupled with fieldwork brought out two geomorphic units viz. (i) Stabilised Flood Plain and (ii) Younger Flood Plain. They are under continuous interaction with dominant fluvial processes of the Brahmaputra, Pagladiya, and Puthimari rivers as well as the ever-expanding anthropogenic processes like construction of dykes, roads, expansion of urban and rural agglomeration etc. The two alluvial land units, having a general altitude of 42 to 47 m,a very gentle southerly master slope, and inconspicuous amplitude of the micro-relief, constitute the landscape on the northern flank of the Brahmaputra. The characteristic morphological expression of this alluvial landscape is the dominance of relict fluvial imprints generally aligned in easterly, northeasterly, and northerly directions. This area is subject to continued channel oscillation by the Brahmaputra and its tributaries and changing channel and bar morphology resulting in geohazards of critical bank erosion and flooding, causing concern for human life and property. The most significant factor associated with these geohazards is the channel widening of the Brahmaputra from about 10–14 km in 1911 to about 14–17.8 km in 1989 with concomitant northward migration of bank line and continuously changing bar morphology. These processes are effectively and fairly accurately discerned from multi-dated imageries and aerial photos. Synthesis of the terrain

attributes referred to above, hydrological parameters, and anthropogenic activities demonstrated the ravaging impact of bank erosion and flooding to be an outcome of mutually influencing fluvial processes and anthropogenic processes. In the present case, the primary data sources are the topographic maps and raster data derived from interpretation of multi-dated visual remote data, depicting the landforms, processes, and hazards. The various maps were vectorised after scanning using AutoCAD and subsequently entered into the computer in layered forms as subfiles. The basic entities considered were points, lines, and polygons representing the geomorphology, hazards, dykes, roads, and rivers. The hazard maps were then generated using data manipulation, projection, and transformation. Besides the implementation of the present mitigation structures in the form of land spur and tie bund, the long-term remedial measures must take into account the causes of channel aggradation and progressive reduction of channel capacity to make protective structures viable and effective.

Proterozoic-Early Palaeozoic Stratigraphy of the Arunachal Lesser Himalaya, India, and regional geology of South Asia

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Recent discovery of microstromatolites, mini digitate stromatolites, and organic walled microfossils from the Buxa Dolomite (Menga Limestone, Dedza Dolomite, and Chillipam Dolomite) of Arunachal Lesser Himalaya is quite significant in understanding the early biological evolution across the Precambrian-Cambrian boundary in South Asia. The Buxa Dolomite of NE Himalaya in Bhutan, Sikkim, Darjeeling, and Arunachal is so far considered Mesoproterozoic in age. The earlier workers have interpreted that there is no record of sedimentation between Neoproterozoic and Carboniferous in the Arunachal Himalaya. On the contrary, the author has recorded a complete sedimentation history from Neoproterozoic to Early Cambrian in the Upper Subansiri and West Kameng districts of the Arunachal Himalaya.

Regionally, the Buxa Dolomite in the Eastern Lesser Himalaya is characterised by cherty dolomite, stromatolitic dolomite (mainly Terminal Neoproterozoic assemblage *Stratifera-Colleniella-Aldania-Collumnaefacta-Liniella*), mini digitate and microstromatolites, oncolites, fenestral dolomite, oölitic-intraclastic dolomite, organic walled microfossils, algae, and micrometazoans. The sedimentological facies change, palaeobiological records, Raman Laser Spectroscopy (Fig. 1), and the carbon isotopic

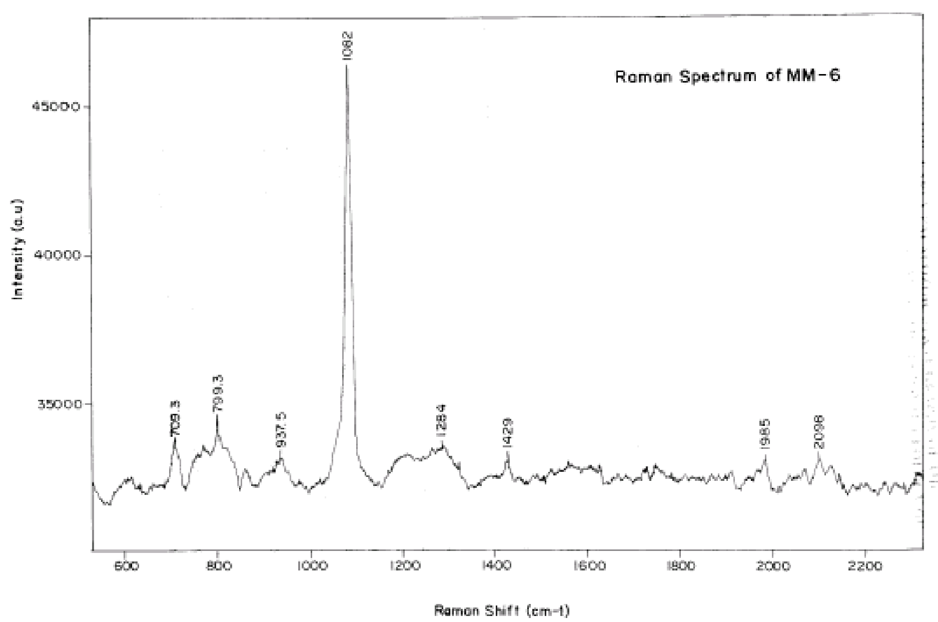

Fig. 1: Raman Laser Spectroscopy of the Buxa Dolomite from the Arunachal Lesser Himalaya, India

excursions from the Buxa Dolomite strongly suggest that the terminal Proterozoic–Early Cambrian transition lies within the Buxa Dolomite (Menga Limestone/Chillipam/Rupa Dolomite/Dedza Dolomite).

In the Central Lesser Himalaya, in Uttaranchal, the Blaini–Krol–Tal succession of the Krol Belt sediments represent Neoproterozoic to Lower Cambrian boundary events along the northern margins of the Gondwana. These events are now also recorded from the Arunachal Lesser Himalaya, and the Buxa Dolomite is identical to the Krol Dolomite in sedimentary facies and palaeobiological remains. The terminal Proterozoic Blaini–Krol–Tal Group of sediments also correlates with the Marwar Supergroup of western Rajasthan, which is also extending into Pakistan. The diamictite–carbonate–phosphorite facies of South Asia developed in these basins were palaeogeographically located at the same palaeolatitude in the Rodinia Supercontinent. The various events recorded in Neoproterozoic–Lower Cambrian are summarised in Table 1.

The break in sedimentation is reported from Upper Cambrian to Devonian in the Lesser Himalaya and Rajasthan. This may be attributed to the larger global event of Pan African orogeny well documented from India, Nepal, Bhutan, and Pakistan by 500 Ma old granitic intrusions. A correlation of major geological events in South Asia like breakup of Rodinia, terminal Proterozoic glaciation, carbon isotopic records of sea level change and climatic change, Pan African rifting events, and transgression–regression of sea from the region is also discussed in the paper.

Table 1: Major palaeoclimatic and biotic changes across Neoproterozoic–Cambrian transition in the Lesser Himalaya, India

Palaeoclimatic events				
Age/Stage	**Period (Lesser Himalaya)**	**Climate**	**Carbon Isotope**	**Fossils**
Cambrian	Talian	Warm	Changing (-ve to +ve)	Brachiopods, trilobites, trace fossils, small shelly fossils, sponge spicules, and stromatolites
Ediacaran	Krolian	Warm	Positive	Ediacaran, vendotaeniids, algae, and stromatolites
Varangian	Blainian	Glacial	Negative (lighter)	Acritarchs, microbialites
Riphean–Early Vendian	Deobanian	Warm	Positive (heavier)	Predominantly stromatolites, cyanobacteria, organic walled microfossils, sponge spicules, and epiphyton algae

A structural transect in Lower Dolpo (Western Nepal)

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The South Tibetan Detachment System (STDS) is a major tectonic feature running all over the Himalayan belt (Burchfiel et al. 1992). It is well recognisable in eastern and central Nepal. However, in the Kali Gandaki it becomes less evident and uncertainties arise in its location owing to the downward increase of metamorphism from the Tibetan Zone (TZ) to the Greater Himalayan Sequence (GHS) (Brown and Nazarchuck 1993; Garzanti et al. 1994). The situation is quite uncertain in western Nepal, where the contact between the TZ and GHS is reported to be transitional after the geological explorations by Fuchs and Frank (1970) and Fuchs (1977). Therefore, the identification of the STDS in western Nepal is a crucial point in the tectonic evolution of the belt.

Geological studies were carried out along a NE–SW transect in Lower Dolpo (western Nepal), cutting across the GHS and TZ. The extensive mapping and works of Fuchs and Frank (1970), Frank and Fuchs (1970), and Fuchs (1977) provided invaluable information in the field.

Preliminary results show that:

- The GHS shows a reduced thickness compared to the other sections of Nepal, especially in the uppermost part;
- The GHS has a monoclinal attitude of the main schistosity contrasting with the attitude of the folds in the overlying metasedimentary rocks of the TZ;

- There is a jump in the metamorphic grade passing from the biotite-bearing marbles of the metapelite sequence of the TZ, to the underlying diopside- and forsterite-bearing marbles of the sillimanite-bearing metapelite sequence of the GHS;
- F2 asymmetric folds with a NE vergence characterise the TZ;
- In the TZ, the strain increases towards the boundary between GHS and TZ. The deformation mechanisms change from pressure solution to crystalline plasticity going down from the Ordovician limestones to the marbles of the Dhaulagiri Limestone; and
- The base of the TZ is affected by a static recrystallisation reworking the high strain fabric.

On the basis of these features, we regard the boundary between GHS and TZ as an high strain extensional zone, linked to the STDS.

Geological, structural, and metamorphic features across the boundary between the GHS and TZ allowed to recognise and to map a "cryptic" detachment in western Nepal.

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Metamorphism in the Nepal Himalaya: The Arun Valley transect

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Based on fieldwork during the last ten years and on literature data, P–T paths and metamorphic zonation in the Arun Tectonic Window (ATW) are described. From the core of the ATW northwards, the following lithotectonic units are exposed:

1) **The Tumlingtar Unit** (Nawakot Nappes of Hagen 1969), a thick sequence of greenschist-facies metasedimentary rocks, bounded to the north by a syn-metamorphic thrust zone (Main Central Thrust 1 of Maruo and Kizaki, 1983; Main Central Thrust zone of Meyer and Hiltner 1993).
2) **The Lesser Himalayan** Crystalline Nappe (Kathmandu Nappes of Hagen 1969) comprised of staurolite- to kyanite-grade micaschists and granitic orthogneiss lying on top of the Tumlingtar Unit.
3) **The Higher Himalayan** Crystalline Nappe bounded on both sides of the ATW by thrust sheets defining a major syn-metamorphic thrust (Main Central Thrust of Bordet 1961; Main Central Thrust 2 of Maruo and Kizaki 1983).

Further north in the Arun Valley, (in the Kharta region of S Tibet, 30 km east of the Everest-Makalu massif), the tectonic sequence exposed at the core of the ATW is the same, but a deeper tectonic level of the nappe pile can be investigated. There, the Main Central Thrust 2 is a syn-metamorphic shear zone, in which slivers of granitic orthogneiss, quartzite, and mylonitic marble separate granitic orthogneiss hosting granulitised eclogites from the overlying garnet–biotite–sillimanite gneiss (Lombardo and Rolfo 2000). The granitic orthogneiss is believed to correspond to the Lesser Himalayan Num Orthogneiss defined further south in the Arun Valley (Lombardo et al. 1993), whereas the garnet–biotite–sillimanite gneiss is lithologically identical with the Barun Gneiss, the lowest lithological unit of the Higher Himalayan Crystalline Nappe in the Everest–Makalu region.

The Kharta Eclogites occur as sub-concordant sheets deriving from discordant mafic dykes in the granite, precursor of the orthogneiss. Reaction textures indicate that mineral assemblages produced in the first metamorphic event of eclogite facies (M1) were overprinted by mineral assemblages of granulite facies during a later event (M2). Geothermobarometry suggests medium P (5.5–6.5 kbar) and high T (700–750 °C) for M2. The granitic orthogneiss hosting the eclogites has kyanite inclusions in plagioclase as the only relics of M1, and was equilibrated at T about 680 °C and P about 5 kbar during M2.

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Metamorphism in the Nepal Himalaya: the Bhote Kosi transect

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The nature of the Himalayan inverted metamorphism together with the geological significance and position of the Main Central Thrust (MCT) are among the most actively discussed modern topics in Himalayan geology. As a contribution to this discussion, field, petrographic, and geothermobarometric data were collected along a N–S traverse, about 30 km long, in the Lesser Himalayan Sequence and the MCT zone in the Bhote Kosi Valley between Barabise and Kodari, up to the Nepal border with China (D'Anna 2001; Mangiapane 2001).

In the Bhote Kosi transect, the following main units are defined on the base of their mineralogical and thermobarometric characteristics. To the south, the Lesser Himalayan Nawakot Complex (NC) has the common assemblage:garnet+oligoclase+biotite+muscovite± chloritoid; a thin layer of quartz–biotite–muscovite–oligoclase mylonite separates the NC from the MCT zone to the north; and the MCT zone shows the assemblage: garnet+biotite+muscovite+amphibole+oligoclase+ staurolite+kyanite**.**

In the study area, there are various lithologies including augen gneiss; garnet–muscovite–biotite–oligoclase micaschist; margarite–staurolite–kyanite–garnet–muscovite–biotite–oligoclase micaschist and blastomylonite; garnet–hornblende–biotite–andesine micaschist and fine-grained gneiss; kyanite–garnet–muscovite–biotite–oligoclase/andesine micaschist and fine-grained gneiss; and garnet–oligoclase–amphibole schist. Their petrography, mineral chemistry, and geothermobarometry reveal that the metamorphic grade is clearly increasing towards the higher structural levels. A jump in equilibration temperature east of Tatopani is evident with T increasing in the MCT zone. Moderately high P conditions are common all along the sequence.

Microstructures show a relict foliation, which is common to all structural levels. Moreover, late static growth of polyphase garnet postdates the tectonic stacking of two distinct geological units. In the NC and in most samples from the MCT zone, garnet zoning profiles record a prograde metamorphic history, while in other samples of the MCT zone thermobarometry suggests a decompressional evolution coupled with a moderate temperature increase, always within the kyanite stability field. Minerochemical and thermobarometric data, together with microstructures, suggest that the MCT does not occur between the two studied units. The progressive increase in peak metamorphic temperatures and deformation styles of the units northwards, may be interpreted as a direct consequence of the occurrence of the MCT further north.

The studied sequence can be consequently considered as a continuous lithological sequence with a strong ductile deformation affecting mylonitic quartz-rich micaschist structurally below the augen gneiss in the Tatopani area. There, mylonites separating the upper and lower units are probably a ductile shearing band separating garnet–kyanite–staurolite-grade and biotite–garnet-grade rocks, which all are part of the Lesser Himalaya.

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Late Quaternary soil development and vegetation changes in the Hetauda Dun, Nepal Sub-Himalaya

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The Hetauda Dun is a Sub-Himalayan intermontane basin in Central Nepal. Its valley floor is occupied by the Late Quaternary terraced alluvium. The age of younger fluvial terraces of Nayabasti 1 and 2 (33–18 ka) and Pashpatinagar 1 and 2 (11– 4.5 ka) was determined by radiocarbon dating. As their ages reveal, these deposits are expected to record the palaeoenvironmental changes from the Last Glacial Stage to the present. They may provide some information for clarifying the relationship between the monsoon fluctuation and the orographic effect of the Himalayas.

The Nayabasti 1 terrace is covered by reddish brown soil. The topsoil on the Nayabasti 2 terrace is slightly oxidised and its colour is yellowish brown. The Pashupatinagar terraces and younger alluviums are covered by grey or brown soils. Reddish yellow soils are generally considered the products of long-term weathering under the tropical or subtropical environment. The gap in soil development between the Nayabasti 1 terrace and younger alluviums suggests that the former experienced an earlier subtropical environment in Stage 3. By contrast, the immature soils on the younger alluviums indicate that the Himalayan front did not experience the subtropical environment in the Last Glacial Climax (LGM = Stage 2).

The pollen samples collected from the Nayabasti 2 terrace deposits, which were formed in the LGM, are dominated by *Pinus* and *Gramineae*. The results show that the palaeoclimate in the Hetauda Dun was dry and cold (i.e., very similar to that of the Kathmandu Valley). By contrast, the present climate of the Hetauda Dun is humid subtropical covered by *Shorea*. The annual precipitation in the Hetauda Dun is over 2,000 mm, which is almost double the precipitation in the Kathmandu Valley. This very humid climate is attributed to the orographic rainfall due to the summer monsoon and presence of the Mahabharat Range. In the LGM, the Mahabharat Range already existed and its height was comparable to the present one. Therefore, the summer monsoon in the LGM was not strong enough to produce the orographic rainfall.

Active faults along the Himalayan front in Eastern Nepal

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We summarise here the geomorphological as well as geological evidence of active faulting in the eastern and central Nepal Himalayan frontal belt based on the interpretation of the aerial photos and field surveys. The study area is bordered by the Koshi River in the east and Bagmati River in the west.

A series of Himalayan Frontal Fault (HFF) traces from the Kamala Nadi (river) to the Amlekhgunj village in central Nepal run for nearly 120 km and are geomorphologically well defined. They are north-side-up thrusts, as commonly exhibited by tilting of fluvial terrace surfaces and south-facing scarps ranging in height from 3 to as much as 30 m.

There are two excellent exposures of the HFF in the Khairmara village (N 27º 4' 00", E 85º 7' 03") area. At the first site, the Lower Siwaliks override the fluvial terrace deposits along the fault, and the flexural deformation has caused the horizontal layers of the terrace deposits to stand vertically in the vicinity of the fault. At the second outcrop, the fluvial terrace has been dislocated by the HFF for about 6.6 m, vertically. The fault dips 34º due north. The radiocarbon dating limits the age of the terrace to nearly 1,371±67 years BP, yielding a vertical uplift rate of 4.8±0.2 mm/year. In combination with the dip, the observed uplift rate equated to horizontal shortening across the HFF is 8.6 ±0.3 mm/year. The slip rate of the HFF is calculated at 8.6±1.5 mm/year. This uplift rate is less than half of 21.5±1.5 mm/year as estimated by Lavé and Avouac (2000) based on the age and deformation of fluvial terrace along the Bagmati River in the same area.

At the trench excavated near the Kemalipur village (N 26º 06' 36", E 85º 09' 11") on the right bank of the Aurahi River (north of Janakpur), we observed a fault in the fluvial deposits, and it tilted the sediments at an angle of 15º towards south. The sample collected from the faulted sediment gave the radiocarbon age of 896–795 BC (2 Sigma) and 763–404 BC, whereas the sample from the unfaulted sediments showed an age of 1327–1439 AD. The radiocarbon age of the sediment layers suggests that the latest faulting event in this area had occurred between 896 BC and 1439 AD. In addition to it, Nakata et al. (1998) carried out a trench excavation study at the Himalayan frontal belt at Hokse in eastern Nepal and concluded that in that area the latest faulting event of the HFF had occurred around 1200 AD. The displacement along the fault was 4 m. If the next event takes place soon and displacement is of the same order as that of the latest event, the average slip rate will be about 5 mm/year. The slip rate calculated from the present study seems more reasonable for palaeoseismic activity of the HFF than that observed by Lavé and Avouac (2000).

Bilham et al. (1995) believe that the strain of the crust in this area was released by the Bihar–Nepal earthquake in 1934. However, the present study indicates that there is no evidence of surface rupture caused by the Bihar–Nepal earthquake. In addition, there is no evidence of faulting with surface rupture at least during the last 560 years. We therefore conclude that the HFF in this area is vulnerable to next movement and can cause a great earthquake in the region.

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Genesis of clay deposit in the Panchmane area of Kathmandu, Nepal

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The clay deposits of Nepal were studied by a few researchers in the past (Bhattarai 1998; Bhattarai and Okada 2000). Kaolin, one of the most important clay minerals, is widely used for the production of best-quality porcelains in the world. In Nepal, a comprehensive study of porcelain properties of kaolin was carried out at Daman (Bhattarai and Okada 1992), Tarekeswar (Bhattarai 2000), and Panchmane (Bhattarai and Okada 1992; 1999). Present work focuses on the genesis as well as chemical and mineralogical studies of kaolin occurring in the pegmatite of the Panchmane area, Kathmandu. The samples were investigated using X-ray powder diffraction (XRD), transmission electron microscopy (TEM), infrared (IR) spectroscopy, optical microscopy, and differential thermal analysis (DTA). The pegmatite occurring in the Panchmane area (named as Nardanda pegmatite) consists mainly of K-feldspar, plagioclase, and muscovite (Rai 1998). K-feldspar has altered to kaolin mainly along cleavage and similarly muscovite has altered to kaolin around its rim. This alteration from K-feldspar and muscovite to kaolin is due to weathering. A qualitative mineralogical analysis of clay minerals showed that the Panchmane kaolin consists mainly of tubular halloysite with subsidiary amounts of mica, feldspars, and minor amounts of gibbsite. The clay samples showed a very low Fe_2O_3 and TiO_2 content, and therefore, the whiteness of the sintered body at vitrification temperature range is on a very good level. This study proved the suitability of the clay mineral deposit for making best-quality porcelain products in Nepal.

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Geology and structure of the Sundarijal–Melamchi area, Central Nepal

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Stöcklin (1980) and Stöcklin and Bhattarai (1977) classified the rocks of Central Nepal into the Nawakot Complex and Kathmandu Complex. However, in the Sundarijal–Melamchi area, it is not possible to trace out all the formations of the Kathmandu Complex owing to higher grade of metamorphism, intense deformation, and changes in facies as well as the presence of various types of gneisses, pegmatites, and migmatites. Therefore, the following subdivisions are proposed based on detailed field mapping at 1:25,000 scale (Table 1).

The Talamarang Formation is well exposed near the MCT at Bahunepati, Melamchi Pulbazaar, and Sera. It is light grey to dark grey in colour and contains bands of kyanite schist, garnetiferous schist, banded gneiss, and quartzite. The contact with the overlying Gyalthum Formation is a gradual transition. The thickness in the type area is more than 2,000 m.

The Gyalthum Formation constitutes the core of the Patibhanjyang Anticline along the Sindhu Khola. The Gyalthum Formation is represented by thin to thick-banded, light grey to grey, laminated quartzite with mica partings and bands of feldspathic schist, garnetiferous schist, and augen gneiss. It is frequently laminated and shows cross bedding. The Gyalthum Formation transitionally passes into the overlying Bolde Quartzite and is about 1,700 m thick. In the Sundarijal–Chisopani area, augen gneiss, granitic gneiss, and banded gneiss are observed within this formation. They constitute the Sheopuri Injection Gneiss zone. Near Patibhanjyang, the banded gneiss is interfingering with the laminated quartzite.

Table 1: Main lithological subdivisions in the study area

Formation	Lithology	Thickness, m
Golphu Formation	Grey to dark grey feldspathic schist and banded gneiss with bands of quartzite, large pegmatite veins, grey augen gneiss	>700
Timbu Formation	Light grey to dark grey, intensely deformed and folded quartzite, schist, banded gneiss, and migmatite with abundant sillimanite	950–1,100
Bolde Quartzite	Grey to light grey, very thick-banded, massive quartzite with mica parting and schist bands with sillimanite and garnet	400–500
Gyalthum Formation	Thin- to thick-banded, light grey to grey, laminated quartzite with mica partings, and bands of feldspathic schist, garnetiferous schist and gneiss, augen gneiss, granitic gneiss, and banded gneiss	1,200–1,700
Talamarang Formation	Dark grey feldspathic schist, banded gneiss, and laminated quartzite with garnet and kyanite	>2,000

The Bolde Quartzite is exposed in the Bolde Khola, at Boldegaon, Kakko, Bhumidanda, and south of Timbu. It is composed essentially of thick- to very thick-banded, massive, medium- to fine-grained, grey quartzite with mica partings. There are also a few sillimanite-bearing thin schist bands. The quartzite is frequently laminated. The upper part of the Bolde Quartzite gradually passes into the overlying Timbu Formation or the Golphu Formation. The total thickness of the Formation is about 500 m.

The Timbu Formation is exposed around the village of Timbu. It is represented by light grey to dark grey, intensely deformed and folded quartzite, schist, banded gneiss, and migmatite with abundant sillimanite. The Timbu Formation is a discontinuous unit lying between the Bolde Quartzite at base and the Golphu Formation at the top. The migmatite zone occupies mainly the central and upper part of the formation and exhibits various types of ptygmatic folds, small-scale faults, and flow structures. The maximum thickness of the Timbu Formation is about 1,100 m.

The Golphu Formation is represented by coarse-grained, thick-banded, dark grey feldspathic schist, garnetiferous schist, and banded gneiss with a few bands of laminated quartzite. The rock is sometimes crenulated. There are many pegmatite veins in it and there is a large pegmatite body at Sinnech Danda and a zone of augen gneiss between Kutumsang and Golphu Bhanjyang. It is more than 700 m in thickness.

Geological structures and position of MCT

The study area constitutes the hanging wall of the Main Central Thrust. A schematic geological cross-section of the study area is depicted in Fig. 1.

The MCT passes through Majhitar, south of the Sindhu Khola and crosses the Indrawati River. It is moderately steep (35–50^o) and dips due NW. The MCT is characterised by about 50 m thick zone of garnet-chlorite schist that rests over the fine-grained white quartzite (?Dunga Quartzite) of about 25 m thick, followed by the Benighat Slate (Bg). The garnet-chlorite schist zone is followed by the kyanite-garnet schist belonging to the Talamarang Formation.

The inverted metamorphism is well observed, especially on the hanging wall of the MCT. At first, the chlorite schist is observed, which passes rapidly upwards to garnet schist and kyanite schist. Kyanite is observed throughout the Talamarang Formation in the Sindhu Khola, at Bahunepati, Melamchi, and around Talamarang. Sillimanite was observed first in the Bolde Quartzite and it becomes abundant in the Timbu Formation. Similarly, sillimanite was also observed NE of Sankhu. The footwall of the MCT is made up of slate and phyllite and the grade of metamorphism is quite low in comparison with that of the hanging wall. The schematic cross-section (Fig. 1) depicts the kyanite (ky) zone (*grey tone*) along the MCT and the sillimanite (Sil) zone (*cross-hatched*) as pockets just above it. The sillimanite zone is followed again by the kyanite and garnet (Ga) zones (*black dots*). There is a large gneiss (Gn) injection (*ornamented*), which assimilates the country rock. There are also many pegmatite veins (Pg) around the injection gneiss.

The Patibhanjyang Anticline passes through the Sindhu Khola. The northern limb of it is moderately dipping due NW whereas the southern limb is moderately to steeply dipping due SW. The fold is gently (10–20^o) plunging due NNW. Gneisses invade the upper part of the northern limb and most of the southern limb of the Patibhanjyang Anticline. It seems that the Sheopuri Injection Gneiss zone (Sh) is the continuation of the Kutumsang Gneiss zone in the north, and it also entails that the rocks were folded after the granite and gneiss injection. The banded gneiss is found either near the MCT or in the proximity of the core of the Patibhanjyang Anticline, and the gneiss away from the MCT and the core zone is mainly of augen-type. This type of distribution pattern is most probably attributable to the stresses responsible for thrusting and formation of the anticline.

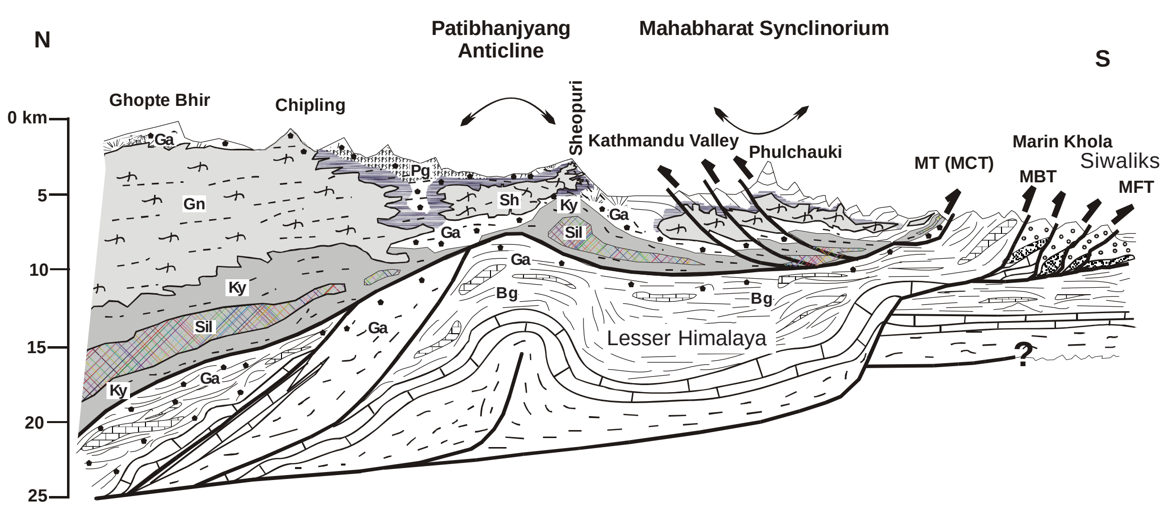

Fig. 1: Schematic geological cross-section across Central Nepal

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Stratigraphy and structure of the Lesser Himalaya between Kusma and Syangja in Western Nepal

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Detailed geological mapping was carried out in the Lesser Himalaya of Western Nepal between Kusma and Syangja. The study area lies between latitudes 27° 55' N and 28° 15' N, and longitudes 83° 30' E and 83° 55'E. It consists of the low-grade metamorphic rocks of Nawakot Complex (Stöcklin 1980), and the sedimentary rocks of Sirkot Group. A narrow zone of sedimentary rocks belonging to the Tansen Group (Sakai 1983) is also present in the southern part.

In the study area, the Lower Nawakot Group (Stöcklin 1980) is represented by light grey-green to dark green phyllites, gritty phyllites, and chlorite schists alternating with grey and grey-green metasandstones of the Kuncha Formation; medium- to very thick-bedded, pale yellow to white Naudanda Quartzite; grey-green phyllites, slates, and metasandstones of the Nayagaun Formation; red-purple, grey, and green-grey phyllites, slates, and quartzites of the Nourpul Formation; and medium- to very thick-bedded, grey to light grey dolomites containing columnar and branching stromatolites belonging to the Dhading Dolomite. The rocks of the Upper Nawakot Group (Stöcklin 1980) are represented by the Benighat Slate, which is made up of grey to light grey slates and interlaminated slates with sporadic carbonate beds. The rocks of Benighat Slate transitionally pass into the overlying Sirkot Group.

The Sirkot Group is represented by the Sorek Formation and the Dhanpure Limestone. The Sorek Formation contains grey-green, dark green, and red-purple shale or slate interbedded with light yellow, light green, pink, and white orthoquartzite. Towards the upper part, the green-grey dolomite beds contain columnar and dome-shaped stromatolites. The Dhanpure Limestone overlies the Sorek Formation and is represented by grey-green and dark grey, parallel-laminated limestone and shale.

The Tansen Group overlies the older rocks with a disconformity. It is represented grey and green-grey diamictite (the Sisne Formation); grey to brown orthoquartzite interbedded with brown and purple shale (the Amile Formation); and red-purple shale and grey-green sandstone (the Dumri Formation).

The rocks of Benighat Slate transitionally pass into the Sirkot Group, which is partly equivalent to the rocks of Kali Gandaki Supergroup (Sakai 1985) and Gwar Group (Dhital and Kizaki 1987). It seems that the rocks of inner Lesser Himalaya (i.e., the Nawakot Complex) are older than those of outer Lesser Himalaya (i.e. the Kali Gandaki Supergroup and Gwar Group). The Benighat Slate can be compared with the Mandhali Formation whereas the Sirkot Group is inferred to be equivalent to the rocks of Krol Belt (Valdiya 1980) in the Kumaun Lesser Himalaya. It is inferred that the Dhading Dolomite is Middle Proterozoic (Riphean) and the Benighat Slate is Late Proterozoic in age.

The area is complicated by strongly south verging folds, and south- as well as north-dipping imbricate faults. Probably the south-dipping back thrusts are younger than the north-dipping faults, as the latter are deformed and also crosscut by the former. It seems that a large roof thrust covered the area, and it was responsible for the intense deformation of the footwall rocks adjacent to the thrust. The roof thrust was subsequently eroded away exposing the present rock sequence.

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Preliminary results of the study on fossil freshwater molluscan fauna of the Kathmandu Basin

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Fossils of freshwater mollusca from the lacustrine sediments of Kathmandu Basin were collected from the upper part of the Lukundol Formation of Late Pliocene to Early Pleistocene, and the Gokarna Formation of the Last Glacial Age. Despite the temporal differences between the two localities, the molluscan faunal composition in each locality shares the dominant species. The fossil molluscan fauna in the older Lukundol Formation is composed entirely of prosobranch gastropod shells belonging to the genus *Bellamya* and opercula of the genus *Digoniostoma*. The fauna in the younger Gokarna Formation includes similar species with addition of other aquatic gastropods, unidentified terrestrial gastropods, and a bivalve species. These aquatic gastropods are of the genera *Gabbia*, *Radix*, *Gyraulus*, and *Planorbis*, and bivalve species belong to the genus *Pisidium*, which are not found in the older molluscan fossil-bearing beds.

In the Lukundol Formation, fossil molluscs are abundant but poor in number of species and the assemblage is dominated by lacustrine taxa preferring permanent lentic water body of shallow depth. Conversely, in the younger Gokarna Formation, species diversity is comparatively higher, with marginal to terrestrial habitats that can tolerate seasonal drying-up. The fossil molluscan fauna is most similar to the recent fauna found in the warmer southern Terai region of Nepal.

Geology and structure of the area between Kusma and Behadi, Lesser Himalaya, Western Nepal

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The Kusma–Behadi area lies in the Lesser Himalaya of Western Nepal in the Kali Gandaki Valley. It is divided into two groups: Lower Nawakot Group and Upper Nawakot Group (Stöcklin and Bhattarai 1977, Stöcklin 1980). The Kuncha Formation consists dominantly of ‘gritty’ phyllite and micaceous quartzite with a few fine quartz conglomerate horizons. The Naudanda quartzite is composed of strongly rippled and highly cross- and graded-bedded light green quartzite with subordinate green phyllite and amphibolite bands. Lineated phyllite and light green quartzite represent the Nayagaon Formation. The Nourpul Formation at the footwall of the Phalebas Thrust is represented by light green to white quartzite in the lower part, green to purple slate with limestone and dolomite bands in the middle, and an interbedded sequence of green phyllite and pink siliceous dolomite in upper part. The Dhading Dolomite is unique in having a large number of stromatolitic biostromes in the light grey dolomite. Besides dominant *collenia* and *conophyton* morphotypes, laminated to crinkled flat stromatolites characterise the formation. The Benighat Slate of Upper Nawakot Group is represented by highly cleaved carbonaceous and sometimes calcareous slate with banded slate in the upper part.

The area is divided into two structural belts: an openly folded Balewa–Shankerpokhari Fold Belt to the north, and complexly folded Bhoksing Fold Belt to the south separated by the Phalebas Thrust. The former consists of doubly plunging, nearly cylindrical, steeply inclined, open folds with small-scale folds of higher order on both of its flanks. Their fold axes and axial surfaces are nearly parallel. The Bhoksing Fold Belt consists of a large number of asymmetrical, periodic, noncylindrical, and refolded gently dipping folds with their overturned short limbs. They are inferred to be genetically related to the Phalebas Thrust. Rocks at the fault zone are strongly recrystallised with the development of pressure shadows and two sets of pucker lineation.

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Locating the Main Central Thrust in Central Nepal by lithological, microstructural, and metamorphic criteria

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Although the Main Central Thrust (MCT) is believed to be an intracrustal thrust extending throughout the length of the Himalaya, its nature and location is obscured, and has been debated for many years. For discriminating the MCT more accurately, a study was carried out along the Seti River and Modi Khola valleys in the Pokhara area of Central Nepal. For this purpose, field observations, microstructural analysis, and metamorphic data were combined to work out some recognisable criteria for objectively locating the MCT. The study demonstrates that the MCT is a sharp and discordant tectono-metamorphic boundary separating the Lesser and Higher Himalaya in the Pokhara area. It is marked by changes in:

- lithology;
- style of microfolding;
- deformation mechanism and microstructures of quartz and feldspars;
- garnet texture, compositions, and zoning patterns; and
- muscovite and plagioclase compositions.

Some or all of the above changes may be observed across the MCT in other parts of the Himalaya and they may provide important criteria for locating it.

Palynological study of the pre-Siwalik rocks of Central Nepal

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The pre-Siwalik rocks are exposed in the Inner Terai of Central Nepal. The area is located north of the Bakiya Khola Valley, in the Bagmati River section and also in the northern parts of the Marin Khola Valley. The sediments occur within the Lower Siwaliks, north of the Marin Thrust (Fig. 1). The Inner Terai of the Siwalik Range is developed during thrusting. At that time, a thin slice of pre-Siwalik rocks might have slipped up along with the Siwaliks.

The pre-Siwalik outcrops are dominated by red sandstone with subordinate amount of grey sandstone and grey shale. Small volcanic bodies are associated with the red beds. The sandstones are mainly fine-grained, occasionally medium-grained, and rarely gritty. The altered red sandstones are pinkish white and exhibit red and white banding. The shales are light grey and observed mainly in the middle and upper sections. Sandstones are hard better stratified than the Siwalik sandstones.

So far, no fossils have been reported from these rocks. Hence, their age is inferred to range from Gondawana to Miocene. In this paper, an attempt is made to determine their stratigraphic position and age based on the palynological study. A number of spores and pollens were recorded from the samples. However, the palynomorph assemblages in the samples include only stratigraphically long-ranging taxa (Eocene to Quaternary).

The identified spore and pollen such as Zoncosites and Compositae are found from the Lower Eocene to Recent Epoch, and Dinocyst (*Lingulodinium machaerophorum*) is found from the Miocene to Recent Epoch. Besides, the pre-Siwalik outcrops are lithologically similar to the Murree red beds of India and Pakistan, which range in age from Oligocene to Miocene. Hence, considering their polynomorph assemblages and environment of deposition, it is concluded that the pre-Siwalik sediments were probably deposited in the Tertiary Period. However, their age may vary from Oligocene to Miocene.

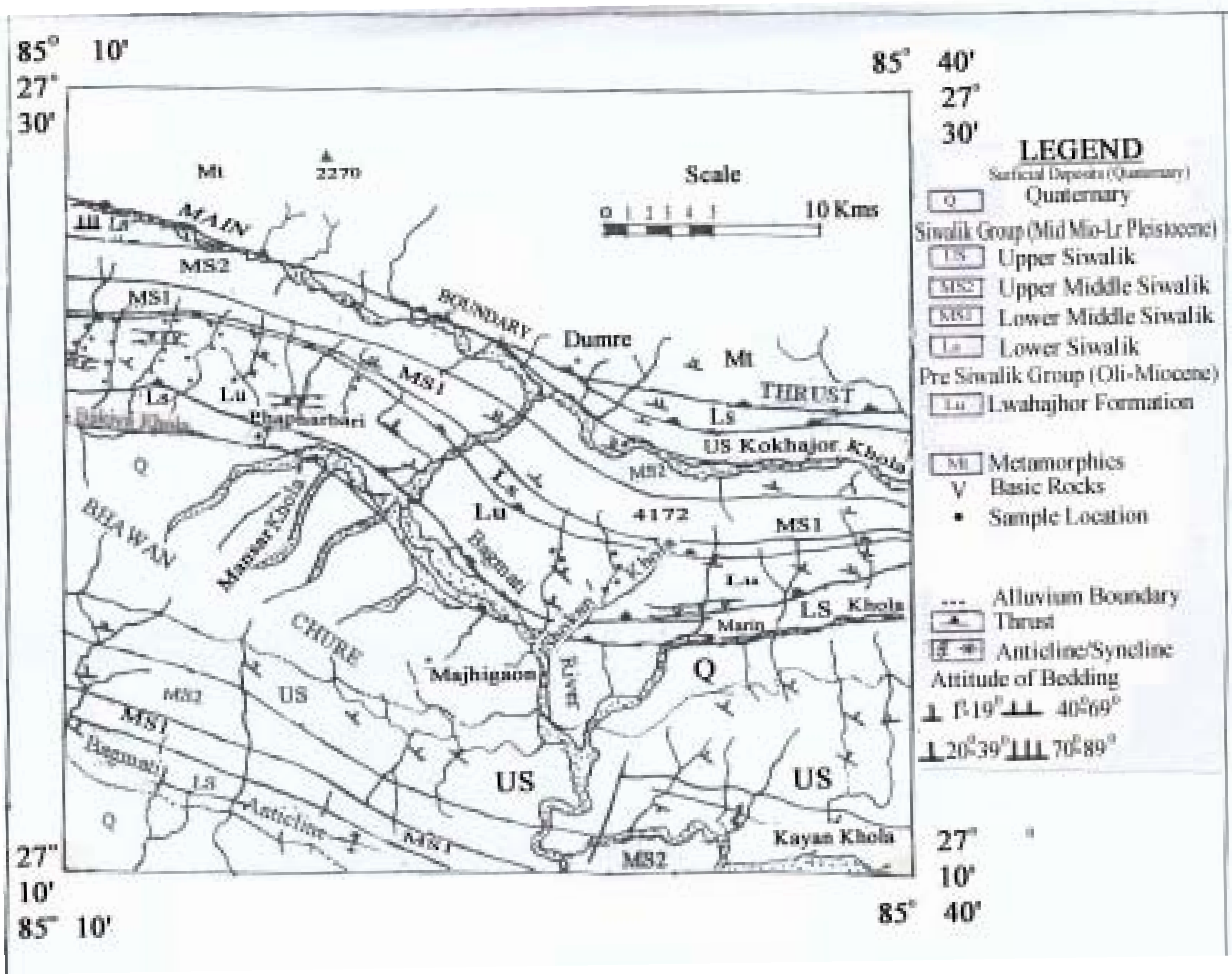

Fig. 1: Geological map of Siwalik and pre-Siwalik sediments exposed around central part of Southern Nepal

Geology, structure, and metamorphism of the Taplejung Window and frontal belt, Eastern Nepal

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The Taplejung Window and the frontal part of the thrust sheet near the Main Boundary Thrust (MBT) in Eastern Nepal comprise the following three tectonic units:

(a) the Lesser Himalayan Sequence (LHS) exposed in the window;

(b) the thrust sheet comprising the Higher Himalayan Crystallines (HHC) and forming the hanging wall of the Main Central Thrust (MCT) exposed around the window, and which has travelled far south reaching very close to the MBT; and

(c) the frontal Lesser Himalayan Sequence sandwiched between the MBT and the southern extension of the MCT.

The phyllite, schist, quartzite, and augen gneiss of granitic origin (Ulleri-type augen gneiss) are the main rock types of the Lesser Himalayan Sequence. In the frontal Lesser Himalayan Sequence, in addition to the above rocks, amphibolite and marble are also found intercalated with the phyllite. In the Taplejung Window, highly deformed and foliated granite is exposed within the phyllite and quartzite on the lower section of the Lesser Himalayan Sequence, as exposed near the confluence between the Tamor River and Kabeli Khola. The Higher Himalayan Crystallines are composed of garnet-kyanite-sillimanite banded gneiss, calcic gneiss, granitic gneiss, and quartzite with incipient traces of mobilisation in the upper section.

The area is affected mainly by two deformational episodes: (i) syn-metamorphic and (ii) post-metamorphic. The syn-metamorphic deformation is represented by S–C structure and NNE trending mineral lineations. The S–C structures preserved in phyllite, schist, and augen gneiss indicate the top-to-south shearing sense and are related to the MCT movement. The platy minerals (mica and kyanite) are aligned due NNE–SSW, i.e. along the direction of the MCT movement. The post-metamorphic deformation is well marked by the formation of the Taplejung Window, Tamor Khola anticlinal dome, new-generation foliations, drag folds, and extensional features. These structures may be related to the deformation during the southward propagation of the MCT. In the northern part of the Taplejung Window, along the Tamor Khola section, the rocks dip north–northeastwards. While in the southern part, they show a southerly dip, the rocks dip due east in the eastern part. The window is thus a large dome-shaped anticline, which is known as the Tamor Khola Dome (Schelling and Arita 1991). This anticline may be equivalent to the Gorkha–Pokhara anticlinorium (Pêcher 1978) and Likhu Khola Anticline (Rai 1998) in Central Nepal.

In the southern part, both the rocks of LHS and HHC dip to the north. The E–W trending longitudinal folds are well developed in the southern part of the HHC thrust sheet. Small-scale drag folds: ptigmatic folds, and Z-type and S-type folds are developed in both the LHS and HHC. The extensional shearing structures are well developed within the augen crystals of quartz and feldspar in the Ulleri-type augen gneiss of the LHS.

The region has undergone at least two metamorphic episodes. These episodes are correlated with the pre- and syn- to post-MCT movements. The evidences for the different episodes can be observed in the field as well under the microscope. The phyllite and quartzite of the LHS exhibit a relict, pre-MCT isotropic fabric (deformed granoblastic mosaic), incorporated by prominent anisotropic fabric imposed during the syn-MCT metamorphism. The syn-MCT metamorphism is evidenced by the inverted metamorphic zonation with well-characterised Barrovian type isograds in the footwall of the MCT. The chlorite isograd starts at the bottom and grades upward to garnet isograd at the top of the LHS, and sometimes a little higher. The same can be observed in the sandwiched LHS in the south. The kyanite isograd is achieved above the MCT and then sillimanite appears towards the upper section of the HHC. The chlorite crystals in the HHC gneiss are obliquely oriented with respect to the main foliation, and the conversion of the garnet to chlorite suggests the incipience of the retrogression of metamorphism.

The tectono-metamorphic history of the Taplejung Window and the HHC thrust sheet can be summarised as follows: The pre-MCT stage is characterised by prograde regional metamorphism. The syn-MCT stage resulting from the MCT movement gave rise to the inverse metamorphism. The movement along the MCT exhumed the metamorphic rocks of Higher Himalayan Crystallines to the mid-crustal level. During the continued MCT movement, a domal uplift resulted into the Tamor Khola domal anticline, and the HHC thrust sheet moved southwards to reach the frontal part of the mountain. This domal structure and the development of the longitudinal folds within the thrust sheet may be related to the southward propagation of the MCT. Finally, the tectonic uplift and intense denudation resulted into deep incision of the rocks of HHC, and the rocks of LHS were exposed forming the Taplejung Window.

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Stratigraphy of fluvio-lacustrine sediments of Kathmandu Valley

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The Kathmandu Valley is filled up with 500 m thick sequence of fluvio-lacustrine sediments of Plio-Pleistocene age. Considering lithological features like composition, grain size, sedimentary structures, and thickness of individual beds, the succession of the valley has been classified into the following seven basic mappable units: the Tarebhir Conglomerate, Lukundol Formation, Nakkhu Khola Formation, Sankhu Formation, Gokarna Formation, Thimi Formation, and Kalimati Clay.

Tarebhir Conglomerate: It is composed of a thick succession of pebble-cobble conglomerate beds with sporadic lenses of sandstone. It is about 200 m thick and well developed in the Tarebhir and Dunbargaon area. This unit lies over the Palaeozoic succession of the Phulchauki Group with an angular unconformity.

Lukundol Formation: It is well developed at Lukundol, Bhaterchaur, and Naikhandi. The succession is composed of alternating beds of pebbly conglomerate, medium- to coarse-grained micaceous sands and dark grey to black clays with occasional lignite layers. The succession is about 200 m thick and is covered by a 2–3 m thick layer of palaeosol.

Nakkhu Khola Formation: It consists of an alternation of massive to thinly laminated dark brown to black clays and medium- to fine-grained micaceous arkosic sands with occasional pale yellow diatomaceous clays. It is more than 100 m thick and well developed in the vicinity of Pharsidol, Sunakothi, and the Nakkhu Khola.

Sankhu Formation: This formation is observed at Sankhu, Sundarijal, and Mahakal. It consists of alternating beds of pebbly sand or gravel and dark grey to black clays with a sporadic intercalation of lignite layers. The Sankhu Formation is 20–30 m thick, and its uppermost part is covered by red-yellow palaeosol.

Gokarna Formation: It is composed mainly of sand beds with a few intercalations of massive to thinly laminated, dark grey to grey-brown clay beds. The sand beds are very thick (5–6 m) and exhibit large-scale cross-bedding. About 20–30 m thick upper part of the succession is well exposed at Gokarna, Karkigaon, and Mulpani.

Thimi Formation: This formation is observed around Thimi. About 30–40 m thick succession of this unit is composed of very thin alternating beds of very fine sands and thinly laminated silts and clays. The succession often contains small-scale cross-laminations, convolute bedding, and cut and fill structures.

Kalimati Clay: This unit is widely distributed in the central part of the valley, including the city area of Kathmandu and Patan. The succession is dominated by dark grey and dark grey-brown to black clays or silts very rich in organic detritus. The unit is 200–300 m thick.

The distribution pattern of the lithological units, gradual change in the lithological succession within the basin (coarser sediments in the periphery and finer in the centre), intertonguing of individual beds, and gradual change in the grain size of individual beds clearly indicate an existence of lateral facies variation.

The Lukundol Formation was dated as Late Pliocene–Middle Pleistocene by Palaeomagnetic studies and vertebrate fossil records. The Nakkhu Khola Formation and Tarebhir Conglomerate are possibly equivalent to the Lukundol Formation. Therefore, they could be of the same age and the deposits of an older lake developed in the southern part of the valley.

Radiometric dating gave an age of Late Pleistocene for the Gokarna Formation, Thimi Formation, and Kalimati Clay. The Sankhu Formation possibly represents lateral facies of the Gokarna Formation. Hence, they all represent the sediments of a younger lake developed in the northern and central parts of the valley. According to borehole data, these sediments seem to be much thicker (200 to 300 m) and therefore, the lower part of these successions may be of Middle Pleistocene age.

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Geomorphology, sedimentology, and hazard assessment of the Koshi alluvial fan in Eastern Nepal

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The Sapta Koshi River, one of the largest rivers of the world, is known for exceptionally high sediment-carrying capacity as well as channel-shifting nature (about 112 km in 246 years). Flooding, river oscillation and soil erosion are the main environmental problems in the fan region.

The Sapta Koshi Watershed, which covers a vast area of geomorphic regions, extends from the Tibetan Plateau (in the north) to the Indo-Gangetic Plain (in the south). The Sapta Koshi River flows through a narrow deep gorge from Tribeni up to Chatara. After emerging out from the Siwalik Hills near Chatara, it forms a vast fan (latitudes 26° 56' N–27° 00' N and longitudes 86° 56' E–87° 15' E) having a total length of 45 km and width of about 15 km in the Nepalese territory.

The Sapta Koshi River fans out with distributaries and tributaries, which are bordered by undulating lowlands both in the eastern and western banks. The alluvial plain of the river has a monotonous landscape, incised by such local features as old abandoned courses now occupied by smaller streams, old blocked channel lakes, oxbow lakes, sand mounds, and peat bogs along old dry channels.

The apex to the mid-fan area of the Sapta Koshi River shows a great variability in texture and composition of the sediments (Fig. 1). The boulders, cobbles, and pebbles (Chatara Formation) near Chatara gradually give way to pebbly sand (Chakarghatti Formation) and silty sand (Prakashpur Formation), and finally silt and mud (Tilathi

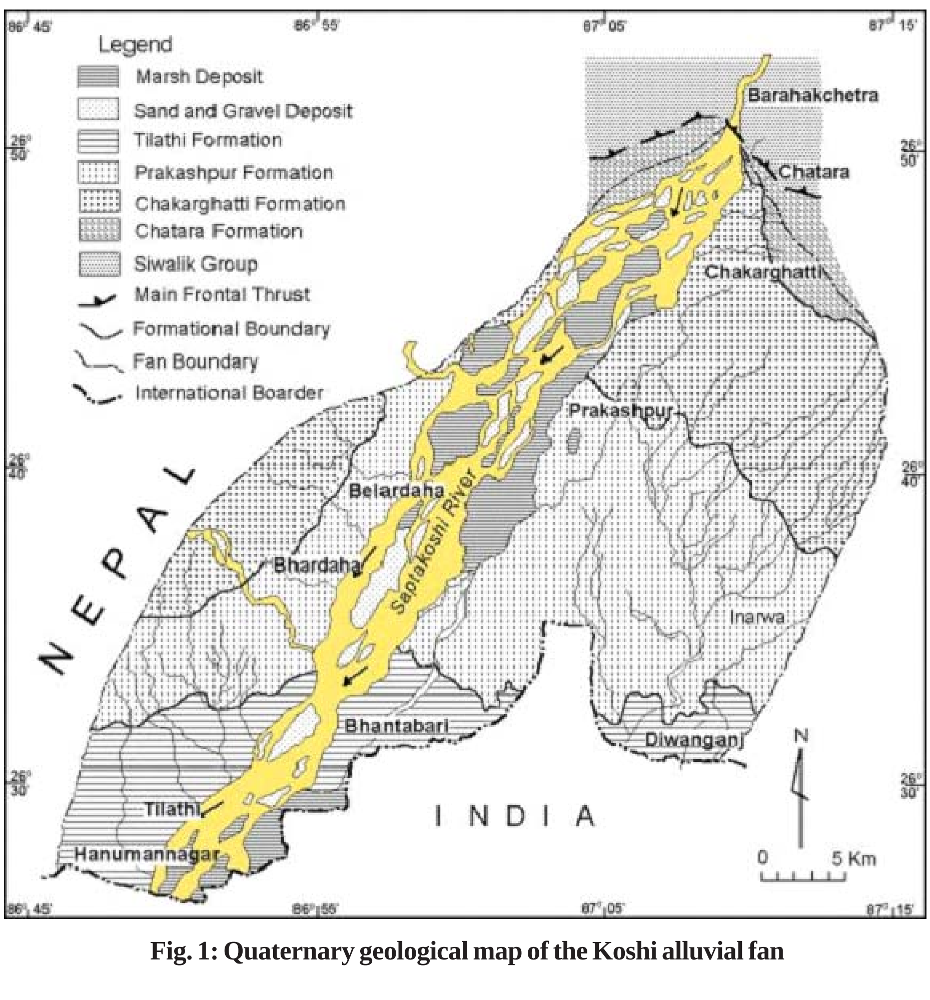

Fig. 1: Quaternary geological map of the Koshi alluvial fan

Formation), respectively from the north to the south of the fan region. All these deposits corresponding to the various formations also form geomorphic terraces and floodplains of the Sapta Koshi River. The boulders, cobbles, and pebbles of the Chatara Formation are sandy matrix-supported and were resulted from debris flow, whereas the pebbly sand of the Chakarghatti Formation resulted from debris as well as cohesionless flows. On the other hand, the silty sand of the Prakashpur Formation was produced in crevasse splays. The silt and mud of the Tilathi Formation were deposited by vertical accretion in the low-lying areas such as swamps and marshes. These alluvial fan deposits of the Holocene age are unconsolidated, and therefore are prone to rapid erosion.

The flood hazard in the alluvial fan area was assessed using criteria such as slope, relative relief, distance from the active channel and its shifting pattern, engineering protection-structures, and man-made activities. The alluvial fan region was zoned into the three hazard levels such as high, medium, and low. The western bank of the Sapta Koshi River, around Balardaha, Bhardaha, and Hanumannagar are identified to be highly prone to flooding and waterlogging. These areas are low-lying and have weak embankments, which are not well functioning as compared to the eastern bank of the river. The annual monsoon floods are mainly responsible for loss of life and property. For the proper flood management and minimising the effects of flood hazard, the following measures are recommended.

(a) The discharge in the drainage basins of the Lesser Himalaya and the Siwaliks should be managed;

(b) Masonry embankments should be constructed along the western bank (as in the eastern bank) of the Sapta Koshi River;

(c) It is necessary to carry out routine maintenance and monitoring of spurs and dykes; and

(d) Flood forecasting and early warning systems as well as rescue system during the disaster should be developed.

Morphometric analysis of the Arun Watershed, Eastern Nepal

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The paper describes morphometric analysis of the Arun Watershed, Eastern Nepal (latitudes 26° 45'–27° 30' N and longitudes 86° 55'–87° 30' E). The analysis covers only Nepalese territory of the watershed. It has a number of tributaries extending to all portions of the drainage basin and accommodates 30 micro-basins.

The Arun River shows antecedent characteristics and almost all of the tributaries show consequent characteristics. The drainage system of the valley is controlled by local geological structures in a number of ways. The sharp bending of river channel, sudden steep valley slopes, narrow valley sides that suddenly widen are common.

In the Arun Valley, the major tributaries are of sixth order. As their order goes higher, the total number of stream segments becomes progressively smaller, but their physical dimensions increase gradually.

Valley deepening is affected by several factors, such as hydraulic action, abrasion of the valley floor, and weathering of the streambed with subsequent removal of weathered material by hydraulic action. Valley deepening is very high between the Pisu La and Barun Dovan, Num and Yamchung, and Leguwaghat and Barahakshetra. These are the areas where the transverse valley erosion is dominant over longitudinal valley erosion.

Valley widening is dominant near Kimathanka, Tumlingtar, Surtibari and Sattare, i.e. these are the areas where the longitudinal valley erosion is dominant over the transverse erosion.

The cross profile of the Arun Valley shows that it is a young fluvial valley influenced by the local tectonics, lithology, and climate.

The shape of micro-watersheds is mostly elongated but a few of them have sinuous configuration, possibly controlled by their geological and hydrological conditions. The Arun River is flowing in a state of channel equilibrium with partial modification by the local tectonic events, and there is very little probability of channel shifting in the near future.

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Sedimentology and Palynology of Palaeocene–Eocene rocks of lower Neelum Valley, Northwest Lesser Himalaya, Pakistan

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In lower Neelum Valley, the Cambrian Abbottabad Formation comprising dolomite and limestone is overlain unconformably by a Tertiary sequence of carbonates and siliciclastics (Ghazanfar et al. 1987). The contact between the Cambrian and the overlying Tertiary sequence is unconformable.

The Hangu Formation marks the unconformity. It is composed from bottom to top of black shale, coarse- to medium-grained quartz arenite, a layer of black shale, coal, and bauxite or bauxitic clay. The black shale marks the onset of a transgression under restricted water conditions. The overlying quartz arenite sequence represents upper to lower shore face facies. The black shale and coal horizons represent supratidal marsh, whereas topmost bauxite or bauxitic clays represent residual deposits. The Hangu Formation contains poorly preserved palynoflora. Pollen and spores are equally represented. The pollens are of Stephanocolpate and Polycolpate type whereas the spores are predominantly psilate–trilete types. The pollen and spores of Hangu Formation are of dark brown to black-brown colour indicating moderate to high thermal maturity. They indicate Palaeocene age.

The 72.80 m thick Lockhart Formation (Ahsan et al. 2000) marks the onset of transgression when the area turned into a carbonate shelf. The limestone varies from nodular to massive type and it is thick-bedded. The limestone is composed of mudstone to packstone facies and contains abundant corals, mollusc, echinoids, and sporadic algae. There was an overall dominance of Acritarchs and Algal spores with sporadic occurrence of Pteridophytic spores and angiosperm pollen. Low frequency of Pteridophytic spores and Angiospermic pollen indicate their occurrence in a remote area quite far away from the depositional site. Palynomorphs bed with thin dark yellow to light brown exine indicate low to medium thermal maturity. Prominent benthic foraminifera include *Ranikothalia sindensis, Miscellanea miscella, Lockhartia haimei, Discocyclina ranikotensis* and *Lockhartia conditi*. This unit was deposited on a carbonate shelf in a lower to middle subtidal environment.

The conditions then changed from the carbonate shelf to siliciclastic depositional environment that deposited the Patala Formation. It is composed of khaki shale with abundant larger benthic foraminifera of Upper Palaeocene to Lower Eocene age. The Patala Formation contains abundant palynoflora in good state of preservation. Pteridophytic spores were most conspicuous, viz., *Dandotiasporites sp., Osmundocidites comaumensis*, *Punctatisporites sp., Leiotrites sp.,* and *Triplanosporites sinuous.* Angiospermic pollen includes the domination of *Polycolpites pseudogranulatus,* and *Tricolpites sp., Nothofagidites* in a few samples. A high frequency of fungal spores and cuticular fragments in most samples indicate well-oxygenated aerobic environment suitable for biological degradation. It seems that the Patala Formation was deposited in the near-shore environment in the close vicinity of the level occupied mainly by Angiosperms. Pteridophytes existed as major/minor subordinates or were transported to the depositional site from a nearby upland area. This is indicated by their good state of preservation.

The Margala Hill Limestone is composed of nodular limestone, massive limestone, calcirudite, and argillaceous limestone. Texturally, the limestone is composed of mudstone to wackestone. It contains larger benthic fauna. It was deposited on a ramp (Ahsan et. al. 2000). Palynoflora of the samples include moderate population of Dinoflagellates, Mycorrhizal spores, and Acritarchs. Pollen, spores, and cuticular fragments were rare to very rare. Most conspicuous were Pteridophytic spores (*Punctatisporites*, *Lacinitriletes and Acanthotriletes)* and Colpate pollen (*Tricolpites*). Inclusion of Dinoflagellates and Mycorrhizal spores is noteworthy here. Dinoflagelletes indicate a benthic environment with a slight decrease in salinity level whereas Mycrorhizal spores indicate an influx of material rich in terrestrial plant remains.

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Tithonian to Danian sedimentation in Hazara Basin, Northern Pakistan

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The Tithonian to Cenomanian rocks in the Hazara Basin of Northern Pakistan (Butt 1989; Latif 1970) are characterised by quartz arenites (Lumshiwal Formation) that are cemented with quartz, clay, iron oxides, or glauconite (Ahsan and Chaudhry 1999). They were deposited in mildly reducing environment in subtidal depositional regime. The average lithified rates of sedimentation were about 0.96 mm/1,000 years.

In the Cenomanian Epoch, due to rapid northward drift of India from near Madagascar, the Hazara Basin started to sink gradually to deposit the Kawagarh Formation (Ahsan and Chaudhry 1998). The formation is composed of pelagic limestones and marls with globigerinids and oligostegina.

The study of five sections of the Kawagarh Formation located in the Hazara Basin shows that it is generally composed of glauconitic arenaceous mudstone facies, planktonic facies, planktonic–oligosteginid facies, and oligosteginid–planktonic facies with some dolomites and marls. The average lithified rates of sedimentation were about 9 mm/1,000 years and they compare favourably with the American and European chalks.

On the basis of the microfacies and planktonic fauna, it can be concluded that the depth of the Tetchy Sea was not more than 250 m in the Late Cretaceous time in the Hazara Basin. The base and top of the Kawagarh Formation were deposited at relatively shallower depths (up to 80–100 m) with input of detrital quartz.

The top of the Kawagarh Formation was exposed subaerially when the Indian Plate established its first contact with the Kohistan Island Arc about 67±2 Ma ago. This event reworked the Maastrichtian sediments into pisolitic laterites, bauxites, and fireclays now represented by the Hangu Formation of Danian age (Chaudhry et. al. 1998).

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An appraisal of the Middle Eocene biostratigraphy of the Kala Chitta Range, Northern Pakistan

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The Middle Eocene sequence of the Kala Chitta Range, Northern Pakistan, comprises two stratigraphic units, namely the Kuldana Formation and the Kohat Formation.

The Kuldana Formation is essentially a red bed facies. However, a closer examination of its lithological characters indicate a varied environmental style – from evaporitic facies (gypsiferous beds) to marginal marine facies (a dominant facies of variegated argillaceous beds of red and green, red sandstone, and shale), and a shallow marine facies (which is foraminiferal) containing nummulitic fauna.

The overlying Kohat Formation appears to be deposited in a normal marine shallow water environment. It represents a nummulitic band facies, which also contains abundant coin-size *Assilina exponens* (Sowerby).

Tertiary palynofossils from subsurface sediments, Thar coalfield, Sindh, Pakistan

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Present study deals with the palynological analysis of the borehole core (STP) of the Thar coalfield, Sindh, Pakistan. Sixteen samples from varying depths and lithologies were selected for the present study. The Thar coalfield is located in the Thar Desert in the eastern part of Sindh, Pakistan. The area is covered by recent sand dunes, sub-recent mudrocks and sandstones underlain by the Tertiary coal-bearing zone (coal and intercalated rocks) resting directly over the Basement Complex (Middle to Late Proterozoic).

Thirteen samples out of sixteen were highly to moderately productive, containing 31 palynospecies belonging to 20 genera. Palynoflora was dominated by angiospermic pollen, cuticular fragments and fungal spores, and indicated an Early Eocene age. Most palynotaxa exhibited changes in vertical distribution. Dominant palynogroups included Monocolpates, Tricolpates, Tricolporate, Polycolporates, Triletes, Monoletes, and fungal spores. Except triletes and monoletes, all were evenly distributed. The palaeophytic analysis of palynological data showed the dominance of Dicotyledons and Monocotyledons and a rare occurrence of Pteridophytes and Gymnosperms.

The palynoflora reflected tropical to subtropical climate with low to high humid conditions during the deposition of the investigated strata. Based on Munsell Prod values (17,391–20,520), it is suggested that the coal is under-mature, and may be ranked between peat and lignite.

Alveolinid biostratigraphy of the Eocene succession of the Salt Range, Northern Pakistan

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The Alveolinid biostratigraphy of the Eocene succession of the Salt Range is the first comprehensive study of its kind. It includes detailed taxonomy and biostratigraphic framework, and it is very important for the standard shallow water benthonic biozonation (SB Zones).

The present study establishes SB 5 to SB 9 Alveolinid zones for the Eocene succession of the Salt Range. These are Alveolina vredenburgi Zone (SB 5 Zone), Alveolina ellipsoidalis Zone (SB 6 Zone), Alveolina mousoulensis Zone (SB 7 Zone), Alveolina corbarica Zone (SB 8 Zone), and Alveolina trempina Zone (SB 9 Zone).

The upper part of the essentially Upper Palaeocene Patala Formation in the Trans Indus Surghar Range at Makarwal, happens to be of Eocene age because of the occurrence of *Alveolina vredenburgi* which has been transported from the shallow water habitat into the deeper environments substantiated by the presence of planktonic foraminifera. Twelve species of *Alveolinids* including two species of *Glomalveolina*, one new species (*Alveolina conradi*), and one new subspecies (*Alveolina rotundata bhadrarensis*) have been recorded.The study further concluded that *Alveolina cucumiformis* Hottinger, 1960 is a junior synonym of *Alveolina vredenburgi* Davies, 1937.

The significance of Kirthar Formation and post-Eocene Baselap, eastern slopes of Foreland Fold and Thrust Belt, Sulaiman Range, Pakistan

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For the purpose of geological interpretation, TM satellite data scenes TM 151–37, 152–37, 151–38, 151–49, and TM 152–38 were used. A number of multi-directional filters to enhance the structure were applied to the raw data. The contrast of satellite data was also enhanced to increase the perceptibility for lithological interpretation. The study of satellite scenes was supplemented by actual ground check at the various sections of the Eastern Sulaiman Range from south to north and afterwards by extensive laboratory studies.

The Kirthar Formation (Middle to Upper Eocene) and post Eocene stratigraphic units run in N–S direction along the eastern slopes of the Sulaiman Range. In this area, the Kirthar Formation is underlain by the evaporite-/carbonate-bearing Baska Formation, which is the indication of the initiation of the tidal flat environments on the fluvial part of the underlying Ghazij Formation of Early to Middle Eocene age.

The Kirthar Formation throughout its extent along eastern slopes of the Sulaiman Range can be divided into four members. The basal Habib Rahi Member is composed dominantly of carbonates with marl and chert. Some oil shales are the integral part of this member. It represents deeper part of the transgresive system. Both reservoir and source rocks are present in this member. The overlying Sirki Member is composed of varicoloured gypsiferous shales with two sandy limestone beds towards the top. This horizon was deposited during the regression of sea. The third member is the Pirkoh Limestone and Marl. The basal part contains *Discocyclina* and it is overlain by thin-bedded limestone. This member also contains mixed benthic and planktonic foraminifera, marking the position of maximum flooding surface during the Eocene Epoch. This member is followed by the Drazinda Member composed dominantly of varicoloured shales with sandstone and two limestone horizons with larger benthic foraminifera. The marine environment terminated in the Upper Eocene, which represents the youngest record of Eocene Epoch in the Sulaiman Range. The sequence boundary can be placed where the marine environment changed into the dominantly fluvial environment dominated by siliciclastic sediments. The Nari Formation of Oligocene Epoch is composed dominantly of sandstones with carbonaceous matter. This formation wedges out south of the Sherana Nala. The overlaying Vehowa Formation is equivalent to the Chinji Formation of Late Miocene age, which disappeared south of the Gomal Pass. The four members of the Kirthar Formation reduced in thickness here, this successive post-Eocene baselap is best represented by the Tochi River section northwest of Banue where the Litra Formation (equivalent to the Nagri Formation) directly overlies the carbonates and shales resembling the Kirthar Formation. This is also a sequence boundary.

The depositional and diagenetic parameters display that the possible source rock may be present in the Habib Rahi and Pirkoh limestone and marl Member. The basal part of the Habib Rahi Member has good reservoir potential. The marl and shale of the Sirki Member can act as an effective top and lateral seal. The excessive thickness of fluvial horizons can provide desired burial for the conversion of organic matter into hydrocarbon.

The post-Eocene units (dominantly siliciclastics and non-marine) are truncated as traced from south to north until the Kirthar-like carbonates are overlain by the Litra Formation (Middle Siwaliks).

The carbonates of Kirthar Formation show very well developed intra-skeletal solution, matrix, and fracture porosity, which make it important possible reservoir for petroleum.

Microfacies and foraminiferal assemblages of the Late Cretaceous-Early Tertiary succession of the Murree–Brewery Gorge and Hanna Lake, Western Sulaiman Range, Pakistan

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Depositional environments and the biostratigraphic framework of the Late Cretaceous – Early Tertiary carbonate succession of the Murree–Brewery Gorge and the Hanna Lake around Quetta in the western extremity of the Sulaiman Range are outlined in this paper. The Late Cretaceous succession begins with the deepening environmental style when the Goru Formation and the overlying Parh Limestone developed the planktonic foraminiferal lime mudstone to packstone. Shallow shelf carbonate platform deposition is envisaged along the Cretaceous–Tertiary boundary. The Late Cretaceous Murree–Brewery Limestone (formerly Orbitoidal Limestone) contains characteristic foraminiferal fauna such as *Orbitoides apiculatus* (Schlumberger), *Omphalocyclus macroporus* (Lamarck), and *Siderolites calcitrapoides* (Lamarck), whereas the overlying Early Tertiary Dungan Limestone is characterised by the presence of following stratigraphically important foraminiferal fauna: *Nummulites mamillatus* (Fichtel and Moll), *Discocyclina dispansa* (Sowerby), and *Somalina stefaninii* Silvestri. The above succession contains various microfacies of shallow shelf environments grading up to grainstone. The Murree–Brewery Limestone is flanked by a widely distributed blanket of fossil-starved regressive facies of the Pab Sandstone, which can be visualised on the regional framework.

Use of rock magnetic characteristics for decrypting rhythmically bedded sedimentary rocks from West Caucasus

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A few Cretaceous–Palaeogene sections were selected from various structural zones in the West Caucasus for the study of rock magnetism, and the rocks were correlated on the basis of magnetic susceptibility (ê).

In the terrigenous carbonate flysch deposits from the western terminus of the Caucasus, a slight but statistically significant increase in magnetic susceptibility was revealed at the Cretaceous–Palaeogene boundary as a result of detailed (layer-by-layer) rock magnetic study.

This rock magnetic borderline is in essence an event boundary and can be used as a tentative Cretaceous–Palaeogene boundary in the West Caucasian flysch sections. Such sections cannot be easily deciphered because microfaunal remains are practically non-existing and the Cretaceous–Palaeogene sequence is lithologically monotonous.

The increase in rock magnetism may be supposed to reflect changes in sedimentation settings at the Cretaceous–Palaeogene boundary. The Maastrichtian and Palaeocene sediments of the West Caucasus were deposited in a rift zone. According to modern views on genetic nature of flysch deposits (Frolov 1995), the lithological and rock magnetic differences in a number of sections allow to confirm the earlier suggestion (Hine 1962) that feeding of the process of sedimentation and sagging of flysch in the Novorossyisk trough took place from two sides.

The sedimentation in trough was obstructed by local uplift of the Scythian platform from north and south, and the flysch deposition took place in the Maastrichtian and Palaeocene Epochs in the manner of periodic drift of terrigenous material from disintegration of shallow or even inner areas. As stated in the earlier studies (Muratov 1980; Malovizky 1982; Tugolesov 1985), the shoals and islands were the principal sources of sediments for the northern areas whereas the intermediate massif with complex sedimentary formation was the main sediment source for the south. We do not exclude the possibility that the rock magnetism was influence by the volcanic activities in the basin (Viginsky 1997).

The magnetic difference of sections reflects consequent changes in physico-geographic situations in the Maastrichtian Epoch, whereas the Palaeocene flysch basin is closely associated (tectonically as well as historically) with the Alpine geosyncline. According to the physical and mineralogical nature of rock magnetic parameters, it is possible to confirm that this border marks two stages: the sedimentation separated by a hiatus. The first stage in the Maastrichtian Epoch is noted by carbonate flysch sedimentation. The second stage of Palaeocene Epoch, sedimentation took place due to the tectonic reactivation in the region at the Mesozoic–Cenozoic boundary, which resulted in the accelerated transport of highly magnetic terrigenous material.

The results presented here do not exhaust the possibilities of the rock magnetic method in the reconstruction of geological events at the Cretaceous–Palaeogene boundary. The efficiency of the rock magnetic data in solving the problems of stratigraphy and palaeogeography was previously tested by various authors (Molostovsky 1986, 1996, 1997; Guzhikov 1997; Molostovsky 1997) on Permian, Triassic, Cretaceous, and Neogene deposits from various geological provinces. Further, the rock magnetic study of Maastrichtian and Palaeocene deposits from the West Caucasus may help in solving some other problems associated with regional correlation of the sections, sedimentation rhythms, and reconstruction of palaeo-geochemical settings.

Himalayan-type metamorphic core complexes in Central Asia (Southern Siberia)

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The Cenozoic metamorphic core complexes (MCC) of North American Cordilleras and Himalaya are the tectonotypes of the MCC. Therefore, it would be possible to assume that such types of tectonic structure were formed only during relatively young tectonic processes.

However, the research carried out within the fold belt of Central Asia (Siberia, Russia) testifies the existence of more ancient MCC. The Upper Mesozoic MCC close to the Cordilleran type is found in Trans-Baikalia. The Palaeozoic complexes structurally and petrologically similar to the Himalayan type MCC were recognised in the East Sayan Ridge and the Baikal area. The formation of the Palaeozoic MCC in the fold belt of Central Asia was connected with the Ordovician collisional events. One of such Palaeozoic MCC (Shutkhulay Complex) occurs in the Eastern Sayan Ridge. On the basis of its structural and metamorphic characteristics, this complex could be equivalent to the Himalayan type MCC. As in the Himalayan MCC, it is typical for the Shutkhulay complex to exhibit two types of metamorphism along the thrust zones. In the upper plate, high-temperature and low-pressure metamorphism (T = 540–650 °C, P = 2–7 kbar) was recognised, whereas in the lower plate, metamorphism under moderate temperatures with increased pressure (T = 410–630 °C, P = 5–14 kbar) was observed.

Within the lower plate, the inverted metamorphic isograds were observed. In the cross-section, metamorphism increases upwards – chlorite is followed successively by biotite, garnet, and further up by staurolite.

For the Shutkhulay complex with inverted metamorphic zonation, an increase in pressure at a simultaneous fall of temperature is observed within the lower plate while moving away from the fault zone. It is a distinctive feature of the Shutkhulay complex, as with the MCC of Himalaya where the inverted metamorphic zonation with decreasing P–T conditions below the thrust zone is characteristic. However, for both cases, the occurrence and preservation of the inverted metamorphic isograds are possible only at very rapid and short-time tectonic and metamorphic processes with fast exhumation of the deep-level rock complexes to the surface.

For the Shutkhulay metamorphic complex, a maximum pressure developed at the culmination moment of thrusting. At the next stage, a decrease in pressure took place in a zone of metamorphism as a result of the removal of loading connected with the destruction of orogen and denudation of overlying complexes. Moreover, at this stage the heat of the overlying plate caused some increase of temperature in the metamorphic zone.

It is quite possible that the MCC in collisional orogens, including some Cenozoic complexes of Himalaya, have the inverted metamorphic zonation similar to that of the Palaeozoic Shutkhulay complex of Central Asia.

Criteria for correlating metamorphosed strata

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The metamorphosed sedimentary strata are characteristic for collision zones. They are generally deprived of palaeontological remains, especially in the sediments metamorphosed under greenschist to granulitic facies of metamorphism. In this case, there are no criteria for correlation of these sediments. The results of long research on the Protrusion–Early Palaeozoic strata at the southern margin of Siberian craton show an opportunity to correlate the metamorphic rocks. We propose the following methodology for correlating these metasedimentary rocks of fold belts.

The initial stage of investigation includes the study of structure and previous sequence of bedding, lithological and petrographic analysis of the main rock types, and recognition of metamorphic facies and metamorphic zoning. It allows revealing marker horizons for sedimentary rhythms and assuming conditions of deposition. Taking into account a facies heterogeneity of sea deposits, only large lithostratigraphic units can be used as the effectively markers. Stratigraphic and using the results of these studies, the interior stratigraphic structure for a region having a few alternatives could be worked out. Moreover, at this stage, a preliminary geochemical and radioisotope study should be done.

More detailed litho-geochemical and the radio-chronological studies of most complete cross-sections should be carried out in the following stages. More attention is given to geochemical studies, which include the analysis of pelitic and carbonaceous metamorphic rocks. The well-developed system of genetic model and diagrams for terrigenous deposits allows separating various tectonic domains in the cross-sections for further correlation. The correlation based on REE and incompatible elements for carbonaceous rocks could be established by cluster method analyses. It allows making the conclusions on the petrogenetic nature of elements. The statistically suitable conclusions about changes of concentrations of sidero-chalcophile elements in sedimentary rocks and the anomalous concentrations of juvenile and organo-phile elements and their bonds have an important role in correlating the metasedimentary rocks.

The received data allow to plan the litho-geochemical correlation between the isolated sections and to select the mostly suitable variant for the regional stratigraphic model. Simultaneously, the results can be used for the reconstruction of depositional environments.

The chronological correlation of metasedimentary rocks is more conjectural. The radioisotope definitions of protolith usually remain ambiguous. The representations about the time of sedimentation are constrained by the time interval between the data from underlying rock complexes and magmatic rocks or by the age of the last metamorphic event.

The proposed methodology could be used for correlating sedimentary rocks of wide time interval and varied metamorphic conditions. In Asia, these metasedimentary rocks frequently occur at the collision zones and fold belts like the Himalaya and the fold belt of Central Asia.

Morphotectonics of the Himalayas

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The Himalayan tectonic relief can be subdivided longitudinally as well as transversely into various elements. The transverse subdivisions are the following:

- the Siwaliks, as a system of piedmont anticlinal massifs;
- the Lesser Himalayas, as a combination of foreridges, median depression, and tectonic steps of different heights;
- the Higher Himalayas, composed of the main tectonic step and a system of the highest massifs called Himals; and
- the Trans–Himalayas, with monoclinal or domal ridges and intermontane depressions.

The longitudinal subdivisions are determined by transverse lineaments dividing the mountain ranges into some sections. The lineaments themselves are deep tectonic passes accompanied by block uplifts of a triangular form (Mustang and Arun passes) and continue to the north into Tibet where they are connected with rifts.

The Morphotectonic structure of the Himalayas has a clear transverse bilateral symmetry, which is well expressed in the drainage pattern. The valleys of Indus, Tsangpo–Brahmaputra, Sutlej, Arun, and other rivers are distributed in a mirror-like symmetrical manner. Such a kind of symmetry points out to the formation of the mountains under the influence (movement) of masses of the Indian craton and its surroundings from the south.

The Himalayas are not a water divide that is disposed northwards, in Tibet. This mountain range is situated on the largest slope of socle surface in the Earth (difference between heights up to 5,000 m). This circumstance determines a gravitational instability of the Himalayas, and it has significant geodynamic implications.

Recent geodynamics of the Himalayas is a combination of various processes. The main process is the closing and interaction of crust–mantle blocks of high density with vertical dimensions up to 1,500 km and limited from east and west by the lineaments permeating up to the core–mantle boundary. The displacement in the north of the Indian and Indo-oceanic block of high density determines collision events in Inner Asia and clustering of thrusts and wedges in the Himalayas. This process is accompanied by underthrusting of India under the Himalayas with the formation of the Siwalik anticlines. Other important geodynamic phenomena are:

- pushing out of synclinal cores and erosion outliers of allochthones in the fore-uplifts of the Lesser Himalayas (the Mahabharat Ridge);
- gravitational tectonics above the steep slope of socle surface of the Higher Himalayas; and
- isostatic floating of granitic batholiths in the Trans-Himalayas (the Ladakh Ridge).

Together with the morphotectonic elements of the Himalayas–Zagros on the southern flank of the Mediterranean mobile belt we observe a process of tectonic clustering of lithosphere in two denudational levels:

- transverse shorting of the lithosphere due to a complex system of thrusts in a basement of an uplifted margin of craton in the Himalayas and
- near-surface folding of sediments above a submerged margin of the craton in the Zagros.

Hydrogeology

Waterlogging problem in Dhaka, Bangladesh

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Waterlogging during the monsoon is a common problem in Dhaka. Waterlogging in the Dhaka City is caused mainly because of artificial filling of natural water bodies and lowlands. This problem is further aggravated by the unplanned urbanisation. Artificially filled areas are mapped by using the aerial photographs, topographic maps, and IRS satellite imageries of different years. Water stagnancy in the city is caused by some obstruction of main natural drainage system. Houses partially or completely occupy many drainage channels. Road systems of the city also play a major role in this problem, as most of the roads are constructed on fill material and do not have any culvert to maintain the water flow. In many places, single catchment is divided into many segments. Filling activities in depressions and abandoned channels in the city almost obstruct the natural water flow. The artificial drainage system is not very efficient for draining off the stagnant water from the city. The flood protection embankment around the Dhaka City has obstructed most of the channel flows towards the rivers.

Geological, geochemical, and electrical constrains on the transient flow mechanism of a periodic spring in Western Nepal

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The Dhor Barahi spring in the Tanahun District, Western Nepal, is characterised by intermittent periodic flow or unsteady continuous flow depending on the time of the year. This behaviour can be attributed to a siphon that can be constrained by the local geology and water chemistry data. During periodic discharges, electrical signals are observed with amplitude proportional to the water flow rate, as predicted by the electrokinetic effect, with a maximum coupling of -1.3 ± 0.3 Vsm^{-3}. The spatial structure of the surface potential leads to a qualitative description of the electric sources, also compatible with an electrokinetic mechanism, but additional contributions are possible. This study illustrates how combined geochemical and electrical measurements can provide access to the dynamics of groundwater circulation with possible implications for the monitoring of hydrological, tectonic or volcanic processes.

Sustainable groundwater management in Ganga Basin, India

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The Ganga Basin occupies an area of 8,61,400 sq km and forms one of the largest river basins in the Indian Subcontinent. The Ganga River originates from the Gangotri Glacier in Uttaranchal and covers a distance of 2,525 km before it falls in the Bay of Bengal. The foredeep region in the basin occupies an area of 5,00,000 sq km including part

of southern cratonic region in the States of Uttaranchal, Uttar Pradesh, Bihar, and West Bengal. Under the groundwater exploration programme, Central Ground Water Board has constructed wells down to 800 m depth. Rock formations underlying the Ganga Basin vary widely, comprising consolidated gneissic complex and associated intrusives, semi-consolidated formations of Upper Palaeozoic, Mesozoic and Tertiary, and unconsolidated formations of Quaternary age. Tertiary aquifers are represented by the Upper Siwaliks and upper part of Middle Siwaliks. Quaternary sediments represented by piedmont deposits and fluvial sands formed by mega fans of rivers emerging from the Himalayas and Vindhyans. They form most potential aquifers in the basin. There are 4 to 5 leaky aquifer units down to the depth of 750 m, which behave like a single aquifer system under strained conditions. Granularity in aquifers decreases towards the Central Ganga Plain both from north to south and from south to north. The aquifers are unconfined at marginal alluvial part and semiconfined to confined in the central part. The surface water entering into the basin through rivers and channels from Himalayas and Aravallis. The basin has vast potential of surface water as well as groundwater resources. Average annual discharge of the river is of the order of 493 BCM (billion cubic metre). The replenishable groundwater resources of Ganga Basin have been estimated as 171 BCM, out of which 26 BCM is available for domestic and industrial uses and the rest 145 BCM is available for irrigation. The stage of groundwater development in the basin is 33.5%. Besides replenishable groundwater resources, which are assessed within the zone of water level fluctuations, the basin is endowed with enormous instorage groundwater resources, which have been assessed to be 7,500 BCM down to depth of 450 m. The deeper aquifers in the basin occurring down to the depth of 2,000 m also hold vast untapped groundwater potential.

The basin is densely populated due to its rich water potential. Increasing population and related development activities in the basin have created an increased water demand, which has in turn deteriorated the available groundwater resources. As a result, groundwater levels have registered fast declining trends. Surface water is also getting polluted day by day. Therefore, deeper aquifers which hold vast potential of groundwater need to be explored besides adopting artificial recharge measures to augment the groundwater storage in shallow aquifers for sustainable development of groundwater for meeting present and future water requirements.

Hydrogeological and geomorphic settings of the Lower Subansiri Basin, Assam, India

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Geomorphic settings of an area provide valuable supplementary information regarding groundwater recharge, its occurrence, and distribution. The geomorphic settings of the Lower Subansiri Basin can broadly be represented by three distinct geomorphic units viz., structural hills, piedmont zone, and alluvial plain. While the elevation, slope, lithology, drainage pattern, and various relevant morphometric parameters vary from one geomorphic unit to another, the conditions of recharge and discharge as well as occurrence and distribution of groundwater also differ in different units. The structural hills occupying only 4.5% of the area along the northwestern boundary represent a high runoff zone characterised by steep slope and fairly dense parallel to subparallel drainage. The piedmont zone, built up of coalescent alluvial fan deposits, represents 7.7% of the area. It occurs in a long and narrow NE-SW trending and steeply sloping belt along the foothills of Arunachal Pradesh. Owing to high permeability, this zone hardly retains any water and hence forms a high recharge zone with relatively deeper groundwater level. The alluvial plain, covering 87.8% of the basin area and characterised by a gentle slope, serves both as discharge and recharge areas where groundwater occurs relatively close to the ground surface. Panel diagrams prepared for the Lower Subansiri Basin showing the thickness and extent of granular zones display that the unconsolidated alluvial sediments are composed primarily of sands of various grade and gravel with minor amounts of silt and clay. The sand–gravel isolith maps showing the cumulative thickness of the granular zones down to the depth of 40 m reveal that the subsurface formations in the major part of the alluvial plain of the Lower Subansiri Basin are entirely represented by granular zones. The granular zones in most part of the area form one single aquifer system where groundwater mostly occurs under unconfined to semiconfined conditions. Due to the presence of thin clay and/or sandy clay lenses at shallow depths, however, the single aquifer system gets locally dissipated into multiple aquifer systems where, barring the uppermost aquifer, groundwater mostly occurs under semiconfined to confined conditions. The overall regional variation of depth to water level, from the piedmont zone in the north and northwest to the alluvial plain of the south and southeast, is controlled by the prevalent geomorphic settings of the area. The water table contours of the area indicate that the configuration of groundwater table is similar to the general topography of the area. The steeper hydraulic gradient observed in the north and northeast seems to be controlled by the geomorphic setting, i.e. topography, relief, and lithology.

Hydrogeological characteristics of fractured hard rock aquifers in Kozhikode Coast: a case study from India

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This paper outlines fractured hard rock aquifers along the coastal belt of the Kozhikode District of Kerala in southwestern India. Due to the scarcity of drinking water and limited thickness of sandy aquifer along the coast, a number of boreholes were drilled into the basement (granitic gneiss) rock. For the purpose of carrying out hydrogeological studies, twenty-six bored wells were examined. Based on the borehole log, three types of hard rock aquifer can be identified along the coast. They are the weathered aquifer above the crystalline rock, a combination of weathered and fractured rock aquifer, and fractured crystalline aquifer at the depth between 50 and 80 m, where the fractures are horizontal to sub horizontal. The yield of bored wells tapping the weathered and fractured aquifer varies from 2,500 to 31,000 litres per hour. The aquifer parameters of the fractured aquifer are also evaluated from the pumping test. The study shows that heavy pumping of such bored wells may cause a decline of water level in the surrounding wells in certain pockets of the Kozhikode Coast.

Hydrogeology of the Brahmaputra Basin

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The Ganga–Brahmaputra river system forms one of the largest deltas in the world. The delta occupies an area of about 59,570 sq km. The waterpower resource of the Brahmaputra has been presumed to be the fourth biggest in the world being 19.83 x 10^3 m^3/s. The entire lower portion of the Brahmaputra consists of a vast network of distributary channels, which are dry in the cold season but are inundated during the monsoon. The catchment area of the entire river is about 580,000 sq km, out of which 195,000 sq km lies in India. The maximum discharge as measured at Pandu in 1962 was of the order of 72,800 m^3/s while the minimum was 1,750 m^3/s in 1968. The drainage pattern in the valley is of antecedent type while the yazoo drainage pattern is most significant over the composite flood plain to the south of the Brahmaputra.

The Brahmaputra Valley is covered by Recent Alluvium throughout its stretch except a few isolated sedimentary hills in upper Assam, inselbergs/bornhardt of gneissic hills in the Darrang, Kamrup and Goalpara districts and a few patches of Older Alluvium in the Darrang and Goalpara districts.

The basin is very unstable. The present configuration of the basin is the result of uplift and subsidence of the Precambrian crystalline landmasses. Four geotectonic provinces can be delineated in the NE India through which the Brahmaputra flows. These are bounded by major tectonic lineaments such as the basement E–W trending Dauki Fault, a NE–SW trending structural feature of imbricate thrusts known as the ‘belt of Schuppen’ and the NW–SE trending Mishmi Thrust.

Hydrogeologically, the Brahmaputra Basin can be divided into two distinct categories, viz. (a) dissected alluvial plain and (b) the inselberg zone. The first category is represented in the floodplain extending from the south of the Sub-Himalayan piedmont fan zone in the north to right up to the main rock promontory of Garo Hills and Shillong Plateau. The inselberg zone is characterised by fractured, jointed, and weathered ancient crystalline rocks with inter-hill narrow valley plains, consisting of thin to occasionally thick piles of assorted sediments.

From the subsurface lithological data, two broad groups of aquifer are identified. These are: i) shallow water table and ii) deeper water table or confined ones, separated by a system of aquicludes. The shallow aquifer materials, in general, consist of white to light grey, fine-grained micaceous sand and the thickness ranges from 1.2 to 10.3 m. The sand and clay ratio varies from 1: 2.5 to 1: 26. The bedrock occurs at a depth of 30.4–39.5 m. The materials of the deeper aquifers comprise grey to light grey, fine- to medium-grained sand. The sand and clay ratio varies from 1:2 to 1:7. The effective size of the aquifer materials varies from 0.125 to 0.062 mm with uniformity coefficient around 4.00, porosity 38 to 42 %, and coefficient of permeability 304 to 390 galls per day/ ft^2. The groundwater is mildly alkaline with pH value 6.5–8.5, chloride 10–40 ppm, bicarbonate 50–350 ppm, and iron content ranging from a fraction of a ppm to 50 ppm. Total dissolved solids are low, hardness (as $CaCO_3$) ranges from 50 to 300 ppm, and its specific conductance at 25 ^oC is 150–650 mhos/cm. The yield from shallow aquifers is 1,440–33,750 litres/hour and for deeper aquifers ~1700 litres/hour at a drawdown of 13.41 m, and specific capacity of 21 litres/minute. The temperature of groundwater is 23–25 ^oC during the winter, 24–26 ^oC during the pre-monsoon, and 27–28 ^oC during the peak monsoon. The general hydraulic gradient in the northern bank is 1:800 whereas it is 1:300–400 in the southern bank. The Tertiary sediments yield a range of water from 200 to 300 lpm whereas the yield from the Older Alluvium is 500–700 lpm. The estimated transmissibility and coefficient of storage is of the order of ~ 800 lpm/m and 8.2 x 10^{-3}, respectively. Depths to water level range from 5.3 to 10 m below ground level (bgl). In the Younger or Newer Alluvium, groundwater occurs both confined and unconfined conditions. Depths to water levels vary from the ground level to 10 m bgl. Depth to water ranges from 6 m bgl to 2 m above land surface. The yield of deep tube wells ranges from 2 to 4 kl/minute for a drawdown of 3 to 6 m. The transmissibility of the aquifers varies from 69 to 1,600 lpm/m and the storage coefficient is of the order of 3.52 x 10^{-2}.

Hydrogeological conditions in the Jhapa, Mahottari, and Banke districts of the Terai

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The results of groundwater resources evaluation in the Jhapa, Mahottari, and Banke districts of the Terai from 1991 to 1993 are summarised below.

Jhapa District

A flat alluvial plain extends in the Bhabar Zone, south of the Himalayan Frontal Thrust (HFT). The Gangetic Plain extends up to the nearby Indian border, and it is bounded by the uplifted terrain from the Bhabar Zone. The optimum well yield by 20 m drawdown is calculated at 165 l/s, while it is 90 l/s in the Bhabar Zone.

A widely extended uplifted terrain is located 15 km south of the HFT and it forms a rectangular belt in E–W direction with 5 km width and 15 km length. Semi-consolidated siltstone and sandstone are underlain in the uplifted terrain, which is probably correlative with the Upper Siwaliks. The terrain forms an 8 to 10 m high cliff from alluvial riverbed in the northern edge whereas in the southern edge, it gradually submerges into the Gangetic Plain. The temperature of the free-flowing groundwater collected from an exploratory well in the northern edge of the terrain was 33.5 ^oC, while in other places the groundwater temperature was ranging from 25 to 26 ^oC. Therefore, the former is similar to the Tatopani (hot spring) located in the central part of the Himalayan Zone.

Mahottari District

The Bhabar Zone is underlain by fan and river terraces and it slopes gently southwards to the Gangetic Plain. The zone was uplifted to form three steps of river terraces.

The Upper Siwaliks underlie the terrace deposits in the south of the HFT and they extend up to the Gangetic alluvial plain. The groundwater potential of the Gangetic Alluvium is rather small as compared to the Upper Siwaliks. Specific capacity of the Upper Siwaliks is calculated at 15 l/s/m, while it is 3 l/s/m for the Gangetic Alluvium.

Banke District

The Bhabar Zone occupies a large area lying mostly between the Churia Hills and E–W Highway. A small-scale alluvial plain is also present along the Rapti River. A slightly undulating alluvial plain is observed south of the E–W Highway. The Gangetic alluvial plain shows flat topography and it lies along the Indian border with an altitude of less than 150 m.

According to the drilling data, the Siwalik Group is found at a depth of tens of metres in the area south of the E–W Highway. The Gangetic Alluvium near the Indian border is more than 300 m thick. Specific capacity of the Rapti and the Gangetic Alluvium is about 4 l/s/m, and it is 0.8 l/s/m for the Siwaliks lying in the south of the E–W Highway.

The study led the authors to the following conclusions:

- Although an extensive alluvium lies in the Terai, its vertical and horizontal extent and lithological composition vary locally.
- The HFT is a conspicuous topographic break between the Churia Hills and the Terai Plain, and it is still tectonically active.
- The northern part of the Terai Plain is topographically defined as the Bhabar Zone where the Siwalik Group is found at a depth of tens of metres with various topographic features.
- The Siwalik Group in the south of the HFT is probably correlative with the Upper Siwaliks in the Jhapa and Mahottari districts, and it extents up to the Indian border.
- The Siwalik Group in the south of the HFT is in the form of an erosional remnant, and another tectonic boundary between the Siwaliks and Gangetic Alluvium is presumably located further south of the Terai Plain.

Harvesting roof water for livelihood improvement: case study from the Yarsha Khola Watershed

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The roof water collection technology for the purpose of ensuring safe and reliable drinking water supply to rural households was introduced in the Yarsha Khola Watershed of the Dolakha District, Eastern Nepal, in 2000. The communities residing along the water-divides, elevated terraces, hilltops, and spurs, are facing acute water-shortage, particularly during the dry period. The traditional water sources, namely, dugout ponds, springs, seepage, shallow well, and streamlets dry out soon after the end of monsoon. Piped water to the scattered households is not cost effective owing to their unfavourable geographical location and long distance from water sources. Therefore, harvesting of rooftop water in ferro-cement jar was chosen as a viable option to meet with this challenge, as the average annual rainfall is substantial. Formal practical training was provided to selected local masons, who installed several water-harvesting jars on the farmer's house yard and school premises.

A preliminary assessment of the intervention indicated that a majority of respondents had a positive impression on the technology, as it saved water-fetching time, provided convenience particularly to the aged people who prefer to avoid slippery trial during the rainy season, and supplied cool and clear water from the jar. Although it is highly accepted, a heavy initial investment restricts a majority of poor rural farmers' access to this technology.

The paper describes the management aspects of water harvesting technique, details of the materials required, and role of local authorities for institutional strengthening to ensure access to safe and independent water supply.

The complex monitoring of Himalayan nival–glacial zone of Nepal Himalaya

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Up to now in Nepal there is no constant observation service for the elements of Himalayan nivation–glacial area: proglacial lakes, snow avalanches, debris flows etc. Glacier studies were carried out during mountaineering ascents, incidentally and also by episodic glaciological expeditions of 1955–1963 (Wang Li Lun 1983) and 1970–1978 (Fushimi et. al. 1973). However, a catalogue of glaciers is not available. Over the Himalayan territory, there is only scanty information about the glacier's end position since the middle of the last century. Even to date, there are no works on complex monitoring of glaciers (Popovnin 1979), and some of the most dangerous proglacial lakes are studied episodically (lves l997).

As a result of reconnaissance studies conducted by us in the Everest region in April 1998, some inaccuracy in depicting glaciers was noticed (i.e. their sizes were significantly exaggerated on topographic maps).

In connection with the further enhancement of economy in high-mountain areas, there appeared the necessity for a detailed study of the Himalayan nival-glacial system. For this, it is necessary to carry out monitoring of glacier fluctuations in the potentially dangerous areas with frontal glacier lakes, snow cover avalanches, and glacial debris flows.

The main attention must be given to the organisations that monitor glaciers, proglacial lakes, and debris flows. The collection of information on glacier fluctuations, mass-balance, state of glacier lakes, fresh tracks of debris flows, and snow avalanches should be given a high priority.

Monitoring service must be founded on remote sensing, aerial photo interpretation, and overland route studies. The remote sensing data can be obtained from such satellites as LANDSAT, NOAA, and SEO. Monitoring and remote sensing must be conducted annually in spring when glacier tongues have no snow. It will permit to work out the breaching mechanisms of proglacial lakes and the formation of debris flows. Similar investigations conducted by the Geography Institute of Russian Academy of Sciences, Moscow State University, and North Caucasus Administration of Hydrometeorological Service testified the usefulness of such studies.

Economic Geology

The Sargipali sulphide deposit of Orissa, India: its atypical lead-high character and genesis

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The sulphide deposit of Sargipali, in the Proterozoic fold belt of Gangpur, is strikingly lead dominant in character. It has an ore reserve of 2.06 million tons with an average grade of 6.73% Pb and 0.33% Cu, with a little Ag (about 50 ppm). The Zn content in the ore is insignificant, below recoverable limit.

The unusual compositional character of the deposit will be evident when compared with that of many known sulphide deposits. Pb- and S- isotope studies (Vishwakarma and Ulabhaje 1991; Ghosh et al. 1999) reveal extreme uniformity of Pb isotope composition, along with high source m (238U/ 204 Pb) value of Pb, which suggests a single-stage lead, derived from isotopically homogeneous, uranium enriched, felsic upper crustal source, though sulphur was derived from reduction of contemporary seawater sulphate source. However, the Pb-isotope study may well indicate that the Sargipali deposit is a 1,682–1,695 Ma-old sedimentary-exhalative (SEDEX) deposit. The petrographic and chemical studies of ore and host rocks indicate the metamorphosed synsedimentary-exhalative genesis of the deposit. It is inferred that the abnormal enrichment of Pb in the residual fluid was caused by the buffering of metal containing hydrothermal fluids by mica present in the felsic rocks or sediments at a low pH and relatively low temperature. Pb–Pb ages of ores (ranging between 1,682–1,695 Ma) suggest that mineralisation occurred during the closing phase of sedimentation in the Gangpur Basin.

The present study may help in throwing new light on the genesis of similar sediment-hosted Pb-rich deposits in terms of the SEDEX model.

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Age of metamorphosed base metal deposit of Ganesh Himal, Central Nepal, compared with some similar deposits in the eastern Lesser Himalaya

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The Pb isotope ratios of metamorphosed Zn–Pb deposit of Ganesh Himal, Central Nepal, suggest an age of 785 to 875 Ma. This age was compared with Pb–Pb ages for a few other base metal deposits of the eastern Himalaya covering Nepal, Sikkim and Darjeeling (India), Bhutan, and Arunachal Pradesh (India). Of the six ore occurrences covered, one (Phakuwa) is located in Nepal, two (Dikchu and Rangpo) in Sikkim, one (Gorubathan) in the Darjeeling District of West Bengal (India), one (Genekha) in Bhutan, and the remaining one (Shergaon) in Arunachal Pradesh (India).

The carbonate-hosted, highly metamorphosed Ganesh Himal deposit is Early Neoproterozoic, and very closely comparable in age with the Genekha deposit of Bhutan, which is also carbonate-hosted with some other similarities with the Ganesh Himal deposit. But the variously metamorphosed pelitic to psammo-pelitic metasedimentary rock-hosted Dikchu, Rangpo, and Gorubathan deposits of Sikkim–Darjeeling sector are much older (1,700–1,800 Ma), while the Phakuwa deposit of Nepal has a somewhat younger age (1,650– 1,700 Ma) than those of the Sikkim–Darjeeling sector.

The data for the Shergaon prospect indicate a Mesoproterozoic to Neoproterozoic age.

Pb–Pb ages of ore deposits, not very exact although, appear to give reasonable age estimates. Accordingly, the deposits may define two groups: Early Proterozoic and Late Proterozoic, which are equivalent to the peninsular Indian Aravalli and Vindhyan rocks, respectively. Other implications of detailed analysis of data shed light on ages of base metal mineralisation in the eastern Lesser Himalayan rocks occurring in apparently comparable stratigraphic levels.

Dimension stones of Makwanpur District, Central Nepal

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An exploration of dimension stones was carried out in the Makwanpur District. In the study area, various rock types were checked for their suitability and potential areas were delineated for the detailed study of their polishing characteristics. The area is found to comprise various rock types suitable for dimension stones. Among them, the most viable rock types are granite, aplite, marble, limestone, quartzite, and amphibolite. This paper describes mineralogy, chemical composition, weathering grade, structure of discontinuities, and physico-mechanical properties of rocks from the potential sites.

Earth resources of Lahore metropolitan area, Lahore, Punjab, Pakistan

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The earth resources of the Lahore metropolitan area are sand and silty clay of Holocene age. The sand is used for light aggregate and mortar while silty clay is for bricks, tiles, and pottery. All of these earth resources of the Lahore metropolitan area have a huge reserve of sand and silty clay and these commodities have been heavily used.

The main source of sand is the Ravi River and its floodplains, whereas the silty clay has sufficiently thick deposits around it. A rapid population growth has led to the increased demand of construction materials. The exploitation of these commodities has an adverse impact on the environment. Therefore, it is recommended to covert the abandoned pits of silty clay into the agricultural land, recreational parks, and residential areas. The earth resources of Lahore metropolitan area are presented on three maps.

Evaluation of selected deposits of Indus gravel and sand as potential aggregate sources for cement concrete

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The Indus River is the main potential source of both water and power in Pakistan. It has an estimated power potential of more than 30,000 MW of electricity and a storage capacity of above 50 million acre-feet of water. Planning for hydroelectric power projects on the Indus River has already started between Kalabagh and Skardu. These projects would require billions of cubic metres of coarse and fine aggregate. A preliminary study on the Indus aggregate has already been carried out between Kalabagh and Skardu (Chaudhry et al. 2000, 2001; Ahsan et al. 2000). This paper presents a

comprehensive study of some selected sites along the Indus River where future hydroelectric projects are planned.

In the study area, the Indus River flows from north to south through the Asian Continental Margin, the Kohistan Island Arc (demarcated by bifurcated Indus Suture), and the Indo-Pak Continental Margin. Because of diverse geology, the Indus aggregates are generally composed of a large number of rock types that are mainly igneous and metamorphic.

The rock types generally encountered are amphibolite, diorite, granodiorite, granite, mylonite, greywacke, quartzite, schist, acid to intermediate volcanics, phyllites, slates, carbonates, basic volcanics, chert, and diabase.

The fine aggregate of Indus River is composed mainly of quartz, polycrystalline quartz, quartzite, granite, granodiorite, amphibolite, feldspar, micas, greywackes, amphibole, schist, phyllite, slate, iron oxides, epidote, carbonate, volcanics, garnet, sphene, chert, tourmaline, apatite, and zircon.

The Indus aggregates were tested for their engineering properties such as soundness (2.68 to 3.10%), L. A. abrasion value (4.62 to 21.3%), aggregate crushing value (2.32 to 16.36%), specific gravity (2.68 to 2.83%), water absorption (0.3 to 1.0%), and flakiness (12 to 32%).

The Indus fine aggregate was tested for engineering properties. Its soundness value varies from 4.63 to 8.64%, specific gravity is 2.69 to 2.82, and water absorption is 0.5 to 0.9%. It contains traces of chloride, sulphate, and organic matter. It is free from coal and lignite.

The deposits occur in a wide range of grading and can be processed and sieved to attain the required grading for a job mix formula.

The potentially deleterious rock/mineral types with Alkali–Silica/Silicate Reaction (ASR) potential are greywacke, slate, phyllite, and chert, acid to intermediate merocrystalline volcanics, mylonite, and micro-fractured quartzites and strained quartz.

The experiments carried out show that the deleterious reactions could be controlled by using low-alkali cement, slag cement, or fly ash. Natural pozzolana and silica fumes have not yet been tested to see if they can control the ASR potential.

It is concluded that most of the Indus River aggregates meet the engineering requirements for cement concrete. However, they are potentially deleterious with respect to ASR.

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The have-nots have it all…., a global oil scenario

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Hydrocarbons are the most sought after commodity and the industrialised countries, in particular, cannot sustain for long without it. After the Drake's pioneer well drilled in the USA in 1859, which is generally taken as the start of the modern petroleum industry, the world has never been as before. Since the first-ever recorded oil production of 30 barrels/day from Drake's shallow well of only 69.5 m, the well depths have now increased to several kilometres, and the production to hundreds of thousands of barrels per day from a single well in certain regions. The exploratory efforts are now being diverted to offshore areas where it is said that future supplies could be found.

The one-and-a-half-century-long story of oil is not only full of international intrigues but also of perseverance, innovations, hopes and disappointments, and above all, the greater role played by the lady luck.

The USA initially dominated the oil scene, due to rapid growth of its reserves, up to the end of the 19th century, but then Europe also emerged to share the exploits because of its technological and political monopoly. Since the discovery of first gusher in Middle East at Masjid-e-Sulaiman, Persia (Iran) in 1908, the scenario has changed, however, the domination is still continuing but in a different manner altogether.

The industrialised countries, including those in North America, Western Europe, and Australia, contain less than 5 per cent of the global oil reserves of more than one trillion barrels (as of 2001), while the rest of the world constituting the under-developed and the developing countries hold right to the remaining 95 per cent.

It was in the late nineteenth century that the oil was discovered in Russia and Indonesia, at the beginning of the twentieth century in Middle East and South America, whereas the gushers of the Persian Gulf countries were discovered in and around the 1930s. Despite the oil revenues earned over a period of about 100 years or more, the development in these regions is still pathetic.

As per latest estimates, about 1.2 billion people in the world survive at an income of less than one dollar per day and most of them live in Asia and Latin America. Whereas, Asia in particular, contains 73 per cent of oil and 78 per cent of the world's gas reserves. The Asian reserves are, however, concentrated in the Middle Eastern countries, around the Persian Gulf, where 65 per cent of the world's known (as of 2001) oil reserves are located.

The paper attempts to trace the worldwide history of oil exploration, the distribution of world reserves and their growth, production trends, consumption and resulting pollution, and the historical price fluctuations. The future trends as predicted by oil experts are also shared.

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Torrent and avalanche control by sacred Buddhistic constructions in the Langtang Himalaya, Nepal

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The Langtang Valley lies about 60 km north of Kathmandu in the crystalline rocks of the Higher Himalayan Sequence. In this valley, permanent settlements reach an altitude of almost 4,000 m. With its high relief energy after rapid uplift (Hejl et al. 1997) and morphological overprinting by ice-age glaciation, the valley has extraordinarily steep mountain flanks. Hence, the area is highly vulnerable to landslides, avalanches, and debris flows. Besides the world's biggest landslide in the crystalline rocks at Tsergo Ri (4,984 m) in the upper reaches of the valley (Weidinger et al. 1996), several smaller recent rock avalanches are reported from there (Weidinger 1997 and 1998). An interesting fact, which is especially related to the Buddhistic areas over the whole Himalayan region (i.e. in the Indus Valley in Ladakh at Lamayuru and Shey, and at the outflow of the Phoksundo Lake in Dolpa, Western Nepal) and also in the Langtang Valley, is pointed out in this paper – sacred buildings (such as stone walls with mantras on them or Chörten) have been erected not only around monasteries and other holly places, but also as torrent-, avalanche-, and debris flow-controlling or stabilising input around active alluvial fans, which are endangering villages and farmland. Their position gives evidence for a connection between religious practices of the Himalayan people and the harsh natural conditions in which they are living.

A panoramic view (Plate 1) from the southern flank of the Langtang Valley (altitude of standpoint: 4,550 m) to the north shows the village Möndrong (m) at an altitude of 3,600 m. Mt. Langtang Lirung (ll) in the background is 7,234 m high and is situated just above one of the highest permanent settlements in this region. Positioned between the two huge debris fans created by avalanches from the steep wall, – the left (western) fan (df 1) with a deep gully and the right (eastern) one (df 2) with recent debris flows (see small arrows) – Möndrong could remain for hundreds of years without any damage from the natural hazards. The farmland (fl) in front of the village positioned on a glacial terrace along the river Langtang Khola (lk) is protected from debris flows by dry walls (w) containing stones carved with the mantra: *Om Mani Padme Hum.*

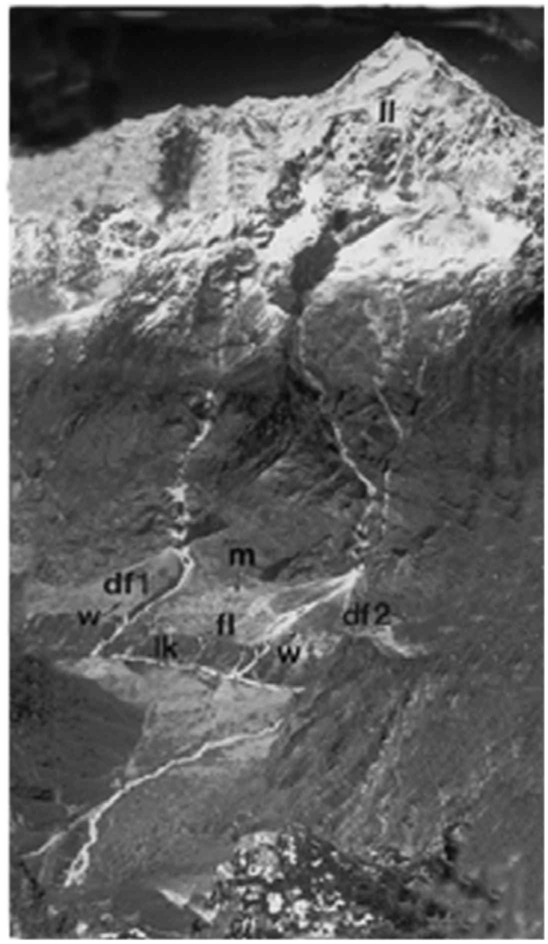

Plate 1: Panoramic view of the Langtang Valley (*Photo: J. Weidinger 1991).*

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Geo-environmental study for urban planning– a case study of the Khulna City, Bangladesh

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Khulna is the divisional headquarter as well as one of the largest coastal cities in southwestern Bangladesh. It is located on the bank of the Bhairab–Rupsa River and comprises fluvio-tidal sediments of Holocene age. Recently, the Khulna City is expanding haphazardly and rapidly owing to a high rate of population growth. The situation is further aggravated by complex geo-environmental conditions of the area. In this context, the geological information together with other environmental parameters can play an important role in urban planning to ensure sustainable development of the city through mitigation of natural hazards and resolution of environmental issues.

Low elevation (1–3 m amsl), bad soil conditions, bank erosion, and salinity are the main constraints on the development of the Khulna City. The sediments constituting the city and its surroundings can be classified into the natural levee deposits, bar deposits, floodplain deposits, old meander belt deposits, back swamp deposits, and tidal marsh deposits. The natural levees and bar complexes are the most suitable land units for urban development. The southeastern part of the Khulna City is the most promising area for future urban development or establishing satellite towns. In the east and west of the city, there are low depressions containing peat deposits. Here, building of infrastructure is costly but the peat deposits can meet the fuel and energy demand. In the future, the peat pits would be fresh water reservoirs, and they may also be useful for pisciculture and tourism. The monsoon sediments of the Atharabanki and Atai rivers can be collected by constructing sediment pits along the bank and can be used as the renewable raw material for brick industries. Surface water augmentation of the Gorai River from the Padma River can be used for decreasing the salinity in Khulna and increasing the possibility of using surface water. The areas with thick impermeable clay layers are identified as the safe and suitable sites for waste disposal. The west bank of the Bhairab River is susceptible to erosion and this fact must be taken into consideration for any future developmental planning. Drainage improvements in the Gollamari and Solmari rivers can reduce the waterlogging problems in the northwestern and southwestern parts of the city.

The geo-environmental maps of the city and its surrounding areas on 1:50,000 scale can provide a guideline to opportunities for and constraints on future development of the city.

Status of urban geology in Bangladesh

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The urban area brings together millions of people of different cultural and educational levels in a very confined area. Most of the city dwellers are not aware of geoscientific and environmental aspects, and the possible hazard susceptibility of the area. Dhaka, the capital city of Bangladesh, is now one of the ten densely populated cities of the world. The other major cities are densely populated with more than 4 million people.

Most of the unplanned rapid developmental activities ignoring the geoscientific factors are triggering the hazards and deteriorating the environment. During construction, proper civil construction techniques and the normal urbanisation rules are ignored. A major urban population and many vital civil structures in newly developed areas are placed in very high-risk zones. The existing Urban Development Master Plan was prepared paying a very little consideration to the geoscientific and environmental aspects. In most of the major planning events, the planner and decision-makers do not use the geoscientific information, because they do not realise that it is an essential component of urban planning. The communication between the high-level planners and decision makers, and geoscientists is rather absent or difficult. To focus on the need of geoscientific data in urban planning, the Geological Survey of Bangladesh established the Environment and Urban Geology and Natural Hazard Branch as an individual discipline-oriented branch devoted to the study of urban areas. In recent years, after facing some hazards, the major city development authorities are now paying attention to the geoscientific data and beginning to think that it is an essential component of urban planning. The relation is developing gradually. Nowadays, most of the major city development authorities are keeping liaison with the Geological Survey of Bangladesh.

Controlled urbanisation is essential for implementing properly the city development plan as well as adopting the established construction techniques considering the geoscientific setting to avoid the future hazard in newly developed areas. Special attention is needed for reducing the hazard/risk and improving the present condition of the developed areas. The sources of pollution and hazard need to be identified, and care should be taken accordingly to improve the sustainability. With this practice of urbanisation, damage during natural hazard will be minimum and the city environment will be improved significantly. The communication between the all-level planners and decision-makers, and geoscientists should be established.

A new filtering technique for correcting time variations in magnetic data

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Time variations in magnetic data distort the geological anomalies. The standard method for removing the time variations from the magnetic data is based on the assumption that the time variations measured in the base station and those encountered at the field stations are exactly the same. Accordingly, the time variations are removed from the field data simply by subtracting the base station reading from the corresponding field station reading. This assumption is practically true for very local and land-based surveys, in which the base and field stations are close to one another. For large-scale surveys, when the base and the field stations are at a considerable distance apart, the standard method introduces errors because, although the time variations measured at two different places are practically identical in shape, they differ in amplitude and phase depending on the separation between the base station and the survey location.

For correcting the time variations in magnetic data, a new filtering technique is proposed here. The new filter α is defined as

$$< |T - \alpha B|^2 > = \text{minimum}, \qquad (1)$$

Solving equation (1) we get

$$\alpha = \frac{< OB^* >}{< BB^* >} \qquad (2)$$

where T, B, and O correspond to frequency-domain representation of the time variations t, base data b, and field data o. The symbol $< >$ stands for ensemble expectation values.

The new filter α is based on the base and the field data only, and it is capable of correcting the time variations in magnetic data by taking care of the differences in amplitude and phase between the time variations in the base and the field data. Results obtained by applying the filter to model data demonstrate that the new filtering technique successfully removes the time variations from the field data by compensating for the differences in amplitude and phase between the time variations in the base and the field data.

A geological mapping approach for liquefaction potential assessment in Bangladesh

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Bangladesh forms a crucial geodynamic part of the Indo-Burmese seismic belt that has generated a number of world-ranking earthquakes in the recent past. The plot of recorded earthquakes shows that most of the major earthquakes are located outside the territorial boundary of the country. The epicentres are distributed in the Himalayan Main Boundary Fault and Naga–Disang Thrust region. There are a number of published generalised seismic zone maps, mostly prepared considering the distribution of historical earthquakes. This study identifies that these generalised earthquake zone maps have a number of observational constraints and do not provide appropriate seismic factors, and they lead to over-estimation or under-estimation of seismic risk levels. Delineation of geological boundary conditions is necessary for estimation of earthquake risk factors. Earthquake-induced liquefaction of subsurface materials is considered as an important constraint in the context of geology of the landmass. This paper deals with a preliminary mapping of liquefaction potential areas using the existing geological maps of the country.

Major part of Bangladesh is occupied by one of the largest deltas of the world, formed by the Ganges–Brahmaputra–Meghna river system. It is essentially a vast alluvial and deltaic plain with a few strips of hills and terraces. The alluvial and deltaic land is composed of Holocene deposits consisting of unconsolidated sand, silt, and clay. The terraces and hills are formed of moderately consolidated clay (mudstone), shale, siltstone, and sandstone of Pleistocene and Tertiary ages. The valleys and depressions in the hills and terraces are filled up with soft sedimentary deposits. The distribution of geological units is not as simple as the earthquake zones. The geological environments are not considered in the available seismic maps of Bangladesh. This study indicates that most of the geological materials in the plain land are young and susceptible to liquefaction during earthquakes.

This paper describes the liquefaction potentiality of different geological units of Bangladesh. The country is divided into six zones for different grades of liquefaction potentiality, determined on the basis of geology, geomorphology, lithology, groundwater conditions, seismicity, and depositional environments. These divisions will be useful for estimating attenuation characteristics, ground accelerations, and defining possible seismic hazard level caused by earthquakes.

The state of environment in Bangladesh: key issues and action for sustainable development

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Bangladesh is the most densely populated country of the world. The pressure of population along with recurring natural calamities and man-induced environmental degradation of the country's resources make planning an economic imperative. It is now perceived that environmental concerns have to be integrated into all sorts of planning processes. To implement environmental strategy for sustainable development, multi-sectoral initiatives are of paramount importance. These include development of new administrative mechanisms, expansion and reorientation of existing governmental departments and agencies, and formulation of appropriate policies, strategies, and action plan. It is also imperative that the ideas and view of people be incorporated in the planning of any national strategies. In the recent past, the National Environmental Management Action Plan (NEMAP) was enforced in Bangladesh. The format of NEMAP was based on the environmental concerns and on the realisation of the fact that people are the ultimate decision-makers.

The environmental issues in Bangladesh can broadly be addressed into two categories viz., the natural hazards (geo-genic) and environmental degradation (anthropogenic). The natural hazards are due to the geographical position and complex geological setting of the country, whereas the environmental degradation of the country is a consequence of human's imprudent interaction with the nature. In the past, the scanty resources of the country were either overexploited or used sub-optimally. After a long-term scientific studies and observations at grassroots, the NEMAP has identified institutional, sectoral, and long-term key issues. It is now working towards conservation, improvement, and reduction of degradation, promotion of sustainable development, and improvement of the quality of human life.

An assessment of Thulagi Glacier Lake monitoring in 2000

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The Thulagi Glacier Lake at Manaslu Himal is located at an altitude of 4100 m and stores a water volume of about 32 million m^3. It consists of a very old, thick and slow-melting ice body covered by debris. Unlike other glacier lakes in Nepal, the Thulagi Glacier Lake is thus not dammed by a system of terminal and lateral moraines. The lake is currently retreating very fast. Melting and ablation rates are considerably higher than the supply of ice from the catchment of the Manaslu Range. The outburst flood from the glacier lake may lead to a devastating debris flow in the downstream valley destroying villages, infrastructures, and the existing as well as planned hydropower projects.

The paper attempts to compare the findings of previous investigations with those of the present study. At present, the existing natural dam, which is the result of complex glacial processes, excludes the possibility of glacier lake outburst flood (GLOF) disaster since the melting rate of the buried ice body is very slow. Most of the typical triggering mechanisms of GLOF, such as ice surge from the retreating or neighbouring glaciers, huge snow avalanches or collapse of ice- cored moraines, can be ruled out.

However, it is necessary to continue with the careful monitoring programme of the lake condition as well as of the geological, hydrological, and meteorological processes. The main objectives of monitoring are to check the melting rate of the ice, fluctuation of the flood levels, slope stability, and the climatic changes. This monitoring is essential because it is not possible to predict correctly on a long-term basis the combined effects of all active natural processes at any particular juncture of time.

A certain residual risk always remains and it requires a continued reassessment of the risk based on the additional monitoring data. Although a potential GLOF is excluded presently, the possibility of overtopping of the existing natural dam by an exceptionally high displacement wave cannot be ruled out. The only possible mechanism recognised at the Thulagi Glacier Lake to create such surging huge waves is a major fall or slide of rock material into the lake from the unstable rock slopes on the lake's flanks. The instabilities could also be triggered by a major seismic event in the vicinity.

TV Tower stability problems in Gangtok, Sikkim – the need of terrain evaluation studies prior to civil construction on hill slopes

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The major causes of post-constructional problems in many civil works have been improper site selection, inadequate assessment of terrain and subsurface conditions, and unwillingness to implement geotechnical advice. The TV Tower in Gangtok is an illustration where such a heavy structure was constructed on the edge of an old landslide (known as the Chandmari Slide) without proper site assessment. Subsurface exploration prior to construction indicated the presence of 2.4 to 6.0 m thick slope-wash/debris material followed by highly weathered very poor-grade rock persisting at least 16.0 m below the surface. Yet, the foundation of the tower was laid at a depth of 4.5 m. The single-storey Arms Guard Dormitory (AGD) building, having an RCC foundation close to the tower foundation on the upslope was severely damaged due to subsidence, as it was located on displaced blocks and dislodged boulders on the right flank of the Chandmari Slide, immediately after its construction in July 1994. Subsurface exploration after construction indicated that about one third of the RCC raft of the TV Tower foundation to the east was on the landslide debris and the remaining portion on the western side was laid over 3–4 m thick slope wash/debris underlain by highly weathered bedrock. The formation of a large cavity below the tower base on the eastern side indicated the removal of soil by subsurface water along preferred path determined by the space and size of boulders/displaced blocks below the foundation. The hydraulic head caused by seepage of the surface runoff along cracks on the ground was responsible for the movement of soil and consequent subsidence/sinking. The analysis of tentative pressure isobars below the TV Tower foundation revealed that a considerable amount (about 1/4) of the total pressure (design load) of the superstructure was acting over the present head of the slide debris of the Chandmari Sinking Zone and the rest (about 3/4) was presently being transmitted into the weathered bedrock. Both short-term (immediate) and long-term slope stabilisation measures were recommended for the area. The short-term measures included immediate demolition of the uninhabitable highly damaged AGD building (to minimise the unnecessary load imposed on the head region of the slide/sinking zone); construction of a network of surface drains; and effective sealing of all open joints, space between disjointed blocks, and cracks in the soil. The long-term measures included gravity cement-grouted micro piling to stabilise the slope instead of constructing conventional heavy retaining walls. This system was recommended considering the deep (20–27 m) bedrock profile along the eastern slope, as the micro piling would add little load on the head region of the active slide, but would be able to withstand the lateral pressure of the overburden.

Debris flows episodes in Nant Ffrancon, North Wales, dated by lichenometry

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Debris flows affecting the main Nant Ffrancon road in North Wales are a threat to traffic. Such events may occur after dry summers following episodes of intense rainfall. A number of mass movements were dated by lichenometry using two approaches: one supplying absolute dating and the other based on lichen population size frequency distributions supported the growth rate estimates. Dating, based on a *Rhizocarpon geographicum* subsp. prospectans growth rate of 1.47 mm/yr and a colonisation period of 18 years, suggests that there was a major debris flow period in the 1890s, with later events in 1913–1917 and 1920–1947. Events in 1954 and 1973 were confirmed using the size frequency distributions. The frequency of the flows strongly suggests that the whole slope is unstable and prone to movement. In view of this ongoing activity, it is proposed that future work should be directed at investigating the state and condition of source material.

Challenges of disaster management in the Himalayan region

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Natural hazards represent extreme fluctuations in the average dynamic state of the earth's environment, e.g., ground motion (earthquakes), slope (landslides), atmospheric temperature, pressure, precipitation (storms, floods, drought, sea-level), magnetosphere (space weather) etc. In modern context, the usage of the term 'hazard' stresses qualification signifying the probability, with which a given value of departure from the average state, at a location, will not be exceeded over a future timeframe. Natural hazards are considered part of intrinsic dynamical behaviour of the composite earth systems. Thus, it is going to remain with us forever – as long as the earth systems continue.

Most natural hazards are known for their destructive power to cause varying degrees of damage to manmade structures, changes in natural landscape, and take heavy toll of life. The magnitude of the disaster is determined in terms of value of losses caused by the hazard and also by the number of people suffered in its aftermath.

Similar types of natural hazard may have different location-specific disastrous effects. During 1991, three volcanic eruptions took place within a short span in three places in South Asia viz. Mt. Pinatubo (Philippines), Mt. Unzen (Japan), and Barren Island (India). The eruption at Pinatubo killed more than 300 people and damaged a huge amount of property. Eruption at Barren Island, on the other hand, did not cause any loss of life (the island being uninhabited and located far from the maritime routes), and the 12 m tall lighthouse (the only manmade structure in the island) was completely buried under lava and two subsidiary craters were created. Uninhabited places are rare in the planet due to a galloping increase in global population and thus 'natural hazards' in most cases cause 'disaster' of varying magnitude. There are another types of 'disaster' caused by anthropomorphic activities, which are not discussed here.

Let us look at the Himalaya from the point of view of "natural hazards" of disastrous consequences. This 2,500 km girdle of longitudinal ridges hosting a large number of peaks rising 6 km above mean sea level separates South Asia from "the roof of earth" and Central Asian planes. This magnificent mountain chain is the meeting ground of seven countries: India, Pakistan, Nepal, Bhutan, Kazakhstan, China (Tibetan Autonomous Region), and Myanmar. Bangladesh comes within the watershed of the Himalayan system. A detailed discussion on the space–time distribution of natural hazards in these countries and the strategy adopted for taking steps for their mitigation is beyond the scope of the present paper. An attempt, however, would be made to focuses certain 'grey areas' where interdisciplinary studies to delineate 'risk zones' are required and mutual exchange of relevant data between the different countries are done for disaster preparedness.

Admittedly, simple preparedness cannot put the plug on earthquakes, landslides, floods, or droughts but it may instil a sense of collective responsibility, which would be a departure from a mindset ready to surrender to fate and destiny and have a knee-jerk response to natural disaster.

- It is generally considered that the entire Himalayan area is more or less seismically hazardous zone but for effective assessment of potential risks to engineering structures, 'micro-zonation' is required. There have been galloping increase in population in almost all the towns/villages and consequently the structures owned by public and government have increased considerably. Almost nothing is known about the 'risk' or 'vulnerability' of them in the event of a low- to moderate-intensity earthquake.
- New roads, bridges, and power plants have been built along the slopes for the improvement of infrastructure facilities. No detailed information is available on the damage to 'slope stability' caused by deforestation necessary for erection of the structures (both civilian and military) and additional load of the structures themselves.
- Neotectonic activities are considered to be still continuing in the Himalayan area. Geodetic survey performed by the Geological Survey of India has recorded centimetre-level movement (both horizontal and vertical) at several places. The movement may be slow but may have disastrous effects on heavy structures.
- The 15,000 – odd Himalayan glaciers form the largest body of ice outside Polar Caps and this unique reservoir supports several perennial river systems, which are the lifeline for millions of people. According to recent studies on Asian glaciers by International Commission for Snow and Ice (ICSI), the Himalayan glaciers are receding faster than in any other parts of the globe. Unfortunately, policymakers are yet to comprehend the gravity of the problems caused by receding of glaciers, and the possible impact of such phenomenon on the lifeline of millions of inhabitants of the subcontinent.
- The Himalayan river systems occupy a highly dynamic environment and thus are less stable and less predictable in contrast to the peninsular rivers. It poses problems in the study of 'flood cycle' and the estimated hazards. Besides, rainstorm floods (i.e., the

floods associated with low pressure system) are more common in the Himalayan region. One single cloudburst in 1993 affected the Kulekhani reservoir of Nepal and more recently, the floods in Arunachal caused by similar event have displayed the possible impacts of such a hazard. Here again very little is known.

The above points show that we are broadly aware of the 'disaster', which may happen anytime. However, we lack data on several aspects for preparing the 'vulnerability maps' of a designated area for specified levels of hazards – the first requirement for having a contingency plans to tackle the natural disaster. It is now accepted that disaster management requires coordinated activities of specialists from diverse groups (viz., earth scientists, engineers, administrators, finance people, and social workers) and to achieve the goal, they have to be properly structured in the framework of policy, institutions, and hierarchy of executive agencies from the national to local levels. Recently, the Government of India has adopted a policy of 'proactive' approach rather than the hitherto accepted attitude of 'reaction' after major national disasters. Already, many states have formed the state-level disaster management committee, and such committees are designing the framework.

The Himalayan region is not only a unique physiographic province but it has also its characteristic feature from disaster management point of view. Communication facilities are restricted and in many cases, capabilities of carrying extra load of relief materials are meagre; airports to handle bulk carriers are very few; the climate is inhospitable for several months during winter and rainy seasons. Scientific data for risk mapping are largely inadequate. Though the disaster prone zones do not always coincide with the territorial boundaries of different countries, there is not much exchange of scientific data across frontiers.

For disaster management in the Himalayan region, it is not only essential but also imperative to have a change in mindset of scientists and policymakers to tackle the situation in this century. Under "Antarctica Treaty", we took a pledge that the only commodity, which would be exported out of the continent, would be 'scientific information' for the betterment of human society. Therefore, it is needed to exchange relevant scientific information to prepare vulnerability maps of the specified domains in the entire Himalaya and start thinking about viable structured plan for disaster management.

Facet-based landslide hazard zonation maps for the Himalayas

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A method for preparation of landslide hazard zonation is suggested. It is based on hierarchical classification of terrain into homogenous units called facets (Pachauri 1970, 1998; Pachauri and Krishna 1984; Pant and Pachauri 1989; Wagner 1981; Wagner et al. 1987; Deoja et al. 1991). Facets are essentially slopes of varying degrees mapped at 1: 50,000 or higher scales. The weighted rating of parameters like slope angle, distance from active fault, relative relief, geotechnical factors, drainage density, joint density, distance from ridge, and others is taken into account for arriving at a cumulative score for each slope facet. A landslide hazard zonation map is prepared with different colours showing red, yellow, and green shades. This can be achieved through lower level aerial platforms in which 3D information can be obtained and monitored over a period of time. The preparation of such maps at progressively larger scale is helpful in selection of rehabilitation sites besides identification of slopes that are risky with different levels of values attached to them. The scheme is suitable for high-relief terrain like the Himalayas and has been applied to generate maps of parts of the Garhwal Himalayas, which are presented here. However, in India, this level of remote sensing is yet to find grounds due to several reasons but we have to prepare for the future when restrictions would be minimised. The application of this work spans the Himalayan terrains of Nepal and Bhutan as well as other similar regions. It is also proposed to prepare a database for the landslides in the Himalayas using this technique, which is both cost effective and cheap.

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Glacier morphometry: a case study of the Gangotri group of glaciers from the Garhwal Himalaya, India

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It is generally believed that glaciers, especially in the Himalayas, are gradually receding, and the geomorphological investigations carried out in the Gangotri area confirm this fact. The Gangotri glaciers have receded considerably in the last hundred years. The process is still continuing although now at a slower pace.

The Gangotri group of glaciers have the main trunk glacier along with sixteen tributaries, out of which the Raktavarna, Chaturangi, Bhagirathi Parvat, and Kirti are the important ones.

Various glacier morphometric parameters were calculated on the basis of field observations aided by a detailed study of the topographic maps and satellite imageries. The main parameters considered were: altitude of snout, length and width of the glacier, snout width, snout area, and relief. Based on these primary parameters, some secondary parameters such as relief ratio, elongation quotient, and snout indices were also calculated and statistically analysed.

The results show that, while the main trunk glacier is receding, almost all the tributaries are advancing or slumping, while only one viz., the Bhrigupanth tributary glacier is almost static.

While the recession is believed to be because of global warming, the slump may be because of neotectonic uplift due to isostatic adjustment. In this study, an attempt is being made to present a model for a receding group of glaciers.

Assessment of landsliding indices along alternate alignments for transport of ore from Mussoorie mines, Uttaranchal, India

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The Dehra Dun–Mussoorie area comprises a combination of Krol–Tal formations constituting the doubly plunging Mussoorie Syncline. The limestone belonging to the Krol C Stage of the Krol Formation is being extensively mined in the west and southwest of Mussoorie. Main Boundary Fault (MBF) and a large number of folds and faults affect the succession exposed all along the Dehra Dun–Mussoorie highway. Large landslides were reported near the Kalagad *Nala* and the Nalota *Nala* that cut across Dehra Dun–Mussoorie highway, resulting in problems for uninterrupted movement of tourist and mine traffic along the highway.

In order to ensure uninterrupted traffic and safety of tourists, it became necessary to explore alternate routes for transport of ore. Two of the alternate alignments identified are the Dehra Dun–Kiarkuli and Dehra Dun–Kimiari (Lambhidhar). Based on the evaluation of various parameters, such as lithological variation, structural attributes of rocks, folds and faults, hill slopes, density of vegetal cover, the extraneous influences of rock cut slopes, mining, and the mining traffic, different levels of sliding indices for sections of these routes were assessed and calculated.

The methodology adopted included assigning numerical values for degradation levels suffered by different parameters as a result of landsliding: the highest and the lowest degradation levels being assigned 100 and zero values, respectively. The index of landsliding for a particular section was arrived at by averaging different values assessed for these parameters. Thus, an index of landsliding in the range of 91–100 represents a zone of open forests where the rocks are thinly bedded/ highly jointed, dip parallel to the steep (20^o-45^o) slope that has suffered disturbance due to mining, truck traffic or faulting. A lower index of landsliding represents correspondingly more stable status of hill slopes.

The MBF affects the rock formations along the Dehra Dun–Kiarkuli alignment and Dehra Dun–Kimiari alignment near Punkulgaon and Galjwari, respectively. Phyllite, shale, and quartzite exposed along parts of these alignments have suffered excessive shattering and the highest level (91–100) of landsliding. The level of landsliding index is also of higher order in the vicinity of the mine areas near Kiarkuli and Lambhidhar (Fig. 1 and 2).

In the context of extensive landsliding in the vicinity of MBF and the mines, it is advisable that an equitable distribution of transport load is made over these alignments to save these routes as well as the Dehra Dun–Mussoorie highway from excessive destabilisation and degradation.

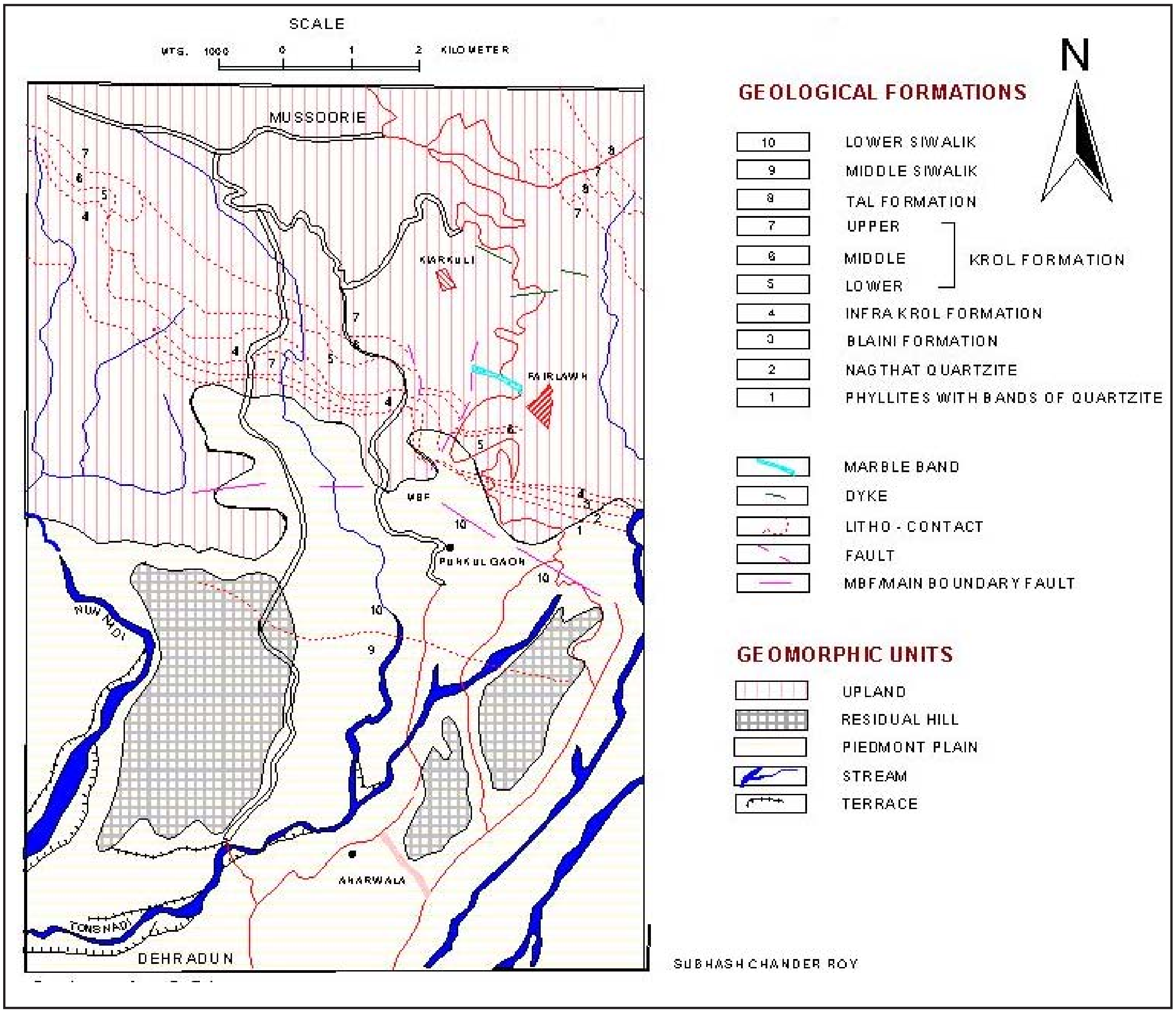

Fig. 1: Geological and geomorphological map of parts of Dehra Dun–Mussoorie area, Uttaranchal, India

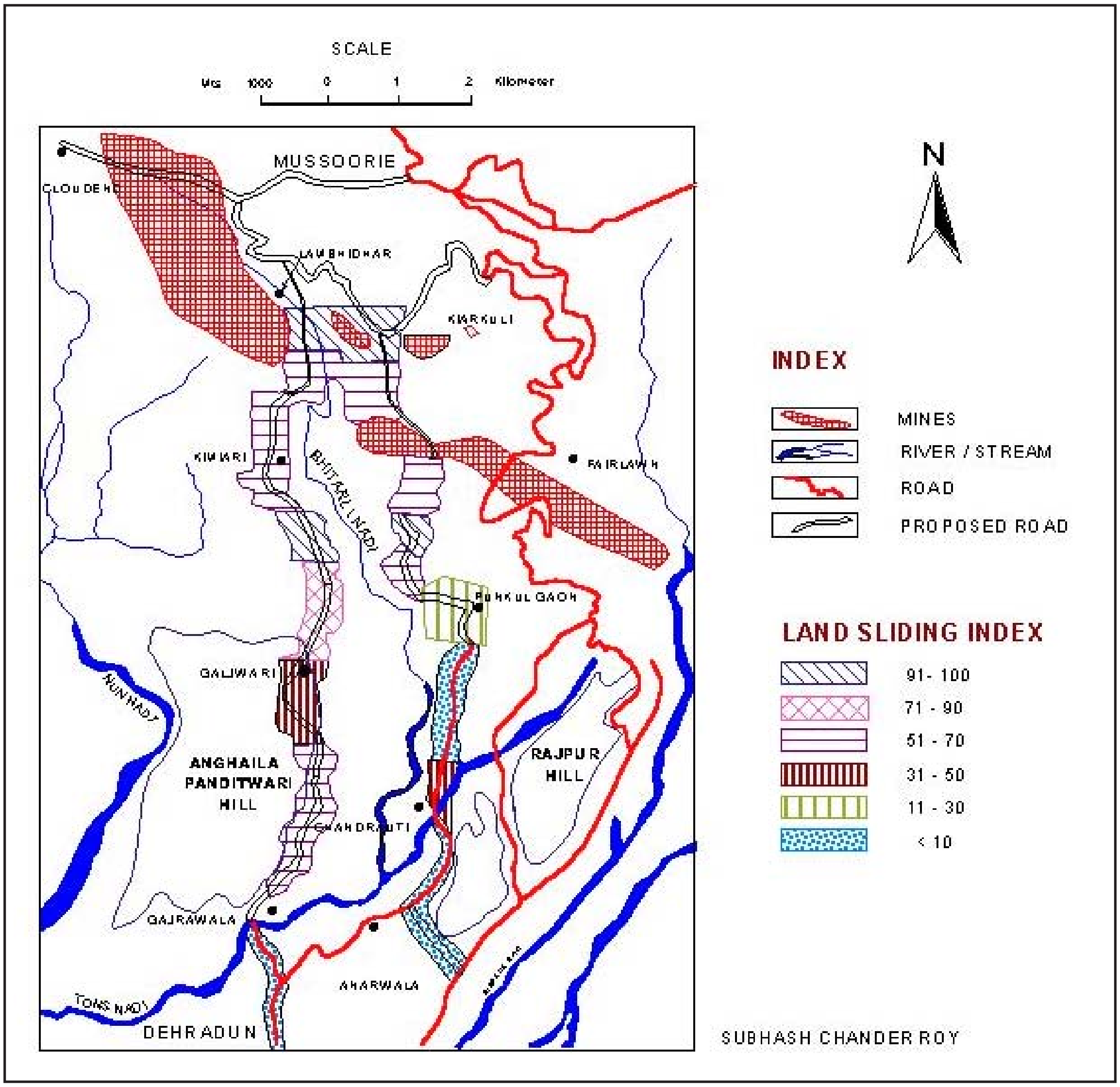

Fig. 2: Map showing landsliding indices along part of an alternate alignment for transport of ore from Mussoorie area, Uttaranchal, India

Prediction of hazards in coal mines through directional change-point analyses

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It has been noted in many coalmines that changes in the mean trend or preferred direction are good predictors of potentially hazardous mining conditions induced by faults or dykes lying ahead. An example of this consists of a data set constituted of 63 measurements/needle-plots of median trends of samples of five cleat trend measurements taken at 20 m interval along a tunnel in the Wallsend Borehole Colliery, NSW, Australia. Here, observations are not in the linear scale but are rather directional in nature, e.g. the mean or median directions of face-cleat from the colliery. Some preliminary tools for predicting possible hazards ahead were presented by Shepherd and Fisher (1981; 1982) and by Lombard (1988). Quick exploratory data analytic techniques are naturally essential. These should be followed up by formal stochastic analyses for better understanding and for exposing the causes, which may lead to the hazard, thus enhancing development of preventive measures. For the former case, we present here Changeogram, Smooth Rank Cumulative SUM (SRACUSUM) and Sequential Linked Median (SLIME) plots. However, the impending hazard may not always be detected easily or convincingly by such shortcut methods.

The online prediction problem is then formally tackled using generalisations of recent techniques in sequential statistical analyses to directional data. For the latter case, the retrospective analysis is performed by elegant yet powerful formal optimal statistical tests for change-points using, e.g. the Von Mises or circular normal, probability models for the angular data. The required significance points are obtained using results on the tail probabilities of time-reversed Brownian motion. The methods are illustrated through real-life data sets. For the aforementioned Wallsend Borehole Colliery data it will be shown, by evaluating our findings in the light of subsequent factual information collected about geological features in the site, that the changes of directions as detected by the plots or by the formal tests are good indicators to provide forewarnings of possible hazardous mining conditions. The analyses thus allow “special precautions to be taken when mining in the new zone following a direction change”.

Preliminary discussions on some of the proposed methods may be found in Jammalamadaka and Sen Gupta (2001). The recently developed statistical package (Sen Gupta 1988): DDSTAP (Statistical Analysis Package for Directional Data) will be utilised for such analyses and demonstration.

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Aseismic system with magnetic insulators

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The proposed system is based on the following two operations: interruption of the link between the building and the foundation-soil complex, and laying of bearings with magnetic insulators. Each bearing consists of two different systems of direct current electromagnets, reciprocally facing each other with the same polarity. One of them, consisting of four distinct electromagnets, is connected to the building; the other, consisting of only one uninterrupted electromagnet, is linked to the foundation. When an earthquake begins, the electromagnets are activated by a device consisting of a sensor, an electronic control station, a current generator, and a magnetic flux regulator. During an earthquake, the magnetic flux between the two electromagnets is able to raise the building, separating it from the foundation-soil complex. The layer of air between the electromagnets permits the rigid translation of the foundation-soil complex with respect to the building, which remains motionless. A special device, placed along the external perimeter of the bearing, guarantees the perfect verticality of the building. At the end of the earthquake, the magnetic flux gradually stops and the building returns to its initial rest position, after any eventual horizontal eccentricity with respect to the foundation being annulled by a device whose function is to centre the building. The main advantage of the proposed system is that the seismic energy in the building is completely eliminated.

Aseismic bearing with partially or totally curved sliding surface and with angular corrector

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The aseismic system that uses the proposed bearing has the following characteristics: interruption of the continuity between the building and the ground-foundation complex and positioning of bearings with the double function of being: they are fixed in the absence of an earthquake and are movable (with sliding or rolling friction) during an earthquake. The sliding surface of each bearing consists of the central and perimetric parts. The central part is circular in shape, and it is flat and horizontal. During an earthquake, its function is to keep the building in a perfectly vertical position, almost still and non-deformed with respect to the horizontal traverse of the ground-foundation complex. The perimetric part, on the other hand, has a curved vertical section and its function is to allow a spontaneous and partial centring of the building if the horizontal displacement of the bearing exceeds the design value. If the bearing has completely circular sliding surface, on the other hand, at the end of the earthquake the building is subjected to a spontaneous and complete centring. While during the earthquake, it is subjected to a variable vertical movement in accordance with the curvature of the sliding surface. Unlocking and locking of the building, respectively at the beginning and end of the earthquake, are affected by electronically controlled electromechanical devices. There is also an angular corrector in each bearing, which is able to compensate for any eventual rotation of the building on its own axis and to allow locking at the end of the earthquake. The sliding friction bearings are used in case of a moderate level of seismic energy in the building, equal to approximately 1% of the weight of the building. On the other hand, if rolling friction bearings are used, the sliding friction is negligible. The total or partial psychophysical unease for the inhabitants depends on the fact whether the sliding surface is partially or totally curved. This system is economically more viable than the conventional systems or those with similar base isolation systems. The higher cost for the bearings is amply compensated by the lower cost of the building structures (as the system is completely independent of the seismic frequency), and it is also

Geo-environmental problems to highway defensive structures in the Niigata Prefecture, Japan

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Fence-type defensive structures are very common on highway hillsides in Japan. They are constructed to protect the highway mainly from snow avalanches and rockfalls. At the beginning, these structures behave well. However, as the time lapses, the foundation of these well-designed structures weakens and they collapse. The situation is further aggravated by the static load of accumulated thick snow cover behind them. As mudstone is the dominant rock type in the Niigata Prefecture, it is a challenging task for geotechnical engineers to cope with such a severe geo-environmental problem.

Although the mudstone exhibits a high strength while it is dry and fresh, it becomes quite unstable after sometime. When it comes in contact with water and atmosphere repeatedly, it starts weathering. Consequently, its shear strength is reduced and it cannot resist the upcoming shear stress and moment, and ultimately fails.

For the purpose of laboratory investigation, variously sized mudstone blocks were collected from the two typical mudstone areas: the Matsunoyama area and Nagaoka area in the Niigata Prefecture. These samples were submerged and dried alternately for several cycles. The particle size analysis of the weathered material showed that the proportion of fine particles increased with the frequency of weathering. The laboratory tests of these samples exhibited a decrease in shear strength with an increasing degree of saturation. Besides, the swelling effect of smectite, a dominant mineral of the Niigata mudstone, was observed in various degrees. In general, the swelling factor increases geometrically. The periodic swelling and contraction of clay gives rise to displacements in the foundation inducing further weathering of the fresh bedrock.

Distinct element method-based model and its utilisation in slope stability analysis

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Since a large-scale progressive failure in rock masses may not be analysed satisfactorily with the limit equilibrium method, numerical methods such as finite element method (FEM), coupled FEM and boundary element method (BEM), and finite difference method (FDM) are utilised to analyse jointed rock masses. Nevertheless, these methods are suitable only to those situations where the number of joints and their displacements are small. Accordingly, problems of highly jointed rock masses, where joint displacement is comparatively larger, cannot be dealt efficiently with these techniques, and hence, other discrete methods of modelling like distinct element method (DEM) are in use.

The DEM is one of the best-known and most advanced discontinuum methods conceived as a means to model progressive failure of rock slopes, because it allows for large displacements along discontinuities and rotation of blocks (Cundall 1971). It uses force displacement law that specifies forces between blocks, and a motion law, which specifies the motion of each block due to imbalance of forces acting on the blocks. In addition, the rock mass is modelled as an assemblage of rigid or deformable blocks, and the discontinuities are regarded as distinct boundary interaction between these blocks. Thus, the precise input data regarding, among others, geometrical characteristics of joints are required to model a rock mass. However, existing literatures reveal that there has not been any rigorous procedure applicable for this purpose. Besides, further experience in the application of DEM to practical design situation has also been felt to understand where, when, and how this method could be applied properly (Hoek et al. 1995).

In this paper, a process of input data preparation for DEM-based model construction is discussed, which starts with revealing geology of the site followed by identifying statistically homogeneous region for further joint measurements. In each homogeneous region, joints are then observed by collecting data on orientation, trace length, and spacing. Afterwards, orientation data are plotted in the Schmidt contour diagram whereas the trace length and spacing data are plotted in histograms separately to quantify their values. In addition, the joint-gap length is also established based on the value of statistically analysed trace length and spacing to establish the joint geometry in a rock mass. Finally, the DEM-based analytical models of a rock slope are constructed and slope stability analysis is carried out.

The slope of this investigation is situated in the Island of Kyushu, Japan. It consists of about 35 m thick sandstone underlain by alternating sequence of shale and sandstone of comparatively smaller thickness. Besides bedding, two sets of discontinuity prevail in the rock mass.

The DEM-based models of the investigated slope were constructed to analyse the three different situations: 1) the existing situation intended to examine the stability of natural slope, 2) excavation situation designed to understand the stability after making excavation of the slope for a dam foundation, and 3) rock reinforcement situation considered to verify effectiveness of cablebolts proposed to stabilise the excavated slope.

The results of DEM indicate a stable condition of the natural slope as expected, but it reveals plane failure as a response to the excavation of the slope. It further suggests that the excavated slope may be stabilised by installing 15 m long cablebolt maintaining their vertical spacing of 2 m. These findings also reveal that the DEM may be used effectively to study various aspect of plane failure occurring on the slope of discontinuous rock masses.

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Landslide hazard evaluation in and around the Ilam Hydropower Project, Eastern Nepal, Higher Himalaya

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Most of the landslides and related mass wasting phenomena are observed along the Mai Khola and Puwa Khola valley. More than 30 landslides were studied. Large landslides are especially concentrated on south-facing dip slopes, while the north-facing slopes seem to be more stable. The number of wedge failures and toppling failures is more than that of the circular and plane failures. Most of the rockfalls are observed in schistose gneiss and coarse-grained, fractured, white quartzite. The main triggering factors for mass movement of the area are high intensity of rainfall, rock discontinuities and their relation to natural slope, topographic stress, poor vegetation, and river scouring.

The rocks of the study area can be correlated with the Formation I of Le Fort (1975) on the basis of mineral paragenesis and lithology. Two litho-units can be traced out. Among them, the lower units is characterised by garnet-kyanite-sillimanite gneisses, orthogneiss, and white quartzite whereas the upper unit comprises garnet-kyanite-sillimanite gneisses and grey quartzite. A synclinal structure is observed in the lower units of the northern part (Chamlagain 2000).

The soils in the study area were categorised as residual, colluvial, and alluvial types. Residual soil is mostly observed on the ridge whereas colluvial soil is found on the flanks of hills and covers most of the area. The depth of soil varies according to rock type and topography. According to their depth, the soils were classified into the following three categories: 1–3 m, 3–6 m, and more than 6 m deep. In the study area, the first category is most widely distributed whereas the last one is comparatively infrequent. Slope of the area was classified as 0–15^{o}, 15–25^{o}, 25–40^{o}, and > 40^{o}. Most of the landslides are found on the slope category of 25–40^{o} whereas large rockfalls are confined to the slope category of >40^{o}. Land use pattern of the area has equally contributed to the initiation of landslides. Gully erosion and bank undercutting are common on the slope adjacent to streams and gullies.

Landslide hazard is defined as the probability of occurrence of mass movements in certain area with specified period of time (Varnes 1984). This landslide hazard mapping refers to an arithmetic method of portraying the spatial variation in the susceptibility of slopes to failure, based an assessment of various landslide causative factors that led to past and present landslides. In the study area, various hazard components like structural component, geo-mechanical component, hydrogeological component, seismotectonic component, soil type versus slope component, soil depth component, hydrodynamic component, and landslide and gully erosion component were identified and their contribution to the landslide hazard were assessed on the basis of their rating values.

The superposition method was followed to prepare landslide hazard map in which the above attributes were taken into consideration. Rating values for each component was taken from Deoja et al. (1991) with some modification. Relative rock mass strength was assessed using the rating values given by Selby (1980). The high hazard zones for rock slopes are confined to the steep dip slopes with highly fractured rocks whereas soil slope hazard is confined to fault zones and south-facing slopes. The soil slope hazard is more severe than the rock slope hazard.

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Engineering geological investigation of trail bridges in western Nepal

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The engineering geological investigation of eight bridges was carried out according to the manuals and checklist developed by Swiss Association for Technical Assistance (HELVETAS) for the Suspension Bridge Division of His Majesty's Government of Nepal. The bridge sites were: 1) Puima Gad, Humla; 2) Kunalo Gad, Bajura; 3) Lode Gad, Achham; 4) Listra Bagar, Bajhang; 5) Kailashmandu, Bajura; 6) Ghatte Gad, Darchula; 7) Khaniya Ghat, Baglung; and 8) Samar, Mustang.

The site of the Puima Gad Bridge has high risk of flood hazard as it lies on the lower river terrace of the River Puima. Although the Puima is fordable in all season, it has a large watershed, and there is a high risk of washout. The bridge over the Budhiganga River at Kailashmandu also has same problems. On the right bank, the main anchorage area was selected in the lower terrace of the Budhiganga River. A high flood immediately after the field survey washed out the whole anchorage area and a new anchorage site was fixed behind the previous anchorage area during the construction of bridge.

The bridge construction cost was significantly reduced by using the actual rock and soil index parameters obtained from the laboratory test instead of the empirical range values given in the manuals.

Geotechnical properties of soil at Sundhara and Jamal in Kathmandu, Nepal

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The Kathmandu Valley lies in a synclinal basin filled up by fluvio-lacustrine sediments of Pleistocene age. Sundhara and Jamal lie in the core of Kathmandu City. For the purpose of construction of multi-storeyed complexes in that area, borehole logging and laboratory test of disturbed and undisturbed soil samples were carried out from fifteen drill holes. In the laboratory, index and mechanical properties such as grain size, natural moisture content, specific gravity, Atterberg limits, penetration resistance, cohesion, uniaxial compressive strength, angle of shearing, rate of consolidation, and settlement were evaluated.

Statistical analysis shows that in the study area, the return period of major earthquakes is about 30 years whereas minor earthquakes are more frequent. Therefore, for the construction of tall buildings, special consideration was given to the earthquake-resistant design of structures. The Kathmandu Valley is located in Seismic Zone V, and the recommended coefficient of horizontal acceleration for this zone is 0.08 g. Since the multi-storeyed buildings in the core of the city are expected to be functional, especially for public gathering and the Sundhara and Jamal area is underlain by thick unconsolidated clay and sand strata, it was recommended to increase the coefficient of horizontal acceleration for the design of multi-storeyed complexes in that area. Based on the study of geotechnical properties of subsurface strata, the study recommended increasing the coefficient by up to 50 per cent for important structures.

For a multi-storeyed building, the tentative allowable bearing capacity for different types of foundation (strip, isolated, and raft) at different depths are determined as per the average parameters valid for the whole area. On an average, owing to the presence of compressible fine-grained material within 5 to 15 m depth, due care was given while designing various types of foundation at various depths. Water table in the area was found to lie close to the ground level (i.e., at 1.5 to 3.5 m depth) in the month of December, and it is subject to rise during the monsoon. Hence, necessary measures were also taken for controlling the groundwater in the foundations and basements.

Engineering and environmental geological investigation in Butwal area

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The Town of Butwal lies at the junction of the Siddhartha (N–S) and Mahendra (E–W) highways. It is endangered by many landslides and floods every year during the monsoon season.

The area consists of the Tertiary sedimentary rocks (Siwaliks) in the north and Quaternary sediments (Terai Plain) in the south. The Main Frontal Thrust (MFT) marking the contact between the Siwaliks and Terai runs along the break of the slope little north of the main settlement of Butwal.

The landslide at Jyotinagar (north of Butwal) triggered after the heavy monsoon of 27 August 1998 is considered the main geo-hazard in the area. Wide-open cracks are marked around the crown of the slide with the slope of 40–60 degrees. Infiltration and percolation of water through these cracks is further aggravating the situation.

Engineering and environmental geological investigations were carried out in the area with an objective of preparing the engineering and environmental geological map at 1:15,000 scale. This map would be a help to urban planners and decision-makers at local level particularly in hazard mitigation, sustainable utilisation of natural resources, and environmental management. The types of information included in the map are lithological description of rocks and sediments, geo-hazards (natural and manmade, erosion, block fall and mass movements), mineral resources, features of environmental significance (water and air pollution), riverbed mining, landfill site, land use, forest, and urban geology.

Environmental changes in the Kathmandu Basin inferred from oxygen isotope records of gastropod shells

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The aim of this study is to reveal the environmental and climatic changes during the deposition periods in the Kathmandu Basin. Modern and fossil gastropod shells as well as river and meteoric waters were analysed for oxygen and carbon stable isotopes. The gastropods were sampled from sediments of the Lukundol Formation, drilled core samples obtained from about 1 Ma old deposit (Fujii and Sakai 2001) in the central part of the Kathmandu Basin, sediments of the Gokarna Formation, a swamp in the Kathmandu Valley, and from modern rivers and lakes of Nepal.

Both C and O isotopic compositions show wide compositional variations ranging from 18 to 37 ‰ for oxygen and -13 to 3‰ for carbon. Altogether there is a rough positive correlation between oxygen and carbon isotope compositions. The isotopic analyses allow distinguishing between the following different populations of gastropods:

– Modern river and lake samples have the lowest $\delta^{18}O$ and $\delta^{13}C$ values, which are compatible with known C and O compositions of the river water. For the lakes of Tansen and Pokhara, this implies that the lake water is being rapidly renewed.

– In the Gokarna Formation, the $\delta^{18}O$ and $\delta^{13}C$ values obtained from fossils are very close to those measured on the present-day gastropod shells collected from the swampy habitat in the Kathmandu Valley. $\delta^{18}O_{smow}$ values are higher than 30‰ and are not compatible with "normal" values of meteoric water and temperature. These high values therefore clearly indicate that the water during equilibrium with the shell had been significantly enriched in ^{18}O by evaporation. Similarly, $\delta^{13}C$ values around 0‰ are much higher than dissolved inorganic carbon (DIC) in modern rivers (-6 to -12‰, Galy and France-Lanord 1999). This suggests that DIC in the parental water was re-equilibrated with atmospheric CO_2 implying limited renewal of the water.

– In the drilled core samples, the $\delta^{18}O_{smow}$ values found for the shells are lower, around 20–25 ‰, which is very comparable to the values measured for modern freshwater shells (Fig. 1). Assuming that the average meteoric water was -10‰, which is near the modern average in the Kathmandu Basin, the calculated temperatures of equilibrium are between 12 °Cand 20 °C. $\delta^{13}C$ values are between -5 and -1 ‰, which are higher than the range of modern DIC of rivers. This suggests that the surrounding water was in a relatively closed system to allow for CO_2 re-equilibration without significant evaporation. Alternatively, high $\delta^{13}C$ values may reflect high productivity in the lake water.

We interpret these results in the following way: during the Pleistocene, the Gokarna Formation was deposited in a confined drainage system, where evaporation concentrated heavy oxygen isotopes in the water of the palaeo-lake and the stagnant water. On the contrary, sediments deposited ca. 1 Ma ago and sampled by drilling suggest that the palaeo-lake was a more open system with surface waters comparable to the modern meteoric water.

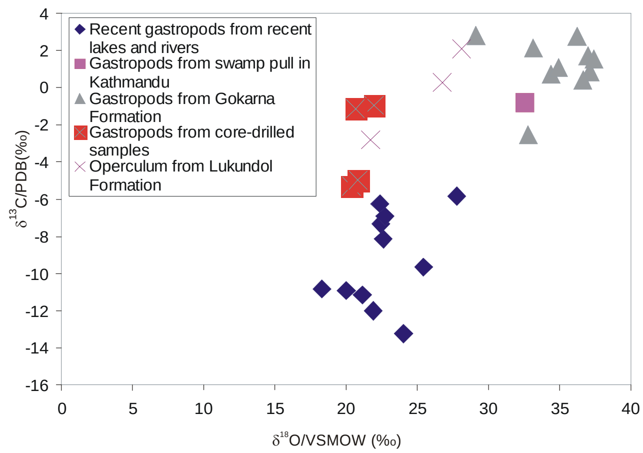

Fig. 1: Plot of $\delta^{13}C$/PDB versus $\delta^{18}O$/SMOW obtained from gastropod shells and operculum

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A comparative evaluation of hazard maps of the Banganga Watershed based on bivariate statistical and rating methods

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The present paper attempts to evaluate the landslide hazard maps of the Banganga Watershed produced from two different methods: 1) bivariate statistical method developed by the Institute of Aerospace Survey and Earth Sciences (ITC), The Netherlands, and 2) the rating method proposed in the Mountain Risk Engineering Handbook (Deoja et al. 1991). Meanwhile, the paper has also analysed the slope instability phenomena based on statistical relationships between landslides and terrain parameters. GIS and Remote Sensing techniques were used to obtain these objectives. Potentially unstable slopes were found to be high in steep slopes, high relative relief, in areas underlain by the shale and the Siwalik rocks, and nearness to the lineament distance. Interestingly, the slope movements are high in the areas of dense to moderately dense vegetation (forest) than in sparsely vegetated areas. Similarly, the cultivated slopes were found to be less unstable than the forested slopes. The distribution pattern of landslides on the two hazard maps is significantly different. The distribution of landslides complies more with the hazard map produced from the bivariate statistical method.

Schmidt Hammer tests on the rock units of the Kathmandu Nappe

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It is necessary to carry out careful documentation and evaluation of rock outcrops for engineering geological studies in a mountainous country like Nepal (Humagain 2000). Present study was carried out in the area lying south of the Kathmandu Valley, where the rock units of the Kathmandu Nappe are exposed. The rock units of Phulchauki and Bhimphedi Groups (Stöcklin and Bhattarai 1981) are within the Kathmandu Nappe. The Kathmandu Nappe is a geologically distinct tectonic unit in Central Nepal (Upreti and Le Fort 1997).

In order to get an idea about their in situ strength, field estimation of the unconfined compressive strength (UCS) of the rocks belonging to different formations of the Kathmandu Nappe was carried out using the Type L Schmidt Rebound Hammer. The Schmidt Hammer rebound was applied in a direction perpendicular to the discontinuity (bedding, foliation, or joint) surface. Ten tests were carried out on each major discontinuity plain at each location and the mean value of the five highest readings was noted down. The test was carried out on a clean and dry surface in the winter season. Most of the Schmidt Hammer rebound values fall between 10 and 70. The mean values of the Schmidt rebound test and the estimated value of rock density for a given discontinuity are used to estimate the joint wall compressive strength (JCS). Generally, following expressions are used for the estimation of UCS:

$$\log UCS = 1.831 \log SHV + 1.533 \text{ (Aufmuth 1974), and}$$

$$UCS = 7.752\, SHV - 213.349 \text{ (Irfan and Dearman 1978),}$$

where SHV is the Schmidt Hammer rebound value.

In this study, the expression proposed by Aufmuth (1974) was used for estimating the UCS. The maximum, minimum, and mean of Schmidt Hammer values of each rock unit are given in Table 1. The maxima and minima given in the table are the average Schmidt Hammer values of each discontinuity set in each rock outcrop of a particular rock unit. A plot of Schmidt Hammer strength values is presented in Fig. 1.

A wide variation of in situ rock strength was observed within a given geological unit of the study area, and it is attributed to the varying intensity of weathering.

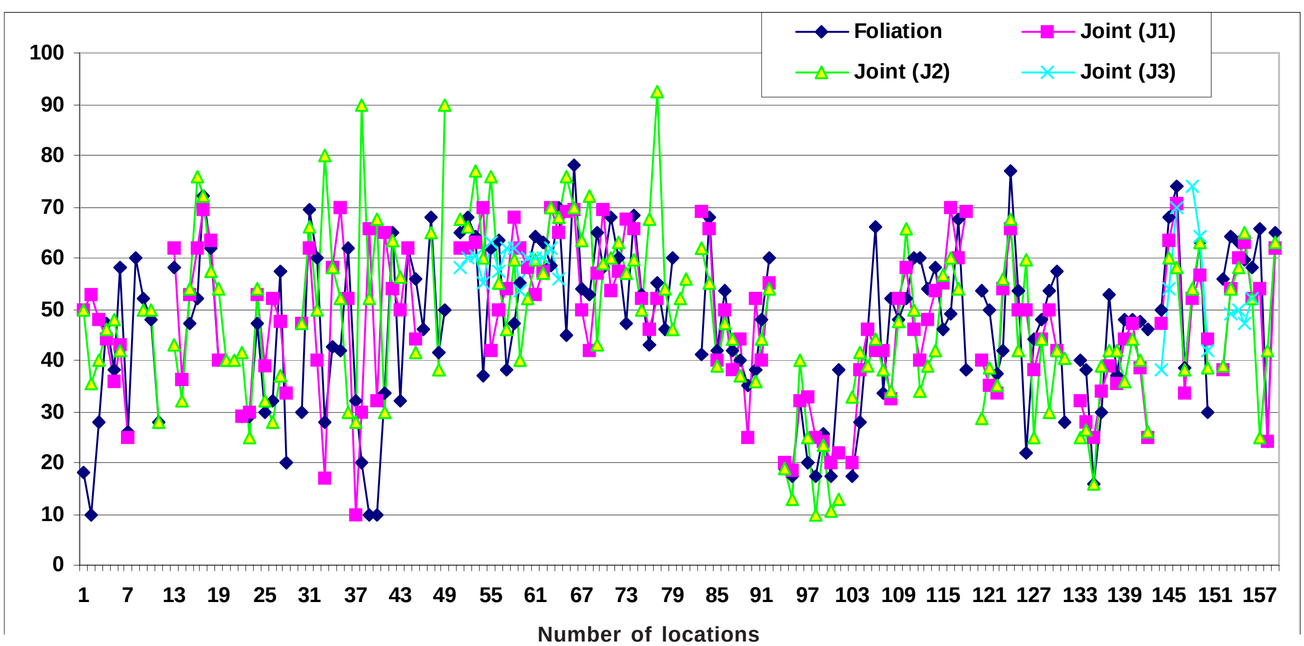

Fig. 1: Schmidt Hammer rebound values obtained for the rock units of the Kathmandu Nappe

Table 1: Minimum, maximum, and mean Schmidt Hammer values

Geological units		Discontinuities	Schmidt Hammer Value		
			Min.	Max.	Mean
Palung Granite		Joint (J_1)	24	65	56
		Joint (J_2)	24	63	50
		Joint (J_3)	25	65	49
		Joint (J_4)	47	52	49
Metamorphic contact aureoles - Palung Granite		Foliation	30	74	53
		Joint (J_1)	33	70	52
		Joint (J_2)	38	63	51
		Joint (J_3)	38	74	57
Chandragiri Limestone		Foliation	22	57	47
		Joint (J_1)	33	65	45
		Joint (J_2)	25	67	42
Chitlang Formation		Foliation	16	53	40
		Joint (J_1)	25	47	34
		Joint (J_2)	16	44	33
Sopyang Formation		Foliation	17	67	48
		Joint (J_1)	20	70	48
		Joint (J_2)	33	65	45
Tistung Formation		Foliation	17	38	23
		Joint (J_1)	18	33	24
		Joint (J_2)	10	40	19
Markhu Formation		Foliation	35	68	46
		Joint (J_1)	25	69	47
		Joint (J_2)	36	62	46
Kulikhani Formation		Foliation	37	70	57
		Joint (J_1)	42	70	58
		Joint (J_2)	40	77	60
		Joint (J_3)	53	63	58
Chisapani Quartzite		Foliation	10	69	43
		Joint (J_1)	10	70	47
		Joint (J_2)	28	90	55
Kalitar Formation	Schist	Foliation	20	58	34
		Joint (J_1)	29	53	40
		Joint (J_2)	25	54	36
	Basal Quartzite	Foliation	40	72	55
		Joint (J_1)	36	69	55
		Joint (J_2)	32	76	52
Bhainsedobhan Marble		Foliation	10	60	37
		Joint (J_1)	25	53	42
		Joint (J_2)	28	50	43

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Assessment of barrier potential of sediments for selection of waste disposal sites in the Kathmandu Valley

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The Kathmandu Valley is an intramontane basin filled up with fluvio-lacustrine sediments of Quaternary age. The deposits of the valley comprise lake sediments that accumulated due to damming of the Bagmati river system during the Pleistocene time by the rising Mahabharat Range. The northern and northeastern parts of the basin are occupied by coarse sediments, mainly micaceous sand and gravel, derived from the Sheopuri gneiss, while in the central and southern parts of the valley, occur very fine sediments mostly black carbonaceous clay with lignite and diatomaceous earth at places. The maximum thickness of the sediments as revealed by the deepest drill hole in the valley is about 550 m in the central part. The valley floor has a highly undulating topography with buried ridges of Precambrian basement rocks.

The Kathmandu Valley with population of around 1.5 million is witnessing rapid urban growth, unplanned development and environmental degradation leading to increased pollution. Consequently, the valley is confronted with major problem of safe disposal of urban waste produced at a scale of 500 tones per day. This is largely due to the lack of awareness and realisation at planning and decision-making levels about the importance of geoscientific information in identification of suitable landfill sites for solid waste management. This work is an attempt to deal with the waste disposal problem by preparing a geoscientific map showing the potential areas for selecting proper landfill sites based on the assessment of subsurface sediments in combination with other relevant aspects related to waste disposal.

The assessment of barrier potential of sediments is based on the lithological description of boreholes to a depth of 7 m assuming that clay has a high barrier potential, silty to fine sandy sediments have moderate, and sandy to gravelly sediments have low barrier potential. The thickness of low-permeable zone has to be at least 5 m to act as natural barrier against toxic leachate originating from waste to protect the groundwater. The effectiveness of such a barrier against migrating pollutants depends on the ability of this layer to retard or exchange pollutants and fix them into soil complex. This is evaluated by determining the cation exchange capacity (CEC) values of the soil derived from laboratory analysis of samples taken down to 2 m depth. Other important parameters for an estimation of the soil barrier function are percolation rate, soil texture, grain size, and soil depth.

Using GIS ARC/INFO, a map was prepared delineating areas of barrier potential in three classes: high, moderate, and low. The high barrier potential areas are considered as the most favourable sites for waste disposal, whereas the low barrier potential areas are assessed as the negative areas, which should not be considered for selecting waste disposal sites. These three groups in conjunction with other selecting criteria (e.g., infrastructures, settlements, water bodies, cultural heritage sites etc.) are presented on a map at a scale of 1:50,000. This map provides a good basis for planners and decision-makers for selecting geoscientifically viable landfill sites for urban waste management.

Estimation of S-wave velocity structure and its application to ground motion simulation

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Microtremor array technique is the most inexpensive and easy-to-perform method for the estimation of S-wave velocity structure. Microtremor array measurements were carried out in the Shizuoka Prefecture, Japan, to estimate a S-wave velocity structure up to the basement. Phase velocities at a wide period-range were determined by frequency–wavenumber spectral analysis of vertical microtremor array records. The determined phase velocity is inverted to get one-dimensional S-wave velocity profile by genetic algorithm inversion method. A four-layer S-wave velocity model with a basement velocity of 3.5 km/s was constructed. In the second part, simulation of ground motion was carried out with two-dimensional finite difference method. For the simulation, the subsurface structure was derived on the basis of the microtremor array measurement and previous seismic refraction survey. The simulation was carried out along two profiles, one from Hamaoka to Ryuhyoh and another from Hamaoka to Shimada. From the simulation of ground motion, it can be concluded that the effect of 2-dimensional subsurface structure is very important in the estimation of ground motion at a site.

Natural hazards and environmental geological assessment of Pokhara Valley, Western Nepal

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The Pokhara Valley is an intramontane basin located in western Nepal. It is situated on the southern foothills of Annapurna and Machhapuchhre Himal. The valley is surrounded by hills, which are represented mainly by low- to medium-grade metamorphic rocks. There are several streams, lakes, and small hillocks in the Pokhara Valley. It is believed that the ill-sorted valley-fill sediments of Pokhara were derived from far north in the Himalaya, during three different catastrophic debris flow events through the Seti River in Upper Pleistocene–Holocene Epochs. These valley-fill sediments of Pokhara are rich in calcareous constituents and they are susceptible to sinkhole and land subsidence hazards.

The Seti River flows through the central part of the valley and forms several deep (up to 53 m) gorges separated by open areas with wide cracks. New unplanned settlements on the riverbanks, especially in the Laltin Bazaar area and other lowlands, are at a high risk of flood hazard. Similarly, the earlier settlements along the gorges are also at a high risk of bank erosion, side collapse, and block fall.

In the Pokhara Valley, karstification is widespread in the form of sinkholes, caverns, and subsoil pinnacles. Such sinkholes and pinnacles are frequently observed in the karstified Ghachok Formation mainly in northwestern and western parts of the investigated area at Ghachok, Hyangjabensi, Batulechaur, and the old part of Pokhara and Chhorepatan (Devi's fall/Gupteshwor area). New sinkholes of various dimensions are developed almost every year during the monsoon time.

Soil erosion and landslides are other frequently occurring natural hazards on the steep terrain represented by deeply weathered and densely fractured phyllites, quartzites, and schists. As a result of heavy rainfall (up to 4,000 mm/year), a number of fresh landslides occur and many old and dormant landslides become active in the monsoon season. These landslides are the sources of huge amount of loose sediment that causes loss of lives, damages to public properties, infrastructures, cultivated lands, and siltation in the Phewa and other lakes. Haphazard mining of river gravel and sand has also created the problem of riverbank erosion and flooding in the rainy season.

The earthquake Catalogue of Nepal shows that several earthquakes greater than magnitude 4 have occurred in the past within the Pokhara Valley and its close proximity. Of these, the largest earthquake events were of magnitudes 7 in 1939 and 6.5 in 1954 by which Pokhara suffered damages. Therefore, it is evident that the Pokhara Valley faces a high degree of earthquake hazard.

Unplanned urbanisation, haphazard development of infrastructures, improper location of industries, improper land use, uncontrolled surface drain and haphazard disposal of municipal waste are the root causes of environmental degradation in the Pokhara Sub-Metropolitan area.

All types of hazard-prone areas are identified and categorised as low, medium, and high on the engineering and environmental geological map of the Pokhara Valley. Some recommendations are given on the map, which could be helpful to the users (planners, implementers, and promoters) for urban planning and disaster mitigation.

Investigation of seismic sources at the two ends of the central Himalaya by waveform modelling

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Two earthquakes of body wave magnitudes 6.0 and 6.1 that occurred at the two ends of the central Himalaya were investigated by waveform modelling technique. Synthetic seismograms generated by wave number integration method show strike-slip and thrust mechanisms, respectively. The difference in their source mechanisms indicates that this part of the Himalaya has been influenced by local structures, especially transverse faults.

The source parameters obtained by comparing the synthetic seismograms with those recorded by the Global Digital Seismograph Networks (GDSN) are given in Table 1. This model was able to constrain more effectively the depth of focus and source time function.

Table 1: Data obtained from the Global Digital Seismograph Network and results of present investigation

Data obtained from the Global Digital Seismograph Network						Results of present investigation				
Event	Date	Time of origin	Latitude (°) N	Longitude (°) E	Depth (km)	Strike (°)	Dip (°)	Slip (°)	Source time function (sec)	Depth (km)
HIM1	1980.11.19	19:00:46.9	27.394	88.752	17	119	74	85	7	22
HIM2	1980.07.29	14:58:40.8	29.598	81.092	18	110	26	90	7	17±3

Geological and hydrogeological considerations for minimising the effect of equivalence in VES interpretation: an example from Xiakou Landslide, Yaan City area, Sichuan, China

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Before the investigation using geophysical methods, the sliding mechanism of the Xiakou Landslide was inferred based on the observation of surface features and only one drill hole. After the study of landslide using VES and seismic refraction methods, geological and hydrogeological conditions became better known. In the following years, the area was further investigated by four additional drill holes. The purpose of drilling was to verify the geophysical interpretation, monitor the displacement of material and the water table, and to collect data for mitigation purposes. During the early stage of geophysical interpretation, no geological and hydrogeological considerations were made. In the following year, the data were reinterpreted accommodating geology and groundwater hydrology. Although the initial interpretation was useful for inferring subsurface geological and hydrogeological conditions, it was unable to provide the depth of slip surface in an agreeable range. By monitoring the displacement in drill holes, it was also found that the previously estimated depth of slip surface (i.e., 10 m) by logging drilled cores was inaccurate. The mass thought to be intact bedrock was actually a sliding material with possibly detached blocks.

After the modelling of sounding curves using the geological and hydrogeological information, the results were found to be significantly better than the previous ones. This study shows that the electrical resistivity data interpretation even from a small area such as a landslide could be strongly affected by adverse geological and hydrogeological conditions. However, good results may still be obtained by incorporating the geological and hydrogeological information in the model.

Subsurface geology of Kathmandu Valley based on well lithologs

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A subsurface lithological study of the Kathmandu Valley was carried out using 152 borehole data. The lithological information up to the depth of 30 m was considered for this purpose. This depth was chosen considering the requirements for waste disposal, large-scale construction, planning of drinking water, and the like. A well log was prepared for each borehole. During the lithological study, the sediments were classified according to the percentage of sand, silt, and clay.

The subsurface study reveals that the southern part of the valley is dominated by fine-grained sediments (mainly clay with minor silt and sand layers) and the northern part is made up of coarse-grained sediments (mainly sand). The depositional pattern of sediments in the valley indicated that the southern part had a calm and quite lake environment whereas the northern part was dominated by streams flowing from the Sheopuri Range. The dominance of sandy material in the north and clayey material in the south could also be due to the mineral composition of the hills surrounding the basin. As the Sheopuri Range contains mainly gneiss, migmatite, and granite with some schist, it supplied mainly sandy material on weathering and erosion, whereas the ridge in the south of the valley contains mainly limestone, phyllite, and some schist, which on weathering and erosion produced mainly fine-grained material.

One-dimensional seismic velocity structure beneath Western Nepal

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An attempt was made to study the velocity structure of Western Nepal using the arrival time data of local earthquakes recorded at National Seismological Network of the Department of Mines and Geology.

The study requires a reference model. The model used in the routine localisation of earthquakes at National Seismological Centre, DMG (Pandey, 1985) was applied as a reference model in this study. It is a three-layered model with P-wave velocity in the first, second, and the third layers as 5.6, 6.5, 8.1 km/sec, respectively. Similarly, the corresponding S-wave velocities are 3.17, 3.71, 4.73 km/sec. The thickness of the first layer is 23 km, the second layer is 32 km, and the third layer is a half space.

The arrival times were inverted using the simultaneous inversion method for model parameters and hypocenter parameters developed by Crosson (1976). In this method, travel-times were calculated for various stations corresponding to the initial hypocenters. The sum of the square of residual (O-C), i.e. the difference between observed and calculated arrival times was minimised to provide small changes in the velocity model and the hypocenter parameters.

After inversion, a new set of improved hypocenter parameters and an improved velocity model was achieved. In the final model, the P-wave velocities in the first, second, and third layers were 5.53, 6.29, and 8.11 km/sec, respectively. Similarly, the S-wave velocities were 3.18, 3.62, and 4.66 km/sec, respectively.

Geological criteria for waste disposal site selection: a case study from Kanichadar, Dhangarhi, Far-Western Nepal

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Proper management of municipal solid waste in an environmentally friendly way needs first-hand knowledge of site geology. A clay layer (geological barrier) of sufficient thickness and extension just beneath the surface is suitable for a sanitary landfill (disposal) site. The clay layer acts as a natural barrier against the migrating pollutants (leachate) into the subsurface. The leachate generated in the site can pollute the groundwater.

The Kanichadar area consists of about 3 m thick fine-grained soil (Table 1). The topmost soil layer is 20–50 cm thick dark brown organic clay. There is a highly compact, dark brown, and dry inorganic clayey silt layer of more than 1.5 m thickness below the organic clay layer. Soil samples collected from different auger holes were subjected to laboratory analysis for determining their physical and chemical properties (Table 1 and 2). The value indicated that the soil belonged to 'CL' type, implying that the soil is inorganic clays of low to medium plasticity. However, the hydrometer analysis showed that the samples were of clayey silt (Table 1).

The cation exchange capacity (CEC) values obtained from the depth of 0.5–2.30 m (Table 2, auger holes A5–A8) revealed that the soil had moderate to high barrier potential capacity. Therefore, the area close to these auger holes was found to be suitable for sanitary landfill.

Table 1: Results of laboratory analysis of soil samples from the Kanichadar landfill site

Sample no.	Depth (m)	Fines (%)	Liquid limit (%)	Plastic Limit (%)	Hydraulic conductivity	Specific gravity	Soil name
A4	0.2 – 1.55	67.94	32	27.53	Low	2.7	Clayey silt with sand
A5	0.35 – 0.90	83.2	39	23	Very low	2.6	Clayey silt
A6	0.35 – 1.25	66.8	31	22	Low	2.6	Clayey silt
A8	0.5 – 2.30	94.69	37	21	Very low	2.7	Clayey silt
A10	0.5 – 2.75	84.78	45	20	Very low	2.6	Clayey Silt

Table 2: Results of chemical analysis of soil samples from the Kanichadar landfill site

Auger hole no.	Depth (m)	pH	Cation exchange capacity (meq/100 g)
A4	0.2 – 1.55	6.53	7.8
A5	0.35 – 0.90	7.08	14.3
A6	0.35 – 1.25	7.73	12.2
A8	0.5 – 2.30	7.57	19.1
A10	0.5 – 2.75	7.30	10.0

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On 11 September 2000, a big landslide occurred on the left bank of the Kakrahawa Khola in the Dang District. This phenomenon was first reported by a national newspaper as a mound-rising phenomenon.

The Kakrahawa Landslide is at the southern extreme of the Deukhuri Valley. It lies on the Upper Siwaliks consisting of loose conglomerate with a high proportion of sandy matrix. The landslide lies on the southern limb of a major syncline.

The conglomerate beds are dipping 40° due N. The landslide is 375 m long, 103 m high, and its scrap is about 30 m high.

This landslide was triggered by heavy and continuous rainfall for over 4 days. Due to the high porosity of the loosely compacted conglomerate of the Upper Siwaliks, the rainwater percolated into the rock developing pore water pressure. Owing to the presence of underlying impervious clay layer, the pore water pressure increased and reach the critical condition. The failure started along the clay layer, which apparently formed the failure plane. This clay layer acted as a slip zone for further downward movement of landslide body. It is a rotational landslide and the depth to the slip surface is estimated at 30 m. Because of gentle hill slope, large size of the landslide, and deep slip plane, considerable stress developed along the failure plane that might have transmitted to the toe, causing the rise of riverbed.

Rock squeezing problems in the Nepal Himalaya: its prediction and rock support design

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Rock squeezing is a common problem in the Himalayas when tunnelling through the weak rocks, faults and sheared zones. Rock squeezing is stress induced problem. If in situ stress exceeds the rock strength, squeezing in weak rock likely to occur. In the Nepal Himalaya, the maximum tunnel convergence of 26% of tunnel diameter was recorded from the Modi Khola Hydroelectric Project.

In this paper, different existing prediction methods are analysed with field data collected by the author from the Khimti Hydropower Project (KHP), Nepal. All prediction theories are mainly based on the stress-strength parameters i.e. overburden and uniaxial compressive strength of intact/ rock mass. When comparing the predicted data with the observed data from the KHP only 32% data are found to be correct in rock squeezing. Therefore these prediction theories could not predict accurately but give good guidelines like a thumb rule. Squeezing ground conditions are influenced by strength, stress condition (overburden), orientation of discontinuity, pore water pressure, excavation methods and stiffness of support but contributions are not the same degree which have been experienced during the construction of the KHP.

In practice, active and passive support principles have been applied around the world. There is still controversy between tunnellers in selecting these principles. Based on the Himalayan experience, the best choice of rock support in the squeezing ground is a combination of active and passive support systems. In this regard, an attempt has been made to develop suitable rock support designs and preventive measures for the squeezing ground.

Engineering characteristics of fluvial soils and their associated problems in the district of Sheikhupura, Punjab, Pakistan

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The area under study is part of the second largest basin of Indus drainage system. It is located between latitudes 30° 58' and 32° 04' N, and longitudes 37° 16' and 74° 41' E. The region falls in semi arid subtropical climate receiving 305–508 mm of annual precipitation. The area is drained by the River Ravi in the south and is traversed by the Nullah Degh and Bhed, which are semi-perennial/ephemeral streams presently acting as seepage drains in lower reaches.

The Nullah Degh confluences with the River Ravi at Syedwala at the southwestern end of mapped area. The landforms were developed by fluvial processes, and they are comprised of sub-recent to recent floodplains, back-slope basin, an old river terrace, old channel levees, and remnants. The area lying between Sheikhupura and Khanqah Dogran constitutes the old river terrace sloping NW. The upper part of terrace in mapped area is comprised of silty clay loam whereas in the lower part loams are prevalent. These soils are moderate- to well-drained silts (ML) to silty clay (CL-ML) with occasional lean clay (CL) falling in A-4 group with subordinate A-6 group in topographic depressions. The sub-recent deposits on the old river terrace are composed of poorly drained silty clay (CL-ML) to lean clay (CL) falling in A-6 group with subordinate A-4 group. The soils of old channel remnants are also composed of silty clay (CL) to clayey silt loam (CL-ML) falling in A-6 and A-4 groups. The soils of old channel levee remnants are well-drained sandy loam (SM) to loamy sands falling in A-2-4 group. The most conspicuous feature of the project area is known as the Kalar area extending from Narang to Syedwala possessing numerous elongated depressions sloping NE–SW. It is comprised of silty clay (CL-ML) with dominant clay (CL). The major soil group is A-6 with subordinate A-7 and A-4 groups. The recent floodplains are flooded quite often. The soils are silty loam (ML) and silty clay loam (CL-ML) in the abandoned channels whereas poorly graded sand is encountered in active channels. The dominant soil group is A-4 with subordinate A-2-4, A-3, and A-6 groups. The soil profile in this area is stratified with rhythmic mode of deposition. The geotechnical problems associated with these soils are expansion/swelling, salinity, and waterlogging. The soils with low to medium potential of expansion/swelling occur in the back-slope basin and sub-recent deposits on the old river terrace. Salinity is a menace in southeastern and northwestern parts of the study area and is characterised by barren land with poor vegetation. The extent of salinity is moderate (in the Kalar area) to highly alkaline (between Beriwala and Shahkot). Waterlogging has been a serious problem since the recent past, especially in the back-slope basin, old river terrace, and sub-recent deposits on the old river terrace. All these problems when coupled had severely deteriorated the infrastructure of the area (i.e. roads, residential and industrial buildings). Taking into consideration the engineering behaviours of soils in the waterlogged and saline areas, the following recommendations are made.

1. From 1 to 2 feet-thick sand cushion under shallow foundations be provided to combat with the swelling/ upheaval pressure of the soil and capillary rise of water;
2. In waterlogged areas, the road embankment should be constructed 4 feet above water table and in waterlogged clayey soils (A-6 and A-7 groups) at least one thick capillary cut-off layer be provided under the carriageway to avoid differential settlement/failure of the road pavement;
3. To combat with fluffiness/loss of compaction caused by fluorescence of salts in the sub grade of roads running through the saline areas, granular material may be used under carriageway and for the construction of shoulders; and
4. If economically feasible, chemical stabilisation may be done for the construction of durable carriageways in the saline areas.

Geotechnical properties, stratigraphy, and fluvial facies of Sahiwal Pakpattan soils, middle Indus Plain, Pakistan

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Two main terraces are identified in the Sahiwal District. They are separated by a shoulder. The Sahiwal terrace is a composite terrace bar upland, which can be correlated with the River Ravi. The second is the Pakpattan terrace, which can be correlated with the River Sutlej. These terraces interact in a complex fashion both downstream as well as across the two active rivers (i.e. Ravi and Sutlej) and one extinct river (i.e. Beas). In the study area, the following four main fluvial facies can be recognised: mature Palaeosol, overbank floodplain deposits, point-bar channel belt, and channel deposits. All these facies were studied down to a depth of 13 to 40 ft for their stratigraphy and geotechnical properties. An attempt is made to tentatively correlate the fluvial facies with their geotechnical properties. The geotechnical and geological data can be used as guidelines for planning, designing and construction of infrastructures, and exploration for groundwater resources.

Geo-environmental hazards caused by neotectonics with reference to surface water reservoir: case from the Northwest Himalayas, Pakistan

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The Federally Administrated Northern Areas suffer from extensive mass movements that give rise to abnormally high sediment load in the drainage system of the Indus River. On average, 107.4 MST (0.059 MAF) of sediments are recorded at the Besham gauging station every year that ultimately land in the energy generating Terbela Water reservoir. The sediments received by this dam have created a huge delta in the lake. The sediment is continually moving towards the main embankment at an average rate of 6,600 metres per year. Besides reducing storage capacity of the reservoir, it has the potential to cause havoc to the structure as a result of any accidental mobilisation.

It is essential that mass wastage processes in the northern areas are fully understood, particularly the role that various factors play in its collective contribution to the sediment load of the Indus river system. In this connection, the paper highlights the role of neotectonics in mass wasting in the Northern Areas. Neotectonics has not yet received due importance although it influences significantly the Himalaya–Karakorum mountain systems. It is urgent that this factor should be considered in preparing strategies to minimise influx of sediments in new reservoirs, such as the Bunji Dam and the Bhasha Dam being presently planned in the north and south of Chilas, respectively. In this connection, the extensive sand terraces that extend along the Indus Valley are the potential source of voluminous sediments that will land in the reservoirs. There is yet another source of loose sediments, so called high-level Jalipur molasses, which constitutes old river terraces. This will also be involved when the lake level rises.

Notable also is the neotectonics of the uprising Naga Parbat, which is notorious for activating gigantic landsides and mass movement. Presently, the mass movements from the Naga Parbat block the Karakorum Highway at Gunar Farm northeast of Chilas. The Rikhot Fault and the Liachar Fault are two major faults, which destabilise the area.

Management of solid waste disposal of Lahore metropolitan area and its effects on soil

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The management of solid waste is a primary urban problem of each country. The Lahore metropolitan area in Pakistan, with a population of 5.65 million is generating 3,103 metric tons of solid waste daily encompassing municipal waste, hospital waste, industrial, and hazardous waste. The Lahore Metropolitan Corporation is disposing only 70–80 per cent of the solid waste by landfill method, open dumping method and incineration, while the remaining 20–25 per cent of solid waste is not being dumped due to lack of vehicles and staff, and it has an adverse impact on environment. The organic and inorganic pollutants from the industrial waste are dumped indiscriminately and have adverse effect on soil due to the leachate from the landfill. Hence, the Lahore Metropolitan Corporation is seeking information on designing the landfill site to avoid pollution from the industrial waste. The second vital factor of management is recycling of waste material into new products and recovery of energy from solid waste.

This study includes various maps and plates of solid waste management in the Lahore metropolitan area.

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Impact of coal on groundwater at Lakhra, Sindh, Pakistan

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The Lakhra coalfield is the second largest coalfield of Pakistan. The rocks exposed in this area belong to the Ranikot Group, which is composed mainly of the Bara Formation (Early Palaeocene), Lakhra Formation (Late Palaeocene), Sonhari Member (Early Eocene), Laki limestone Member (Early Eocene), and Manchar Formation (Pliocene). There are only six dug wells (Fig. 1) in the area yielding a limited quantity of water. Samples from these wells were collected and analysed using the atomic absorption spectroscopy. The results (Table 1) show that the electrical conductivity (EC) and total dissolved solids (TDS) are high (i.e. EC = 800–121 µS/cm and TDS = 568–847 mg/l, respectively) in all the samples, and $S0_4^{++}$ is also higher at some places. Among the heavy metals, Fe content is also high (i.e. 844 mg/l), while Ni, Cu, Pb, and Cd contents are within the standard limit set by US-EPA for water. The high concentration of TDS may reduce solubility of gases (like oxygen) and the utility of water for drinking and irrigational purposes, as many salts are found dissolved in natural water. Pollution zone can be established by measuring EC; it is related to the concentration of total dissolved solids and major ions. Excessive bicarbonate may cause eye irritation problems, as this alters pH of lachrymal fluid around the eyes. Elementary sulphur may slightly irritate, while sulphate is poorly absorbed by the human intestine; it slowly penetrates the cellular membrane of mammals and is rapidly eliminated through kidneys; and the high values of iron in water may cause diseases like haemosiderosis, liver damage, and diabetes.

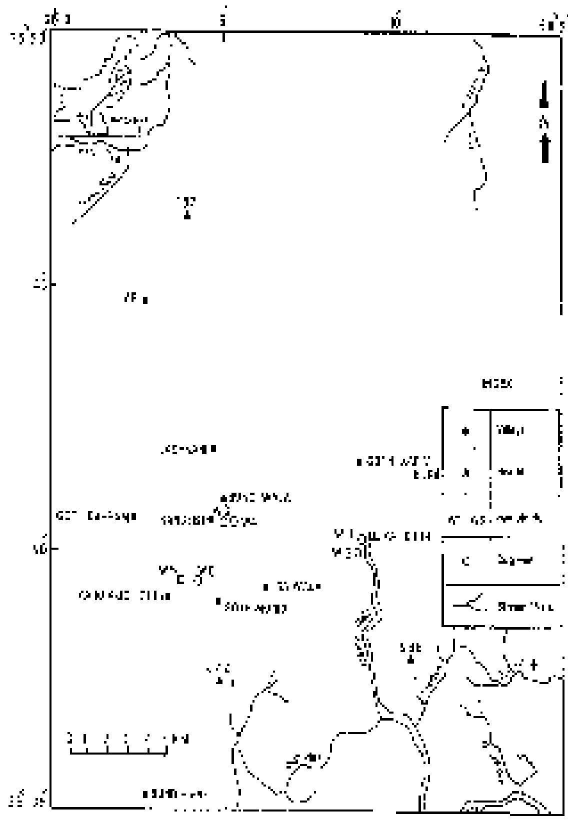

Fig. 1: Location of dug wells in the Lakhra coalfield

Table 1: Quality of well water at Lakhra, Sindh, Pakistan

Sample No.	Location/Name of the dug well	EC µS/cm	TDS mg/l	HCO_3 mg/l	SO_4 mg/l	Fe µg/l	Ni µg/l	Cu µg/l	Pb µg/l	Cd µg/l
	US-EPA	300	500	500	250	300	1000	1000	50	10
W1	Lialian-I	910	637	305	52.5	6	0	10	4	1.9
W2	Lialian-II	860	595	115	300	223	7	70	47	2.4
W3	Kandeer-I	830	581	70	40	53	4	68	20	0
W4	Kandeer-II	800	560	202	42.5	45	5	11	0	1.3
W5	Yaro's well-I	1010	707	85	352	844	5	89	24	0.1
W6	Yaro's well-II	1210	847	360	125	0.28	5	79	38	0

An application of geophysical methodology to monitor the movements of Kahagalle Landslide in Sri Lanka

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The damages caused by landslides to engineering structures, agricultural land, and natural environment is a threat to development on slopes. Determination of slope stability and obtaining information on the direction and velocity of dislocation of soil masses, and on the change in their stress state must be clearly understood to plan landslide control procedures.

Present engineering geological methods are of little use for detecting dislocation of soil masses at different depths. However, geophysical methods can be applied to overcome this difficulty, as the displacement of deep magnetic position markers and anomalies of natural electrical field can be easily found using these. For long term monitoring of a landslide, subsurface geophysical exploration procedures are of immense help.

The Kahagalle Landslide was selected to carry out the monitoring procedure using geophysical methods. The overall aim of the research was to introduce scientific approaches and practices to reduce the vulnerability and risk in landslide-prone areas.

The VES curves show that the subsurface profiles consist of 3 to 4 layers while the high resistive bottom layer can be interpreted as the bedrock. The resistivity value interpreted for the bedrock was comparatively high. The low resistivity value interpreted for the basements represent the limestone. On the basis of geoelectric sections, it was inferred that the overburden in the area might consist of two to three layers having an appreciable resistivity contrast.

Magnetic anomalies over the site surface were measured using GSM 8 proton precession magnetometer. Magnetism at the site does not vary much except for two magnetic anomalies that are underlain by culverts of the road from Haputale to Bandarawela.

Strong magnets were lowered into two boreholes in order to detect the displacement of magnetic markers buried at different depths. These displacements are correlated with immovable geodetic position markers in order to calculate the rate and direction of soil mass displacement.

Movements of pegs fixed on the borehole mouths were detected with respect to immovable geodetic position markers located on the bedrock. These initial altitudinal and planer fixations were made immediately after the magnetic markers were emplaced.

The direction and magnitude of displacement of a magnetic marker were determined from the distance between epicentres of the corresponding anomalies. The velocity was calculated by getting the time difference between such anomalies.

Mapping of possible iron-hydroxyl alteration zones using Landsat TM image data, Central Highlands, Sri Lanka

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The geology of Sri Lanka and its mineralisation has been studied for many years using traditional mapping techniques. The mineral exploration history of Sri Lanka is in many ways typical of most of the world's great deposits, in that they have been discovered by conventional exploration methods around obvious surface indications of mineralisation. Technologies available in present days such as computer-based satellite remote sensing and GIS techniques were rarely applied for mineral exploration studies in the country.

Some of the lineaments, faults and shear zones, located within the Central Highlands of Sri Lanka, are evidently related to mineralisation accompanying with wall rock alteration. Possibility of discovering such prospective alteration zones is a difficult task when using conventional mapping techniques. With the intention of overcoming these problems, satellite remote sensing techniques were applied in this study.

In order to map possible alteration zones associated with lineaments in Central Highlands, Loughlin's technique (1993) was performed. The method uses only four of the seven Landsat TM bands for mapping iron (bands 1, 3, 4, and 5) and hydroxyl (bands 1, 4, 5, and 7) alteration zones readily apparent in TM imagery. A careful examination of the eigen vector loadings allow the identification of the correct Principal Component needed to map these alteration types.

In the resultant Colour Composite image, areas with anomalous concentrations of hydroxyl minerals appear as brown to orange in colour whereas areas with more influence of iron oxides are highlighted in blue. Theoretically, areas that have undergone both types of alteration should appear in light blue to white colours. By careful examination of the image, it is possible to identify linear arrangements of light blue to white zones, which coincide with the major lineaments, faults, and thrust zones observed in the area (e.g. Kotmale–Haputale Shear, Alagolla Thrust). By considering these features, it is possible to interpret that the areas covered by these zones would have been subjected to both types of alterations. Therefore, these zones can be considered as prospective zones for future exploration activities. It is interesting to note that previously identified gold occurrences near Sita Eliya, Ramboda, Badulla, and Bogahakumbura areas are also located within the prospective linear zones identified from the resultant image.

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Nature and distribution of landslides in the Satluj Valley, Higher Himalaya, India

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In the early 1990s, a regional landslide project was started in the Satluj Valley. The goal of this project was to map the nature and distribution of landslides at the regional scale and to assess various landslide hazard susceptible zones. The investigation was carried out at different scales and it confirmed that landslides are widespread in the region. Steep slopes, high relief, a number of structural discontinuities, and underlying geology combined with anthropogenic activities constitute a propensity towards failure affecting both massive country rock and the Quaternary cover. An inventory of landslides was prepared using a variety of geological and geomorphological techniques, such as the interpretation of satellite imageries and the extensive field mapping.

Morphologically, the entire Satluj Valley shows two major types of slope. Slopes covered with glacial and periglacial material of the Quaternary Period and slopes carved out by neotectonic activity. The slopes covered with glacial and periglacial material can further be divided into three zones on the basis of continuity of two slope breaks. Neotectonic slopes are the slopes carved by neotectonic activity and are characterised by steep gorges. Each geomorphological setting was studied with respect to the nature of landslide in the region.

Zone 1

It includes the uppermost higher mountain ridges, (Elevation > 3,500 m), generally covered by perennial snow. Present-day glaciers and permanent snow patches in this zone supply continuous meltwater into the lower zones. This zone is characterised by the presence of horns, arête, glaciers, and cirques with steep slope (> 45^{o}) and high rate of physical weathering. This zone is the least interfered by human activity. Vegetation is scarce and therefore, mass movements in the form of rockfall and debris slide are common.

Zone II

This zone is followed by relatively medium elevation ridges (Elevation between 2,500 m and 3,500 m) and is characterised by the presence of dry cirques, which receive snow only during winter. The slopes of this zone are moderately steep (30 to 40^{o}) and covered by Pleistocene glacial and periglacial material. The occurrence of talus cones and debris fans in this zone is very common. The debris flow during snowmelt and avalanches during winter is a common phenomenon in this zone.

Zone III

The areas below Zone II (Elevation < 2,500 m) down to the Satluj Gorge have gentle slopes. These slopes are generally covered by dumped glacial debris, hill slope scree and old landslide material, thus forming a thick regolith and well-developed soil profiles. Therefore, these gentle slopes are extensively cultivated. Most of the villages, orchards, agricultural terraces, and road network lie in this zone. The high rate of percolation of water from the upper slope through the unconsolidated material of this zone generates fresh mass movements as well as reactivates the old ones in the form of creep, and translational and rotational debris slide.

The slopes carved by neotectonic activity are generally straight, barren cliffs, exposing fresh rocks in the form of gorge of about 50–150 m depth and are characterised by active rockfalls.

Glacial hazards in the upper Rolwaling Valley, Dolakha District, Nepal

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The Rolwaling Valley, Dolakha District, Nepal, is populated by niche, hanging, and outlet glaciers that have a history of producing natural hazards. The largest outlet glacier in the valley is the Drolamboa Glacier, which flows into the Trakarding Glacier whose snout terminates in the Tsho Rolpa, the largest glacier lake in Nepal.

An ice avalanche occurred in February 1998 near the village of Naa and appears to have originated from a hanging glacier at high altitude. The lower-lying glaciers have ablated so much that they themselves do not pose any risk from ice avalanching. Snow and ice avalanche activity from some of the flanks of Bigphero Go Shar present a potential risk to trekkers who attempt the crossing from Rolwaling over the Trashi Laptsa pass into the Khumbu region to the east.

Areas of stagnant debris-covered glaciers to the northwest of Tsho Rolpa, such as Ripimo Shar and Ripimo Nup, appear to be developing small supra-glacial ponds. At present none of these poses any threat downstream. However, continued melting of the buried ice at Ripimo Shar may permit the former Chubung Lake that burst in 1991 to form again. Consequently, this area should be monitored regularly.

The overview in the Rolwaling Valley demonstrates the various styles of glaciers and glacial hazards that may exist in such environments. The lessons learnt from this work should be adopted into a glacial hazards response strategy for dealing with the likely hazards arising from stagnating debris-covered glaciers and their immediate environs.

Managing the risk from glacier lakes in Nepal

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The issue of glacial hazards is now being recognised as an increasing problem as glaciers worldwide retreat in response to climate change. In Nepal, this has been manifested particularly in the development of large supraglacial and proglacial lakes. Some of these lakes (such as the Tsho Rolpa, Dolakha District) have been identified as potentially dangerous and necessitating remedial works. In addition, the perceived risk from glacial floods in Nepal has been sufficient to provoke a planning response at a national level. A successful risk management strategy at local and national levels requires guidelines for planners and technical practitioners. The guidelines are necessary to ensure that the stages of a risk management programme are properly specified and that any investigative works are undertaken in accordance with best practice.

Here we provide details of a British Government-funded project to develop the procedures for glacial hazard and risk assessment. The project addresses for the first time, in detail in the Himalayan region, the integrated assessment of both the glacial hazards and consequential risks to local communities. A risk management framework has been established, encompassing elements of the management process from hazard identification, hazard assessment, and risk assessment, through to appropriate methods of risk control. Using the Solukhumbu District as one case study area, ways of increasing the objectivity and efficiency of each stage of the risk management process are being researched. The resulting procedures will be integrated with local government planning in order to aid the formulation of risk reduction strategies. Findings and reports from the project are being disseminated through international project workshops and technical forums such as this conference held by the Nepal Geological Society.

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