ISSN: 0259-1316 (Print)
ISSN: 2676-1378 (Online)

Volume 64 November 2022 Special Issue

# JOURNAL OF NEPAL GEOLOGICAL SOCIETY

## ABSTRACT VOLUME

## 35TH HIMALAYA-KARAKORAM-TIBET WORKSHOP (HKT)

November 02-04, 2022

Pokhara, Nepal

# $35^{th}$ Himalayan-Karakoram-Tibet Workshop (HKT)

***"Geosciences for People's Prosperity and Sustainable Development"***

**November 02-04, 2022**
**Pokhara, Nepal**

**Organized by**

## Nepal Geological Society

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# Acknowledgements

Nepal Geological Society (NGS) is pleased to bring this abstract volume of the 35th Himalaya Karakorum Tibet (HKT) workshop held in Pokhara, Nepal on November 02-04, 2022. Founded in 1980, the Nepal Geological Society (NGS) is a professional geoscientific organization with over 1000 members. The Society is the National Group Member of International Association for Engineering Geology and the Environment (IAEG) and was a member of Nepal National Committee on International Decade for Natural Disaster Reduction (IDNDR) to lead the IDNDR activities in Nepal for a decade. The Society was honored with the 1998 United Nations Sasakawa Disaster Prevention Award Certificate of Merit in appreciation for its contribution to disaster prevention, mitigation and preparedness and Science and Technology Promotion Award from Nepal Academy of Science and Technology (NAST) in recognition of its contribution in the research and promotion of Geosciences.

The Himalaya-Karakorum-Tibet (HKT) workshop has been organized annually since 1985. The Nepal Geological Society already organized the 9th and 27th HKT workshops, respectively, in 1994 and 2012, in Kathmandu, Nepal. The society happily accepted the approval of the attendees at the 33rd HKT that occurred in Lausanne, Switzerland in 2018, to organizing 35th HKT workshop in Pokhara, Nepal. The decision for organizing the event in Pokhara, Nepal was continued by the attendees of 34th HKT workshop held in Montana, USA. Because of COVID-19 pandemic, the 35th HKT workshop has been shifted from the previous date to November 02-04, 2022.

The main theme of the 35th HKT workshop is **"Geosciences for People's Prosperity and Sustainable Development"** Aiming to update and enhancing the concurrent knowledge and new findings among the participants following sub-themes are outlined:

1. Geomorphology, Geological mapping, Stratigraphy and Regional tectonics
2. Advances in Mineralogy, Petrology, Geochemistry, Geochronology and Thermochronology
3. Mineral Exploration, Mineral Resources and Mining, Petroleum, and Natural Gases
4. Engineering Geology, Tunneling, and Hydropower development
5. Geo-Hazard Assessment, Risk Reduction and Mitigation for Sustainable Infrastructure Development
6. Environmental Geology, Hydrogeology, and Water Resources
7. Advances in Geophysics, Seismology, and seismo-tectonics
8. Glaciology, Environment, Climate Change, and adaptation
9. Plans, Policies, and Strategies of the Nepal Government for the application of geosciences in Sustainable Infrastructure Development
10. Gender history in geosciences
11. Geo-tourism and Geo-heritage Conservation
12. Promoting Geo-ethics for Sustainable Development
13. Recent Development in Geoscience Software, Laboratory Facilities, and Findings
14. Recent Trends and Advances in Geosciences

This volume contains 160 abstracts of scientists and researchers from 16 different countries representing the United States of America, France, Germany, Poland, Italy, New Zealand, United Kingdom, Nepal, Canada, China, Hong Kong, Japan, Singapore, Norway, India, and Pakistan. The papers are categorized as Keynote and Invited Presentations, Oral (80) and Poster Presentations (80), which are grouped into 15 technical main and sub-sessions run parallelly in three conference halls. In addition, the HKT workshop has organized pre- and post-conference excursions from Kathmandu to Pokhara and Pokhara to Muktinath, respectively.

Welcoming all the delegates of the 35th HKT workshop, we bring to you the memorable event abstract volume on your hand as a useful collection.

The Nepal Geological Society is grateful to all the organizations and individuals for their support, including financial in various ways, to make this international scientific event a success.

**The NGS is very much thankful to:**

- The HKT community for providing this opportunity to host the event in Pokhara, Nepal.
- National Planning Commission, Government of Nepal
- Office of the Chief Minister and Council of Ministers Gandaki Province, Pokhara, Nepal

- Department of Water Resources and Irrigation, Pulchwok, Lalitpur
- Ministry of Energy, Water Resource, and Irrigation, Gandaki provinces
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- Ministry of Physical Infrastructure, Urban Development and Transport Management, Gandaki Province
- NORHED II 70141 6 (NTNU-Norway), IoE-WRC, Tribhuvan University, Pokhara
- Nepal Tourism Board, Kathmandu
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- Others supporting organizations

We are grateful to the members of the Nepal Geological Society, HKT participants and presenters, and participants in the excursion, as well as the various organizations and individuals who provided generous support for the successful organization of the 35th HKT workshop in Pokhara, Nepal.

**The Nepal Geological Society and**

**The Organizing and Advisory Committees, 35th HKT**

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# Keynote Speakers

# Evaluation of the future seismic hazards in Nepal and need for establishment of an Earthquake Early warning system

**B. N. Upreti[1], S. Subedi[2,3]**

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Himalaya is the best-known modern example of the continent-continent collision tectonics. The collision of the northward drifting Indian plate with the Eurasian plate around 60-55 Ma ago was the final act of the initiation of the Himalayan orogeny. India continues to push Eurasia at a rate of around 4 cm per year building up an immense stress field along the Himalayan Arc causing it continuously to rise and create devastating earthquakes all along this mountain range. Thus, the entire length of the Himalaya is a zone of intense seismic activities. A number of great devastating earthquakes of magnitude $M_w$ 8 or more have occurred along the Himalayan Arc in the recent past. The recent work on paleoseismological studies have provided us more information on even older large earthquakes that were missing in the historical records.

About 2/3 of the Himalayan arc covers Nepal. Nepal Himalaya is seismologically the best monitored (started in 1978) sector of the Himalaya uninterruptedly since over 4 decades. This fairly long seismological research has provided us a great deal of understanding of the seismotectonics of the Himalaya and earthquake mechanism.

As a result of the long-term seismic monitoring, GPS data acquisition, paleoseismological studies and geologic research carried out in the country has provided a firm base for the seismic hazard assessment for Nepal. Based on these studies, the April 2015 Gorkha Earthquake in Nepal was well anticipated and advices to the government and public were given much in advance. Accordingly, considerable disaster preparedness was initiated before the Gorkha Earthquake, and as a result it helped to a great extent in smooth management of search and rescue and relief operations following the earthquake. As the risk for the next great earthquake in Nepal is very high, these efforts alone are insufficient to save people from future earthquakes. Using modern scientific instruments and communication systems, it is possible now to protect people from an earthquake by sending them an alert before the destructive seismic waves reach to them. This is Earthquake Early Warning (EEW) system and has been successfully implemented in many other high-risk countries, for example, Japan, the USA, Mexico, Indonesia, China, Switzerland, Taiwan etc. Therefore, to start with we aim to establish a network and develop protocols for an EEW in eastern Nepal under Nepal Academy of Science and Technology (NAST). The article discusses the future earthquake hazards and the proposed plan for establishing an EEW System for Nepal.

**Keywords:** Earthquake Early Warning System, Gorkha Earthquake, paleoseismology, Seismotectonics

# The Neogene record of Himalayan erosion in the Bengal Fan, IODP Expedition 354

**Christian France-Lanord[1]*, Aswin P. Tachambalath[1], Albert Galy[1], Valier Galy[2], Pascale Huyghe[3], Jérôme Lavé[1], Sébastien Lenard[4], Thomas Rigaudier[1]**

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Over the Tertiary, the uplift of the Himalaya combined to the development of the monsoon generated the largest erosion basins of the planet. More than 80% of the erosion is exported to the Bay of Bengal by the Ganga-Brahmaputra river system and generates turbidity currents which convey detrital sediment building the Bengal Fan. In Himalaya, the monsoon rainfall and tectonic processes shape the erosion pattern. The monsoon seasonal precipitation ensures efficient transport of sand-rich sediments in the basin despite long distances through a very flat floodplain and delta. Rapid transport also acts as a limiting factor for weathering as it reduces residence time in the floodplain but favors efficient carbon burial.

The IODP Expedition 354 drilled the Bengal Fan over a 320 km E-W transect at 8°N that allows constructing a sedimentary record of Himalayan erosion over the Neogene and Quaternary. Sediments are predominantly composed of turbidites generated from the Ganga-Brahmaputra delta. Turbiditic sediments show mineralogical, geochemical and isotopic characteristics which reveal a close analogy with those of the modern Ganga-Brahmaputra river sediments. Sand deposition is dominant and is expressed in sand lobe as well as in levee turbidite (Bergmann et al. 2020). Sand was used to determine average range erosion rates using quartz in situ concentrations of cosmogenic $^{10}Be$. Those show stable rate in spite of the onset of a more unstable climate from the Pliocene to the Pleistocene (Lenard et al. 2020).

Major element concentrations and Sr-Nd isotopic compositions of turbidite samples reflect combined effects of geological sources exposed to erosion, weathering and mineral sorting during transport. Deciphering these controls is based on the comparison between turbidite samples and modern river sediments of the Ganga and Brahmaputra basin. Changes appear in the abundance of detrital carbonates likely reflecting decreasing exposition of the Tethys Himalaya to erosion since Miocene. Clear increase in the Na and Ca concentrations from Miocene to Pleistocene also reveal changing conditions of weathering conditions in the basin.

**References:**

Bergmann et al. 2020, G. cube 10.1029/2019gc008702
Lenard et al. Nat Geosc. 2020, doi:10.1038/s41561-020-0585-2

# Methods applied for the stability assessment in rock engineering

**Krishna Kanta Panthi**

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The rock mass is exposed to stress changes after the excavation is made for the construction of infrastructures such as roads, railways, hydropower and irrigation projects. The expansion of the roads requires slope cuts which cause the natural discontinuities to daylight leading to the rock slope failure of different type and magnitude. The construction of tunnels and underground caverns for different infrastructure projects will pass through rock mass with varying rock cover leading to different stability challenges. The changes in in-situ stress condition therefore will have direct impact on the stability of infrastructure projects. This key-note lecture will highlight methods used to make a stability assessment of rock slopes and underground excavations. The focus will be given on the most important expect of design and stability assessment covering rock slope failures, block falls in tunnels and issues associated to in-situ stress conditions on elastic brittle and elastic plastic rock material. Tunnels and underground caverns located in shallow overburden are subjected to de-stresses conditions causing block falls. On the other hand, tunnels and caverns located deep into the rock mass (high rock cover) are subject to instabilities caused by induced rock stresses. If the rock mass is relatively unjointed and massive, the instability is associated to brittle failure called rock spalling / rock bursting. On the other hand, if the rock mass is weak and deformable, the instability is associated to plastic deformation called squeezing. Therefore, stability assessment in rock engineering is a challenging task and needs deep knowledge on the behavior of rock mass and is of the challenging issue for engineering geologists and rock engineers.

**Keywords:** Rock mass, rock stress, rock slope, tunnels, caverns, stability assessment methods

# Long-term seismological monitoring documents persistent structural segmentation of the seismicity along the Main Himalayan Thrust in Nepal

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The study of the microseismicity spatiotemporal variations has sometimes the potential to reveal the mechanisms of seismicity generation and the geological structures involved. However, the general scope and representativity of these studies are often complicated by biases and uncertainties difficult to ascertain. Indeed, permanent nationwide seismological alert networks are rarely optimised for monitoring the microseismicity, while dedicated dense temporary network are often deployed for short durations only.

Here we combine the benefit of both short and long-term seismological experiments at imbricated scales, thanks to the long-standing (40 years old) collaboration in seismology between the Department of Mines and Geology (DMG) and CEA/DASE.

The collaboration contribute to 22 permanent stations, about 50% of the total number of stations of the Nepal national network. A dense temporary experiment of 15 stations deployed in Far Western Nepal complemented this network during 2 years, enabling a better quantification of the biases and uncertainties.

This presentation illustrates the joint benefit of these networks in their capacities at characterizing the microseismicity. It reveals the presence of persistent lateral variations and segmentations along the downdip-end of the seismogenic zone. This suggests that processes and structures involved in the microseismic production are perennial. Confrontations with balanced geological cross-sections reveal that the lateral variations of tectonic structures at depth control the lateral variations of the microseismicity. Main active ramps and flats of the megathrust system are primarily involved in the seismicity generation. Secondary structures, including hinges, backthrusts and paleo-ramps or tectonic contacts between tectonic slivers are sometimes involved in transient microseismic cluster, eventually controlled by fluids and transient slow slip. The improvements into the documentation of these midcrustal microseismic features underline a deep segmentation of the fault system. This segmentation could reveal potential start-and stops locus of the rupture of intermediate and large earthquakes.

**Keywords**: Seismology, Microseismicity, Main Himalayan Thrust

**References:**

Hoste-Colomer, R., et al. 2018, Lateral variations of the midcrustal seismicity in western Nepal: Seismotectonic implications. Earth and Planetary Science Letters, 504, pp. 115-125.

Laporte, M., et al., 2021, Seismicity in far western Nepal reveals flats and ramps along the Main Himalayan Thrust. Geophysical Journal International, 226(3), pp. 1747-1763.

# Field evidence for cross faults in eastern Nepal

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While researchers have documented lateral variations in thrust geometry and metamorphic features along the Himalaya, recent work has identified several discreet ~NE- striking cross faults. These structures have potential implications for the segmentation of seismicity, but also form dip slopes in many of the south-flowing river systems of Nepal, thus enhancing the landslide hazard. The Benkar fault zone is a NE-striking system of fault segments that we have identified in Greater Himalayan rocks from the Khumbu glacier valley south of Everest Basecamp, through the peak of Tabuche, along the Dudh Kosi river valley through the village of Benkar. In the Lesser Himalayan units this structure was mapped from just east of Phaplu, through Patale, Okhaldunga, Ketuke and Ghurmi. In the Greater Himalayan units, the zone of non-penetratively sheared rocks is 3 to 11 km wide with the wider areas including granitic intrusives. Deformation is commonly concentrated along sillimanite-rich planes with the minerals aligned about a shallowly, S- to SW-plunging lineation. In the Lesser Himalayan region, the deformation is expressed on brittle, NE-striking fault segments with moderate to steep, SE-dips. These segments overlap in a zone that is ~5-8 km wide. Individual segments are ~10-150m thick and include slickensided surfaces, breccia, and/or fault gouge. Lineations on brittle surfaces plunge ~40° southward. The Gauri Shankar lineament is a NE-trending, linear topographic feature that roughly coincides with the surface projection of the planar termination of aftershock foci associated with the 2015 Nepal earthquakes. In the Rolwaling area, NE-striking fractures are common though evidence for fault deformation has not been found along this trend. Roughly 5 km west of Jiri, there is brittle deformation along NE-striking zone with shallowly northward plunging lineations and possible left-lateral sense of shear. This region also has WNW-striking zones that appear to truncate the NE-striking fault segments. Other cross faults have been identified at the Himalayan range front to the east and west of Nepal. Causes for cross faulting remain unclear, however faults at high angle to the Himalaya are seen both in the Indian basement rocks to the south and bounding extensional basins to the north in Tibet. While reasons for their existence are not known, they are important in their connection to natural hazards. In eastern Nepal, these cross structures are parallel and in some cases are co-located with the NS river valleys. The structures create dip slopes that likely increase the occurrence of landslides. The Gauri Shankar lineament's coincidence with the eastern boundary of aftershock foci, suggests a possible limitation of lateral rupture of the main thrust event. This co-location could mean that cross faults play a role in the segmentation of large earthquake events in the Himalaya.

**Keywords:** Cross fault, Himalaya, Nepal, Benkar Fault Zone

# Channel Flow along the Greater Himalaya, Nepal

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Collision of the Indian and Asian plates and closure of the intervening Neo-Tethys Ocean at ca 50 Ma resulted in crustal thickening and shortening along the northern continental margin of the Indian plate. Burial of dominantly Proterozoic-Palaeozoic rocks to depths of 30-40 km by folding and thrusting resulted in regional Barrovian metamorphism and staurolite-kyanite metamorphism between ca 44-30 Ma. Minor kyanite-bearing partial melts are the first indication of partial melting at pressures up to 1 GPa. Decompression melting of sillimanite + muscovite and sillimanite + K-feldspar gneisses led to widespread mid-crust anataxis and formation of garnet + tourmaline + muscovite ± cordierite leucogranites between ca 28-13 Ma. The initiation of the Main Central Thrust (MCT) along the base of the Greater Himalayan Sequence (GHS) and the South Tibetan Detachment (STD) low-angle normal faults along the top of the GHS led to the southward extrusion of a hot, ductiley deforming mid-crustal layer, a process termed 'Channel Flow'. Melting facilitated channel flow and led to large-scale folding of metamorphic isograds associated with channel flow. Inverted metamorphic isograds along the MCT zone at the base can be linked to right way-up isograds beneath the STD zone along to top of the GHS. Mid-crustal channel flow was operating during the Late Eocene to Mid-Miocene and ductile deformation along both MCT and STD zones led to brittle faulting with time and 'cooling' of the channel once leucogranite melting ceased. Thrusting propagated down structural section to the Lesser Himalaya and Main Boundary thrust since ca 11 Ma. Mid-crustal melting and channel flow may be unique to the Himalaya, due to distinctive protolith source rocks, internal radioactive heating, thermal differentiation and interaction of regional Barrovian metamorphic and structural processes.

**Keywords**: Greater Himalayan, Sequence, Channel Flow, Main Central Thrust, South Tibetan Detachment

# Neotectonics of the Himalayan Frontal Fault Zone in NW Himalaya

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Neotectonic investigations made, by our group, are elucidated from the Jammu region in Kashmir Himalaya, the Kangra reentrant in Himachal Himalaya, and the Dehradun area in Garhwal Himalaya. In Shimla Hills, the faulted contact between the lower Tertiary (Subathu, Kasauli, and Dagshai formations) and the underlying Siwalik was designated the Main Boundary Fault (MBF) by Medlicott, whereas the presently defined Main Boundary Thrust (MBT) was mapped as the Krol Thrust by Auden. In the Jammu region, Kashmir, the present MBT was mapped as the Murree Thrust, and faulted contact between the Siwalik and the Murree was defined as the Boundary fault by Wadia, synonymous to the MBF. In order to evade confusion between the MBF and the MBT, we designated the MBF as the Medlicott Wadia Thrust (MWT). In the Jammu region, the stromatolite bearing Proterozoic Reasi Limestone, overlain unconformably by the Paleocene – lower Eocene Subathu Formation in turn succeeded by the Murree Formation, is thrust over the Vaishno Devi gravels dated late Quaternary in age along the MWT. Based on the tectonostratigraphic setting, the MWT extends from Reasi to the east to the Kangra reentrant as Palampur Thrust and Bilaspur Thrust and further eastward to the Yamuna River as the Nahan Thrust (Thakur et al., 2010). The occurrence of stromatolites is a characteristic feature of the Reasi Limestone of Proterozoic age. This limestone is correlated to the stromatolite-bearing Shali or called Deoban Limestone of the Lesser Himalaya. The tectonostratigraphic disposition in the Reasi area suggests that the Reasi Limestone was one of the unit of the Lesser Himalayan basement for the deposition of the Cenozoic sequence of the foreland basin in this part of the NW Himalaya. This tectonic setting implies thrusting of the basement wedge over the Siwalik along the MWT. In its NW lateral extent, the MWT appears to extend, with the right – step, to the Balakot Bagh fault associated with the 2005 Kashmir earthquake. This implies that the MWT (MBF) is seismogenic and capable of producing a large earthquake. Subsequent workers have estimated the shortening rates through the dating of the strath surfaces. The estimated shortening rate for the MWT is 11.2 ± 3.8 mm/yr over the last ~ 14 ka and for the MFT (HFT) is 9.2 ± 3.2 mm/yr over the last ~24 ka (Vasallo et al.2015). Whereas in the same area, the total shortening for both strands of the Reasi Thrust (MWT) is 6 – 7 mm/yr over the last 100 – 40 ka (Gavillot et al 2016). According to Mugnier et al. (2017), the MWT constitutes a splay of five steeply dipping faults, placing the Precambrian limestone over the Siwalik with the displacement rate of 13.3 ± 2.8 mm/yr.

In the Kangra reentrant area of Himachal Sub Himalaya, there is the widest, ~ 100 km, Cenozoic sequence of the foreland basin comprising the Subathu and Dharamsala formations of Paleogene and Neogene Siwalik group. They form a fold-thrust belt between the HFT and the MBT. In the frontal Siwalik range, the Januari and Chandigarh anticlines are complemented to the north by the broad synformal depressions of the Soan dun and the Pinjor dun, respectively. Based on OSL dating of gravels cover over the bedrock strath surface, measuring the elevation of the strath surfaces from the alluvial plain surface, and assuming 30º dip of the underlying thrusts, the estimated shortening rates over the Himalayan Frontal Thrust, Soan Thrust, and the Jawalmukhi Thrust are 6.0 ± 0.5mm/yr, 3.0 ± 0.3 mm/yr, 3.5 ± 0. 4 mm/yr over the last 42.9 ± 3.6 ka. 29.0 ± 2.6 ka, and 32.6 ± 3.6 ka, respectively (Thakur et al. 2014).

In the Dehradun area of Garhwal, the Sub Himalayan belt is considerably narrower in width, ~ 30 km, about one-third the width of the Kangra reentrant. It is composed essentially of the lower, middle, and upper Siwalik group. The frontal Mohand anticline is complemented to the north by the synformal depression of Dehra - dun filled by the post – Siwalik Dun gravel fans. The Mohand anticline is a fault–bend fold formed over the HFT, and the Dun is interpreted as the piggyback basin. The seismic profile reveals an upright anticline over the nearly flat decollement, and a hydrocarbon exploration well reveal quartzite - slate at a depth of ~ 3km, likely to be the basement. The timing of formation of the anticline is estimated around 500,000 – 100,000 ka. The Dun is filled with fluvial fans that show four levels of geomorphic surfaces. The Bhauwala Thrust was developed out of sequence south of the MBT between 28 ka and 20 ka. The shortening rate estimated over the southern front of the Mohand anticline is 14 ± 2 mm/ yr (Wesnousky et al.19990. The active faults have been mapped along the Sub Himalayan front extending laterally from Dehradun to Kali River, western Nepal border (Jayangondaperumal e tal. 2018) The fault scarps of 3 - 13 m elevation occurring within the post – Siwalik gravels are interpreted as the surface ruptures of paleo – earthquakes. The paleoseismology studies carried out at 7 trench locations along 240 km lateral extent reveal a major earthquake event dated ~ 1450 (Kumar et al. 2006). Paleoseismology investigations have been made at several other locations, but there is a difference of opinion assigning the surface rupture to a particular historical earthquake, for example, 1505 AD and 1803 A D or some other event. The reactivation of MBT is observed at two locations: a) Near Rajpur in Dehradun, the Chandpur slate of the Lesser Himalaya overrides the Dun gravels dated 30 ± 1 ka, b) at Hedakhan, east of Haldwani, a semicircular fan overlaps the trace of the MBT between the Lesser Himalayan volcanic – quartzite and the Siwalik. The fan is cut by a north facing scarp that coincides with the trace of the MBT. The deflection of a major stream along the scarp indicates left–lateral motion over the MBT.

**Keywords :** Himalayan Frontal Thrust, Medlicott Wadia Thrust, Late Quaternary – Holocene deformation, Active tectonics, Shortening rates

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# Invited Talks

# The Mw7.8 Gorkha Earthquake: A Watershed in Nepal's History of Disaster Risk Management Efforts

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The 2015 Mw Gorkha earthquake, occurring along the east-bound Barpak - Sunkhani axis, defined the virtual watershed of concerted national efforts of Disaster Risk Management (DRM) that was started de facto after the devastating ML6.6 Udaypur earthquake of 1988 and further by the 1993 floods of south-central Nepal. The history of disaster risk management processes adopted by Nepal coincided with the advent of organized approaches globally, especially after the promulgation of the International Decade from Natural Disaster Reduction (IDNDR) that heralded such milestone concepts as "paradigm shift from reactive practice of disaster response to proactive disaster reduction", use of science in Disaster Reduction, and revamping of disaster governance globally. Nepal adopted and adapted these, and subsequent concepts promulgated by the UN ISDR. HFA 2005-2015, SFDRR and also other global frameworks concepts such as the SDG. Urban Agenda and Paris Agreement.

The efficacy and appropriateness of such efforts and the evolution was ruthlessly tested by the Gorkha earthquake. Contrary to the much-hyped statement of "Nepal being doomed in case of a devastating earthquake because of *Japan-like hazard in conditions of Haiti-like vulnerabilities"*. Nepal managed the Gorkha earthquake much better than what was generally anticipated even by the optimists: emergency response was organized in the best way historically despite lack of previous experience, appropriate tools and technologies. A comprehensive PDNA guided the process with the government excellently coordinating the efforts made by local stakeholders with extremely valuable support obtained from people and governments from all over. Lack of reconstruction policies and procedures delayed the reconstruction process, but it soon recovered the pace and the principles of owner-driven build back better approach, government investing in the reconstruction of public infrastructure and assisting the damaged private households for code compliant reconstruction by providing evidence-based financial assistance commensurate with the progress in code-compliant reconstruction in three trances.

Disaster risk reduction and prevention activities implemented over the two preceding decades actually paid many times over. The earthquake help identify gaps and needs, which were addressed timely: numerous policies and regulatory processes and procedures were developed based upon felt and identified needs locally, and institutionally reforms including establishment of the National Disaster Risk Reduction and Management Authority (NDRMA) tasked with addressing the need s for risk identification and development/enactment of polices and governance instruments commensurate with the ongoing federalization with an unprecedented shift of responsibilities and authority of DRM and CCA to the 753 local level governance organizations in the country. In doing so. the753 country and people have learned a series of lessons that are being addressed through updating of policies and implementation of DRR initiatives in increasing coordination with the social and economic development efforts the country has been implementing.

This paper will analyze the Gorkha earthquake experience, describe the lessons in earthquake reconstruction and the strategies Nepal has formulated for addressing the gaps identified.

**Keywords:** Gorkha Earthquake, disaster risk management, resilience, national building code, climate change adaptation

# The positon of Dadeldhura Nappe and Main Central Thrust in west Nepal

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The Dadeldhura (or Almora) Nappe and the Main Central Thrust have been variously mapped in West Nepal and the adjoining part of Kumaun, India. Detailed field mapping in west Nepal revealed that a few klippen of the Greater Himalayan Nappe, representing the hanging wall of the Main Central Thrust, rest over the Dadeldhura Nappe. Therefore, the Dadeldhura Nappe occurring between Darchula and Budar in west Nepal is a separate Lesser Himalayan thrust sheet. The Dadeldhura Nappe is folded and its several synformal outliers are distributed in west Nepal. In the inner zone, north of Darchula, Chainpur, and Martadi, the Dadeldhura Nappe is rooted under the Greater Himalayan Crystallines and extends in the northwest-southeast direction for a few hundred kilometres. Most of the Lesser Himalayan Sequence is of Proterozoic age, but a few slivers of Palaeocene–Miocene succession also occur below the Dadeldhura Nappe within some imbricate slices. Palaeozoic granites found in west Nepal and Kumaun, India, intrude the Dadeldhura or Almora Nappe. The Nappe is affected by inverted metamorphism and towards its upper part the Dadeldhura Granite is transformed to augen gneiss, presumably during the southwards propagation of the Greater Himalayan Nappe. In this process, the incompetent dolomite and slate succession of the inner Lesser Himalaya was also folded and faulted. The movement of the Dadeldhura Nappe was facilitated by the youngest Palaeocene–Miocene strata occurring in its footwall.

**Keywords:** Dadeldhura Nappe, Thrust sheet, Greater Himalaya, Lesser Himalaya, Main Central Thrust

# Almost steady erosion rates in the Himalayas through late Cenozoic climatic changes

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Large increase of erosion rates during the late Cenozoic has been observed on the basis of a substantial change in worldwide sediment accumulation rates and in exhumation rates derived from in situ thermochronologic data. Such an increase has been attributed to the amplification of climate variability and/or repeated glaciations. Because the reality of this Quaternary increase is still harshly debated, complementary and independent approaches are required to fuel to debate and possibly solve the conjecture. Cosmogenic nuclides such as $^{10}$Be in detrital sediment are common tracers for modern erosion rates. They can also be used to unravel palaeoerosion rates in sedimentary series and reconstruct exhumation history of mountain range over the Late Cenozoic. Because this later method relies on a number of hypotheses, in particular the stability of the contributing drainage area of the deposited fluvial sediments, it is welcome if not required to combine it with provenance study based on mineralogic, geochemical or isotopic data. At the end of the Cenozoic, the Himalayan chain experienced a cooling with an extension of the glaciers on its high summits as well as possible variations in the intensity of the monsoon. It therefore represents a prime target to explore the response of landscape erosion to climate changes.

To address this issue, we have measured the palaeoerosion rates of the Himalayas since the late Miocene (~6-7 Ma) by the analysis of $^{10}$Be accumulated in the terrigenous sediment of the Bengal Fan (IODP expedition 353 and 354) (Lénard et al., 2020) and of two Siwaliks sections in central Himalaya (Surai section and Valmiki section, a new section dated by magnetostratigraphy). The cosmogenic measurements were complemented by geochemical and isotopic (Sr and Nd) analysis of the sediments to trace their provenance. The comparison between distal signal, integrating the contributions of the Ganga and Brahmaputra rivers, and proximal records that represent discrete segment of the Himalayan range offers the possibility to disentangle local and global climatic or tectonic forcing.

For the different records, despite large uncertainties, our reconstructed past erosion rates show, to first order, no long-term increase for the past six million years, i.e. steady erosion rates in the Himalayas though the Late Cenozoic climatic changes. In Himalaya, fluctuations in ice cover vary from less than 5% today to up to 20% during the LGM: such limited glacial cover increase combined with an elevated background erosion rates resulting from active tectonics, abundant monsoon rainfall and steep relief, might explain such reduced sensitivity of the erosion to the Quaternary glaciations onset. Nevertheless, locally in central Nepal, the record in the Siwaliks series indicates a brief ~35% increase in average erosion rates between 2 and 1.5 Ma in the Paleo-Narayani basin, associated with a more pronounced geochemical signature of the High Himalayan units. We therefore interpret this increase, which roughly agrees with the thermochronological data of this region, as the signature of sustained glacial erosion (x2-3) on the Himalayan high peaks, and the carving and deepening of the main glacial valleys. This greater sensitivity of the Narayani Basin to the early glacial period is likely to be related to higher present (~10%) and past glacial cover in central Nepal than elsewhere in the range. At the scale of the whole range this local signature of the entry into the Quaternary is, however, mostly diluted and undetected in the Bengal Fan.

**Keywords:** Paleo-erosion rates, cosmogenic nuclides, Himalaya, Narayani watershed, Siwaliks

# Engineering geology in hydropower development of Nepal: Design and challenges

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Nepal, with the potential of 83,000 MW, is one of the largest hydropower potential countries. Hydropower structures are mostly built in mountainous terrains by constructing underground openings in tectonically active Himalayan rock mass and excavating hill slopes in boulders mixed heterogeneous soils and weathered rocks. Georisks such as tunnel collapse, rock squeezing and water ingress are more pronounced during the construction of underground structures in rock mass having shear/weak zones, weathered/heavily jointed in presence of groundwater. Similarly, the majority of georisks such as landslides, rock falls, floods and debris flow for surface structures will be induced by heavy continuous rains and seismic events. Georisks will damage hydropower structures, cause even losses of lives, and offset the construction schedule, causing a substantial increase in the project's cost. Examples can be considered from different projects:

- failure in operation of the diversion weir of Melamchi Water Supply project due to it being completely buried and damaged by June 2021 LDOF and flood,
- delayed in the construction of headrace tunnel of Khani Khola and Dordi Hydro Projects by almost one year due to tunnel collapse and water ingress (Fig. 1),
- construction delayed and additional cost in reshaping of the headrace tunnel of Chameliya, Middle Modi and Lower Solu Hydro projects due to extreme rock squeezing,
- massive cost and time required to rebuild damaged surface structures in headworks and powerhouse of running 45 MW Bhote Koshi Power plant by July 2016 GLOF (Fig. 1),
- huge expenses in rebuilding penstock pipe of running 45 MW Bhote Koshi Project, 9.6 MW Sipring Project and 5 MW Mailung Project that were severely damaged by rock falls and landslides induced by 2015 Gorkha Earthquake, and
- additional cost incurred for rehabilitation of inundated powerhouse of 2 MW Sunkoshi Hydropower plant and the damaged barrage of 10 MW Sunkoshi Hydroelectric plant by 2014 Jure Rock slide induced flood.

**Fig. 1: Tunnel collapse and water ingress of Khani khola hydro project and Bhote Koshi dam damaged by GLOF in 2016.**

Engineering Geology plays a major role in predicting georisks and providing valuable timely input in design to tackle predicted georisks. Georisks can be minimised and managed if georisks assessment process is considered from the very beginning. Georisks assessment process includes site investigations, construction of geological models and prediction of georisks whereas the mitigation process comprises design considerations to optimise the predicted georisks and sharing of unforeseen georisks by contractual practices. Engineering geology strongly influences almost every major decision for planning, site selection, design and construction of major structures in hydropower projects and other civil structures.

It highlights the importance of engineering geology to predict and mitigate the georisks, georisks with case studies, georisks assessment and mitigation by design considerations in the hydropower development of Nepal.

# Speleothems from Indian caves and their implication on Holocene Climate and Indian Summer Monsoon

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Speleothems from the Indian caves have been studied with special emphasis on their morphology, mineralogy, carbon and oxygen isotope data for the intensity of the Indian Summer Monsoon (ISM). The paleoclimatic events recognized in the NW Lesser Himalaya, Meghalaya in East India and Peninsular India includes, Last Glacial Maximum (LGM), Heinrich stadials, Bølling-Allerød(BA) and Younger Dryas (YD) periods. The Intertropical Convergence Zone (ITCZ) has been located over the studied caves during wetter/warmer season. Recently, a new Youngest Holocene Series is recognized in the Mawmluh cave of Meghalaya by International Commission on Stratigraphy. The Holocene Series is divided into three Stages of which the Meghalayan Stage is the Uppermost Holocene. It starts at 4200 years ago when agricultural societies around the world experienced an abrupt and critical mega drought. Speleothems are continental archives and provide important record of palaeo-climate and palaeo-monsoon during Quaternary – Holocene period. Speleothems are very well preserved in the caves of Indian sub-continent. The $\delta^{18}O$ record from the Mawmluh cave indicates a significant ISM variability in the Meghalaya, NE India. ISM strength is highly sensitive to mean latitudinal position of Inter Tropical Convergence Zone and controls the $\delta^{18}O$ of stalagmite significantly. The relationship between the Indian Summer Monsoon, Himalaya and Tibetan plateau is quite significant and discussed.

# Oral and Poster Presentations

# Quaternary offsets and slip rates along the western Nepal Fault System as evidence for active orogen-oblique deformation

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Neotectonic mapping along the ~350 km, northwest-southeast striking Western Nepal Fault System (WNFS) indicates orogen-oblique, right-slip deformation within the Himalayan thrust wedge. From northwest to southeast, the WNFS is comprised of three segments, 1) a northwestern right-slip segment that includes the Talphi and Tibrikot faults; 2) a central region comprised of oblique-slip faults including the Dhaulagiri Southwest fault, and a north-striking extensional stepover near Dhorpatan; and 3) a southern right-slip segment that includes the Bari Gad fault. The geomorphic evidence for active faults is observable at multiple scales. In the northern segment, the trace of the ~N40W striking Talphi fault traverses high topographic relief for >35 km and is expressed by prominent fault scarps with alternating facing directions, shutter ridges, and fault plane exposures. Field measurements and Infrared Stimulated Luminescence geochronology of feldspar-grain aliquots document a terrace riser that is younger than 177.3 ± 16.7 ka and is offset with 389 ± 29 m of dextral separation across the fault, yielding a minimum slip rate of 2.2 ± 0.3 mm/yr. In the central segment, glacial deposits are truncated and offset along the ~N55W striking Southwest Dhaulagiri fault, which is expressed by prominent fault scarps, deflected and offset streams, sag ponds, fault core exposures, and truncated metamorphic foliation over its >45 km length. Directly to the south, the north striking Dhorpatan fault is expressed by prominent fault scarps, shutter ridges, triangular facets, a 2 m wide fault gouge zone, fault plane exposures, an intermountain basin, and truncated metamorphic foliation over its >20 km length. In the southern segment, we document terrace risers and an abandoned channel that have been truncated and offset dextrally across the ~N30W striking Bari Gad fault, an ~100 km long structure that floors the linear river valley.

This project has documented evidence for Quaternary slip along the length of the WNFS, indicating active orogen-oblique, right-slip deformation within the orogenic wedge. We anticipate 10 sites will yield slip rates, data that will inform seismic hazard and risk models and our understanding of intra-wedge deformation.

**Keywords**: Neotectonics, Nepal, splay, fault, WNFS

# Geology and paleontology of the Siwalik Group around Arjun Khola area, mid-west Nepal

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The Siwalik Group of the Arjun Khola is divided into three litho units, the Lower Siwalik, the Middle Siwalik, and the Upper Siwalik in ascending order. Structurally, the Siwalik Group in the study area is divided into three belts namely southern, central and northern belts by Central Churai Thrust (CCT) and the Arjun Khola Thrust (AKT). Altogether eight species of plant mega fossils belonging to seven families are identified to their specific level. They are *Artocarpus arjunkholaensis*, *Bambusa siwalika, Bauhinia* sp., *Clinogyne ovatus, Daphnogene makumensis, Dipterocarpus* sp., *Shorea siwalika,* and *Lagerstroemia himalayaensis.* These plant fossils are from age late Miocene. The floristic assemblage of the study area suggests dominance of evergreen condition. On the basis of physiognomic features of fossil leaves, it implies that there was a tropical humid climate with MAT 30.84ºC and 32ºC and MAP 665.3 mm during late Miocene time. The analysis of present distribution and climate of closest modern equivalent of fossil taxa suggests that the climate of the late Miocene time was relatively wet than present day climate.

**Keywords:** Siwalik Group, Arjun Khola area, plant mega fossils, late Miocene

# Slope stability analysis along Mailung-Dhunche road section of Pasang Lhamu Highway

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The stability of the slope is one of the biggest challenges for geologists and geotechnical engineers, mainly in the Himalayan regions. The study area lies in the Lesser Himalaya, Mailung - Dhunche road section of Pasang Lhamu highway, with steep slopes of rocks and colluvium soil. The cut slopes along the highway in the study area are vulnerable to failure due to vertical cut sections and fragile geology. The area experiences rock falls and landslides on the roadside. A field survey has been carried out to understand the detailed geological and geotechnical conditions of the area. Laboratory experiments have been carried out to determine some geotechnical properties, cohesion, friction angle, plastic limit, and liquid limit of the soil and classify the soil according to the USCS. The limit equilibrium method has been used to calculate the safety factor of the slope in static dry conditions. Slope/W of the GeoStudio software has been used to prepare the slope models for the analysis. The cut slopes of highway made on the slopes of the colluvium soil having dominant silty sands shows the factor of safety between 0.44 to 0.518 even in dry condition. The study indicates that the slopes of the study area are likely to fail and need some protection measures.

**Keywords**: Slope stability, cut slopes, limit equilibrium method

# Stratigraphy of the Jajarkot Klippe, the Karnali Klippe and the midland succession of the Jajarkot district, western Nepal

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Geology of Jajarkot, western Nepal is explored and investigated by previous researchers in their regional scale mapping. There exist discrepancies among previous researchers regarding the boundary of the autochthonous unit and the overlying crystalline thrust sheet (Jajarkot Klippe and Karnali Klippe). The present Chheda- Saureni area, the southern and the middle portion of the Jajarkot district, was selected for the investigation with the objective to explore the geology and metamorphism in detail so that lithostratigraphy can be clarified that can helps in resolving the existing discrepancies. Four major routes and several subsidiary traverses were selected for primary data collection in the field for forty-five days followed by the preparation of the columnar section of each unit from different traverse, geological mapping, and petrographic analysis. The area can be classified into two different allochthonous units viz Jajarkot Klippe and Karnali Klippe and Midland succession. Midland succession is sandwiched between two allochthons by the Main Central Thrust (MCT) in the north and the Thalaha Thrust in the south. It isnomenclature as the Batulekhet Formation.It primarily comprises quartzite intercalated with metabasite, metasandstone, phyllite and schist. The Karnali Klippeis exposednorth of the MCT towards the northern portion of the study area compriseskyanite-garnet bearing gneissic succession. Jajarkot Klippe exposed south of the Thalaha Thrust can be categorized into three units namely Managar Formation with Chhera Diamictite, Karkigau Schist and Banskot Marble from oldest to the youngest. The klippe comprise the succession of quartz, schist, diamictite schist, metasandstone and marble. Rocks of the area are subjected to the chlorite to kyanite grade and also show inverted metamorphism. The metamorphism increases both upward and southward from the Midland succession which is located in between the Jajarkot Klippe and the Karnal Klippe. There is Bhoor Syncline and Suwa Khola Anticline. The boundary and lithostratigraphy of the Midland succession and the Jajarkot Klippe is revised. Most of the previous researchers have placed the klippe towards the eastern portion present Karkigau Schist and Banskot Marble. The present investigation extends the boundary more southward and westward based on the lithotype and metamorphism.

**Keywords:** Jajarkot Klippe, Karnali Klippe, midland succession, stratigraphy, metamorphism

# Geology and mineral resources of Holbang-Arkhabang areas of Gulmi Districts, Lumbini province, Nepal

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The Lesser Himalaya is geologically bounded by the Main Central Thrust in north and the Main Boundary Thrust in south. The Lesser Himalaya is a fold-and-thrust belt of the Himalaya. Few detailed geological studies conducted in the area have shown that the Lesser Himalaya has a high potential for metallic minerals like copper, iron, nickel, cobalt, lead, zinc etc. Present study has aimed to prospect the possible minerals resources from the Holbang-Arkhabang section of Lumbini Province of Nepal. For this purpose a detail geological mapping was carried out in 1:25,000 and the location of mineral deposits was shown in the geological map. Detail columnar sections are made to show the geological control of mineralization. Metallic minerals like copper, iron and cobalt are found in this region. Similarly, graphite, dimenstion stone and garnet are found as non-metallic minerals. The host rocks of these mineralization belongs to the Jajarkot Klippe.

**Keywords**: Lesser Himalaya, Potential, Metallic minerals, Geological control, Geological mapping

# Seismic source mapping by surface wave time reversal: Application to the great 2004 Sumatra earthquake

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Different approaches to mapping seismic rupture in space and time often lead to incoherent results for the same event. Building on earlier work by our team, we "time-reverse" and "back-propagate" seismic surface-wave recordings and study the focusing of the time-reversed field at the seismic source. Currently used source-imaging methods relying on seismic recordings neglect the information carried by surface waves, and mostly focus on the P-wave arrival alone. Our new method combines seismic reversal with a surface wave ray tracing algorithm based on a generalized spherical-harmonic parameterization of surface-wave phase velocity, accounting in principle for azimuthal anisotropy. It is applied to surface-wave signal filtered within narrow frequency bands that we can treat as "membrane waves": the inherently three-dimensional problem of simulating surface-wave propagation is thus separated into a suite of two-dimensional problems, each of relatively limited computational cost. We validate our method through a number of synthetic tests, then apply it to the great 2004 Sumatra-Andaman earthquake, characterized by the extremely large extent of the ruptured fault. Many studies have estimated its rupture characteristics from seismological (e.g., Lomax, 2005; Ni et al., 2005; Guilbert, 2005; Ishii et al., 2005; Krüger & Ohrnberger, 2005; Jaffe et al., 2006) and geodetic (Banerjee et al., 2005; Bletery et al., 2016; Catherine et al., 2005; Vigny et al., 2005; Hashimoto et al., 2006)data. Applying our technique to recordings from only 89 stations of the Global Seismographic Network (GSN) and band-pass filtering the corresponding surface-wave signal around 80s-to-120s, 50s-to-110s and 40s-to-90s, we confirm the findings of earlier studies, including in particular the northward direction of rupture propagation, its approximate spatial extent and duration, and the locations of the areas where most seismic energy appears to be released.

# Petrography and mineralization of granite: A case study on Palung Granite, Lesser Himalaya at central Nepal

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The Palung Granite is the lenticular granitic body of Cambro-Ordovician leucocratic type of medium- coarse grained granite originated at shallow depth. The Palung Granite lies at Mahabharat range of Lesser Himalaya of Central Nepal with the metamorphosed sedimentary facies consisting with the rocks such as marbles, quartzites and schists. The granite was studied by thin section and chemical analysis in the laboratory with plotting QAP diagram and Harker's diagram with geological mapping. This paper was investigated petrology and mineralization of Palung Granite in Lesser Himalaya at Central Nepal. This paper revels the grain size (few mm to few cm), mineral composition (quartz, feldspar, tourmaline, biotite, muscovite) of the Palung Granite for the classification of Lesser Himalayan granite. The zoning of granite body using QAP data is differentiated into tonalite, granitoids and quartz rich granitoids. The granite is not so change megascopic but it differs microscopically and chemically. The granite has been separated into several zones depending upon dominancy/appearance of mineralogical constituents like quartz, feldspar, biotite, muscovite and tourmaline.

**Keywords:** Lesser Himalayan Granite, Palung Granite, leucogranite, porphyritic granite, Cabro-Ordovician granite

# An experimental analysis to assess temperature distribution using Rayleigh-based optical frequency-domain reflectometry: a step towards groundwater flow monitoring in vulnerable slopes

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Distributed temperature measurements were performed in a cylindrical mortar specimen using Rayleigh-based phase-noise compensated optical frequency-domain (PNC-OFDR) sensing method with a spatial resolution of 3 cm, a temperature resolution of 0.1 °C, and a data acquisition period of 2.5 ms. Experimental phases at different stages of heating power to locate the position of supplied water were carried out. The suitability of low heating power, three different stages of temperature change (rapid, fast, and gentle), and challenges in establishing data consistency were explored. On naturally occurring slopes, the functionality of such a sensing approach with high processing speed and quick acquisition time for groundwater flow monitoring can be proven.

**Keywords:** Temperature sensing, water activity monitoring, optical frequency-domain reflectometry, rayleigh scattering

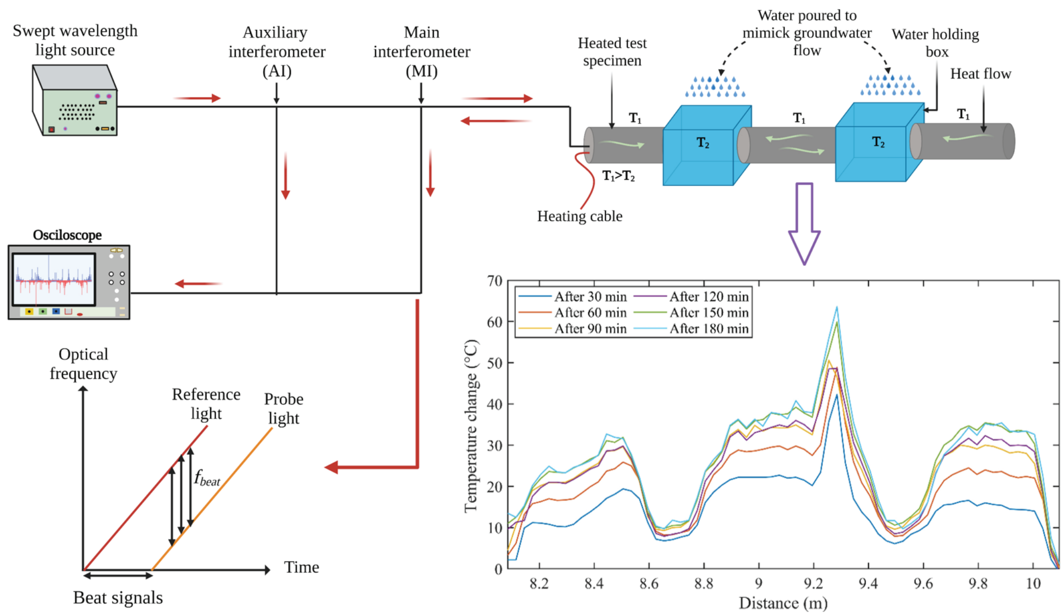


**Fig. 1: Distributed temperature measurements using novel Rayleigh-based OFDR sensing.**

# Mountain hydrogeology in Bhimgethi-Devisthan section of west-central Nepal along Badi Gad Fault

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Mountain springs are the sole dependable sources of water in the hilly region for peoples' daily needs. The present study focuses on the hydro-geological scenario along the active fault zone. Based on the fieldwork with a questionnaire survey, the study examines the characteristics of natural mountain springs with regard to geology, discharge rate, slope, aspect, elevation and electrical conductivity. All the surveyed springs are perennial and two-thirds of springs are concentrated in mid-altitudes (1200 m to 1700 m). About 71 % springs are fracture and fault dominated, so the fractured and deformed rock significantly controls the groundwater occurrence. Our study has shown that the water volume of springs around the fault zone has decreased greatly over the last decade and some springs are shifted to the lower elevation because of shear-induced landslides.

Fault zones can act as either a conduit or a barrier to groundwater flow. The trends of faults, joints and fractures in relation to the local hydraulic gradients can significantly affect groundwater flow. As being fracture-dominated damage zone and clay-rich gauge and breccia, the numerical measure of fault zone architecture and permeability structure shows the conduit-barrier fluid flow system. The damage zone constitutes fractured zone which permits the recharge of rainwater while the core acts as a barrier particularly in the southern half of the study area. The high value of electrical conductivity also supports the result of a barrier-type fluid flow system in the southern section through the fault core. The spring sources with silicified breccia suggest the conduit flow system in the northern section. The fault zones have a considerable effect on spring sources throughout the study area in terms of their origin, discharge rate and flow direction.

**Keywords**: Mountain hydrogeology, springs, Badi Gad fault, Fault zone architecture, permeability structure

# Lamjung 2020 seismic crisis and recent seismicity monitored in Nepal

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Nepal is exposed to large (M7+) and great (M8+) devastating earthquakes which rupture partially or totally the updip locked fault segments of the Main Himalayan Thrust, the plate boundary fault that accommodates the shortening between India and the Tibetan plateau. In addition to these infrequent strong earthquakes, more moderate seismic sources happen frequently exposing areas at close distance from epicenters to strong ground motion and eventual destruction. The National Earthquake Monitoring and Research Center (NEMRC) under Department of Mines and Geology (DMG) is in charge of rapidly locating and informing the governmental authorities and the public about these significant earthquakes when they happen on the Nepalese territory. 390 seismic alerts for earthquakes greater than 4 were delivered to the authorities between 1994 and April 25th 2015, date of occurrence of the large M7.8 Gorkha earthquake. Since Gorkha earthquake, 645 new alerts were provided to the authorities and to the public, while more than 50,000 smaller aftershocks were located by the seismic analysts. On May 18th, 2021 at 23h57UTC (5:42AM local time), a moderate earthquake of ML 5.8 shook central-western Nepal from Pokhara to Kathmandu, within 100 km from the macroseismic epicenter, and was felt in India up to 400 km away at Rae Bareli and Lucknow. The mainshock occurred a few kilometers west from the epicenter of the Gorkha earthquake. The strong shaking damaged several houses, injuring some people. It was followed by a ML 5.3 earthquake that happened within less than 3 hours and 4 other earthquakes with magnitudes greater than 4 within 24h. All these earthquakes were widely felt by the local population. Several smaller earthquakes were also felt in the vicinity of Lamjung – Bensisahar in Marsyangdi valley, attesting for the relatively shallow depth of the seismic sources. In this work, we document the spatiotemporal sequence of this seismic crisis, using various location techniques. We finally discuss the relation of these earthquakes with the midcrustal geological structures, and their implications.

**Keywords**: Aftershocks, Microseismicity, Earthquake location, Nepal Himalaya, Seismotectonics

# Geology of Lesser Himalayan rocks around Dadeldhura-Baitadi area, far western Nepal

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Geological mapping, structural analysis and petrographic study were carried out around the Dadeldhura-Baitadi area, Far Western Nepal. The area is covered by the rocks of the Lesser Himalaya. The Dadeldhura area comprises crystalline rocks such as garnet schist, gneiss, and granite whereas the Patan area of Baitadi is covered by quartzite and slate. Carbonate rocks appear in the northern part of Baitadi up to the border with the Darchula district.

Around Patan, north of Anarkholi, quartzites and slates are intensely deformed and in them superposed folding is noticed. The Melauli area (west of Patan Bajar) is covered by the early Tertiary succession which is made up of red-purple or brown mudstone and shale interbedded with grey-green sandstone. Light grey limestone beds having Formainifera (Nummulites and Assilina) are intercalated in green-grey shale with bivalves. These fossils indicate an Eocene age (Fig. 1).

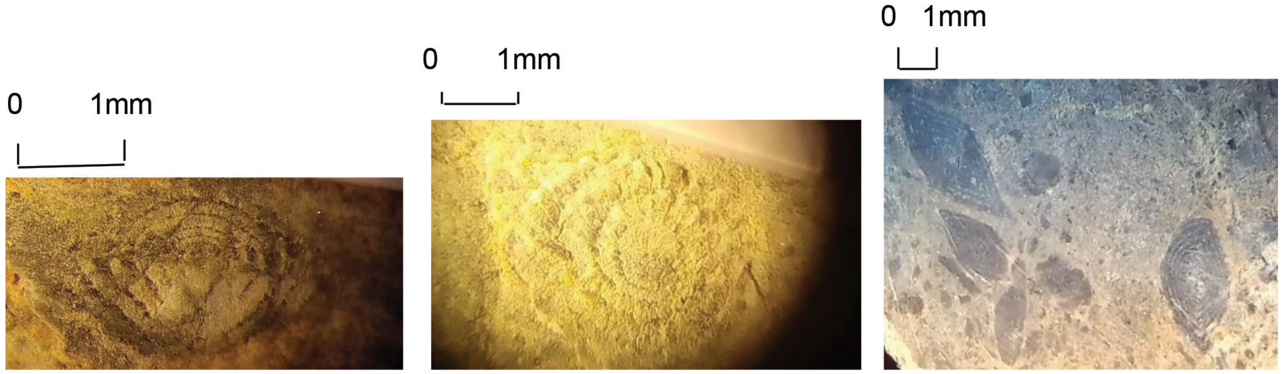


**Fig. 1: Foraminifara fossils observed in grey limestone.**

**Keywords**: Nummulites, Dadeldhura, Baitadi, Lesser Himalaya

# Causes, effects, and potential future effects of the Pallotari Landslide of Marsyangdi Rural Municipality in Lamjung, Nepal

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This study explores the causes, effects, and potential future effects of the Pallotari landslide at Marsyangdi Rural Municipality in the Lamjung district. The area was triggered by a series of rainfall-induced landslides in July 2020 which is located at Lesser Himalaya of Nepal Himalaya. This research has been conducted based on specific geological and engineering geological methodologies to identify the failure mechanism of landslides, their effects, and potential management and mitigation operations of the landslide-affected area. Further, the landslide has been characterized, and potential causes and mitigation strategies have been identified based on fieldwork and laboratory work. Intensive rainfall, steep topography with loose colluvial soil, and some anthropogenic activities such as the construction of the rural road through the crown area are found to be major causes of the landslide. The rock slope stability analysis has shown no major influence of the discontinuity orientation on the slope failure. The study area still has hanging colluvial material on the crown and it seems to be unstable during the dry season based on the limit equilibrium method of the slope stability analysis. The old colluvial material on the middle portion of the landslide also has the risk of failure during the saturation condition due to intensive rainfall. There are several transverse and longitudinal cracks in the peripheral region of the landslide, which are creating the risk of failure in the future. The slope stability can be improved by adding mitigation structures with the addition of instrumentation and regular monitoring. The cost-efficient and long-term solution seems to be the re-location of houses from the high-risk area.

**Keywords**: Pallotari Landslide, slope stability, limit equilibrium method

*Journal of Nepal Geological Society, 2022, Vol. 64 (Sp. Issue)*

# Geological contact between the Dhading Dolomite and the Benighat Slate in the Lesser Himalaya of Nepal: An implication for stratigraphy setup and geological mapping

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The rocks of the Lesser Himalaya are folded and thrusted in nature. The rock succession of this unit is devoid of fossils and scanty in nature except some well-preserved stromatolites in the carbonate rocks. This has made a great trouble in stratigraphy set up and preparation of geological maps. Some of the previous researchers have put the erosional contact between these two geological units, while some other researchers have a view that there is a transitional contact. Thedivision of the autochthonous rocks into the Lower and Upper Nawakot Group is an issue in geological mapping as well as the interpretation of chronology of the rocks. To solve this issue, present study was aimed to verify the geological contact between two above mentioned units from the several sections of central and western Nepal. In this study, the detail geological investigation was made in Labdi Khola-Bhut Khola section of Tanahun district, Jugedi section of Chitwan district, Thopal Khola section of the Dhading district, and Budhi Gandaki sections in Gorkha district, central and western Nepal. Detail bed to bed observation was made with appropriate columnar sections of rocks to show the contact relations. Interestingly, the contact between the Dhading Dolomite and the Benighat Slates is found perfect transitional in nature except in the Budhi Gandaki and the Thopal Khola sections where a sharp contact is observed. However, there is not any sign of erosional boundary between these two units. Present study shows that the division of the autochthonous rocks of the Lesser Himalaya under the Lower and Upper Nawakot Group is not appropriate, and it should be revised accordingly after proper verification even from other sections of the Lesser Himalaya.

**Keywords:** Stromatolites, stratigraphy, Nawakot Group, Lesser Himalaya

# PAHIRO ALERT: A new approach for community based-landslide early warning system in the Nepal Himalaya

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Nepal Himalaya has experienced several disasters induced by both natural and anthropogenic hazards resulting in the loss of lives, properties, infrastructures, and natural assets. Nepal's geographic setting, rugged terrain, topography, hydroclimatic condition, and haphazard urbanization place the country in precarious high-risk areas. Among them, landslide is one of the major hazards, which is increasing in recent decades due to coupling effect of active seismo-tectonic and Asian monsoon along with anthropogenic activities. Whenever a landslide gets triggered, the severity of the impact depends on the existing exposure, sensitivity and vulnerability of the elements-at-risk and are found severe in highly vulnerable communities. The risk of landslide can be reduced by either structural measures or non-structural (community-based early warning system). Therefore, this study has selected a mountainous community in Naraharinath Rural Municipality, Kalikot District, Nepal. The landslide susceptibility, element at risk and vulnerability at household level were analyzed to calculate the risk. The calculated landslide risk was classified in to high, medium and low. The historical data of landslides were used for the determination of landslide thresholds. Then, the 3-days forecast data of Department of Hydrology and Meteorology, Government of Nepal was used for the development of readiness and action trigger. The real time data is automatically loaded in the web and mobile application (PAHIRO ALERT) for the warning (Fig. 1). The user can explore the rainfall amount and the landslide risk in the real time spatial location. The notable deviations from the forecast and nowcast/observed data can signify the chances of false alarm or any abrupt event. Further, the Report feature of this application is very useful in documenting and archiving the spatial landslide events in the given location. Another important component for landslide prediction in a particular region is determining the areas that are highly susceptibleto landslide.

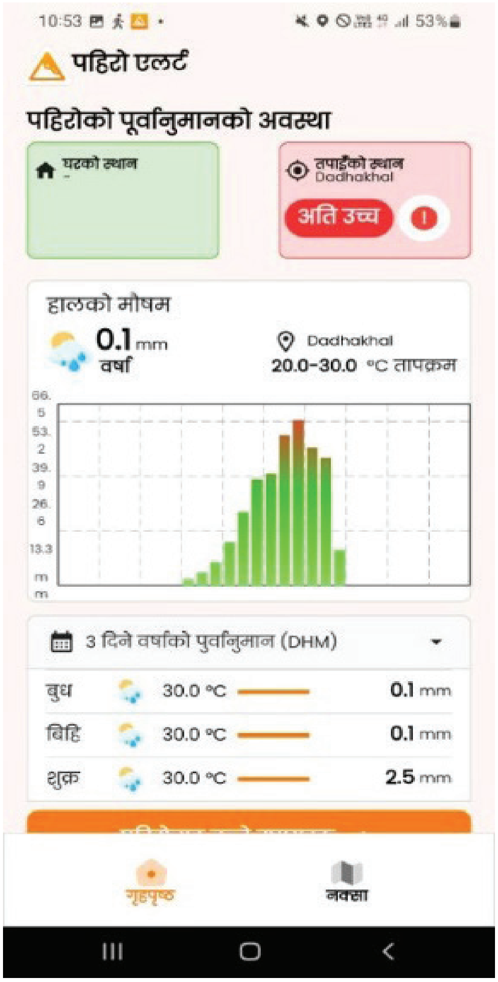


**Fig. 1: Display page of PAHIRO ALERT mobile application.**

**Keywords:** Landslide, early warning system, risk assessment, weather

# Application of direct shear test for shear strength behaviour of landslide soil from the Siwalik Hills of Nepal

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The shear strength of the soil plays a vital influence in the slope stability and failure mode. Thousands of landslides occur in the Siwalik Hills during the Monsoon season as a result of physical and hydrological interactions that modify the shear behavior of slope soil. The direct shear test was used to explore the soil shear strength characteristics and associated parameters from 102 landslides of the Babai River catchment of Siwalik zone. Among the 756 landslides, 102 new and active landslides were selected in such a way that the sampling location covered the total study area. The direct shear test was conducted by using normal stress 20 kPa, 40 kPa, and 60 kPa respectively. The peak shear stress and normal stress were used for Mohr Column Failure criteria. The empirical relation between shear strength, angle of internal friction, and cohesion was used to get the value of shear strength. After a laboratory test and empirical relation between the shear strength parameters, correlation and regression analysis were conducted. The shear strength was taken as the response variable whereas the angle of internal friction and cohesion were taken as predictor variables. The results of empirical relation and statistical analysis were compared.

The shear strength value of the study area was found between 22 kPa to 48 kPa. Most of the values are found between 30 to 35 kPa. The cohesion value was obtained between 2 to 12 kPa. Similarly, the angle of internal friction was found from 12 to 38 degrees. The correlation and regression analysis showed that the shear strength has a significant positive relation with cohesion and angle of internal friction. The value distribution of shear strength parameters and statistical analysis showed that the direct shear test is applicable for the shear strength behavior identification and analysis of landslide soil.

**Keywords**: Landslide, Siwaliks, direct shear test, shear strength behaviour

# Spatial characteristics of large-scale landslide in central Nepal Himalaya

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Nepal Himalaya is characterized by complex geology which is one of the major factors that control the occurrence of large-scale landslides. The research study is intended to evaluate the spatial characteristics of large-scale landslides in the central Nepal Himalaya in terms of various influencing factors. Several landslides were extracted by interpretation of satellite imageries and field observations. Historic evidence of landslides was compiled to analyse their characteristics from the feature of their coverage, dimension, mechanism, and impact. The analyses have shown that most of the large-scale landslides occurred within variable rock strata from Higher Himalayan Crystalline Zone and Lesser Himalayan phyllite, schist, and meta-sandstone. Also, it is found that thrust/fault proximity and inter-layering characteristics of rock sequence have contributed a key role for the spatialisation of landslides in different geo-tectonic units of the study area. The slope characteristics concerning to the major discontinuities within rock strata have significant influence to cause occurrence of large-scale landslides. The valley slopes of river banks as well as rugged hill-slopes are more prone to the initiation and propagation of landslides. The significant number of large-scale landslides are distributed in favourability situations of geologic domain. Topographic factors have a moderate influence, and land-cover changes and human activities are contributing factors to the occurrence of landslides. Thus, it is concluded that the geological factors play a vital role in the spatial pattern of large-scale landslides together with causative and triggering factors (rainfall, earthquake).

**Keywords**: Large-scale landslide, spatial characteristics, causative/triggering factor, central Nepal

# Rock mass quality assessment of proposed Hemja–Patichaur road tunnel, Nepal

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Identification of rock mass quality is important for the safety, stability assessment, and proper design of underground spaces. This paper aims to categorize the rock mass quality for the proposed 13 km long road tunnel alignment along the Pokhara-Baglung Highway which is extended from the Southeast (Hemja, Kaski district) to the Northwest (Patichaur, Parbat District), Gandaki Province, Nepal. For this purpose, engineering geological field mapping has been conducted. The dominant rock type along the alignment is deformed Phyllite, Medium to thick-bedded Quartzite, and Metasandstone comprised at the northwestern portal and central part of the study area. Most of the outcrops dipping northwest along the tunnel alignment are slight to moderately weathered and medium-grade metamorphosed. The uniaxial compressive strength was measured as 35 to 45 MPa for Phyllite and 135 to 150 Mpa for Quartzite and Metasandstones. The rock mass quality was assessed using both RMR and Q- system of rock mass classification methods. The study concluded that the RMR values ranged from 31 to 77 and Q-systems ranged from < 1 to 11.5. The values reflect the rock mass class varies from good to extremely poor.The variations in quality are due to the varying weathering conditions, varying frequency of discontinuity occurrence and, their alterations and infilling conditions.

**Keywords:** Tunnel, discontinuities, rock mass quality, RMR and Q-system

# Application of vertical electrical sounding (VES) for assessment of groundwater potential at Bhimdatta municipality, Kanchanpur district, Nepal

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Vertical Electrical Sounding (VES) survey using Schlumberger array of electrode configuration was carried out with the aim of groundwater exploration at Bhimdatta Municipality of Kanchanpur District. Four Vertical electrical sounding survey with maximum current electrode spacing ranging from 700 m to 1000 m was conducted. WDJD-4 Multifunction digital resistivity meter was used for data acquisition. Acquired data were analysed and interpreted using IPI2Win Software. At the Ward no. 18, the results of the survey reveal the presence of eight to nine geoelectric layers. Top layer comprises of dry soil with sand, gravels and boulders with thickness of layer 3 m -3.5 m. Second layer with low resistivity value of 112 ohm-m represents silt, fine sand layer with thickness around 2 m. The underlying layer with resistivity value 1056 ohm-m revel the presence of gravel, boulders layer with thickness 6- 6.5 m. Underlying layer with resistivity value 75.4 ohm-m represents silt, fine sand layer with thickness of 14.5 m. The resistivity value of 664 ohm- m represents gravel, pebble and cobble. Saturated layer of sand and gravel is expected from depth of 50 m to 120 m which is represented by low resistivity value of 52-250 ohm-m. Below 120 m depth, saturated fine sand layer is expected which is represented by very low resistivity value of 33 ohm-m. The underlying layer with resistivity 341 ohm-m represents saturated gravel with boulders. This result shows the presence groundwater at a depth of 50- 120 m in the area. At Ward No. 02, the results of the survey reveal the presence of 5 to 6 geoelectric layers. Top layer comprises dry soil with silt and clay with thickness of 5-6 m. Second layer with high resistivity value 317 ohm-m represents sand and gravel layer with thickness of 6-6.5 m. The underlying layer with low resistivity of 65 ohm-m reveals fine sand layer with thickness of 47 m. A saturated layer of sand and gravel is expected from depth of 50 to 55m depth and extend up to 130 m depth which is represented by resistivity value of 215 ohm-m. Below 130 m depth, saturated sand dominant layer is expected. This result shows the presence groundwater at a depth of 55- 130 m in the area.

**Keywords**: Groundwater, VES survey, aquifer, alluvial deposit, resistivity, saturated layer

# Spatio-temporal changes in the stress regime on the seismogenic zone of 2015 Gorkha Earthquake

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The continuous Continent-Continent active collision of the tectonic plates can be observed in the Himalayan orogen belt which can be compared with the subduction region as the Indian subcontinent is seen to be subducted and assimilated under the Eurasian plate. Therefore, the region is under the constant accumulation of the compressive strain with respect to time, which from time to time exceeds the threshold strength of the underlying rheology and relieves the energy with the generation of the Himalayan earthquakes. The segmentation of the Himalayan orogen belt throughout the time into different seismogenic zone has produced various mega-scale earthquakes as a part of the seismic cycle of the Himalaya. On 25th April 2015 Gorkha Earthquake relieved the stress of the central seismogenic zone of the Nepal Himalaya which also changed the stress regime on a temporal basis of the region and played a role in inducing the largest aftershock on 12th May in the Dolakha region.

Because the largest aftershock of the 2015 Gorkha event occurred in a different time and location, the relevance of the aftershock was also separately studied in different spatio-temporal bases with respect to the Gorkha region. The pre-seismic stress ratio was calculated to be R= 0.7 which after the main event for 17 days was calculated to be R=0.6 for the Gorkha region and R=0.15 for the Dolakha region. However, after the 17days of the main event, the stress ratio for both regions was calculated to be R=0.35. Similarly, the principal stress vectors for the pre-seismic event were calculated to be $\sigma 1=199^o/\ 15^o$, $\sigma 2=290^o/\ 04^o$ and $\sigma 3=035^o/\ 74^o$ which changed after the Mw 7.8 event for 17 days in the Gorkha region to be $\sigma 1=209^o/\ 40^o$, $\sigma 2=104^o/\ 17^o$ and $\sigma 3=356^o/\ 45^o$ and $\sigma 1=183^o/\ 37^o$, $\sigma 2=276^o/\ 04^o$ and $\sigma 3=011^o/\ 53^o$ in the Dolkha region. After 17 days the principal stress vectors of the Gorkha region were calculated to be $\sigma 1=177^o/\ 08^o$, $\sigma 2=084^o/24^o$ and $\sigma 3=284^o/\ 65^o$ and $\sigma 1=191^o/\ 26^o$, $\sigma 2=098^o/\ 06^o$ and $\sigma 3=357^o/\ 63^o$ were calculated for Dolakha region.

The change in the stress ratios of the Gorkha region and Dolakha region after the mainshock for 17 days shows the region to be temporally affected. However, the stress ratio returned to be equal after 17 days on both regions show that the Gorkha event and Dolakha event are the events of the same seismogenic zone. The stress vectors also agree with the result that for the 17 days the region got temporally affected such that the minimum principal stress vector plunged less than $60^o$. This refers the region to have an undefined stress regime. The results show that the seismogenic zone was initially under the near Uniaxial Compression stress regime. The regime in the Gorkha region and Dolakha region both got undefined stress definitions for the 17 days which were identified to have near Radial Compression afterward. The stress vectors change in Spatial and temporal basis is shown in Figure 1.

The intermediate stress vector has also shed light on the rupture propagation within the seismogenic zone and can be one measure to pre-identify the rupture propagation for the seismogenic zone after the big event. The pre-seismic stress tensors show that the major principal stress is acting in the North-South direction, while if the rupture were to occur will occur along the plane transecting intermediate principal stress vector and minor principal stress vector. Interestingly, the azimuth between Dolakha and Gorkha is $293^o$ which is nearly equal to the direction vector of the intermediate stress which can be used to infer the rupture propagation Hence, even in the plane of rupture the region with intermediate stress is the region with high stress so as for the rupture propagation will less likely to propagate towards intermediate stress. The plunge of the intermediate stress of the pre-seismic period was found to be $04^o$ which is shallow dipping, thus can be assumed to rupture large aerial distance compared to high angle dipping.

The change in the stress regime from Uniaxial Compression to the undefined regime to Radial Compression demarcates the change in the stress regime of the seismogenic zone with the main event in the region. The change in stress environment after the Gorkha event can help us infer qualitatively that the region is safe for some time to bear another mega event in the same seismogenic zone and is safe to assume that the seismogenic zone has now entered the new interseismic cycle.

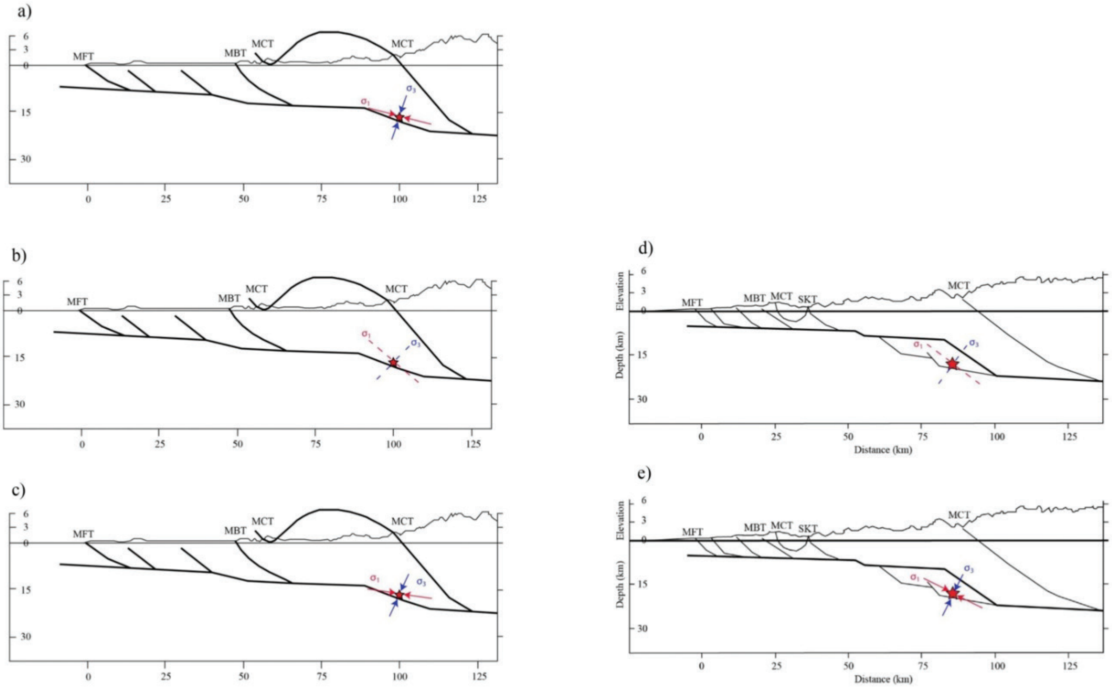


**Fig. 1: Stress change interpretation and schematic rupture propagation in the Seismogenic zone of 2015 Gorkha Earthquake. Figure (a-c) denote Gorkha region and Figure (d-e) illustrates Dolakha region. (Modified after Kumar et al., 2017).**

**Keywords**: Gorkha, earthquake, Dolakha, spatio-temporal change

# Using stable water isotopes to untangle the central Himalayan hydrological cycle

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With global climate change, one of the largest short-term threats to our societies comes from a changing water cycle. Yet, tracing water through landscapes, from rain to river discharge, is challenging, especially in mountain regions. Stable water isotopes offer a good tool to trace water through the water cycle from its evaporative sources, through the atmosphere, into rain and its partitioning into different terrestrial water storage compartments. Stable isotopes have been used to trace the sources of water and also to untangle the transport processes. In this contribution we present data from the Kali Gandki River Catchment in Nepal, spanning a transect across the Himalayas, from the wet south facing slopes to the dry high elevated terrains north of the Himalayan range. Along this transect we have installed two hydrological sampling stations, one located at Lete (north) and one at Purtighat (south), where we sample river water with daily resolution since 2014. This is complemented by grab sampling of springs, rain, ice, snow, tributaries and rivers covering all seasons. We show that 1) the isotopic signature of the river is strongly buffered by a well-mixed groundwater reservoir. 2) Moisture sources and transport processes determine distinct pre-monsoon and monsoon rainfall isotopic signatures. 3) Most likely water recycling in the Gangetic plain sets the isotopic composition of pre-monsoon rainfall across the central Himalayas. To further explore the pre-monsoon evaporative moisture sources and the transport processes to the central Himalayas we have installed an automated rainwater sampling transect along the Kali Gandaki River, from May to August 2022. With this high-resolution automated rainfall sampling we aim to show the isotopic transition from pre-monsoon to monsoon precipitation and track back the rain to its evaporative sources. Our findings will help to better understand the Hydrological cycle in the Himalayas and its sensibility to changes of the regional rainfall distribution.

**Keywords**: Monsoon precipitation, stable water isotopes, mountain water cycle, Himalayas

# Filling the timescale gap: quantitative Sub-Himalayan deformation rates on 100 kyr-timescales

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The ongoing contraction across the Himalayas and interseismic locking along the Main Himalayan Thrust (MHT), the basal detachment of the Himalayas, causes accumulation of elastic strain that is released by Mw 8+ earthquakes that propagate under the Sub-Himalayan fold-and-thrust belt (FTB), and have catastrophic impact on the local population. The Main Frontal Thrust (MFT) is the youngest regional fault system of the Himalayan orogen, and the current active deformation front in most of the Himalayas, accommodating about half, i.e. 12-23 mm/yr, of the convergence between the Indian and Eurasian tectonic plates by uplift and deformation of the Sub-Himalayas.

Whilst GPS measurements constrain modern ($10^{\leq 1}$ yr) deformation rates in the Sub-Himalayan FTB, and geomorphological and geological studies constrain Holocene ($10^{2-4}$ yr) and Myr ($10^{\geq 6}$ yr) timescales deformations, almost no quantitative data are available that constrain deformation rates at 10-100 kyr timescales, despite the proposal that deformation rates vary episodically over geological timescales and that out-of-sequence activity occurs for some faults. Filling this knowledge/timescale gap is thus crucial to better understand Himalayan tectonics that underpin seismic hazard models in this densely populated region.

Here we apply luminescence thermochronometry over a large geographical area of the Sub-Himalayan FTB ranging from western Nepal to eastern Bhutan to resolve deformation at sub-Quaternary timescales ($10^{4-5}$ yr), a timescale hitherto inaccessible to other techniques. Our luminescence thermochronometry samples yield exhumation rates of ~3-11 mm/yr over the past ~200 kyr for the Sub-Himalayan FTB. These values can be converted to minimum cumulative thrust slip rates and horizontal shortening rates of ~6-22 mm/yr and ~5-19 mm/yr, assuming a thrust dip angle of 30°. These results show that although the faults of the Sub-Himalayan FTB, and particularly the MFT, are active and accommodate most of the convergence across the Himalayas since at least 200 kyr, activity is also locally recorded intra-wedge, on the Main Dun Thrusts (MDT), throughout this time period. This imply that internal deformation of the orogenic wedge and strain partitioning may have occurred, potentially endangering an entire population.

**Keywords:** Himalaya, tectonics, thrust, quaternary, luminescence thermochronometry

# Hydrogeochemical assessment of the spring water along the Siwaliks of the Kankai River Basin, east Nepal

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The hydrogeochemistry of the spring water is the outcome of the complex interaction of various physical and chemical environments, which the subsurface water encounters from the initial stage of recharge through the passage and storage in different geological materials. The spring water from the Siwaliks of the Kankai River Basin has been analyzed for major ionic concentrations using the standard analytical procedure. The hydrogeochemical assessment of the spring water includes the characterization of spring water along with the quality assessment for drinking and irrigation purposes. The Piper diagram reveals that in 61% of spring water alkaline earth metals (Ca and Mg) dominates alkali metals (Na and K) and in 56% of springs strong acids ($Cl+SO_4$) dominate over weak acid ($HCO_3$) indicating permanent hardness. The trilinear plot for hydrogeochemical facies classified 28% of springs as Ca+Mg- $HCO_3+CO_3$ type, 33% as Na+K - $Cl+SO_4$ type, and 39% as mixed type with no cation-anion pairs exceeding 50%. The Gibbs plot suggests that the majority of groundwater in the area falls under the rock water interaction domain with meteoric origin. The chloro-alkaline indices indicate that 75% of springs water exchanges $Na^+$ and $K^+$ with $Mg^{2+}$ and $Ca^+$ from rocks. The assessment of water for drinking purpose using the Weighted Arithmetic Water Quality Index suggest most spring with good quality except one with poor quality. The Wilcox plot shows that all the water samples belong to the "Excellent to good category" for irrigation use, whereas the USSLS's plot suggest low salinity and alkalinity hazard except for 4 springs with medium salinity hazard. The water quality is good for drinking and irrigation, however, proper attention is required to conserve these resources for sustainable use.

**Keywords**: Hydrogeochemistry, spring water chatacterization, Water Quality Index, Siwalik

# Connecting innovation and source conservation for meeting water needs: A hydrogeological study-based source conservation planning in solar MUS in Surkhet district, Nepal

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Springs are the major sources of water in Nepal, but the springs are drying up fastdue to, among others, climate change, ill-engineered infrastructures, and associated disasters. A huge sum of money is invested in water supply projects and a significant percent of thosebecomenonfunctional due to source drying. Most of the projects consider the supply side only- not the sustainability. By that, the scarce public investment is wasted. Hydrogeological aspects including climate change, source conservation never had been realized. Once the sources dry up, projects become redundant frustration. People look for alternative sources requiring scarce public investment. Therefore, Government of Nepal and development partners like Renewable World concluded that the sustainability of water projects is crucial and must be considered at the initial phases of project development. It can be assisted and achieved by hydrogeological evidence based water source conservation planning. To implement it, an interdisciplinary research team of Nepal Water Conservation Foundation and RW conducted a hydrogeological study including the climate impactsand participatory planningapplying different tools/methods applied in social and natural sciences including hydrogeological study, key informant interviews, focused group discussions and policy assessment. Consequently, 10 site-specific source protection and conservation plans for solar MUS schemes were developed.

The study found four types of variables: i) Precipitation and temperature: There was no significant impact of climate change in terms of rise in temperature and precipitation; ii)Problems related to conservation: The major problems included drying up and displacement of springs by flood, landslide and road constructions; pollution through agricultural runoff, livestock grazing, and contamination by pesticides and chemical fertilizers; disappearance or conversion of traditional wallowing/recharge ponds; contamination and damage by flood; iii) Innovation: Even a small innovation like Solar MUS can contribute in people's life significantly through lifting water from downhill sources; iv) Planning: Source protection and conservation plan can be formulated democratically and owned by local government and water users and implemented jointly.

**Keywords**: Water, source, water project, hydrogeology, research, conservation, plan, solar MUS

# Contribution of geo-scientific knowledge and geologist in water resources sector in Nepal

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Nepal is rich in water resources and is of prime importance for the prosperity of the country. Young and fragile Himalaya is the situation of Nepal. Geo-scientific contribution on identification, investigation and analysis is solely dependent and important for selection, design and implementation of water resource project in a sustainable way. Remarkable numbers of geologists are in different capacities and being directly involved both in government and private sectors in water resources development. Water Induced disaster management is being critical and most alarming issues in the context of Nepal mainly in landslide disaster management. Proper and in depth geological and geotechnical investigation and analysis is mostly demanding for effective water resource induced disaster management.

Geologist are involved in the irrigation (surface and groundwater irrigation) development, hydropower development, water induced disaster management.

Geological and geo technical knowledge is being used in surface irrigation mainly on-site selection for headworks, canal and/or tunnel alignment, need of canal lining, geotechnical design parameters for headworks and other structure, depth of foundation, tunnel support design etc.

Hydrogeologists have been solely involved in the development of groundwater irrigation since the 1980s. Hydrogeological knowledge is being used in subsurface geological investigation, selection of type and depth of tubewell, design of tubewell, optimum utilization of ground water, implementation of tubewell etc. Year-round irrigation and conjunctive irrigation system is the motto of the groundwater irrigation which is the main backbone for the increase in production and productivity.

The role of geological and geotechnical study and investigation in hydropower development cannot be overstated. Hydropower development in Himalayan region is the main concern and issue due to the geological situation of our country. Since it is impractical to discuss a change to our geological situation it should be addressed properly in investigation, design, construction and operation of different structures e.g. headworks, water conveyance systems, and power house site so as to stand above this and continue our overall development.

Water induced disaster in increasing day to day mainly due to unscientific land use and improper infrastructure development. Involvement and contribution of geologist in water induced disaster management mainly in vulnerable landslide management. Geological knowledge is used on identification of landslide prone zone, reason of land slide & proper mitigation from landslide.

Now about 140 geological professions from field level to policy level are involved in government sector both in central and province level and about 300 geological profession are directly involved for private sectors in water resources' development.

# The drivers of small-scale drip tectonics and proto-plateau development within the Tethyan orogen

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We propose a general model for the drivers of small-scale drip tectonics and proto-plateau development along the Tethyan orogen based on a synthesis of geologic, geochemical, geophysical, and geomorphological datasets from the Central Anatolia Plateau, Turkey. We hypothesize that the development of internally drained, low relief, moderate-to-high elevation plateau interiors can be partly explained by the growth and foundering of dense eclogitic roots (drip tectonics) along thickened suture zones during piecewise, peripheral-arc, foreland propagating structural imbrication of allochthonous terranes. In general, a syn-collisional (?) breakoff event along an active subduction zone underplates the accretionary prism with basaltic melts during a 10–15 Myr isotopically juvenile magmatic pulse. Post-breakoff isostatic rebound of subducted continental lithosphere drives crustal thickening and translates the accretionary prism to the orogenic hinterland during a 1–5 Myr isotopically evolved magmatic lull. During the magmatic lull, the region of underplated basalt metamorphoses into eclogite, depressing a ~10,000 km$^2$ elliptical swath of the uplifted accretionary prism. Dynamic subsidence in the hinterland is recorded by (?)syncontractional siliciclastic, evaporite, and carbonate lake deposits up to 1 km thick. Upon foundering of the eclogitic welt, a 10–(?)20 Myr bi-modal, adakite-like magmatic pulse nucleates adjacent to the structurally inverted lake deposits. Post-foundering mantle return flow drives protracted uplift, tension, and drainage reorganization along the peripheries of the structurally inverted lake deposits, affecting an area up to four times larger (~40,000 km$^2$) than the region directly above vestiges of the eclogitic welt. We observe such processes along the Izmir-Ankara-Erzincan suture zone, located in the northern region of the Central Anatolian Plateau from 55 – <30 Ma. Similarly, the nucleation of an additional subduction zone along the Cyprus trench at 30 Ma was followed by slab breakoff at 10 Ma, resulting in widening of the plateau interior perpendicular to the arc-trench system and the formation of a large 40,000 km$^2$ fault-bound depression, defined by up to 4 distinct elliptical basins within the more southerly Inner-Tauride suture zone. Thus, the development of the Central Anatolian Plateau interior is in part related to the piecewise structural imbrication of allochthonous terranes followed by the development and partial removal of rheologically weak suture zones via drip tectonics. In turn, drip tectonics promotes widespread mantle upwelling, which results in long-wavelength, low-amplitude dynamic topography demonstrably inboard of the active orogenic wedge.

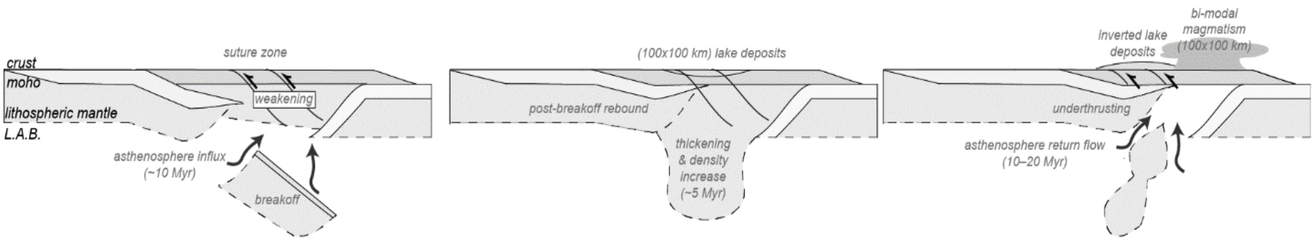


**Fig. 1: Conceptual model describing how lithospheric mantle is removed in the upper plate of a collisional orogen.**

**Keywords**: Proto-plateau development, lithospheric mantle removal, drip tectonics

# Updating the seismological workflow: testing recent evolutions of the alert system and seismic monitoring of the regional seismicity in Nepal

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In a datacenter, the workflow must evolve and adapt to specific needs to be the most efficient possible. The National Earthquake Monitoring and Research Center (NEMRC), under the Department of Mines and Geology (DMG) in Kathmandu, aims to maintain a seismic alert for ML≥4.0 events within Nepal and to share a ML>=4.0 teleseismic and local catalogue with the geoscience community. For research purposes, especially to evaluate seismic risks, the NEMRC is also producing a microseismicity bulletin. To ensure these goals are met, two systems for seismic data processing currently coexist in NEMRC: Onyx and Seiscomp.

Each workflow has its own advantages regarding the different tools it provides: signal display, station integration, alert, autolocation, different locators, tools for processing and presentation of results.

For 20 years now, Onyx has been configured and optimised so it is properly adapted to the alert and microseismicity monitoring needs. Seiscomp is a much more recent workflow that has been tuned since 2019 in NEMRC. Its installation was decided to meet specific autolocation and far-reaching research purposes. Both workflows are used daily and allow an efficient alert and processing system for seismic data.

This work will review the convergence of the workflows for ML≥4.0 seismic detection in Nepal as well as their differences, especially the impact on the magnitude value.

Then, a focus on a local seismic crisis will show the hypocenters' uncertainties by using different locators in the same workflow. The result of this particular work could illustrate the catalogue variability that exists even when processing the same data with the same parameters and picks.

**Keywords**: Seismicity, seismic alert, workflow

# Early history of mapping and exploration in the Himalaya

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The Himalayan Mountains are rich in mineral including coal, gypsum, mica, graphite as well as ores of iron, copper, lead, and zinc. Early reports on the geology of the Himalaya, however, focussed on the palaeontological, geomorphological and general geological characteristics of the mountains, rather than their mineral content. For instance, early Chinese reports, one for example dating from c. AD 1170, noted the likely marine origin of 'stone animals' found at the top of mountains. But it was not until reliable maps of the mountain range were created that geological observations could be properly located and positioned on the map. The mapping work, the Great Trigonometrical Survey, was undertaken initially by the East India Company and then by the Geological Survey of India, at one stage under the leadership of Colonel Everest.

The activities of the Great Trigonometrical Survey also helped us understand what lay beneath the mountains. Work undertaken in the 1850s by their surveyors led to a major geological breakthrough. Surveying work was being undertaken by two methods, triangulation and using the position of the stars. Measurements taken just south of the Himalayan Mountain Range while using a sextant and a plum bob (to level the instrument) turned out to be inconsistent with measurements from triangulation. It was recognized that this might be because an extra gravitational force was being exerted laterally by the large mass of the mountain range and this was affecting the plum bob. But applying corrections related to the mass of the mountain chain failed to provide a convincing match with the data.

It was Professor Airy, the Astronomer Royal in London, who realised that the fact that the gravitational pull of the mountains was less than would be expected could be explained if the mountains had deep roots of relatively light continental material beneath them. And in developing this idea he established the basis for the so called 'Airy model of isostasy', one aspect of which was that the visible mass of a mountain chain would be balanced at depth by a sizable root.

For the broader sweep of geological understanding, we turn to Sir Richard Strachey. In 1848 this British soldier, geologist, meteorologist, and Indian administrator undertook the first geological transect of the mountain chain from the Siwaliks all the way to Mount Kailas in Tibet through the Kumaun region, publishing his results in 1851. This transect established the first understanding of the major divisions of the mountain chain, the 'belts' or 'terranes' we now know as the Lesser, Greater and Tethyan Himalayan Series. Strachey's work helped Greenough provide detail to the Himalayan part of his magnificent 1855 geological map of Greater India, the first of its kind.

It wasn't until the 20th C that detailed regional geological maps were drawn up and published and that ideas brought from the Alps helped elucidate the structural geology of the mountain chain.

**Keywords**: Airy, exploration, isostacy, mapping, strachey

# Adapting to the glacial changes in the Nepal Himalaya: Opportunities and challenges in disaster risk reduction

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Climate change is taking place globally, and the rate of changes in the Nepal Himalaya has been among the highest in the world with more pronounced warming (0.086 $^{o}$C/yr during 1971-2017) in higher altitudes, where snow and glacier exist. In response to the observed warming, varieties of adverse impacts are underway, including widespread glacial retreat (as high as 50 m/yr) and glacial lake outburst floods (GLOFs). Nepal has lost more than 20% ice-covered area in the last three decades due to the warming, and currently, it has about 3,803 glaciers and 2,070 glacial lakes out of which 21 lakes are identified as potentially dangerous to generate mega GLOF events. In addition, there are 26 transboundary potentially dangerous glacial lakes that can seriously impact Nepal, if burst out.

The recently developed climate change scenarios for Nepal across multiple general circulation models show considerable convergence on continued warming, with country averaged mean temperature increases of 1.4 °C, 2.8 °C, and 4.7 °C projected by 2030s, 2060s, and 2090s, respectively. Future impacts associated with the projected temperature rise are likely to be significant to bring more glacial disasters and make life more difficult and hinder its development activities. Glacial risk reduction activities in time save lives and property of the mountainous communities and sustain the existing limited mountain infrastructure including rapidly developing hydropower. Adaptation is viewed as an urgent action to respond to the change in the glaciated area but the complexity of Nepal's terrain and harsh climatic condition in the high mountain and its limited human, financial and institutional, and technological resources are the barriers to overcome. The presentation gives an overview of the observed and projected climate change and the associated impacts on the glaciers of the Nepal Himalaya and discusses adaptation challenges and opportunities in glacial risk reduction.

**Keywords:** Himalaya, climate change, glacial lake outburst floods (GLOFs), adaptation, disaster risk reduction

# Geological mapping for stratigraphy and metamorphic studies in Kalikasthan-Bhalche area of Rasuwa-Nuwakot district of central Nepal, Lesser Himalaya

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Geology of Kalikasthan-Bhalche-Chyamthali section consists of low grade metamorphic rocks of Lesser Himalaya, central Nepal. The study area lies in Nuwakot, Rasuwa and Dhading districts. The main objectives of the study were to prepare geological mapping and relevant cross-section in 1:25,000 scale to work out stratigraphy, petrographic study and depositional environment to carry out metamorphism.

The succession consists of one lithological unit with one member as Chipleti- Chhapchet Gneiss Member. The Kunchha Formation comprises of ash- grey to dark grey, fine- grained phyllite and grey- to greenish- grey, fine- to medium- grained meta-sandstone in various proportions band of pelitic and psammatic phyllite. The meta-sandstone beds are well- laminated, medium- to coarse-grained, thin- to thick-bedded in nature with interbeds of pelitic and psammatic phyllite. The Chipleti-Chhapchet Gneiss contains feldspar, quartz, muscovite and biotite minerals with some opaques. It can be supposed to be intruded into the Kunchha Formation, however, the foliation is similar to adjacent host rocks.

Petrographic study reveals that the rock of the whole area shows that all the litho-units contains almost similar mineral assemblages such as chlorite-biotite-muscovite-quartz- plagioclase. In the study area, the rocks at the southern part belong to chlorite grade while in northern part rocks belong to the biotite grade. The depositional environment of the rock unit in this area is the product of diagenesis and metamorphism of mixed type of deposition under transitional to deeper part of the basin. Parallel lamination and graded beddings are the major primary geological structure found in the rocks. Foliation, lineation, crenulation cleavage, small scale folding, shear zone are the secondary geological structure observed in the rocks. The depositional sedimentary environment of the rocks in the study area shows that the sediments were deposited in the oceanic environment, where phyllitic layers were deposited relatively in the deeper and calm environment whereas the meta-sandstone beds were deposited in relatively shallower in the presence of high current.

**Keywords:** Geological mapping, stratigraphy, Kunchha Formation, Chipleti-Chhapchet Gneiss, central Nepal, Lesser Himalaya

# Landslide hazard mapping: a case study of Ruby valley, Dhading district

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In Nepal Himalaya, during monsoon season, the prime concern for public is landslide and its effects on society. There are mainly two types of landslides generally occur every year in hilly reasons such as small scale and large scale. Rain fall induced landslide and earthquake induced landslide are occurred in Nepal Himalaya. Rain fall induced landslide occurs every years, however, earthquake induced landslide occurs periodically. The rockmass properties, geomorphology, soil depth, orientation of discontinuities, soil type, slope angle, groundwater condition are internal factors to induce mass movements and amount of precipitation, anthropogenic activities, earthquake are external factors.

The landslide hazard mapping has been carried out in Rubi Valley Rural Municipality, Dhading District of Bagmati Province. Geologically, the area belongs to Lesser Himalaya of Central Nepal which is located about 60 km North-East from Dhading Besi. The study area covers an area of about 205 $km^2$. The main objective of this study is to prepare landslide hazard map and others objectives are to protect human people, properties and engineering structures. Since there are several hydropower, road and unified residential area has been under the construction and some of them are under the detailed study phase, the present study shall be of great importance in near future. There are many past landslides in which few are still active and some are inactive. On Google map, the extension of past landslides with respect to time is main concern of the study. For this, field work was done and data have been collected. Kinematic analysis and GIS are two major tools used to analysis the collected data. There are mainly three joints sets which cause wedge failure are observed in field as well as on Dips software. The landslide hazard mapping has been carried out of the area by using different causative factors like elevation, slope, aspect, land use, geology, stream density, rainfall, lineament density, distance to road and distance to river etc. Landslide hazard assessment is the primary tool to understand the nature and characteristics of the area that are prone to failure. So, all the information and data collected from the site has been gathered in GIS and the result is analyzed and interpreted. Five different hazard zones has been categorized such as; very low, low, medium, high and very high hazard zones.

**Keywords**: Landslide hazard mapping, Ruby valley, Lesser Himalaya, landslide hazard assessment

# Building the Himalaya: influence of the Lesser Himalayan-Subhimalayan thrust belt

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Determining the deformation magnitude within the Himalayan thrust belt is important because many models for the evolution of collisional orogenesis are sourced in this young mountain belt. As such, researchers use it as a laboratory to understand continent-continent collisions. Beginning at ~15 Ma, the Main Himalayan thrust propagated southward out of strong Greater Himalayan metamorphic rocks into the relatively weaker Lesser Himalayan sedimentary rocks. Structurally, this demarcated a change from the emplacement of 100+ km-long thrust sheets to shorter, often 10-20 km-long thrust sheets within the Lesser Himalayan duplex. This duplex, as well as the adjoining Subhimalayan portion of the thrust belt to the south, was very influential in the building of the Himalaya. In fact, we argue that its importance has been long overlooked. Between the Namche Barwa and Nanga Parbat syntaxes, 22 published cross sections exist along-strike that detail the structural architecture from the Main Frontal thrust northward to at least the Main Central thrust. To determine how influential the Lesser Himalayan-Subhimalayan part of the thrust belt was, we quantify its contribution to Himalayan thickening. From these 22 cross sections, we measured the structural elevation, accreted area, and shortening accommodated by the Lesser Himalayan-Subhimalayan thrust belt, as well as wedge taper and other important parameters.

In the eastern half of the orogen, the mean structural elevation accomplished by the Lesser Himalayan-Subhimalayan thrust belt is 10-15 km, which increases to 15-23 km in the western half. Because of the shorter thrust sheets, the Lesser Himalayan duplex progressively constructed an antiformal culmination, which increases in N-S width and structural height westward. The building of this culmination controlled the wedge taper, or alternatively critical taper may control the building of the culmination. The high taper angle, which is currently 11±2°, drove the continued southward propagation of the thrust belt. The westward increase in culmination size is accompanied by doubling of minimum shortening and tripling of the accreted area of the Lesser Himalayan-Subhimalayan thrust belt. Thus, duplexing facilitated the growth of an overall larger orogenic wedge moving westward. Possible reasons for the greater amount of duplexing westward are: 1) a greater original N-S width of Lesser Himalayan basins moving westward, 2) limited outward growth due to eastward-increasing precipitation, and/or 3) along-strike variation in convergence partitioning. Mean thickening is 10-13 km in the east and 15-20 km in the west, indicating that Lesser Himalayan duplexing was the primary thickening mechanism in building the Himalaya since ~15 Ma.

**Keywords**: Himalayan thrust belt, Lesser Himalayan duplex, structural thickening

# Role of scientific community in tourism of Nepal glacier hazards and tourism in Nepalese Himalaya

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Diverse geography of Nepal has been a boon to Nepalese Tourism industry, however the prominent glacier hazards in the rugged Himalayan landforms and the extreme events has risked the life of tourist, tourism service providers and dependent communities downstream. Almost all the potentially danger glacier lakes lead down to the potential hazard prone area in downstream, which remains as the trekking trail connecting the major mountain destination of Nepal. The extreme events resulted by the climate change, global warming and extreme precipitation such as Glacier Lake outburst flood, landslide dam outburst flood, Avalanche and Snow-storm has affected the bio-physical environment and socioeconomic condition of vulnerable communities. Safety, as the major concern of diverse group of tourism stakeholders and local community, review of extreme events, situation analysis and key policy recommendation based on Policy Gap Assessment suggest the approach of Trekking and Mountaineering Trail Risk Assessment. Similarly, based on the principle of sustainable land use planning and trail modality, best models of Risk Sensitive Trail Development Planning can be implemented. As a review and policy gap analysis regarding the safe mountain tourism in terms of Natural and Glacier Hazards, joint effort of tourism stakeholders, local community, policy makers and scientific community can enhance the preparedness for the glacier hazard to maintain the safety of entire mountain tourism community.

On the other side, unique geological positioning of Nepal and active geomorphological and anthropogenic activities in diverse geology of Nepal has been an attractive place and platform for the researchers, adventure enthusiasts, and glaciologist as well. Nepalese Himalaya, a dominant indicator for diagnosis, evaluation and realization of policy gaps related to the mountain issued for global scientific community all over the world. In this context, Nepal is realized to be a second home for the scientific community; accordingly Nepal's tourism industry can take the opportunity to streamline the scientific community into the nation's gross domestic production contribution and job creation. Most importantly, the findings by the engagement of the scientific communities can be utilized in policy gap assessment and further intervention based on the findings for the scientific community engagement in Nepal's geography. Hence the paper has realized that Nepal can capitalize the opportunity of knowledge transfer, policy assessment and result based management approach based on the research activities and engagement of global scientific community via tourism and ultimately can contribute on promotion of Nepalese tourism positioning Nepal as a living laboratory with natural, cultural and adventure resources.

**Keywords**: Hazard, mountain tourism, policy assessment, trekking, mountaineering, scientific community

# Geostatistics and IDW multivariate interpolation methods for regional geochemical stream sediment drainage survey for base metal prospecting in parts of Solukhumbu district, Nepal

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A systematic regional geochemical stream sediment drainage survey for base metals copper, lead and zinc over an area of 200 square kilometers was carried out in parts of Solukhumbu district of Nepal. The collected samples from active streams were analyzed using Atomic Absorption Spectrometer (AAS) method and interpreted with geostatistical analysis and Inverse Distance Weighing (IDW) multivariate interpolation method using ArcMap 10.4 GIS software. The results show consistency with the geology, homogeneity and mineralization in the area which is verified with significant copper anomaly over old working area around Wapsa. The $Log_{10}$ transformed data of Cu, Pb and Zn were used to estimate threshold and anomaly determination. The method is valid for regional geochemical stream sediment drainage survey for base metals prospecting in Lesser Himalaya in Nepal.

**Keywords**: Geostatistics, geochemical survey, base metal

# Geological setting of metallic minerals from the Lesser Himalaya of Gulmi district, western Nepal

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The Lesser Himalaya is highly promising for metallic minerals mainly like iron, copper, lead, zinc, cobalt, nickel, etc. But in Nepal; detail exploration of mineral resources based on geological setting, its genesis and overall grade is lacking. Therefore, present study is focused on a small part of the Lesser Himalaya from Tamghas-Neta-Suwarbhumar section of Gulmi district, Western Nepal.

This study was focused to prospect the metallic mineral resources in the area; especially to assess the geological control and genesis of mineralization and finally to prepare prognostic map of the mineral resources. The detailed geological mapping in 1:25000 scale was carried out by taking traverse along the study area and collecting samples from old adits as well. Also, laboratory analysis of the sample is carried out by studying polished and thin sections as well as chemical analysis of the sample.

Geological units like the Nourpul Formation, the Dhading Dolomite and the Benight Slates are the rocks of the Nawakot Group (autochthonous unit)consisting chloride-biotite grade metamorphic rocks like slate, phyllite, quartzite, dolomite, and metasandstone and the Hadhade Formation and the Ratamata Formation of the Jajarkot Nappe (allochthonous unit) with biotite-garnet grade metamorphosed green schist, white quartzite and coarse-grained dolomite-marble are mapped within the area.The Dhaithum copper, Bhadegau poly-metallic and ResungaBan poly-metallic deposits are concern within the Nourpul Formation. Similarly, Samarbhumar poly-metallic, Neta poly-metallic are the major metallic deposits reported from the Hadhade Formation and the Ratamata Formation. Major metallic mineralization is hydrothermal vein deposit associated with dominant lithology of the white quartzite and dolomite with presence of gold, nickel, cobalt, copper, silver, iron and lead. All deposits are considered as the stratiform and stratabound in nature. Most of studied poly-metallic minerals have economic value for the nation while minerals like cobalt and nickel could be strategic minerals.

**Keywords**: Geology, Lesser Himalaya, polymetallic deposits, strataform, stratabound

# Tectonic and thermokinematic evolution of the northwest Indian Himalayas

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In this study, we present a forward modeled balanced cross section in the Himalayas – Uttarakhand, northwest of India. This reconstruction was generated using flexural-kinematic and thermokinematic models. A geological thermal model accounts for processes such as thermophysical rock properties, basal heat flow, and the geometry of the paleotopographies (which evolve via uplift, erosion, and sedimentation). In this forward model, each paleotopography was flexurally compensated to accommodate the load after each increment of deformation. 500 km of shortening were applied to an undeformed geological cross section in 10 km steps. From ca. 28 Ma to present-day, we used a constant rate of shortening of 18 mm/yr for the 50 deformation steps.

This sequential cross section restoration highlights the principal phases of the tectonic evolution on this Himalayan region. It features: 1) the pre Oligocene deformation of the north Indian margin; 2) the emplacement of the Main Central thrust and Great Himalayan Crystalline complex wedging in the Oligocene, and subsequent range growth by uderplating; 3) from the late Miocene to recent, an antiformal stack of the mid-crustal horses, and a duplex system of upper crustal horses which have developed concurrently, and 4) the frontal accretion formed with the foreland rocks that results in an imbricate fan system mostly eroded away.

A number of parameters affect the result of a thermokinematic model – e.g. fault geometry and kinematic, topography, and radiogenic heat production. Here we analyze the sensitivity of predicted cooling ages to variations in the heat production; and discuss the feasibility of integrating other geodynamical elements such as dynamic topography to our model. Furthermore, we compare the outcomes of this research (in terms of structural evolution and thermal history) to previous studies in the Himalayas.

**Keywords**: Selection restoration, tectonic evolotution and thermochronology

# Quality of bricks used in the infrastructure of Chitwan district, central Nepal

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Bricks are the most important construction material because of their reliable physical properties like shape, size, strength, and durability. Now, fired clay bricks are the bricks that are used in Nepal for various types of infrastructures. In this research paper, the physical, mechanical and mineralogical properties of bricks from seven different brick industries of the Chitawan district are studied. For physical analysis, dimension, hardness, soundness, and impact test are done. Twenty samples from each brick industry were sampled for this purpose. For mechanical characterization two samples, one of high quality and one low quality brick were used. The Compressive strength and bulk density for high-quality brick rangefrom 10.95 to 23.49 MPa and 1.739 to 1.949 gm/cm$^3$ respectively, while the water absorption capacity and apparent porosity of high-quality brick ranges from 9.35 to 12.13% and 18.24 to 21.109%. Similarly, for low quality brick samples, the compressive strength and bulk density ranges from 7.02 to 14.13 MPa. The water absorption capacity and apparent porosity ranges from 11.89 to 16.89% and 20.77 to 27.95% respectively. Clay samples from seven different brick industries are taken and handmade brick samples were made. The bulk density for handmade brick samples lies between 2.01 to 2.44 gm/cm$^3$. Similarly, water absorption capacity and apparent porosity for these handmade samples ranges from 9.93 to 13.42% and 24.32 to 27.067%. The bulk density of each brick sample increased along with decreasing water absorption and apparent porosity. For mineralogical analysis X-Ray diffraction techniques was used. Quartz, hematite and other minerals phase are observed.

**Keywords**: Firebrick, clay minerals, compressive strength, water absorption, bulk density

# Aftershock Analysis of the devastating 2015 Gorkha-Dolakha earthquake doublet

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On Saturday, 25 April 2015, a large shallow earthquake of moment magnitude Mw 7.8 occurred at Gorkha (28.23° N, 84.73° E) in Central Nepal. Just seventeenth days later, another large shallow earthquake with Mw 7.3 occurred about 140 kilometers away from the previous epicenter at Dolakha (27.80° N, 86.06° E). This study analyses the aftershocks of these two earthquakes occurred in the region (bounded by 27°- 28.5°N and 84°-87°E) for the period between 25 April 2015 and 28 May 2016 to investigate the spatial and temporal characteristics, the *b*-value of the Gutenberg-Richter's relationship, the *p*-value of the modified Omori law. The spatial distribution of epicenters and previously recognized geological structures in this analysis clearly reveals that aftershocks are limited on the southern side by the surface trace of the segment of the Main Boundary Thrust (MBT) and on the eastern side by the surface trace of the Everest lineament. The obtained *b*-and *p*-values of this earthquake sequence are 0.93 ± 0.03 and 0.79 ± 0.24, respectively. The obtained *b*-value in this analysis is greater than the *b*-value estimated by the earlier analyses, whereas the *p*-value in general consistent with the *p*-value estimated by the previous analysis for the region.

**Keywords:** Aftershock analysis, earthquake, Nepal

# Physical strength and durability characteristics of quartzites from the Fagfog Quarzite of the Lower Nawakot Group, Dhading District, central Nepal

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Railways has played vital role in development of most of the nations around the world. Nepal government has already planned to establish various national and international railway networks in and around the nation. Huge amount of durable rock ballasts are required to develop a sustainable railway network. Quartzites from Central Nepal Lesser Himalaya can be a promising source to fulfill such requirements. Therefore, the quartzites from the stratigraphic unit Fagfog Quartzites of the Lower Nawakot Group located in Dhading District along the Kalu Pandey Highway have been accessed to determine physical, strength and durability characteristics of the ballasts. All quartzite ballasts obtained from bedrocks were of Precambrian, medium-grained, bladed to prolate shaped, white to brownish white, crushed quartzites. Dry density and water absorption were respectively 2336-2641 kg/m$^3$ and 0-2.5%. Bulk density varied between 1204 and 1387 kg/m$^3$. Point load strength index varied from 2.04 to 11.55 MPa (medium strong to extremely strong). Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV) ranged respectively from 14.85 to 22.77% and 15.51 to 22.17%. Some 7% results of AIV and 20% of ACV had exceeded limiting value of 22%. Slake durability index ($Id_{5th}$) ranged between 95.19 and 99.11%, whereas $Id_{2nd}$ ranged between 96.94 and 100%, which showed 80% of the samples were of very high slake durability whereas 20% remaining were of high slake durability. There was no significant change in slake durability index from the second to the fifth cycles. Los Angeles Abrasion Value (LAAV) varied from 12.07 to 31.34%. Sulphate Soundness Value (SSV) also varied in limited range between 0.20 and 4.59%. The overall results indicate that the quartzite ballasts had good test results and are promising in terms of point-load strength, crushing strength, impact strength, and durability against abrasion, slaking and frosting. Hence, the quartzites from the Fagfog Quartzite are considered one of the potential rock types for railway track ballasts.

**Keywords:** Railway track ballast, quartzite, strength of ballasts, slake durability index, Los Angeles abrasion value

# Seismic microzonation and soil-structure resonance condition of Suryabinayak Municipality using ambient vibration measurements

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Bhaktapur, lying in the eastern part of the Kathmandu basin suffered major damages during the 2015 Gorkha Earthquake. The major reason for this might be the abrupt change in topography and soil type even at short distances, ground motion amplification due to fluvio-lacustrine deposits, and ground-structure resonance. This study mainly focuses on the study of frequency-based seismic microzonation and soil-structure resonance possibility in rapidly urbanizing area of Suryabinayak Municipality.

The first part of this study deals with ambient vibration measurement at 115 stations in a 200 x 200 m grid for assessing the fundamental frequency of the basin deposits. The fundamental frequency of the basin sediments ranges from 0.77 Hz to 9.09 Hz. Higher fundamental frequency is observed in the southern part than that in the northern which agrees well with available borehole data.

The second part includes microtremor measurements on different building typologies. The range of predominant periods for 2, 3, 4, and 5-story buildings ranges from 0.1–0.15s, 0.19-0.26s, 0.29-0.36s, and 0.29-0.39s respectively. The predominant period of building is then compared with the obtained free field period. The result shows resonance between ground and structure may be the major reason for extensive damage in the study area. This study’s results will help in seismic hazard mitigation and the construction of earthquake-resilient buildings in the study area.

**Keywords**: Microtremors, Suryabinayak, resonance, horizontal to vertical spectral ratio (HVSR), floor spectral ratio (FSR)

# Geological study of the Pokhara valley with emphasis on quaternary stratigraphy and facies analysis

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Pokhara is one of the intermontane basins in the Lesser Himalaya. It measures about 60km extension longitudinally. The gorges are formed in the different part of the valley; the longest extension of the gorges is in the main Pokhara valley which is upto 200 m long (Fig. 1). The stratigraphy of the valley sediments are divided into ten unit. They are the Gharjati Formation, Begnas Formation, Siswa Formation, Ghachok Formation, Phewa Formation, Pokhara Formation, Rupakot Formation, Gravel veneer, Alluvial fan and recent deposits and flood plain. The fluvio-lacustrine deposits of the Pokhara Formation is differentiated into the Pokhara A, Pokhara B and the Pokhara C. These three unit describes the fluvial deposits and lacustrine deposits. The lacustrine deposits is the Pokhara C and main fan deposit is the Pokhara A. The Rupakot Formation have been observed along the Bijaypur Khola section which consists of clay, silt deposits. It called the Rupa Formation because it is deposited inthe Northern part of the valley, instantly deposited after the Pokhara Formation and contain fine sediments. The facies analysis shows that the facies association 1 (Pokhara A) is deposited by the catastrophic event, facies association 2 (Pokhara B) is deposited by mud dominated debirs flow and rapid suspension fall out, facies association 3 (Pokhara C) is deposited by lacustrine process. The deposits along tributary are also of a limestone, marble, gneiss clast. This provide evidence that they are deposited from collapsing the side wall of previously deposited sediments.

**Keywords**: Debris flow, quaternary stratigraphy, facies analysis, Pokhara valley

**Fig. 1: Gorge formed by the Seti River in the Ghachok Formation.**

# Uncertainities of water ingress problem and its impact to rock masses in underground excavation “A case study of headrace tunnel of Mistri Khola Hydroelectric Project”

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Water ingress problem in underground space excavation is common in the Himalayan terrain. However, there is unexpected huge volume of water ingress in some cases. Water ingress into the tunnels may be intermittent or perennial. Whatever, it adds sever difficulties in underground excavation works as water bearing zones associated with highly weathered and crushed rock mass even altered to soil and equally highly permeable zones like fault, thrust, shear zones. In addition, ground masses of such zones exhibit short stand-up time against excavation and application of designed rock supports. Due to the reason collapses of tunnel face, crown, chimney formation, debris flow etc., are common problem.

The case study of recently completed hydro tunnel of Mistri Khola Hydroelectric Project reveals the aforementioned problem in some extent. The 4.2 m diameter inverted-D shape 2270 m long headrace tunnel was excavated through MCT zones wherein additional faults and buried paleo-channel are also intersected. The recorded data of water ingress total in entire tunnel shows peak volume of about 220±25 liter/sec in monsoon and minimum 35-45 liter/sec in dry season. This problem is the main reasons behind the delay in completion of headrace tunnel by 20.6 more additional months i.e., 82% of initially allocated 25 months in the construction schedule. There had been very tough moments to figure out proper excavation methods and application of appropriate rock supports to deal such adverse tunneling condition. Two excavation faces each at upstream and downstream headings had been left abandoned. Utilizing the case study, the data of investigation phase, construction phase and present site verification, the attempt was made to reconstruct the actual geological setting to prepare subsurface hydrogeological model. The outcome might be the tools to figure out the overlooked area in the assessment of project investigation phase which would be beneficial for upcoming project in its investigation and construction planning phases for minimizing risks of uncertainties to excavation as well as selection of proper and durable rock supports in similar weak geomorphology.

**Keywords**: Rockmass, headrest tunnel, Mistri khola, rock support, hydroelectric project

# Geological mapping and structural analysis of the Barahakshetra-Dummana area, eastern Nepal

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The Barahakshetra-Dummana area of eastern Nepal is divided into the Higher Himalaya, the Lesser Himalaya and the Siwalik tectonic units from north to south separated by the Upper Main Central Thrust (MCT) and the Main Boundary Thrust, respectively. The Lesser Himalaya is subdivided into the MCT Zone, the Dandabazar Group, the Bhendetar Group, the Barahakshetra Group and the Lukwa Formation tectonostratigraphic divisions from north to south separated by the Lower MCT, the Chimra Thrust, the Dharapani Thrust, and an unconformity, respectively. The Kokaha Diamictite, the Sapt Kosi Formation and the Tamrang Formation collectively forms the Barahakshetra Group, whereas the Chiuribas Formation, the Sangure Quartzite and the Karkichhap Formation are the litho units of the Bhendetar Group. The Dandabazar Group comprises of the Mulghat Formation and the Okhre Formation whereas the Belhara Formation and the Jyamire Gneiss forms strongly sheared and recrystallized MCT Zone. The former three lithological units represents sedimentary sequence and the later seven lithological units represent the metamorphic sequence. The petrographical analysis of the metamorphic rocks of the Lesser Himalaya revealed that the Dandabazar Group and the Bhendetar Group are metamorphosed to greenschist facies whereas the MCT Zone show variation in metamorphism from the greenschist facies to the lower amphibolite facies. The rocks of the Higher Himalaya is metamorphosed to amphibolite facies.

The Lesser Himalaya of the area has experienced four different phases of deformational events, D1and D3-D5, along which D1 is pre-Himalayan, D3-D5 are syn- to post-Himalayan events. The bedding parallel foliations represents the pre-Himalayan deformation event. The C' shear bands, the mica fish microstructures represent top to the south sense of shear similar with the shear sense induced during MCT propagation. NW-SE trending drag folds, Joints, crenulation folds and different meso-scale brittle faults states the syn- to post- Himalayan phase of deformation.

**Keywords**: Barahakshetra-Dummana, Lesser Himalaya, MCT, deformational events

# Surface-rupturing earthquakes in the High Himalaya of western Nepal

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Knowledge of potential seismic sources in the upper-plate of Western Nepal is limited. Recent studies of the Western Nepal Fault System (WNFS), an oblique-dextral-slip system of splay faults, is likely connected to the Main Himalayan Thrust (MHT) at depth. The system is comprised of a right-stepover connecting the primary NW-SE-oriented Talphi-Tripurakot fault segments and the Bari Gad fault. The right-step-over is comprised of ~N-S oriented faults, the Dhorpatan and Tumtu Pauwa faults, as well as a more NW-SE oriented Dhaulagiri Southwest Fault (DSWF) that connects to the Tripurakot segment to the north from the Jang la Oblique segment. The WNFS exhibits youthful tectonic geomorphology along its length, and we present evidence that large (> M6), surface-rupturing earthquakes occurred on the fault system throughout the Holocene. Over three field seasons, we established seven paleoseismic sites along a 100 km-long portion of the WNFS. Excavations along the Talphi-Tripurakot fault sections contain evidence for at least one mid-Holocene and a recent earthquake in the last 600 years. Two excavations along the DSWF contain evidence for possibly five earthquakes with the most recent event documented at our Pupal Phedi site in the last 300 years. An excavation on the Dhorpatan fault exposed at least two earthquakes in the last ~5 ky. These events are evidence that the WNFS is a local source for earthquakes in Western Nepal. Lastly, these events also begin to establish the recent paleoearthquake chronology of the WNFS which, combined with new slip rates and fault geometry data, will help update and improve seismic hazard models for the region. Improving these models contributes to risk mitigation and resilience development in the High Himalayas of Western Nepal.

**Keywords**: Paleoseismology, earthquake, seismic hazard, Himalaya, splay fault

# Proxy and climate model results from the NE Tibetan Plateau region indicate an Asian environmental transition at 4.2-2.8 Ma caused by damped obliquity amplitude

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Pliocene is a critical time when the Earth experienced significant climatic and environmental transitions. The intensive onset of the Northern Hemisphere glaciations and growth of the Antarctic ice sheets, intensification of Asian monsoon and accelerated aridification in central Asia all occurred over the Pliocene and they may be genetically linked. Some studies attribute these environmental transitions to tectonic forcing associated with the closure of the Panama Seaway or Tibetan Plateau uplift. We challenge the tectonic impact, and present paleoclimate and climate model simulation results those demonstrate that these transitions could have been caused by astronomical forcing. Paleoclimate evidence comes from trends and spectral signatures of new and compiled available proxy records from the Qaidam Basin (arid climate) and the Chinese Loess Plateau (monsoonal climate) in the northeastern Tibetan Plateau region over the late Miocene to early Pleistocene period. We identify a simultaneous drying trend in Central Asia and a wetting trend in East Asia over the 4.2-2.8 Ma interval, while a synchronous East-Central Asia wetting appears over intervals of low eccentricity in the 400-kyr band. We suggest that damped obliquity amplitudes over 4.2-2.8 Ma has resulted in prolonged cooler summer conditions, promoting the development and growth trend of Antarctic ice sheets and leading to the noticed long-term and orbital scale climatic-environmental change in Central and East Asia. Climate model simulations (the CESM1.2A Model with different Antarctic ice volumes and the ECHAM5 Model with Miocene, Pliocene, Pliocene-eccentricity and Pre-Industrial conditions) corroborate the proxy results. These results demonstrate that orbital forcing could have caused the observed environmental shifts via its impact on the Antarctic ice sheet, without tectonic forcing. Our work provides new insights into the forcing mechanisms for one of the most dramatic environmental events over the Neogene period in terrestrial and marine realms.

**Keywords:** Pliocene, eccentricity, Asian Monsoon, paleoclimate

# Prospecting copper in the Jelban-Seram section of the Rolpa district, Lumbini Province, western Nepal

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The Lesser Himalaya is rich in metallic minerals as well as non-metallic mineral resources. The present study was carried out to prospect for copper in the Jelban-Seram section of the Rolpa District. The objective of the research was to prepare a geological map of the area at a 1:25,000 scale and estimate the concentration and mineral reserve of copper deposits in the area. This study was based on field observation and lab work. Mineral concentration was to be determined by chemical analysis, and the reserve estimation was calculated by the vertical cross-section method. In the present study, lithostratigraphy from Ruiniban to Phuliban was studied and mapped. The geological structures present were studied at mesoscopic and microscopic levels. The mineralization of copper in the area was studied, and ore samples were collected. The study area is composed of low-grade metasedimentary rocks overlined by an allochthonous unit consisting of high-grade metasedimentary rocks of the Jajarkot Nappe, equivalent to the Bhimphedi Group of the Kathmandu Complex. The rocks of the allochthonous unit are named as the Rankot Formation, the Kasala Schist, and the Ghusban Marble from bottom to top, respectively. The Kasala Schist contains the Poban Quartzite, which contains a gneissic body known as the Thanaban Gneiss. The observed mineralization is reported within the gneissic body's contact and is a strata-bound deposit.

**Keywords**: Copper, ore, mineral, Lesser Himalaya, Jaljala Klippe

# Study of Shrawan dada and Siddhababa Landslides

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Landslide, the most common geological hazard in the mountainous terrain like Nepal which creates long term threat to the individuals and also residential properties. The trouble becomes worst especially in monsoon period. The study was conducted in the Siwalik along the border of Palpa and Rupandehi district near Butwal city to find out the nature and geological cause of existing landslides. Those fragile nature sedimentary rocks situated in this geographical and tectonic condition has contributed this zone as a prone area for landslide and soil erosion. For the mitigation and control of these type of landslides, proper understanding of the main causative agent i.e., geological factor is the most. So, the present research focuses on the geological cause behind their occurrence. There are two prominent landslide vulnerable area i.e., Siddhababa and Shrawan dada. These areas are prone to natural as well as human induced landslides. Rockfall is prominently observed along the Siddhartha Highway at Siddhababa area. It has caused the huge loss in life and property. The debris flow occurring at Shrawan dada landslide has also caused a lot of damage in the infrastructure and livestock at the dense settlement at its toe. Alternate beds of sandstone and mudstone is the major cause of landslide in these area as weathering rate between them is contrasting. Lithology and high precipitation are the leading cause. Among them, other factors such as highly fractured rock, poor drainage, deforestation, toe cutting for settlement and road construction have played a vital role in triggering this weak lithology. Ultimately the detailed geological and geotechnical parameters should be analyzed and proper mitigation measures should be carried out to advantage most performance in prevention.

**Keywords:** Landslide, Rockfall, Shrawan dada, Siddhababa

# Airborne geophysical techniques for mapping the Higher Himalaya, Nepal: A scientific call

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The most admired Nepalese Higher Himalaya representing a typical collisional mountain belt is also full of controversies. Many divergent models have been proposed to explain how the Himalayan Mountains have formed. The ongoing controversies are intrinsically linked to 1) vast section of Higher Himalaya still remaining unexplored and 2) poorly defined stratigraphy. Geological mapping in the Higher Himalaya is further challenged by the lack of accessible outcrops and fossils, proto-stratigraphic obliteration by metamorphism and intrusion, and high degree of weathering. Similar metamorphic terrains of the Alps and Alaska have been successfully mapped regionally using geophysical techniques such as magnetometric survey and gravimetric survey. In order to conduct an airborne magnetic and gravimetric survey of the Higher Himalaya, the Department of Mines and Geology in Nepal is seeking technical cooperation from the global scientific communities.

**Keywords:** Higher Himalaya, magnetometric survey, gravimetric survey, Nepal Himalaya

# Reading environmental and geological signals from dissolved organic matter of natural waters

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Dissolved organic matter (DOM) is found in all-natural water like lakes, rivers, creeks and groundwater and the chemical diversity of its molecules holds information on the “history” of the water. This information can be read using ultra-high-resolution mass spectrometry, which is able to identify thousands of different molecules in a single water sample. This presentation introduces the technique and demonstrates its potential to address environmental and hydrogeologic problems in the HKT region. Focal points are organic matter decomposition, DOM transport in soil, extreme drought, and groundwater vulnerability.

**Keywords:** Geological signal, ogranic matter

# Landslide susceptibility mapping along Pokhara-Sikles road for sustainable risk reduction

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Landslide is one of the natural hazards that shape the mountain landscape and destroy lives and properties. The investigation of landslide is very important for the risk mitigation and sustainable infrastructure development. Most of the village roads are non-engineered and thus creating landslide every year. The preparation of landslide susceptibility provides us the probable location of the landslide occurrences. This is particularly important for the village roads. Therefore, this study has conducted along the Pokhara-Sikles road to understand the landslide hotspots, probable landslide occurrences and recommend the mitigation measures. The study has adopted the Heuristic method for the preparation of landslide susceptibility. The factors map such as slope, aspect, curvature, geology, rainfall, land use land cover, distance from stream, distance from road, elevation and Normalized Differential Vegetation Index (NDVI) were prepared in the Geographic Information System (GIS) platform (Fig. 1). The results show that most of the landslide lies in the moderate risk (28.8%) followed by high (24.8%), low (23.7%), very high (12.6%) and very low (10.9%) susceptible area, respectively. The result is validated using area under curve (AUC) of the Receiver Operating Characteristic Curve (ROC) and the accuracy is 0.774. The study further recommends mitigation measures to the roadside landslide where structural as well as bio-engineering measures.

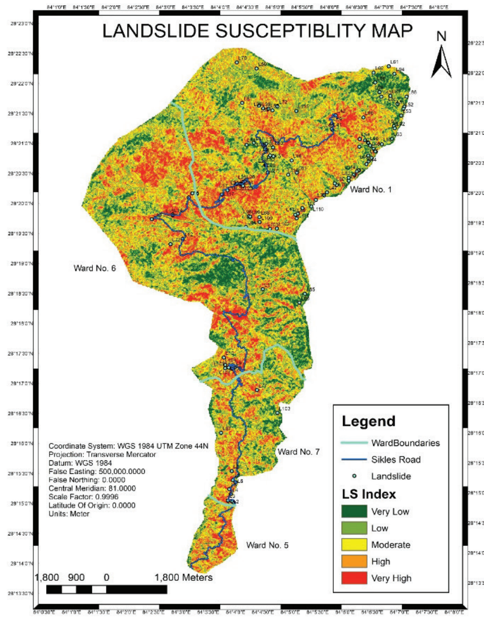


**Fig. 1: Landslide susceptibility map along the Pokhara-Sikles Road.**

**Keywords:** Landslide, heuristic approach, expert-driven approach, susceptibility mapping, GIS, mitigation measures

# Planning and preparedness for the mountain hazard and risk chain in Nepal: the Sajag-Nepal project

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The Himalayan mountains of Nepal are host to a cascade of hazards that are triggered by earthquakes and by the annual summer monsoon, including landslides, debris flows, floods, and sediment aggradation. People living on the mountain slopes are used to these phenomena and have accumulated local experiences and adaptations to deal with persistent hazards. Despite this, the mountain hazard chain continues to cause significant disruption to livelihoods and loss of life annually during the monsoon and in the aftermath of large earthquakes. Ideally, we would like to see the local and external scientific understanding of the mountain hazard chain, and its consequent risks, brought together so that the strengths of both approaches can be used to benefit the people of Nepal. The Sajag-Nepal project builds on more than a decade of research and experience by researchers from Nepal, the UK, New Zealand, and Canada, and from a range of backgrounds including academia, NGOs, the UN, and government organisations. The project seeks to develop new knowledge around the mountain hazard and risk chain, drawing on recent innovations in tracking the change in landslide hazard and risk over time. At the same time, the project seeks to situate that risk within the wider landscape of risks faced by people in Nepal and to draw attention to and reinforce local understandings of and mechanisms for dealing with persistent hazards. In close collaboration with people in four case-study municipalities, we are documenting the experience of risk and the strengths and limits of adaptation. We are also working with those municipalities to identify areas where they are concerned about monsoon-related hazards, monitor their activity, and incorporate that joint understanding into new dynamic modelling of the associated risk. This understanding also informs innovative media engagement via radio and film. Finally, we are working with the UN to build monsoon forecasts, local understanding, and multi-hazard impacts into the next generation of national-scale contingency plans for both the annual monsoon and the next large earthquake. The result is an example of how physical science knowledge around earthquake- and monsoon-related hazards can be merged with other views of the mountain hazard chain and used for planning and preparedness at different scales.

This paper, show how the localized information on risk at the household and community scale may be useful for local-level planning and preparedness. By doing this, the Sajag-Nepal project aims to raise wider awareness of a collaborative model that enhances understanding of local hazards and risks. And brings different knowledge together from community and scientific communities.

**Keywords**: Planning, preparedness, hazard and risk chain, landslides, earthquake

# Landslide hazard and risk assessment before and after the 2015 Gorkha earthquake, Nepal, and implications for reconstruction and public awareness

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Mountainous Nepal faces high landslide hazards. The DesInventar database of Nepal reports that landslide hazards have a significant death ratio among other natural hazards the country faces. Many of the adverse impacts of landslide are due to relatively small-scale, localized events, the perennial nature of which means that they are often seen as part of life, despite their significant chronic impacts on people's livelihoods. This chronic background hazard was then overprinted by the Mw7.8 2015 Gorkha earthquake, which resulted in significant numbers of fatalities, livelihood impacts, and additional landslides across 14 districts in Central and Western Nepal. Seven years after the earthquake, co-seismic and post-seismic landslides are still a threat that impacts lives and livelihoods. There is a real need to build greater resilience to landslide risks in rural mountainous Nepal. Unfortunately, efforts to understand and manage landslide risk are relatively limited in number, innovation, and success.

Research carried out jointly by the National Society for Earthquake Technology – Nepal (NSET) with Durham and Northumbria Universities, in collaboration with other academic institutions, has aimed to enhance the understanding of the change in landslide hazard and risk since 2015. We show that landslide hazard has changed substantially over time due primarily to the expansion and continued activity of co-seismic landslides as well as the occurrence of new post-seismic landslides. For the first time, we can evaluate the effects of these changes on household-level landslide risk. We further explore the implications of these data for post-earthquake reconstruction and explore the use of maps and 3D or physical models for discussion and consideration of risk with exposed communities. We examine the efficacy of the use of the research findings for awareness raising and decision support at local, provincial, and national levels. This research paper presents lessons learned, and analysis of the usefulness and applicability of the adopted approaches as well as the potentials of their scaling–up in terms of landslide hazards and risk assessment and communication. The research concludes by considering how such approaches could be combined to be used at the community level in the future to reduce landslide risks in rural Nepal.

**Keywords**: Post-earthquake landslides, risk assessment, public awareness

*Journal of Nepal Geological Society, 2022, Vol. 64 (Sp. Issue)*

# Testing and evaluation of earthquake rupture simulation for New Zealand

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An initial effort has been made to test and evaluate the output of a synthetic catalogue of earthquake ruptures for New Zealand. The simulated earthquake catalogue has been generated by using RSQSim. RSQSim is a physics-based simulator that works on the principle of rate- and state-dependent friction law to generate long-term earthquake catalogues, for example, hundreds of thousands of years. Fault sources from the 2010 National Seismic Hazard Model (NSHM) have been used to produce a long-term catalogue. Sub- catalogues of 180 durations are withdrawn from the full catalogue and these are compared with the historical on-fault earthquakes from 1840 to 2020 by the way of magnitude-frequency distributions. Further, a probabilistic seismic hazard map for the Alpine fault has been prepared using the simulated catalogue and compared to the 2010 NSHM hazard map. Initial results show that simulated earthquake rates agree well with the historical earthquake rates and peak ground acceleration values obtained using the simulated catalogue are very similar to the 2010 NSHM value for the Alpine fault.

# Sedimentation in the Nepal Himalayas

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Sedimentation in the Nepal Himalaya is a complex process that is dependent upon numerous factors; the principal factors include geological condition, land use pattern, mountain slope and aspect, intensity of monsoon precipitation, weathering depth, etc. Bad engineering practices in local development works exacerbate the process of mass wasting leading to sediment generation in the hills of Nepal. Similarly, climate exacerbates sediment generation and transportation through progressively increasing the intensity of rainfall in the monsoon. Sedimentation in the Nepal Himalayas is essentially supply based.

Estimation of sedimentation in the Nepalese Himalayas have been carried out by various researchers in two different ways: a, based on sediment sampling in the monsoon and their analysis and b, on the basis of sediment deposits due to one or the other surface geological processes of the past. Both processes can complement each other however in the Nepalese context, they have been carried out independent of each other leading to drastically varying results of mean annual sedimentation as well as mean annual denudation. Both procedures have inherent strengths and weaknesses; the weaknesses tend to exacerbate their inaccuracy.

In this context the sediment monitoring of the Kulekhani reservoir since 1993 can fill up the gaps in sedimentation though sedimentation in large river basin is quantitatively much different from the same for smaller river basins. However, it shows the actual trend in sedimentation.

As sedimentation in the Nepalese Himalayas have been dominated by peak floods caused by cloudbursts, GLOF, Landslide Dammed Lake Burst Floods (LDLBFs) with a large portion of the bed load sediments being transported in suspension together with large volumes of floating debris (which do not always float) requires to revisit the definition of sediments adding two additional categories of sediments: namely the bed load sediment that is transported by peak floods in suspension especially within the river bed scouring areas termed as intermediate category and the floating debris as the fourth category of sediments.

Because of rampant sedimentation in the Nepalese Himalayas, the river cross section is reduced leading to increase in the velocity of flow of the flood water causing severe bank cutting as well as water inundation in the neighboring fertile plains of the river valleys in the hills as well as in the Tarai silting and degrading their agricultural quality. Because of the same reason, the rivers change course swinging back and forth. Haphazard riverbed mining adds to the flow hazards. Therefore, research on river sedimentation in the Nepal Himalayas for a better understanding of the phenomenon linked closely to the national economy is the need of the day.

**Keywords:** Denudation, sedimentation, swinging, siltation, outliers, suspended sediments, bed loads, floating debris, sediment sampling, LDLBF

# Seismotectonic context of the Shillong Plateau and precise location of the 1897 great earthquake

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The Shillong Plateau is the primary surface expression of the deformation regime change between the Central and the Eastern Himalaya. This change is marked by the Dhubri-Chungthang Fault Zone (DCFZ), which cross-cuts the Himalaya beneath the Main Himalayan Thrust in a NW-SE direction across Sikkim, SW Bhutan and to the NW corner of the Shillong Plateau. East of the DCFZ, tectonic deformation becomes distributed with numerous visible and buried active faults, and predominantly strike-slip deformation. This results from the interaction between the Indo-Burman Ranges and the Himalaya, and very likely also from inherited structures. Beyond giving and overview of the known seismotectonic features of this region, we focus on the great 1897 earthquake. The magnitude of this event exceeds Mw8.2, and is well-known thanks to the extremely detailed field report compiled by Oldham. Although a subsurface rupture plane for this earthquake has been proposed based on geodetic data, its epicentral location remained very uncertain, partly due to this event occurring in the early-instrumental seismological era with scarce records.

We have carried out an extensive search and gathered original arrival-time data of seismic waves, and combined them with modern, 3D seismic velocity models to constrain the origin time and epicentre of this earthquake. An important part of the analysis consisted in assessing data reliability and to assess uncertainties. Our results precisely constraint the 1897 event, and show that the earthquake has taken place in the northwest part of the Shillong plateau, at the junction of the short, surface?rupturing Chedrang fault and the buried Oldham fault, at 26.0°N latitude, 90.7°E longitude. This latter fault has been proposed earlier based on geodetic data, and is long enough to host a magnitude 8 or larger earthquake. Given this location being at the NW end of the fault, it is likely that rupture has propagated eastward. Furthermore, stress change from the 1897 earthquake may have ultimately triggered the 1930 magnitude 7.1 Dhubri earthquake on the DCFZ.

**Keywords**: Shillong Plateau, Seismotectonic, Himalaya, 1897 Earthquake

# Subsurface investigations of landslide using geophysical methods: Geoelectrical applications in the Amkot Landslide along Sanphe-Martadi road of far Western Nepal

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Landslides occur frequently all over the world and is among major disaster that causes loss of lives and properties. The fragile and young Himalayas with torrential monsoon, earth tremors and environmental degradation together constitute a natural factor while artificial factors such as unplanned construction activities plays vital role to accelerate occurrence of landslides in Nepal. Landslides are complex phenomena whose study necessarily requires a multidisciplinary approach based on a wide range of observations. Geophysical methods are suitable tools for gathering 2D subsurface information quickly, reliably and cost-effectively over traditional technique which are expansive and provide information of limited area. Geophysical survey using 2D Electrical Resistivity Tomography (2D ERT) method has been applied for investigation of Amkot Landslide along Sanphe- Martadi Road of Bajura District, Nepal. Resistivity meter (GD-10 Supreme- Multi-function Digital DC Resistivity/IP) equipment with 120 electrodes system was used during the study. Landslide area was mapped by Eight ERT profiles with 3000 m of linear length with Wenner and Schlumberger configuration. The depth of the investigation was 50 to 80 m. The acquired data were filtered and processed using RES2DINV software. ERT results of the area showed the multi layered earth model, which mainly consisted of dry to saturated landslide mass deposit, saturated to unsaturated weathered/fractured, fresh and intact bedrock of schist. ERT results showed that, thickness of the landslide mass is more than 30 m on the crown and more than 15 m at toe of landslide. Bedrock was found at depth of 5 to 15 m towards the downstream part of the landslide. The thickness of the landslide mass is more towards upstream than towards downstream from the center of landslide. Bedrock was not found up to 60-65 m depth at some section of landslide which has been verified by bore hole log. Result of the study provided information both on the lithostratigraphic sequences and geometry of the landslide (lateral extension and thickness), slip surfaces, thickness of landslide mass and area with high-water content which is essential for the understanding the landslide and apply mitigation measures for slope stability.

**Keywords**: Electrical resistivity tomography, ERT, landslide, bedrock

# Crustal structure and discontinuities beneath the Nepal Himalaya using seismic ambient noise and teleseismic P wave coda autocorrelation

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Nepal is an actively deforming region due to its tectonic setting that hosts many destructive earthquakes including the most recent 2015 Gorkha earthquake of magnitude 7.8. To better understand the physics of earthquakes and their precise location as well as monitoring of seismicity and real-time seismic hazard in the region, a highly resolved 3-D structure of the crust is essential. This study presents a new 3-D shear (S) -wave velocity structure of the crust and discontinuities beneath Himalaya Nepal using dispersions obtained from the ambient noise and autocorrelation of the coda P waveform. Our results show significant differences in the crustal structure within the region and correlate well with known geological and tectonic features present there. The results from the autocorrelation of teleseismic P coda identify major seismic discontinuities in the crust including the Main Himalayan Thrust (MHT). The MHT with two ramps correlates well with a low S velocity layer obtained from the ambient noise tomography. The first ramp agrees with the duplex structure in the MHT beneath Lesser Himalaya while the second ramp connects flat low velocity beneath Lesser Himalaya to a broad low-velocity zone beneath South Tibet. Moreover, the low-velocity layer is located where the GPS data show interseismic creeping and continues down to 20-30 km in the north of the coseismic rupture of the 2015 Gorkha earthquake. The lateral variation of S velocity on the MHT surface provides the details of lateral transitions that might have the potential to control the rupture patterns of the 2015 Gorkha earthquake.

**Keywords**: Seismic ambient, teleseismic, coseismic rupture

# Quality of alluvial clay of Chitwan for different ceramic production

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Alluvial deposit characteristics were examined in order to assess the deposit's quality and appropriateness for the production of fired clay bricks. Particle size distribution, Atterberg limit, linear shrinkage, moisture content, specific gravity, X-ray diffraction, organic content, chemical test were used to determine physiochemical, mineralogical, and technological properties of the alluvial deposit of Chitwan. The average moisture content of the clay ranges from 9-31.75 whereas specific gravity from 1.54-2.727. The sample that were tested in the study area have mostly low to intermediate plastic clay and the sample S5 has high plastic clay among 22 samples collected. The high plastic clay is due to organic content present. The organic content presented in the sample ranges from 2.05-6.32%. The plastic limit of the test sample is from 11.09-38.35 and this is due to the presence of clay minerals. Chemical analyses indicate high silica content (42.36%-76.02%) and low alumina content (7.10%-14.86%) with comparatively low iron content (6.80%-7.90%), MgO content (0.30%-1.22%) and CaO content (0.84%-1.72%). The normal clay minerals have a low plasticity index, and the test sample showed a range of values from 7.50 to 18.11. The greater the plastic limit, the higher the shrinkage on drying, and the sample will crack after firing. The shrinkage value of the tested sample ranges from 2.49 to 7.79% which is non- critical to marginal ranges and is suitable for making brick and there would be a very low probability of deformation. Hence from the tested sample, the alluvial deposits of Eastern Chitwan are mostly suitable for fired brick production.

**Keywords**: Ceramics, alluvial clay, firebricks, plasticity index, shrinkage limits

# Application of geoelectric method in identifying subsurface karst features in the intake area of Nalgad Hydroelectric Project, Nepal: A case study

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Geo-electric method is a familiar and widely used technique for the detection of subsurface structures including karst features. Karstification is a very common feature developed in the carbonate terrain that causes the subsidence of the surface features.

Locating and quantifying the cavities with their actual geometries has important significance in engineering construction. Surface subsidence commonly occurred in the carbonate terrain in the dam axis area of the Nalgad Hydroelectric Project. The 2-D electric resistivity tomography (ERT) technique was used to identify the causes of subsidence in the study area. Four survey lines were selected and deployed to identify possible cavities within the carbonate terrain in the intake area. Survey lines tomogram ERT-01 and ERT-03 revealed a concentric very high resistivity patch that was interpreted as a dry cavity. The results of the 2D- ERT survey were correlated with core log data from geotechnical exploration in the suspicious area to ensure the presence of the karst at that particular point. It was found that the core loss occurred at the specific depth where high resistivity patches were found on the right bank of Nalgad Khola near the dam axis of the Nalgad Hydroelectric Project. The geo-electric methodology permitted to accurately delineate sub-surface geological information and to successfully explain the presence of cavities within the study area.

**Keywords**: Electrical Resistivity Tomography, Karst, Nalgad Hydroelectric Project

# Simulation of rockfall trajectories using CRSP Model

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Siddhartha Highway is a major highway that connects the Terai reason with mountain reason of the mid-central Nepal. Along the Siddhartha Highway around Siddhababa area is highly problematic section due to rock-fall problem during rainy seasons. Geologically, the Siddhababa area lies within Sub-Himalaya of that section. The lithology, orientation of discontinuities, alignment of highway and design of slope cut and role of groundwater are main causes of rock-fall problem in the area. Rock-fall such as live free-fall, bouncing, rolling, and sliding can be observed in the field. The main objectives of the study is to find out the potential of rock-fall problems, critical zones of rock-fall, conduct the rock-fall simulation and ultimately protect people, properties and engineering and historical infrastructures.

Rock-fall is totally probabilistic approach so actual prediction of rock-falls is practically impossible. The variability in slope geometry, poorly defined initial conditions, uncertain material properties (especially coefficients of restitution) and an analysis method that is sensitive to minor changes in these parameters are contributing factors that make accurate prediction extremely difficult. Performing probabilistic simulation and statistical analyses have proven to be an effective and acceptable method for overcoming these difficulties and thereby enabling the production of rational engineering designs. The computer prograrn GeoRork 2D is a tool with probabilistic simulation of rock-falls and the design of remedial measures. For this, different equations and the algorithm used by the program to simulate the rock-falls.

The tool for rock-fall simulation is geostru geoGock2D software in CRSP (Colorado Rockfall Simulation Programmer) model having boundary conditions are; 100 numbers of trajectories of throw step 2m, the slope material properties and boulder characteristics are chosen from the site. Rockfall simulation is done first without the barrier system to find section with low energy and low bouncing height from the software. The profile is again simulated putting the barrier on the section of minimum energy level and bouncing height. If the barrier is able to stop 100% of the rock-fall, then the barrier system of the energy class is used for the mitigation measures during simulation.

The rock-fall simulation is done on the ten different trajectories which are the main path for rock-fall events from the rock-fall source. The height of the systems is standard in accordance to ETAG27. The minimum 1500 KJ, 60°, 400 cm to maximum 2500 KJ, 70°, 600 cm energy, inclination and height of barriers respectively. For this, the flexible barriers at such altitude are being the suitable mitigation measures for rock-fall protection.

**Keywords:** Rock-fall, throw step, barrier system, simulation

# Evidence of long-lasting quiescence of great earthquakes in the central Himalaya

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Despite Indo-Eurasian convergence of ~20 mm/yr, the ~700-km-long segment between the rupture zones of the 1905 Kangra (Mw ≤8.0) and 1934 Nepal–Bihar (Mw 8.2) earthquakes - "central seismic gap" is the most prominent enraptured sector of the Himalayan front. The prolonged seismic quiescence during the last couple of centuries on the Indian side of the central Himalayan segment makes this segment vulnerable to large earthquakes compared to the Nepal segment, which is relatively active. The timing and magnitude of the latest great earthquake in the "central seismic gap" remain ambiguous and have a pronounced scope for paleoseismological Investigations. We have investigated a few trenches, speleothem-growth-perturbations, and damages in karst systems in the Central Himalaya and mountain front along the Himalayan Frontal Thrust (HFT) in India and Nepal. Based on the deformation evidence and chronology, our result suggests a few prominent events of large earthquakes in this region. The studies along the Himalayan Frontal Thrust (HFT) in the Indian part disclose a faulting event between 14th and 15th centuries, and a dominant view presupposes the 1505 CE earthquake as the likely source. Along with our independent inputs, we evaluate the database to define the timing of the last faulting event on the frontal thrust of the central Himalaya. From the historical viewpoint, the Nepalese archives directly reference a significant earthquake in 1344 CE, and the Indian sources hint at a restoration phase for the mid-14$^{th}$ century monuments in the northern plains and the coeval destruction of the ancient temples in the central Himalaya. Aside from the constraints generated by the earthquake proxies, including liquefaction features and deformed stalagmites, the previous and currently acquired geological data from multiple trenches across the frontal thrust show that the last faulting event occurred between the 13th and 14th centuries-the time interval coinciding with the 1344 CE earthquake. The episodic valley fills debris flow depositions identified in the Pokhara Valley in east-central Nepal provide additional constraints for the 1344 CE earthquake along with two previous ones in 1255 and 1100 CE. The consistency of multiple pieces of evidence from India and Nepal, in combination with the new data inputs from two trench locales, implicates the 1344 CE as the last of the medieval sequence of earthquakes. With a rupture length of ~600 km of the central Indian Himalaya and an average slip of 15 m, this earthquake is consistent with a magnitude of Mw ≥8.5. Our study suggests that an earthquake of similar size is overdue in this part of the Himalaya, considering the long-elapsed time of ≤700 years.

**Keywords**: Central Himalaya, Kathmandu Valley, trench stratigraphy, caves, great earthquake

# Geological evaluation and slope instability risk assessment of Jharlan Landslide in Chhyamthali area, Dhading district, Lesser Himalaya, central Nepal

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Jharlan Landslide is commonly called as 'JharlanPairo' and it is one of the active, large-scale landslides located in North West of Dhading District. This paper presents details of geological evaluation, slope failures risk assessment and introduces the mitigation measures. The study area lies in the Lesser Himalayan belt of Central Nepal. Meta-sandstone, UlleriAugen Gneiss and phyllite are the major lithological units of this area. The landslide is being continuous threat to the local inhabitants causing damage of settlements, cultivated land, foot trails and vegetation. '2015 Gorkha Earthquake' has affected the area by opening of new tension cracks, rise of slope failures and propagating the landslide towards nearby villages. In the area fragile, high density soil masses overlies the weathered Ulleri Augen Gneiss, phyllite and meta-sandstone leads to slope failures in various dimensions. Preliminary and detail study of the landslide were carried out by desk study and field investigation. Field investigation was carried out by field work and collected essential data and information of slope failures. Knowledge driven approach, kinematic analysis, visual inspection, satellite image and topographic maps interpretation are the major source of evaluation. It helps to perform comparative study and slope instabilities risk assessment.Jharlan Landslide is combined form of rotational slide, debris flows and debris slide. Risk of slope failures is mainly concentrated in NW and NE direction of the study area. The length of tension cracks is significantly large and propagating trend of the landslide is towards the villages. Based on the study, the major causes of the landslide are (a) weak rock-mass (b) unconsolidated soil mass (c) heavy precipitation (d) oversaturated of soil mass (e) tectonic activities and (f) anthropogenic causes. The field assessment and nature of the slope failures revealed the landslide to be unstable especially during monsoon period. This paper also illustrates some remarkable, cost-effective mitigation measures such as construction of drainage wells, ditches, gully protection and bio-engineering works. Additionally, more stress is given to the installation of continuous monitoring devices to prevent the hazard in future.

**Keywords:** Landslide, Lesser Himalaya, slope failure, rotational slide, debris flow

# Accounting for mass movements in proglacial geosystems

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Due to the glacier melt caused by climate change, the alpine geosystems are affected by drastic environmental changes. As part of the DFG bundle project PROSA (high-resolution measurements of geomorphodynamics in proglacial systems in the Alps), the intensity of the geomorphological processes in the recently de-iced areas ('proglacial geosystems') in the course of glacier melt was examined by investigating the contribution of gravitational mass movements to sediment transfer in the Alps of Upper Kaunertal/Austria was quantified. The gravitational mass movement processes were quantified throughout the catchment based on geotechnical mapping, measurements of rockfall activity on rockfall nets and sediment traps. The rockfall activity and the movement behavior of active rockslides at the glacier edge could be quantified by repeated high-resolution airborne laser scanning (ALS) measurements.

The average material transport through fall processes in the upper Kaunertal is approx. 3077 t/km²/a. Spatially, maximum erosion rates of over 10 mm/a were measured on recently de-iced rock faces. Low erosion rates of around 0.01 mm/a were measured on slopes that have been ice-free since the Pleistocene. The mean rock face erosion rate is 4.28 mm/a, far exceeding rock erosion rates measured in other alpine but non-glaciated catchment areas. The results clearly show an increased dynamic of all investigated gravitational processes in the recently de-iced areas.

**Keywords**: Mass movement, proglacial geosystem, glacier

# Rock Slope Stability Analysis using Photogrammetric approach: A case study from granitic cut slope in Fast Track Road

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Spatial distribution and configuration of discontinuities controls rock slope failure type and its mechanism. Due to the challenges encountered during the data collection phase, it is exceedingly difficult to assess discontinuities-controlled failure phenomena over wide areas. Engineering-geological characterization of rock slopes for stability condition determination with field mapping is limited to only accessible lower slopes. This study shows the application of structure from motion (SfM) digital photogrammetric approach for rock slope stability analysis in newly cut road section slope of Fast Track Road in Sisneri area, central Nepal. Utilization of 3D point cloud processing algorithms/ software in identification, characterization, and evaluation of cut slopes in granites and accurate quantification of geometrical, engineering geological data and photographic documentation of site with 3D surface and structural modelling is carried out. Constraints of conventional hand-mapping to lower slopes is extended with photogrammetric approach with mapping of inaccessible, steep slopes and cliffs. Semi-automatic discontinuities detection techniques with Split-Fx® and its kinematic analysis for possible failure from SfM approach compared with field mapping of discontinuities showed reasonable similarities in identification of joint set and slope failure type. Thus, the applicability of SfM approach can be implemented for slope stability analysis in blocky rocky terrain.

**Keywords**: Photogrammetry, SfM, cut-slope, slope stability

# Metallic mineral resources in Nepal Himalaya: Key for the prosperity of the people and sustainable development of Nepal

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In ancient Nepal, small-scale mining of some important metallic ores (copper, iron, lead-zinc, nickel, and cobalt) was mined, and the products were used for various purposes. In those days, Nepal used to export, these commodities to Tibet and India. The presence of slags, and remnants of low-grade ores around old working are solid indications of past mining activities. At present, several economic to sub-economic and quite large numbers of occurrences and showing of metallic resources are known to exist in Nepal. Economic to sub-economics deposits have been identified for copper, lead, zinc, and iron, and occurrences to showings for gold, silver, cobalt, and nickel. In the present study, an attempt is made to show the geological control of metallic deposits in Nepal. Geological control for the most of metallic minerals is linked with igneous processes while few the stratigraphic in nature. The copper mineralization in Nepal was genetically found to be linked with basic igneous rocks while iron is mostly syngenetic in nature. Recently good mineralization of nickel and cobalt is found in the Gulmi district of western Nepal. The genesis of mineralization is hydrothermal in nature. Minerals like nickel and cobalt are already documented as strategic minerals by USA and China and have a higher value in several industries. Nepal can be one of the nickel and cobalt producer countries if it is well explored and planned for development. Similarly, copper mineralization, documented as non-economic deposits in the past, could be economic in recent times due to the depletion of copper mines in the world along with the advancement of mining and processing technology. Several studies from the past to the present show that the nation has possibilities of mining of metallic minerals.

**Keywords:** Metallic minerals, copper, nickel and cobalt, sustainable development, prosperity, Nepal Himalaya

# Paleostress analysis of Shivnath-Salena area using stress response structures

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Geological mapping and paleostress analysis were carried out in the Shivnath-Salena area of the Lesser Himalaya in Far-West Nepal. Lithostratigraphically, the area is divided into the Dadeldhura Group, Baitadi Group, and Tertiary Group. The Dadeldhura Group consists of quartzites, amphibolites and slates of the Alauda Formation. This formation is followed stratigraphically upwards by the Shivnath Schist. The Baitadi Group consists of carbonates with black slates of the Tetabai Formation followed by red-purple slates with thin carbonate beds of the Chaugau Formation. Similarly, these rocks are succeded by black slates and pale yellow grey quartzites of the Salena Formation. The Tertiaty Group is the youngest succession of the study area, and it consists of very coarse-grained, brown quartzites interbedded with black shales belonging to the Gosal Gad Formation. This Formation overlies the Salena Formation with a disconformity. The Gosal Gad Formation is transistionally overlain by the Chachura Formation, which is the youngest rock in the study area. The Chachura Formation comprises red-purple shales and green sandstones with lenses of grey limestone containing Nummulitic and Bivalvia fossils of Eocene age.

Twenty-seven slickensides and other stress-response structures were mapped in the field to analyse paleostress regime in the study area using stress inversion techniques (Fig. 1). The maximum principal stress ($\sigma_1$) axis in the study area is directed towards the NE-SW. The average value of stress ratio (R) is about 0.30, which indicates an extensional tectonic regime in the study area. R' Since $\sigma_1$ is vertical, R=R', suggesting an extensional regime. The index R' defines the stress regime completely and is suitable for computing the mean regional stress regime from a series of individual stress tensors in each area

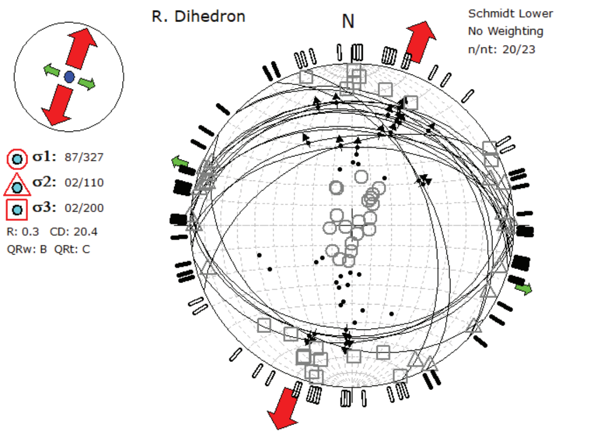


**Fig. 1: Paleostress analysis of Shivnath-Salena area using right dihedral method. The analysis shows an extensional regime.**

**Keywords:** Baitadi, neotectonics, stress, extensional regime

# Relationship between rockmass classification system, RMR and Q in Nepal Himalaya

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The importance of rock mass classification system is increasing day by day in the Nepal Himalayan due to massive construction activities undergoing in tunneling. It has become one of the essential tool for the design and construction works. The widely accepted rock mass classification system RMR and Q is being mostly applied in the tunneling works. Many researcher have published empirical correlations between these classification systems. Series of empirical correlation has been developed due specific site geological condition. The aim of this paper is to proposed relationship between RMR and Q indices in the Nepal Himalayan. For this, data generated from headrace tunnel of Kapadigad Hydroelectric project has been analyzed.1200 m length of headrace tunnel has been examined using 758 blocks. Several regression modeling has been carried out to find out the most suitable equation with the highest correlation coefficients. The obtained relationship shows high correlation coefficient and unique relationship between two classification systems. The developed relationship will certainly be an essential tool for rock engineering Practitioner in the Nepal Himalaya.

**Keywords**: Rock mass classification, RMR, Q, relationship, regression analysis

# Assessing climate change vulnerability of livelihood in Mid-hills of Nepal

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Climate change vulnerability; defined as the propensity to be adversely affected by climate change encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope with and adapt to future changes (IPCC 2014). There are three key elements of vulnerability: (i) exposure (ii) sensitivity (iii) adaptive capacity.

Vulnerability assessment is widely used in various research applications that include ecology, environmental health, sustainability, poverty alleviation, livelihood, development, and hazard and impact assessment for climate change. It has also been useful in factoring in biophysical and socio-economic components for better adaptation and mitigation measures and decision-making. The current study done at a major wetland watershed area in Kaski District uses the livelihood vulnerability index (LVI) and the Intergovernmental Panel on Climate Change (IPCC-LVI) approaches to assess household livelihood vulnerability in the Central Himalayan region of Nepal. The LVI uses various indicators to assess exposure to natural disasters, climate variability, and household social and economic characteristics that influence their adaptive capacity and current health, food, and water resource characteristics that influence their sensitivity to climate change impacts. In this approach, seven major components were classified into three categories, i.e., exposure, sensitivity and adaptive capacity. The exposure index contained natural disasters and climate variability, the sensitivity index contained food, water and health, and the adaptive capacity index contained socio-demographic profile, livelihood strategies and social networks. The min-max method was adopted for the normalization of the quantitative dataset. The overall LVI score (0.416) indicated that the households are vulnerable to climate change. Food (0.642) and natural disasters and climate variability (0.566) were the most vulnerable among all contributing factors. Similarly, the overall LVI-IPCC score (0.104) indicated that the households were moderately vulnerable due to high exposure (0.566), sensitivity (0.448), and low adaptive capacity (0.334).

The study findings suggest an urgent need to reduce high exposure to climate risks, improved livelihood strategies, and boost agricultural productivity and health.

**Keywords:** Vulnerability, exposure, sensitivity, adaptive capacity

# Non-linear surface-subsurface coupled modelling approach to investigate the transient groundwater storage variability in the Nepal Himalayas

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In the Himalayan, mountain range is often termed the "water towers of Asia". In a context where current climate change rapidly melting glaciers and declining snowfall rates, it becomes important to know where water is stored in the mountains to sustain river discharge through the long-lasting dry season and how the infiltration mechanisms are processed. However, the procedures that govern the Himalayan Mountain water cycle are still not well understood. Recent studies have pinpointed groundwater in the mountains as a sustainable large water reservoir which is recharged by sustained monsoon precipitation and is slowly drained in the subsequent dry season.

To further investigate how the groundwater recharge in a changing climate system will work, comprehensive surface-subsurface coupled modelling is needed. This needs to be integrated with field investigations on the subsurface architecture since soil thickness, regolith and the depth of the bedrock are crucial parameters.

To better investigate the role of groundwater in the Himalayan water cycle we choose the not glacierized KahuleKhola watershed in the central Himalayas, around 55 Km north-east of Kathmandu and 10 Km west of Tibetan boundary, as a test and validation catchment. The catchment is located on the rime between the Lesser Himalayas and the High Himalayas, has strong topographic range 1076 m to 3471 m and an area of 33 Km². This catchment represents a typical Himalayan topography and is purely rainfall fed with only very little snow on the high ridges during wintertime.

We developed a new 2-dimensional numerical model for subsurface groundwater variations. This model solved non-linear Richards-type equation using a finite volume approach combined with the Newton-Raphson algorithm. The model has been especially designed to function in mountainous environments with steep slopes and is currently adapted to a fractured bedrock socle. The model is at-present capable of simulating the variations of a water table in a transient regime under the influence of seasonal recharge. The objectives are (1) to train the code with climatic, hydrological and insitu surface-subsurface properties of a watershed. So, it is necessary (2) to understand the infiltration mechanisms on slopes. After verifying and validating the calibration of the model, the ambition of the whole study is (3) to understand and couple groundwater to surface water, and then to link this surface water-groundwater connectivity to the landscape evolution model (LEM). We plan to better investigate the subsurface insitu properties with Geophysical investigation using ERT (Electric Resistivity Tomography) method and constrain the permeability of the subsurface to detect important structures as well as the regolith depth and the bedrock interface. This will be complemented by infiltration capacity measurements of the topsoil layer. Then, a prospecting source is also planned to have a history of the isotopic signature of the samples at the identified sources.

Our study will help to better prepare water availability in the Himalayas and predict the sustainability of the Asian water towers.

# Connecting geoscience with the community: Prospects of geopark and geotourism in the Nepal Himalaya

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Nepal has a unique geological setting characterized by the subduction of the Indian plate under the Eurasian plate which is still an active process. The Himalayan Range formed as a result of continent-continent collision include the highest mountains in the world and Nepal Himalaya is the central part of the Himalayan arc with longest division of the Himalaya occupying nearly one third of the 2400 km long Himalayan Range. Geologically young, and active Nepal Himalaya is characterized by five major longitudinal parallel zones each with its own distinct lithology, tectonics, geomorphology, and geologic history as well as its own climate, vegetation, culture, and livelihood. It serves as a natural laboratory to researchers and scientists for research in geology particularly that pertaining to plate tectonics. The pre-, syn- and post-tectonic evidence can be studied in the region.Nepal Himalaya features rich geological resources of great scientific value offering opportunities for geoparks to enhance geoscience education, geotourism, and economic development of the country.

The Himalayan Mountain system is considered as one of the most vulnerable mountain systems of the world due to active plate tectonics and the region is among the most earthquake prone areas in the world. Monsoon rainfall, frequently occurring earthquakes combined with fragile geology resulting to landslides, and floods makes Nepal a vulnerable and hazardous country. Furthermore, increasing impacts of climate change on glaciers has posed high risk of Glacial Lake Outburst Flood (GLOF) and avalanches for the mountain communities.Geoparks are important to simplify geoscience to local communities andenhancethe capabilities of local people who are prone to disasters mostly landslide, flood, earthquake and GLOF caused primarily due to active tectonic processes, fragile geology and climatic variability. Geoscience emphasizes the importance of nature - the earth - and its protection. For the development of geosciences, as well as for welfare of the local people particularly in countries like Nepal where people live with geohazards, geoparks are essentially important.

Geoparks can serve as one of the cornerstones for geotourism in Nepal leading to region's sustainable development and geotourism can play a vital role for the welfare of local communities protecting the value of earth and environment. Nepal can benefit from its rich geoheritage for which the integrated approach of protection, education and sustainable development of UNESCO Global Geoparks should be taken into consideration. Identification of possible geosites in the country and selection of geosites with great scientific value significant for earth sciences education and geotourism ultimately aims to change geological significant regions to national and global geoparks. For the sustainability of geoparks and geotourism, it is crutial to involve local communities throughout the entire process, transfer geoscience to public and make people realize the value of earth heritage.

**Keywords**: Geohazards, geoheritage, geoscience, geopark, geotourism, Nepal Himalaya

# Climate, land use change impact on water resources availability and agricultural practice: A case study of Indrawati River basin of Nepal

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The SWAT model simulation result in the Indrawati basin showed that daily average water yield was decreased with time from high land to low land areas of the sub-basin. Model predictions on daily basis at Dolalghat shows coefficient of determination (R2) and Nash-Sutcliffe simulation efficiency (NSE), 0.832 and 0.796 for calibration period and 0.859 and 0.807 for the validation period respectively. Similarly, at Helambu the R2 and NSE were 0.797 and 0.70 for calibration period and 0.848 and 0.746 for validation period. As a result, the daily water yield was found within the ranges of 1.61 mm to 7.83 mm, 0.79 mm to 7.95 mm, 2.70 mm to 7.50 mm, 2.69 mm to 7.58 mm, 2.69 mm to 7.58 mm, 2.82 mm to 7.67 mm, 2.62 mm to 7.32 mm for the 1995 land use, 2008 land use, Scenario unchanged, Scenario-1, Scenario-2 and Scenario-3 land use respectively of different 14 classified sub-basins. Also there seems to be deficit in the water demand, for the different cropping patterns on various scenarios (i.e. considering rain fed and irrigation on run of river flow condition) which mainly occurs in the months May and September. The AQUACROP model simulation in intra-sectoral basin indicate that the crop yield of rice decreased from 8.731 ton/ha to 0.137 ton/ha under rainfed system, and a little increase 8.753 ton/ha to 1.23 ton/ha under the irrigation system. On the other hand, the yield of crop maize remains about the same value from 15.150 ton/ha to 13.525 ton/ha in the same years from 1990 to 2060 under different scenarios on assuming the same planting/sawing dates for respective crop. But after shifting the crop calendar by appropriate days towards the preceding months (i.e. 7 days per decade), the yield of the crop seems to be in increasing order. The findings of this particular study suggested that proper irrigation system and appropriate agriculture adaptation should be given due attention urgently to maintain the irrigation and water resource management.

**Keywords**: Climate change, SWAT, Aquacrop, yield of crop, water resources management

# Application of magnetotellurics (MT) method in groundwater exploration: An alternative of controlled source method

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Magnetotellurics is an electrical method of geophysical exploration that makes use of naturally occurring open electromagnetic energy. It measures the low frequency electromagnetic field, and the wave impedance is calculated in terms of electrical resistivity. In electrical resistivity survey using the controlled source method, current is generated artificially for the exploration, however, in MT method, the use of naturally occurring electromagnetic energy propagating into the earth is used to determine the electrical resistivity. A disadvantage of controlled source method lies in the interpretation problems in areas of complex geology and the depth of investigation is also limited. However, the MT is used for the tens of meters to 2 km depths of investigation. In this investigation, the groundwater detector machine changes the field data to colorful image with resistivity profiles automatically. The interpretation is easier than other complex methods. This investigation shows all types of aquifers along with all lithotypes more distinctly. In the context of Nepal, the MT method is recently used for the exploration of groundwater in some locations of Terai, Dun valley, and some hilly regions of the western Nepal. This type of investigation is recently employed in Nawalpur, Rupandehi, Gulmi, Kapilbastu, Dang, Surkhet, Banke, Bardiya, Kailali, Doti and Acham districts. The findings of this survey have become very useful to pinpoint the location of groundwater. It was used in some of the deep tube wells which were not successful to locate the aquifer. It was used locating the water bearing strata in unknown areas for groundwater detection. It minimizes the construction cost of unnecessary drilling for deep tube wells. The result is positive everywhere and the community are taking the advantage of this investigation. In the present study, many wells are developed based on this type of investigation and the success rate is high.

**Keywords**: Magnetotellurics, open electrical source, aquifer, tube wells

# Earthquake impact on the stress magnitude at the area of shear zones

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In-situ stress condition in rock mass is influenced by both tectonic activity and geological environment such as faulting and shearing in the rock mass. This influence is of significance in the Himalayan region, where the tectonic movement is active, resulting in periodic dynamic earthquakes. Each large-scale earthquake causes both accumulation and sudden release of strain energy, instigating changes in the in-situ stress environment in the rock mass. This paper first evaluates the influence of local shear/weakness zones on the magnitude of the minimum principal stress along the shotcrete lined high pressure tunnel of Upper Tamakoshi Hydroelectric Project (UTHP) in Nepal. A detailed assessment of the in-situ stress state is carried out using both measured data and three-dimensional (3D) numerical analyses with FLAC3D. finally, analysis is carried out on the possible changes in the magnitude of the minimum principal stress in the rock mass caused by seismic movement (dynamic loading). A permanent change in the stress state at and nearby the area of shear zones along the tunnel alignment is found to be eminent process.

**Keywords**: Earthquake, principal stress, 3D numerical model, geology, shear zone, The Himalaya

# An overview of cut-slope stability evaluation in Lesser Himalayan Zone of west-central Nepal

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Infrastructure development without due consideration of geo-environmental factors have led numerous slides all over the Lesser Himalayan Zone that has seriously affected the life and properties of the people living in and nearby the slide zone every year. Major cut-slopes in Nepal include various sectors such as road, river banks, open mines, dam and powerhouse (hydropower), railway track, industrial activities, irrigation canals etc. The field evidences and evaluation of 67 cut-slopes in Lesser Himalayan Zone of west-central Nepal indicated that 60% of them lie in soil and 30% lie on bedrock. Within the soil cut-slopes, 55% lie in alluvium, 25% on residual and 20% on colluvium. In terms of slope angle, 88% of the cut-slopes are more than 45 degrees which seem to be unstable. 77% of the cut-slopes are dry and becomes fully saturated during the monsoon season. Based on the weathering grade for those cut-slopes in bedrock, 45% of them lie in moderately weathered bedrock whereas 25% lie in completely weathered bedrock. With respect to dipping of the discontinuities, it is found that 66% of cut-slopes are in obliquely dipping whereas 28% are in dip-slopes. The dip-slope conditions (daylighted) are critical to slope failures. Conclusively, slope geometry, weak rock layer, sheared or crushed bands, soil characteristics etc. of the cut-slopes play the vital role for failures during dynamic conditions.

**Keywords**: Lesser Himalaya, cut-slope, stability evaluation

# Detection, tracking, and potential for early warning of catastrophic flow events using regional seismic networks

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Geomorphic events such as landslides, debris flows, and flash floods are a major source of hazard in many mountainous areas, and are potentially a growing threat due to both changing climate and increased development in mountain regions. This is of particular concern in the Himalayas, where increases in hydropower development involve placing workers and infrastructure in vulnerable portions of the landscape. The threat was starkly illustrated on 7 Feb. 2021 when a rockslide-mass flow-flood cascade in Uttarakhand India caused a large number of fatalities and severe damage to infrastructure. Such hazardous geomorphic events are often difficult to anticipate and difficult to observe, hampering our ability to mitigate their impacts. Our increasing understanding of the seismic signals generated by geomorphic events offers new opportunities for monitoring geomorphic hazards, with potential for both event early warning and a better understanding of event dynamics. We illustrate this potential using data from the 7 Feb. event, which was recorded by a dense network of 3-component broadband seismic stations set up across Uttarakhand by the National Geophysical Research Institute, under the Council of Scientific and Industrial Research, India (CSIR-NGRI). The seismic data capture the evolution of the event from the detachment of the initial rockslide through to the dissipation of the resulting flood ~55 km downstream, and can be used to track the location of the flow as it propagated downstream. The dense seismic network also allows us to determine the detection limits for each phase of the event. Our results show that such events can be widely detected and located within minutes of initiation, illustrating the potential for geomorphic hazard early warning using regional seismic networks.

**Keywords**: Hazard, seismic network, Himalayas, early warning

# Stability assessment of desander cut slope of Seti Khola Hydropower Project

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Due to steep topography in the Himalaya, creating space for the development of infrastructures involves the excavation of slopes which possesses certain degree of risk associated with failure. This paper aims to assess the stability of the rock slope excavated for creating the space for desanding basins of Seti Khola Hydropower Project (22 MW) located in Lekhnath, Kaski district of Gandaki Province, Nepal. The height of the cut slope is about 60 m which is among the challenging part of construction work for this project. The slope is cut in the rock which is highly schistose graphitic phyllite and interbedded with metasandstone at the upper part of the slope. To conduct detailed stability assessment, the characteristics of intact rock, discontinuities and rock mass have been evaluated and some parameters have been assumed from field mapping and relevant literature review. Rock mass quality has been assessed in the field using the Rock Mass Rating (RMR) method of rock mass classification. RMR values are then correlated into Slope Mass Rating (SMR) which is a system of rock mass classification for the rock slope. Furthermore, a 3D geological model has been generated to represent the geometric properties of discontinuities and the cut slope. Kinematic analysis has been carried out using geometric and discontinuity properties to evaluate the structurally controlled failure. The influence of groundwater and earthquakes have been also considered to determine the shear strength of discontinuities empirically. Detailed stability assessment has been carried out analytically using Ordinary Method of Slices of limit equilibrium method and numerically using the continuum approach in Phase$^2$ considering the effect of rock support measures in addition to influence of groundwater and earthquake. The sensitivity and reliability analysis have also been carried out.

**Keywords**: 3D model, groundwater and earthquake, shear strength, stability assessment, sensitivity and reliability analysis

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# Spatially focused erosion in the High Himalaya and the geometry of the Main Himalayan Thrust from thermokinematic modeling of thermochronological data

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The Himalayan Mountain range is the result of the long-lasting collision between India and Eurasia. At the current stage of the collision, rock exhumation in the Himalaya is largely controlled by slip along the seismically active Main Himalayan Thrust and coeval erosion. Owing to the flat-ramp geometry of the Main Himalayan Thrust, cooling and exhumation above the mid-crustal ramp are faster than above the adjacent upper-crustal flat, but the dip angle and the northward extent of the crustal ramp remain poorly known. To better constrain the geometry of the Main Himalayan Thrust, we applied low-temperature thermochronology and U-Pb zircon dating in the northern High Himalaya (Gyirong region, China). Our zircon U-Pb data show that the protolith of the High Himalayan orthogneisses is 478±4 Ma old, and was intruded by a large leucogranite at 19.5±0.7 Ma. The Pliocene-Quaternary cooling of the study area is constrained by apatite fission track ages and apatite and zircon (U-Th)/He ages between ~5 Ma and ~0.5 Ma, which show a marked trend of southward-younging ages. Together with published cooling ages from Nepal, the age data define a well-developed U-shaped pattern across the Main Himalayan Thrust, with ages increasing to the north and south from a minimum in the High Himalaya. A thermokinematic model, which contains a thrust fault with a flat-ramp-flat geometry, is able to explain the observed cooling pattern and indicates that the Main Himalayan Thrust ramp has a dip of 20°N, a width of 55 km, and reaches a depth of 31 km. Farther north, at depths of about 30 to 40 km, the Main Himalayan Thrust is developed as a gently north-dipping ductile shear zone and forms a prominent reflector visible in seismic reflection data.

**Keywords**: Main Himalayan Thrust, thermochronology, U-Pb, leucogranite

# Seismically active structures of the Main Himalayan Thrust revealed before, during and after the 2015 Mw 7.9 Gorkha earthquake in Nepal

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The Mw 7.9 April 25, 2015 Gorkha earthquake is the latest of a millenary-long series of large devastating Himalayan earthquakes. It is also the first time a large Himalayan earthquake and its aftershocks were recorded by a local network of seismic stations. In the five years following the mainshock, more than 31,000 aftershocks were located by this permanent network within the ruptured area, including 14,362 events with ML greater than 2.5, 7 events with ML > 6, including one large aftershock with Mw 7.2 on May 12, 2015. In 2020, five years after the mainshock, the seismicity rate along the ruptured fault segments was still about 5 times higher than the background seismicity before the Gorkha earthquake. Several bursts of earthquakes, sometimes organized in clusters, have been observed from a few days to several years after the mainshock. Some of these clusters were located at the same place as the clusters that happened during the decades of interseismic stress build-up that preceded the large earthquake. They also happened in the vicinity of the high frequency seismic bursts that occurred during the main shock. These heterogeneities contribute to a persistent segmentation of the seismicity along strike, possibly controlled by geological structural complexities of the Main Himalayan Thrust fault. We suggest that these pre-2015 clusters revealed the seismo-geological segmentation that influences both the coseismic rupture and the postseismic relaxation.

**Keywords**: Seismic cycle, Asia, seismicity and tectonics, aftershock, Nepal Himalaya

# Megathrust control on landscape evolution, structural architecture, and active deformation: results from a 3D structural, Thermal, and dynamical study of the Himalaya

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We investigate the architectural complexity of the Himalayan thrust wedge through analysis of a 3D model of shear zones within the central-western Himalaya. The model reveals significant along-strike variations in the magnitude of strain accumulated in the mid-lower crust of the wedge. Comparing the model with surface geology, coupling along the megathrust, stream channel steepness, micro-seismicity, thermochronologic data, and topography, we reconcile the coeval development of orogen-parallel extensional features (a supra-extensional basin and a metamorphic core complex on the orogenic plateau, and a transtensional fault system obliquely cutting the Himalaya), orogen-normal shortening features (thrust faults and duplexes formed at depth with along-strike variation), and along-strike tectonic segmentation in the central-western Himalaya (expressed as an embayment in plateau landscape, coupling pattern of the megathrust, and concentrated microseismicity zone in western Nepal). Our model invokes the effects of oblique convergence in an arcuate orogen and rheologic variability in both dip and strike directions of the megathrust. Its mechanical feasibility is tested by a 3D visco-plastic creeping mechanical model that incorporates an arcuate convergent boundary and mechanical heterogeneity in the megathrust. With a proper combination of mechanical properties, the model can produce the strain pattern highlighted by the geologic model, including the first-order geologic features mentioned above. Because our model posits that the along-strike variability in rheology, expressed by an embayment feature, is primarily controlled by the 3D megathrust geometry, we investigate the 3D geometry of the megathrust by conducting low-temperature thermochronology analysis coupled with inversions of 3D thermokinematic modeling. Models that can best reproduce observed cooling ages suggest that the megathrust in the western Nepal Himalaya in the embayment segment is best described as two ramps connected by a long flat that extends further north than in segments to the east and west and that crustal accretion along the mid-lower crustal megathrust ramp below the margin of the hinterland plateau landscape is required. By synthesizing geological data and morphologic observations, we further propose an evolution model in which the landscape of the central-western Himalaya evolves in response to crustal accretion at depth and the 3D megathrust geometry. Our work highlights the importance of deep tectonics along the megathrust in the partitioning and segmentation of strain; plateau/hinterland growth; landscape evolution; and active tectonics.

**Keywords**: Thrust wedge, megathrust, crustal accretion, strain partitioning

# Application of NEHRP classification to AVS30 obtained from microtremor array Measurement in the Gulariya Municipality of Bardiya District, Nepal

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During earthquakes, adverse site characteristics could result in a considerable local amplification of ground motion. Site effect studies are therefore crucial for the mitigation of future seismic risk. The average shear wave velocity (AVS30) from the ground surface to a depth of 30 m is globally used as an indicator to characterize seismic wave amplification. One of the more convenient methods for estimating AVS30 is microtremor exploration. We conducted the field observation of microtremor (ambient noise and vibration) in the Gulariya municipality of Bardiya district in early 2022 using a mini hexagonal array (r = 2 m) of a short-period seismometer (L22D; Sarcel, 2 Hz) and a multi-channel data logger. We analyzed the data using the Centerless Circular Array (CCA) method (Yokoi, 2021) and derived dispersion curves of surface-wave phase velocity in the frequency range from about 3 Hz to below 20 Hz. The phase velocity corresponds to AVS30 when the wavelength becomes 40 m (Konno and Kataoka, (2000); Brown et al., 2000; Albarello and Gargani (2010)). Consequently, the National Earthquake Hazard Reduction Program (NEHRP) approach is applied for site classification. The applied approach provides a reasonable estimation of AVS30 from microtremors and most of the surveyed sites fall in site class D (stiff soil) of the NEHRP Index (180 m/s < AVS30≤ 360 m/s). Our results support the idea that the CCA method with a NEHRP approach is a useful tool for site classification and then for seismic microzonation studies of semi-urban and urban areas in Nepal.

**Keywords:** Local site effect, hexagonal shape array, short period microtremor, dispersion curve, NEHRP classification

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# Talc and magnetite of the Pancheshwar area, Baitadi district

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The mining of the mineral resources is crucial to the development of the nation. Most of the nations have large volume of the mineral resources. However, only few countries mined those resources. The present study deals with the geology and mode of occurrence of the talc and magnetite deposits of the Baitadi District in Far Western Nepal. The talc is distributed in the narrow zone at the hanging wall of the North Dadeldhura Thrust. The talc deposit is hosted within the Early-Proterozoic metamorphic rocks of the Dadeldhura Group. The isolated pockets of talc occurred in the quartzite near amphibolite contact, in the vicinity of the shear zone. The talc contains 60.03% $SiO_2$, 29.78% MgO, 1.02% CaO, 4.25% $Al_2O_3$, and 0.32% $Fe_2O_3$. The magnetite is distributed in the black slate and white-grey quartzite of the Salena Formation. The Siliceous magnetite beds have thickness more than 4m in some section and contains 42.02% $Fe_2O_3$, and 50.83% $SiO_2$. The sedimentary siliceous magnetite occurred in the intercalation of the slate and quartzite. The old iron mine workings also exists near the Maharudhra.

**Keywords:** Baitadi, talc, magnetite, geochemical analysis, mineralisation

# Fault rocks and the architecture of diffused brittle faults in the frontal Himalayan fold thrust belt

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Brittle fault zones typically evolve as diffused zones that are characterized by a distinct fault rock type and an architecture consisting of a fault core that is flanked by damage zones on either side. Preservation and vegetation cover in the Himalaya make the identification of such diffused fault zones difficult. However, partially preserved brittle diffused fault zones can be identified based on the knowledge of their architecture and fault rock type even in the absence of fault-related displacement markers. We illustrate this from several fault zones in the frontal Himalayan belt.


**Fig. 1: Conceptual model for the Main Frontal Thrust fault zone in the NW Indian Himalaya. The fault core and hanging wall damage zone regions are exposed and the footwall damage zone remains buried. The fault core is characterized by powdered, unconsolidated fault gouge and the hanging wall damage zone by a (1) frontal gouge-dominated zone where meter-scale islands of less deformed rocks are scattered within it and then (2) a rock-dominated zone with fault gouge bands between largely intact but fractured Middle Siwaliks rocks.**

# Application of frequency ratio method for landslide susceptibility mapping at the Thulo Lumpek area, Gulmi Nepal

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Landslide susceptibility mapping using Frequency Ratio method has been applied in the ThuloLumpek area of the Gulmi district, western part of Nepal.The landslide inventory map was prepared on the basis of detailed field data collection and verification.Tenlandslide causative factors; slope, aspect, elevation, curvature, land use, distance to river, drainage density, topographic wetness index, stream power index, geology were prepared in GIS and final landslide susceptibility map was made. Present area is classified into four landslide susceptibility classes i.e., Low, medium, high and very high. Sindi, Kasingthala, Ghardada, Goskot villages belongs to the very high landslide susceptibility class. The prepared landslide susceptibility map can be used for the landslide hazard management at the ThuloLumpek area.

**Keywords**: Landslide inventory, susceptibility, frequency ratio, GIS

# Pros and cons of different groundwater monitoring techniques: A case study from western Nepal

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Government investment in the field of irrigation, drinking water, electrification, promotion of solar pump, industrialization, and urbanization has increased the extraction of groundwater. Themonitored groundwater level provides adequate spatial evidence about the opportunities and risks of sustainable use of groundwaterto the stakeholders. The Groundwater Resource Development Board, in partnership with the CSISA Resilence Project, had conducted the digital groundwater monitoring pilot work to ensure the resource within sustainable limits. Groundwater monitoring approaches were assessed according to their efficiency, effectiveness, and viability. The manual, ODK-based, offline logger, and online logger approaches were applied to obtain the best and most cost-effective monitoring technique in the present context. Total 53 investigation tubewells were monitored from the Banke and Bardiya district. Among them, all 53 tubewells were monitored from manual; ODK-based approach, 9 tubewells from offline loggers and 2 tubewells from online loggers. Instrument, training, ancillary tools, staffing cost, knowledge of data collector, temporal resolution, major risk, operational expenditure, and hosting cost were considered for the evaluation. Data obtained from different techniques were displayed creating online dashboard. The ODK based monitoring approachwas found cost effective as it can be implemented with a small investment as compared to other approaches. However, the data frequency would be the same as the manual method i.e., once in a month. In contrast, the offline and online logger providedthe higher frequency datain the fraction of minutes and seconds useful for conducting specific studies, but the cost of operation was high. This study provides the basis for the advancement of groundwater monitoring techniques in the country.

**Keywords**: Groundwater monitoring, western Nepal, ODK based approaches

# Analyzing the contributing factors of co-seismic landslides after 2015 Gorkha Earthquake using logistic regression in Rasuwa district

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This study had been carried out in Rasuwa district to understand the fundamental contributing factors of landslides triggered by 2015 Gorkha earthquake and to characterize the landslide susceptibility map (LSM) of the study area. Initially, high resolution Google Earth imageries of pre- and post-earthquake were observed and a total of 890 co-seismic landslides were detected in the area. We considered 23 contributing factors (CFs) and grouped them under five classes as topographical, hydrological, geological, vegetation and ground motions respectively. We examined the correlation of each CFs with co-seismic landslides by three landslide abundance indexes in terms of relative density, number and area. As a result, slope, relative relief and peak ground acceleration showed positive correlation with landslide distribution whereas, road proximity, horizontal drainage proximity and thrust proximity displayed negative correlation. Hereafter, we converted categorical factors into continuous data and followed logistic regression model approach for the coefficient of each factor map. Highest positive coefficient value was observed for the relative relief; therefore, it is considered as best predictor among other factors which is followed by landuse and slope respectively. These coefficients are further integrated in ArcGIS software for the final LSM, and the result is classified into five susceptibility indexes based on field observation. Finally, LSM model was validated by making use of area under the curve (AUC) and statistical inferences methods. Both methods showed good terms with previous landslides, therefore, this model can be utilized for categorizing susceptible zones in future which can be helpful for development planning.

**Keywords**: Co-seismic landslides, contributing factors, logistic regression, susceptibility, validation

# Increased erosion along the Sutlej River, NW Indian Himalaya, at < 1 Ma revealed by inverse modeling of apatite (U-Th)/He thermochronology data

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River erosion is considered as a major driver of localized exhumation in contractional orogen systems and may be enhanced by tectonic processes, climate change, or expansion of river drainage area. Published thermochronological data across the Sutlej River region (NW Indian Himalaya) shows high exhumation rates in the last 3 Ma. It has been suggested that this significant exhumation was largely driven by climate along the Sutlej River, which represents the third-largest erosive system in the Himalayan range, in a region characterized by the development of an anticline. Although the capture of the Zhada basin by the Sutlej River at < 1 Ma may have had a considerable impact on the erosive power of this river, to isolate this signal is challenging due to the lack of more sensitive thermochronological data. In order to constrain the last cooling events over the last ~100°C of rocks exposed, we acquired an extensive new apatite (U-Th)/He dataset (n= 349) along the Sutlej River and its main tributaries (Baspa and Wangtu Rivers). Despite a systematic overdispersion of the intrasample single-grain dates, probably related to the Proterozoic age of the rocks, our inverse modeling of these data allows us to obtain consistent thermal histories across this area. We find that exhumation in the Sutlej River region is spatially variable with the youngest cooling dates < 0.8 Ma observed mostly along the Sutlej River anticline core, located between the confluence of the Sutlej River with the Baspa and Wangtu tributaries, and corresponding to the steepest section of the Sutlej River. The cooling ages increased gradually away from the river anticline core, to 1.2–3 Ma and > 6 Ma along the Wangtu and Baspa Rivers, respectively, which is consistent with previous thermochronology data. As a result, the increased erosion concentrated along the steep section of the Sutlej River caused ~1-2 km of rock exhumation in the last 0.8 Myrs. As the main tributaries were not affected by this recent cooling episode, this rapid exhumation focused along the Sutlej River was probably triggered and enhanced by the capture of the Zhada basin at < 1 Ma. Thus, our results show evidence of the influence of the Sutlej River itself on the shallow (< 3 km depth) crustal dynamics of the NW Indian Himalayan Mountain.

**Keywords**: Sutlej River, thermochronology, exhumation, Himalaya

# Student Himalayan Exercise Program 10 years

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A student who visits the Himalaya feels the movement of the crust, and understands the principal importance of studying geology and geomorphology in the field.

The Student Himalayan Exercise Project runs for a two weeks (depart from and return to Japan) Student Himalayan Exercise Tour (SHET) and has been successfully conducted in every month of March since 2012 in the west-central Himalayan Orogen with its full traverse from the north to the south. The program has been nominally sponsored by 6 academic societies of Japan and Nepal. The Gondwana Institute for Geology and Environment in collaboration with the Department of Geology, Tri-Chandra Campus, Tribhuvan University have taken charge of the practical fulfillment of the tour. The exercise tour covers the Tethys Himalayan, Higher Himalayan, Lesser Himalayan, Sub Himalayan and the Gangetic Alluvial zones, observing important geologies of all the geologic zones and major boundary faults. The tour starts from the northernmost area-Muktinath (3800 masl), the world's very holly temple of Hinduism, traversing along the Kaligandaki River and ends in the Pokhara city, the central of the Himalayan sightseeing, as the first part of the tour. The second part starts from Pokhara to Tansen city, a traditional capital town of old Palpa kingdom, then along the Tinaukhola river, and ends at Lumbini (150m asl), the world's most holly place of Buddhism as the birth place of Buddha.

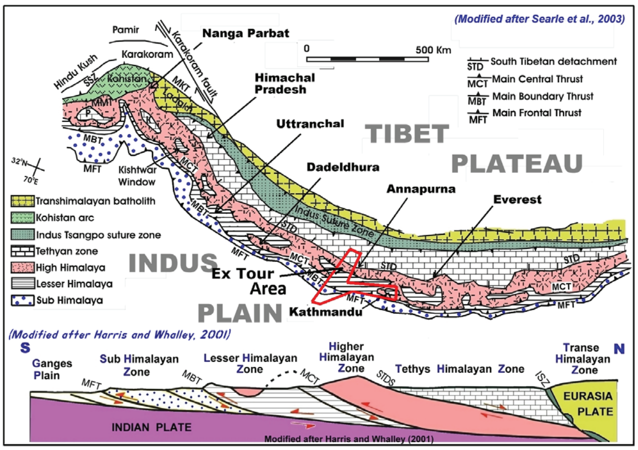


**Fig. 1: Himalayan geologic outline and the exercise tour area.**

The tour course covers from the tundra zone to subtropical climatic zone within its 250km length of the tour rout. The changing climatic zones reflects dramatic changes of vegetations as well as living styles of local people. Thus, the tour includes a variety of interests as well apart from geology.

The textbook of the field exercise was a geo-guidebook published in 2005 (Upreti and Yoshida, 2005) and since 2014 it has been revised 3 times with the last edition by Yoshida and Ulak (2017). Before the start and after the end of the tour, a pre-tour seminar and a summary seminar have been organized, held at the Department of Geology, Tri-Chandra Campus, Tribhuvan University (DGTU), Kathmandu. After the seminars, the participants of the SHET are escorted to city tours by students of the DGTU. Participants of the SHET submit a report of the tour and the tour leader compiles all the reports and tour data into a book titled: Traversing the Himalayan Orogen. The project publishes the book every year. All the total 150 participants of the tour of past 10 years have highly evaluated not only the great geology and beauty of the Himalaya but also friendship and interaction among participants as well as with students of the DGTU.

**Fig. 2: The SHET-7 team with the Dhaulagiri range on the back sight (March 2018).**

The voluntary leaders and teachers of the exercise tours include retired and/or active university teachers and senior engineers who are experienced in the Himalayan geology as well as field geology.

The total number of Participants from the 1st to 10th SHET included 118 students from 25 Japanese universities and 21 students of Nepali, Indian and Chinese universities, and 11 citizens of Japan and Nepal. Participation fee for a Japanese student including the airfare ranged from 139,000—201,000 Japanese Yen. At the Workshop, highlights of the exercise tours of past 10 years will be presented, along with details of constitution of tour members and account summaries. A recruit for the 11th SHET to be held in next March will also be revealed.

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# Geo-Excursion Guidebook Series of the Himalayan Orogen

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The Himalaya is the best laboratory to study nature especially geology and natural hazards. It is because the range exhibits distinct zonal arrangements of geology, geomorphology, and climate, and consequently, a variety of natural hazards occur in this mountain range and they are also zonally arranged along the mountain range.

There is, however, no guidebook of the Himalaya in the world market to study geology and natural hazards. We started a plan of forming a geo-guidebook series in 2004, and some English and Japanese guidebooks for studying geology and natural hazards in the Nepal Himalaya were published.

The guidebooks, as well as geo-study tours utilizing the guidebooks may invite wide spectrum of people worldwide to visit and study the Himalaya, and let Nepalese people to be proud of and get some profits from the Himalaya on which they live. We also expect that the guidebooks may work as a catalyzer to enhance the importance of the field study in related sciences and technology.

Four major north-dipping faults bound the above five zones; they are, from the north to the south, the South Tibetan Detachment System, the Main Central Thrust, the Main Boundary Thrust, and the Main Frontal Thrust. The guidebooks we made and are planning to make include five transects of the Himalayan Orogen (Fig. 1).

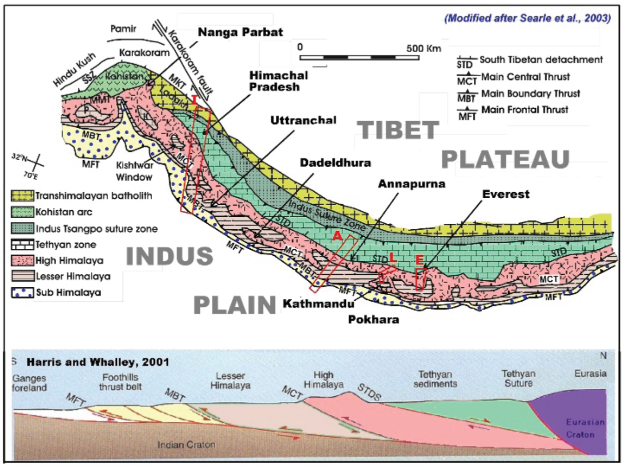


**Fig. 1. Geologic outline of the Himalaya with areas for the guidebook.**

# Hydrogeomorphic and structural approach for groundwater assessment at lower reaches of Lothar Khola, central Nepal

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Geomorphology and geological structures have a dominant role in groundwater recharge and spring occurrences mainly in the mountainous and hilly regions. Although Nepal has a rugged topography with different fault systems and lineament, the study related to structural control of groundwater is yet to be carried out in a systematic approach. The present study is aimed to fulfill this gap through the study of the linkage between major fault systems and geomorphology on groundwater occurrence in the region of lower reaches of Lothar Khola in Chitwan, Nepal. The study was mainly focused on the inventory of the springs, the impact of structure on groundwater occurrences, and groundwater potential mapping. The thematic layers, like geology, geomorphology, land use, aspect, slope, rock/soil, lineament density, and drainage density are integrated to prepare a groundwater potential map. The area is differentiated into low, moderate, and high groundwater occurrence zone. The geomorphic classes of the study area are the low-dissected, medium-dissected, and high-dissected areas. The Maximum number of springs is observed in the high-dissected area whereas a minimum number of springs is in low-dissected areas. The number of springs is increase around the zone of Kair thrust and Main boundary thrust. This shows that the fault acts as both recharge as well as discharge zone and also the spring line is associated with the fault showing that it acts as a conduit behavior for groundwater. Similarly, the majority of joints have NW–SE trending and act as supportive features in recharging the area. Hence the fault, lineament, and geomorphology have an important role in groundwater occurrence in the study area.

**Keywords**: Geomorphology, geological structure, Sub-Himalaya, mountain hydrogeology

# Bedrock mapping of the oblique Talphi fault segment apart of the seismically active Western Nepal Fault System, western Nepal Himalaya

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We present a new geologic mapping and structural analysis of the Talphi fault (TAF). The TAF is a ~36 km NW-SE striking, steeply dipping (>70° NE), oblique-dextral-normal fault located in northwest Nepal and is part of the seismically active WNFS. The WNFS is a regionally extensive splay fault system that cuts obliquely across the high Himalayas in the north to near Tansen at the front of the thrust wedge in the south. It facilitates arc-parallel extension via strain partitioning as a result of varying convergence obliquity along strike of the orogen. The TAF is hypothesized to be the surface expression of thrust wedge translation over an oblique ramp that links two frontal ramps; one located in front of the Gurla Mandhata Detachment and the other in front of the Dhorpatan segment. The TAF cuts the Ranimata formation (RF). The RF is composed of quartzites, phyllites, minor amounts of marbles, amphibolites, and is interpreted to be the ancient Indian passive margin. Our geologic mapping shows that the RF can be subdivided into three members: Member P (crenulated phyllite with abundant quartz veins/lenses), Member QP (interbedded thin (<1 m) beds of quartzite and phyllite), and Member Q (massive beds of quartzite (>1 m) little to no phyllite). These members strike subparallel to the TAF providing a slip estimate of ~2.8 km. Foliation/bedding measurements are consistent with a drag fold along strike of the TAF. Riedel shear fractures are well developed and interpreted to have rotated during progressive shear along the TAF indicating simple shear accommodation. The orogen-oblique strike of the TAF and the orientation of the foliation within the RF members being subparallel to the TAF suggests that this active segment may root into the megathrust via pre-existing shear zones (e.g., Main Central Thrust).

**Keywords**: Talphi, geologic mapping, oblique fault

# Active surface uplift of the Gangdese Range and evidence for associated drainage network reorganization, southern Tibet

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The Tibetan Plateau north of the Himalayas is the largest collision-related continental plateau on Earth. The internally drained southern and central regions of Tibet are defined by high elevation, long wavelength topographic depressions greater than 600,000 km$^2$. We present preliminary work and proposed research along the Gangdese Range, located along the southern drainage divide between the externally drained southern and internally drained central Tibetan plateau. The geology of the Gangdese Range is defined by the Gangdese batholith overlain by Linzizong volcanic rocks that are folded into a south-verging antiform. This structure is cut by the footwall of the north-directed Great Counter Thrust and south-directed Gangdese Thrust, which intersect to form a branch line interpreted as the north-dipping Gangdese duplex. Cross-cutting relationships and the resultsof published thermochronology are consistent with the early Miocene initiation of the Gangdese duplex. Results from published geodetic data are consistent with active surface uplift across the Gangdese Range, which we attribute to a north-dipping ramp in the Main Himalayan Thrust. Additionally, drainage networks along the southern externally drained plateau and along the modern-day course of the Yarlung River exhibit an array of geomorphic indicators of previous drainage network reorganizations, including barbed drainages at large fluvial junction angles beyond what is predicted from optimal channel network theory. These geomorphic features of the Yarlung drainage system and previously published geodetic and thermochronometric data of the Lhasa terrane and Gangdese batholith suggest that the evolution of the Gangdese Duplex, and related topographic uplift of the Gangdese Range, may have caused fluvial network and drainage divide reorganizations, which are potentially intrinsic to the development of the internal drainage of the Tibetan Plateau.

**Keywords**: Gangdese Range, Gangdese Thrust, Gangdese duplex, Yarlung River, drainage reorganization

# The Early Jurassic Kioto Carbonate Platform with *Lithiotis*-type bivalves buildups (Jomosom Formation; Kali Gandaki valley, Thakkhola, Central Nepal)

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The Late Triassic – Early Cretaceous sedimentary sequence of the highest tectonic unit of the Himalayas, the so-called "*Series (zone) of the Himalayan Tethys*" (= „*Tibetan Tethys*”/”*Tibetan sediment zone*”) palaeogeographicaly represents the northern Peri-Gondwana margin. In the Thakkhola region (upper part of the Kali Gandaki valley of the northern central Nepal) the continous uppermost Triassic–Upper Jurassic part of this sequence is documented by deepening upward deposits follow by the Early Cretaceous regressive cycle. The lower part constitute a clastic/carbonate fluvial-paralic deposits of the latest Triassic (Thini Formation), the carbonate platform of the Early/Middle Jurassic (Jomosom/Kioto and Bagung formations), and the Late Jurassic black organic shales with abundant ammonites (the famous Spiti Shales of the Nupra Formation). One of the best places for stratigraphic-sedimentological analysis of the middle, carbonate part of this sequence is located between Jomosom and Kagbeni villages along the Kali Gandaki valley.

The Pliensbachian – Early Toarcian Jomosom Formation with *Lithiotis*-bivalves–bearing horizones have been discovered recently in three sections along this valley. The so-called *Lithiotis*-type facies occurred around whole Pangea in those time with the most characteristic representatives: *Lithiotis*, *Cochlearites*, *Lithioperna*, *Gervileioperna* and *Mytiloperna*. *Lithiotis* and *Cochlearites* were typical infaunal mud-sticker forms which usually constructed pseudo-coloniality buildups. The Jomosom/Kioto Formation represents the main part of the so-called Kioto Carbonate Platform along the Peri-Gondwanian southern shelf of the Eastern Tethys. It has been shallow-marine, subtropical carbonates of coastal palaeoenvironments full of oolitic shoals (recently recorded as cross-bedding oolitic limestones), oncolitic pavements, bioclastic debris, and including *Lithiotis*-type bivalves biostromes which probably occupied either lagoonal-type palaeoenvironments or marginal part of such lagoons between nearshore regions and open marine conditions.

The overlying Middle Jurassic carbonate deposits of the Bagung Formation (Bajocian – lowermost Callovian) is represented by thin- and medium-bedded limestones, rich in fossils of benthic fauna including: bivalves (mainly oysters), echinoderms (especially crinoids) and gastropods, which in some places form shell beds/coquinas (sometimes with hiatus concretions) of tempestites in origin. Their sedimentological character clearly indicates of relatively shallow-water conditions of repeated storm events but a little bit deeper environments than represented by carbonates of the Jomosom/Kioto Formation according to mentioned above general deepening-upward sequence trend.

**Keywords**: Kioto Carbonate, Lithiotis, Jomosom, Kaligandaki

# Hydrogeological study along Marsyangdi River terraces: A case study of Harrabot, Kalimati and Chyangli area of Lamjung, Tanahun and Gorkha districts

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Groundwater, one of the major natural resources of Nepal, is widely used in supplying domestic water and irrigation all over the country. Hand pumps and tube wells are used in the Terai area for the groundwater while in hilly and mountain regions, springs behaves as a major groundwater sources. However, there has been less studies and investigations related to groundwater in hilly areas, making it difficult for study of groundwater potential and occurrence. In this study, the hydrogeological study has been carried out in the terraces formed by the Marsyangdi River for investigating the groundwater potential of the area. The study uses the geophysical survey datas of VES (Vertical Electrical Sounding) and ERT (Electrical Resistivity Tomography) and drilling datas of the deep Tubewells constructed on the study area.

The study reveals that the study area shows the groundwater potentials in the Harrabot, Kalimati and Chyangli Area of Lamjung, Tanahu and Gorkha District respectively. The tubewell of depth 137m in Harrabot gives the discharge of 5 lps and that of Kalimati of depth 102.5m gives the discharge of 8lps whereas the depth of 100m tubewell in the lower plain of the Chyangli area gives the discharge of 7.7 lps suggesting that the terraces formed by Marsyangdi river shows availability of groundwater. The lithology from the drilling samples in Harrabot are mainly clay, silty clay with gravel cuttings and sand, in Kalimati are gravel cuttings with sand and clay materials with fractured rock and in the Chyangli area are sand and gravels which are suitable zone for aquifers formation. The major sources of Groundwater recharge in these areas could be rainfall infiltration and Marsyangdi river flow.

The study area shows that deep tubewells can be a good groundwater sources for domestic and irrigation purposes and these findings will be useful in further groundwater exploration in different areas of the hilly regions comprising similar geology, spring distribution and geomorphology.

**Keywords:** Groundwater, Marsyangdi terrace, geophysical survey, deep tube-well

# Monte-Carlo simulation seismic hazard predictive model of Missa Keswal, Potwar, Pakistan using integeration of geophysical and seismological data

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The present study deals with the formulation of Monte-Carlo Simulation Seismic Hazard Predictive Model of Missa Keswal, Potwar Plateau, Pakistan using integration of Geophysical and Seismological data. Missa Keswal lies in eastern part of Potwar Plateau and is a major oil producing field in Pakistan.

As a first step structural modeling of Missa Keswal, Potwar Plateau, Pakistan has been done using seismic and seismological data. Various workers have addressed the structural complexity of this area by using structural mapping and geophysical data. Integration of seismic method and seismological data has been carried out to confirm/update existing structural models of the area. Using 10 Seismic Lines and 3 wells, structural traps have been identified, which shows dominance of thrust and reverse shallow and steeply dipping NE-SW and nearly EW trending faults.

Seismological studies area based upon the seismological data of United States Geological Survey (USGS) and Pakistan Meteorological Department (PMD) for the time period of 1990-2020. Both shallow to moderate depth earthquakes with magnitude ranges <5.5 are dominant in the area. Focal Mechanism Solutions (FMS) follows the structural type and trends as indicated by seismic data i.e., both thrust/reverse faults with shallow to steeply dipping faults are active from surface to shallow depths.

The integrated structural model not only clearly indicates active shallow depth structural traps (that can act as good ore deposits) but it also shows the activation of surface and very shallow subsurface faults which may cause frequent earthquake of moderate magnitude occurrences in the area. The results are used in the formulation of Seismic Hazard Model of the area using Monte-Carlo Simulation, which provides the future predictive computational earthquake model of the study area. The work is beneficial for both oil industry and earthquake disaster mitigation agencies and researchers alike.

**Keywords:** Mont-Carlo Simulation, Missa-Keswal, Potwar, Pakistan, seismic hazard assessment, geophysical and geological integration

# Geotourism, landforms diversity and dynamics vs economic development along the Kali Gandaki corridor (Nepal Himalayas): opportunities or threat to Geodiversity?

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Geotourism, defined as tourism that sustains/enhances the distinctive geographical character of a place, i.e. its environment, heritage, aesthetics, and culture, represents the abiotic part of nature in tourism development. Nepal offers visitors (domestic and international) a large variety of colorful landscapes in relation with geology, climate, landforms and diversified, traditional land uses and ethnic cultures. Geotourism should promote what makes the geology and natural processes shaping the landforms so unique in Nepal.

We focus on Kali Gandaki road/trails corridor, from Tatopani up to Mustang graben. Geotourism sites are selected for their scenic view and scientific value. Our list includes geomorphosites such as Tatopani (hotsprings, landslide), Dana (MCT), N of Kahiku khola (giant Dhampu-Chooya rock-avalanche), Marpha (palaeo-lake), Lupra bridge (fault, repeated debris flows), Kagbeni upper terrace (Thakhhola graben overview), Muktinath (Saligrams and Spiti shales), Tetang (graben filling, Tetang/Thakkhola formations unconformity), Chhusang (synthesis on graben-tilted formations, Quaternary terrace sediments), Chele (canyon entrance), Dhakmar (W graben fault, Thakkhola Formation), Garphu (caves, early settlements).

Each site should offer educational panels (both in Nepalese and English) including (i) Interpretative sketches of general landscape, visible geological outcrops, including glaciation legacies or other significant events; (ii) Evolution in time, at both long- and short-term, including such landscapes prone to geomorphic processes (landslides, debris flows and floods) in connection with climate and seismic events; (iii) Cultural heritages relying on both bedrock and ethnic, religious characteristics, such as holy fossils.

Collectively such information should help defining Geomorphosites and Geoheritages, worthy of protection in a context of economic and tourism development.

In a context of climate change (permafrost melting, intense rainfall events progressing northward), we eventually question the new (BRI) road and its sustainability, as a structure very vulnerable to geo-hazards, and as an indirect driver for threatening the exceptionally rich Geodiversity sites, which should be preserved, hence protected adequately.

**Keywords**: Geotourism, geodiversity, Kali Gandaki corridor

# Sedimentological evidence of climate-tectonic interaction in the upper Satluj catchment, Kinnaur, India

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Quaternary valley fill deposits act as archives of changing climate-tectonic dynamics in a region. Exposed Quaternary landforms help in decoding the relationship between climate and tectonics. The Upper Satluj catchment of the Kinnaur region falls in a rain shadow zone but has been undergoing a shift in climate over the last few decades with increasing rainfall. Outburst floods are a common phenomenon in the area due to the blocking of headwater in the upper reaches of Satluj valley. As a result, the Quaternary sequence is modified from time to time. The Quaternary sequence of upper Satluj valley in Kinnaur shows varied facies of gravel, sand and clay. The gravel facies are observed as clast and matrix supported. The sand facies are laminated sand and massive sand. The clay facies are either massive or laminated. These facies are interpreted as channel deposits, debris events and ponding events. This trans-Himalayan region of Satluj river valley offers an exciting study of tectonic-climate interaction which can be observed while studying the deposited sediment. In this work, we would like to discuss the deposition of these sediments and explore their relation to tectonics and climate.

**Keywords**: Satluj, quaternary, sedimentology, tectonics, climate

# Geological and geotechnical assessment of Kumaltari Landslide, Barpak-Sulikot Rural Municipality, Gorkha district, Nepal

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The paper deals with the geological and geotechnical assessment of the landslide area at Barpak-Sulikot Rural Municipality-5 of Gorkha District. The link road, connecting Lamjung District towards the west and Dhading District towards the east, has been affected by the land subsidence and land creeping problem for 12 years. Thick deposit of colluvium soil and residual soil are overlaid on the jointed and fractured moderately weathered Quartzite and Phyllitic-schist bedrocks. Soil exploration and hydrogeological study were carried out. The soil parameters, i.e., grain size distribution, consistency, direct shear test, moisture content test, uniaxial compression test, and density and specific gravity test have been carried out. A comprehensive stability assessment was done for slope stability. The conventional techniques, i.e., kinematic analysis (using DIPs software) for failure mode and analytical method (using SLIDE software) for slope stability analysis were adopted. Various design of mitigation measures, i.e., water management, cascade drainage, catch drainage, retaining wall along with bioengineering were recommended.

**Keywords**: Geotechnical, slope stability, Kumaltari Landslide

# Potential mineral resources of Gandaki Province of Nepal: Challenges and opportunities

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This paper explores the present status and utilization trends of the non-renewable mineral resources in the Gandaki Province of Nepal. Based on the literature review and the work experiences of the authors, the Gandaki Providence is potential for metallic, and non-metallic, gemstones, construction materials, and decorative as well as dimension stones. The systematic exploration and mining of mineral resources are not carried out yet as the province covers the potential area of mineral resources like the Lesser Himalaya including the thrust sheets, the MCT zone, and the Higher Himalaya. The challenge for prospecting the mineral resources is the lack of experts, proper equipment for investigations, and financial investment. There is possibility of finding new minerals especially the precious and semi-precious stones in the MCT zone and the Higher Himalayas. The monetary investment from the provincial level is essential for laboratory establishment as well as prospecting and exploration of economic mineral resources. The provincial government should make the plans and policies to develop potential mineral resources of the province.

**Keywords:** Mineral, precious stones, dimension stones, MCT zone, Gandaki Province

# How anthropogenic activities are inviting disaster in Nepal Himalaya? Analysis and recommendation with case examples from Kaligandaki valley, Seti River valley and Manang valley

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With the increase on anthropogenic activities in Nepal Himalaya, number of disaster cases causing loss of lives, properties and environment are increasing so does the risk of disaster. Though disasters are still commonly perceived as natural events by most Nepalese people, hazards are natural, but disasters are not, and should not be seen as the inevitable outcome of a natural hazard's impact. Hazards (flood, landslide, earthquake) cannot be stopped from happening but through proper planning and management, disasters can be avoided in most cases if geomorphic and cascading processes are considered at the catchment scale. We focus on three case studies: in Kaligandaki valley (landslide), Seti River valley (flood) and Manang valley (flood), and show why these natural hazards turned into disasters in relation to specific anthropogenic activities (road side slope destabilization work, wrong site selection for bridge construction and construction in flood plain). Methodology includes hydro-geomorphological mapping, hydraulic analysis including HEC-RAS modelling, use of functional flooding space, land-use and land-cover change analysis. Many bridges and settlements have been identified to be prone to flooding and damming since they have been built either lower level than the high flood level or built in floodplains. Furthermore, we recommend necessary precaution and suitable mitigation measures (i.e. land use and urban planning, engineering structures, early warning systems, education, etc.) to reduce or mitigate the impact of possible flood events along these valleys.

**Keywords:** Kaligandaki River, Seti River, flooding, landslide, anthropogenic activities, natural disasters

# A look on issues of deep-seated gravitational slope deformation in high-dam reservoir basin in Nepal

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The present work is a part of ongoing PhD research on "Deep-seated Gravitational Slope Deformation (DGSD) and their Impact on High-Dam Reservoir". In this part of the research, impact and evolution of the DGSD and slow-moving landslide creeping on the hydropower reservoir rim have been analysed. The study area is a hydro project site explored and designed to build a high-dam (~265m) with a huge reservoir. The DGSDs usually found in the lower reaches of the Budhigandaki river basin in Lesser Himalayan rock formations in Central Nepal. It is a gravity-induced process affecting large portions of slopes evolving over very long periods of time that may displace rock volumes of up to millions of cubic meters, with thicknesses of more than tens of meters. DGSD evolves with a variety of geomorphological changes (earthquake, slope and river/stream incision, valley erosion, and landform changes) over time that affect land surfaces and, therefore, often impact to the dame and whole reservoir rim. The surface dynamics with the tectono-geomorphic processes and lithologic conditions of the active front of the dam abutments and reservoir slopes have been correlated to understand the spatial pattern of the slope movements and to identify triggering parameters of DGSDs. Investigation data of the observation tunnels on either side of the river depicted that the bedrock of the location consists of quartzite, phyllite and siliceous dolomite noticing the wide-open joints in the upper part of the left abutment are interpreted as a consequence of stress relief subsequent to a deep-seated land creeping. The dam site indicated that the slopes of both the banks were triggered by deep-seated landslides in the past. There are two noticeable tectonic deformation zones, located immediate up-stream and downstream. The deformation zones by the tectonic stress was accommodated mostly by second order fractures and shear zones, with different orientations and variable persistence.

**Keywords:** Land creeping, rock mass deformation, DGSD, tectonic geomorphology, high-dam, reservoir, instability

# Crustal thickness and Poisson's ratio in northeast India using receiver function analysis

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Crustal configuration beneath the northeastern region of India has been investigated with the help of receiver function analysis of teleseismic earthquakes recorded by 19 broadband seismological stations. We adopted the H-*k* stacking method to estimate crustal thickness and Poisson's ratio beneath each recording station. The study reveals the large variation in crustal thickness and Poisson's ratio which are correlated with the complex geology and tectonics of the region. The crust is observed to be thinner (36.5-41.6 km) beneath Bengal Basin, Shillong Plateau, and Brahmaputra valley compared to the IBR (~40-54 km) and Arunachal Higher Himalaya (TAWA station, ~45 km) and Sikkim Himalaya (GKT station, ~46.5 km). A large variation of Poisson's ratio is observed in the region (~0.230-0.306). Poisson's ratio is generally low-to-intermediate in the Shillong-Mikir Plateau, Bengal Basin, and Brahmaputra Valley, while it is intermediate-to-high in the Tripura Fold Belt and the northern part of IBR. The high Poisson's ratio in the Tripura Fold Belt is due to the presence of basaltic basement rock and clay minerals existing in the sedimentary rocks whereas the presence of partially serpentinized rock in the ophiolitic melange complex causes a high Poisson's ratio in the IBR.

**Keywords**: Northeast India, crustal structure, Poisson's ratio, receiver function

# Geological control on the major river channel system of the Nepal Himalaya

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The four major river systems of the Nepal Himalaya namely the Koshi River (Sapta Koshi), the Gandaki River (Narayani), the Karnali River and the Mahakali River and their tributaries originate from the snowmelt within the mountains of the great Himalaya as well as the Tibetan Plateau in the North and flows towards the flat southern terrain (the Indo-Gangetic Plain) and finally drains into the Indian Ocean. These river flow in a definite path known as river channel. The rivers follow the path of least resistance and is shaped according to their velocity, energy level and gradient of the riverbed. The investigation of these river channel reveals that these rivers bend eastward or westward at few places and some even turning perpendicularly rather than flowing towards south. The present study is aimed to find out where the rivers are bend and what causes them to bend. For this purpose, a number of existing geological map, topographic map, satellite images, remote sensing and GIS technology were applied to prepare a thematic map containing information related to geology, tectonics, drainage pattern and gradient. Based on the analysis, it is found that these major river systems and their tributaries abruptly change their courses whenever the major faults/ thrusts are encountered. So, we can say that the route of these river system can be directly or indirectly controlled/ shaped by lithology, tectonics and lineaments.

**Keywords**: Nepal Himalaya, Tibetan Plateau, Indo-Gangetic Plain, river channel, gradient, tectonics, lineaments

# Channel behaviour to landslide dam failure in steep headwaters: A case study of the Hapuku landslide dam

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Landslide dams are a major disturbance in steep and complex terrains such as the Southern Alps of New Zealand and the Himalaya of Asia. Formed either in a single landslide event or arising as a consequence of a regional event such as an earthquake or extreme storm event, they result in a potential cascade of geohazards along the river system in the short- or long-term, depending upon the dam size and external forcing conditions. Most dams eventually fail within the first 6 months, leaving a large remnant sediment supply available to the river system. There is a poor understanding of the residence time of this material - which varies considerably - and the process dynamics involved in their evacuation, which may include some mix of mass failure, debris flow, torrent, and fluvial action. The Hapuku landslide dam (20 M·m$^3$) was emplaced by the largest landslide to be triggered in the 2016 Mw 7.8 Kaikoura Earthquake, in New Zealand's South Island. The subsequent dam breach, likely supplemented by unstable debris accumulations in an adjacent gully, led to multiple sediment surges that aggraded the valley bottom by up to 25m on average, profoundly reconfiguring the channel morphology. Terrain analysis was performed on a time-series of high-resolution digital elevation models obtained from airborne LiDAR surveys, supported with field observations. The preliminary results indicate the trajectory of recovery through adjustment of the unstable deposits in flood events via channel incision and sidewall erosion majorly in the headwaters which gradually diminishes downstream. The gradual transition in the debris train morphology, from a debris deposit to a steep, channelized alluvial fill is revealed in a longitudinal sequence of cross-sections. The sedimentary character of the deposit changes gradually from debris flow to debris flood to floodplain channel, in the interval between steep, confined headwaters and partially confined meandering conditions further downstream. The dominant sediment size is coarse gravel to very coarse gravel in the terrace deposits from the failed dam, which include multiple couplets of coarse- and fine-grained layers. In the short term (~6 years), the river has widened up to 200m maximum, and been characterized by active lateral and vertical reworking of the debris terrace deposits in the headwaters via channel incision, selective transport of the finer sediments leaving remnant boulders, rapid evacuation in the confined canyon exposing the bedrock from pre-event condition and extensive braiding in the partially confined section.

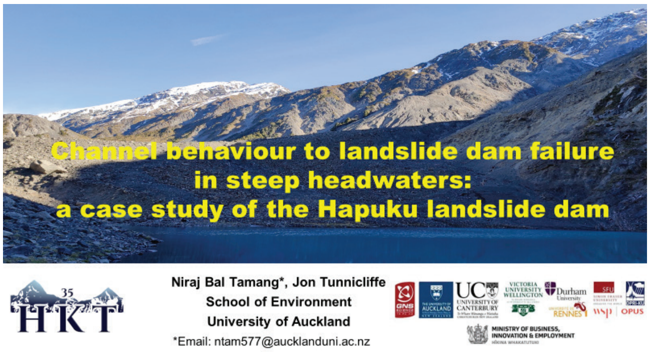


**Fig. 1: Hapuku Lake with the landslide dam and Kaikoura Ranges in background.**

**Keywords**: Landslide dam, Hapuku Lake, geohazard, channel behaviour

# Lithostratigraphy and depositional environment of the Siwalik Group in Northeast Chitwan Dun Valley, central Nepal

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Siwalik Group, the well stratified molasse deposits representing the exhumation history of north lying on the southernmost flank of the Himalaya is well exposed along the northeast Chitwan Dun valley. This study depicts the lithostratigraphy and its depositional environment of the Siwalik Group of the study area. Based on increasing grain size and change in lithology, the Siwalik Group in the present study area is lithologically divided into the Lower, Middle and the Upper Siwaliks in ascending order. The Lower and Middle Siwaliks are subdivided into the lower and upper members on the basis of relative proportion of sandstone and mudstone. The Upper Siwalik comprises the lower and upper members, based on the clast size and its composition in conglomerate. Structurally, the study area bounds by the Main Boundary Thrust (MBT) in the north, the Central Churia Thrust (CCT) in the south, and the Shaktikhor Thrust (ST) is developed in between the CCT and MBT, marked by the observation of fault gauge and repetition of the Lower Siwalik over the Upper Siwalik. The six facies associations (FA1 to FA6) are recognized based on lithology, associated sedimentary structure and architectural elements. The facies association is closely related to each lithostratigraphic units. Based on these facies association, the sediments of lower member of the Lower Siwalik are deposited by the fine-grained meandering river whereas upper member of the Lower Siwalik is the product of flood-flow dominated meandering river system. Similarly, the sediments of lower and upper members of the Middle Siwalik are deposited by deep sandy braided to shallow braided system, respectively and the sediments of the Middle Siwalik is followed by the sediments of the gravelly braided to debris flow-dominated river system of the Upper Siwalik.

**Keywords:** Lithostratigraphy; Siwalik; Chitwan Dun Valley; Facies; Depositional Environment; Siwalik

# Are the Kathmandu valley and Pokhara valley evolved together?

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The Fluvio-lacustrine sediments of Kathmandu Valley mainly consist of Clay (Carbonaceous), sand, silt, and gravel which are formed within the Lesser Himalaya. On the other hand, Pokhara Valley comprises angular to subangular gravels of shale, metasandstone, phyllite, and chlorite-sericite schists which were derived from the Lesser Himalayan as well as from the Tethys Himalaya. Phewa, Pokhara, and Rupakot Formations were deposited under the lacustrine environment whereas, Siswa deposited under fluvial and Begnas, Tallakot, and Ghachok Formations were formed under the Fluvio-glacial environment are the workable stratigraphic units of Pokhara valley sediment. Sediments of Pokhara valley indicate the deposition of sediments by the fluvioglacial environment. Basically, Kathmandu valley was formed due to tectonic activities such as faults that are developed on both sides of the Valley. It is believed that the formation of Kathmandu valley was by the upliftment of the Mahabharat Thrust. Kathmandu valley consists of three types of sediments Fluvio-deltaic facies at the Northern margin, open lacustrine facies in the central part, and alluvial fan facies in the southern part. The fossil records of the oldest unit of Kathmandu valley i.e., Lukundol Formation indicate the age to be Late Pliocene to Middle Pleistocene. The Gokarna and Thimi have been considered as Late Pleistocene by radiometric dating (20000–30000 yrs B.P.). The geological units of the Pokhara Valley sediments are formed during the Pleistocene Epoch and the recent flood–plain gravel deposit is of Holocene. The sedimentation of the Kathmandu valley is slightly earlier than Pokhara Valley(?). The episodic deposits of Kathmandu valley sediments are deposited; (i) before the upliftment of MT and (ii) after the upliftment of MT. The tilting of the Ghachok terraces forming a non-parallel relationship with the Pokhara Formation supports the tectonic upheaval of the northern region of the Pokhara valley.

The Kathmandu valley is genetically formed at the core of the Mahabharat Synclinorium. This synclinorium is believed to be formed due to the southward movement of horses of the thrust sheets. However, there is no such tectonic evidence of the development of Pokhara valley. The basement geology of the Kathmandu valley consists of the rocks of the Phulchauki Group i.e., the rocks of the Lesser Himalayan thrust sheet while the basement rocks of the Pokhara valley consist of an autochthonous succession of the Lesser Himalaya. This indicates that it took a long time to erode the thrust sheet in Pokhara region and the basin may have formed later than the Kathmandu valley.

**Keywords:** Fluvio-glacial, Fluvio-Lacustrine, Mahabharat Thrust, Tethys Himalaya, Sedimentation

# Geological study along Pachkhal-Dolalghat-Sukute area, Kavrepalanchowk and Sindhupalchowk districts, Lesser Himalaya, central Nepal

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A detailed geological study has been carried out in the Lesser Himalayan rocks distributed in the Pachkhal-Dolalghat-Sukute area in Kaverepalanchowk and Sindupalchowk districts. The study area belongs to the Kuncha Formation of the Lower Nawakot Group, the Benighat Slate of the Upper Nawakot Group, Nawakot Complex and the Tistung Formation of the Phulchauki Group, the Kulikhani Formation, Chisapani Quartzite, Kalitar Formation and Bhaisedobhan Marble of the Bhimphedi Group, Kathmadu Complex. These two complexes are separated by Tthe Main Central Thrust (MCT). Four lithounits of the Lower Nawakot Group (i.e. Fagfog Quartzite, Dandagaon Phyllite, Nourpul Formation and Dhading Dolomite) and two lithological units (Malekhu Limestone and Robang Formation) of the Upper Nawakot Group are missing in lithostratigrphy in the area. The area comprises intercalation of coarse-grained, thick bedded quartzite and gritty phyllite of Kuncha Formation, dark argillaceous slate with Jhiku Carbonate beds with sporadic amphibolite of the Benighat Slate. The Bhimphedi Group of the Kathmandu Complex comprises mainly micaceous schist, marble and metasandstone whereas the Phulchauki Group comprises of metasandstone and granite. The lithological units strike NW-SE and dip towards south forming the eastern closure of the Mahabharat Synclinorium in northern limb.

**Keywords**: Central Nepal, lithological units, Main Central Thrust, Mahabharat Synclinorium

# Love wave group velocity tomography images of NE India and its surrounding regions

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We obtained the Love wave group velocity dispersion across NE India and its surrounding regions. The local and regional earthquakes were used to estimate the dispersion curves and they are well recorded at 26 seismic stations in the study region. Love wave group velocity variation maps in the period range of 5 s to 60 s were obtained through the tomographic inversion method. From this study, we observed significantly different crustal types in the study region. At the lower period of < 12 s, Bengal Basin (BB), Indo Burma Range (IBR), Eastern Himalayas Syntaxis (EHS), and part of Tibet are showing low Love wave group velocity. At periods between 12 to16 s, the entire BB, IBR, and EHS still have lower group velocity values compared to those at Shillong Plateau, Mikir Hills, and the Eastern Himalayan Ranges. The low-velocity value in these regions indicates the presence of sedimentary rocks in the uppermost crust. Increasing periods from 16s to 42s, we also found a systematic shift of the low-velocity zone in BB and IBR toward the east. The low velocity in BB and the southern part of IBR at higher periods is due to the presence of sedimentary rocks in these regions up to greater depths. Higher velocities in the Nepal Himalayas and the Indo Gangetic Plains (IGP) even in the lower period ≤12s are due to the anisotropy effects in these regions.At periods ≥34s, a distinct high-velocity zone at a mid-crustal level along aNE transect passing throughthe Singhbum craton, Shillong Plateau, Mikir Hills, and Assam syntaxis is observed. This supports the result of upward crustal buckling of the Indian plate along these portions suggested by Kumar et al. (2021) and Raoof et al. (2017). At periods >50s, lower velocity is observed in the Tibetan plateau compared to NE India, EHR, and BB, indicating the presence of a thicker crustal layer in this region. The low velocity at 27 s to 50 s in the Tibetan Plateau is the indication of partial melt present in the middle-to-lower crust that has been suggested by several workers.

**Keywords**: Love wave, dispersion curve, tomography images, crustal structure

# Distribution of active tectonics in the Himalayan piedmont (Darjeeling, Eastern India) inferred from Horizontal-to-Vertical Spectral Ratio analysis of passive seismic records

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The pattern of active deformation of frontal structures in Darjeeling Himalaya is complex with out-of-sequence reactivations in the chain and development of scarps associated to earthquake ruptures reaching the surface in the piedmont. To clarify the distribution of active deformation in this area, we analyze passive seismic records by the Horizontal-to-Vertical Spectral Ratio method along three NS trending profiles. We image the Siwalik sedimentary rocks/ recent deposits interface under the piedmont and show folded and faulted geometries. Two of these faults are located under scarps of about ten meters affecting the 3.7 ± 0.7 ka old surface of the Tista megafan. Such features imply that about half of the convergence is expressed south of the Himalayan front while the other part occurs out-of-sequence in the chain, suggesting a very limited activity of the Main Frontal Thrust itself.

Therefore our study allows to study the thrust-fold system hidden beneath the plain already displayed by the seismic profiles of oil companies in east/central Nepal. The evolution of the hidden structures corresponds to an embryonic thrust belt mainly affected by a long-term shortening rate. The details of the deformation associated with the embryonic thrust belt are still poorly understood but are of high importance for assessing seismic hazard in densely populated regions in the plain.

# Geology of Dhaubadi iron deposit, east Nawalparasi, Gandaki Province of western Nepal

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The regional geology of the Dhaubadi Iron Ore deposit area comprises the Lakharpata Group and Surkhet Group rocks with low-grade metamorphic rocks close observations of several deformational structures assist to understand the nature of the large-scale structures. It is exposed in the Lesser Himalayas along the northern part of the Main Boundary Thrust. The area has developed a huge amount of deformational and very complex structures. The hematite Mineralization zone lies in the middle parts of the Melpani Formation it can be divided into upper and lower hematite horizons. Iron ore hematite is intercalation with a non-ferruginous quartzite and slate. Dhaubadi iron ore is characterized by oolitic nature of hematite with fine to coarse-grained Ooidal texture. The hematite at places consists of hematite clast and faint gradation indicative of a current deposition environment.

**Keywords:** Dhaubadi Iron Ore, Lesser Himalaya, Hematite, Oolitic, Current Deposition

# Microtectonic analysis of the boundary region of Jajarkot Klippe and Karnali Klippe, Jajarkot district, western Nepal

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Jajarkot Klippe and Karnali Klippes are located adjacent to each other in western Nepal and represent the variation in stratigraphy and metamorphism. Previous researchers included the area between these two klippe or in individual klippe in their regional geological mapping. However, discrepancies exist among them regarding the boundaries of each klippe and the underlying autochthons. Most of the previous studies are focused on field-based data and not on laboratory data. Microtectonic analysis has been carried out very few in western Nepal covering these two klippes. An attempt is made to carry out the microtectonic analysis in each tectonic unit and to correlate the microtectonicanalysis with the regional and local geological structures and stratigraphy. The study area is selected in such a way that it touches the western part of the Jajarkot Klippe and the eastern part of the Karnali Klippe in the area between Bakharka of the Surkhet district and the Saureni of the Jajarkot district. About 45 days of fieldwork was carried out and the systematic oriented sampling is taken followed by the preparation of thin sections in the laboratory. The microfold trending toward E-W direction can be correlated with the outcrop scale fold and also with the regional scale syncline and anticline fold. The pre-tectonic type of garnet is observed in the Karnali Klippe while the syn-tectonic type of garnet is found in the Jajarkot Klippe and the autochthonous unit (Midland Succession) located adjacent to MCT that separates the Midland Succession with the Karnali Klippe. The shear sense indicator given by micafish, microboudinage, curved inclusion trails in the syn-tectonic garnet and shear band cleavage shows top to the south sense of shearing with few exceptionsi.e. Top to the north sense of shearing in shear zone developed within Jajarkot Klippe. On analyzing quartz grain microstructure, the Midland Succession located in between the Jajrkot Klippe and Karnali Klippe is characterized by the bulging (BLG) type of recrystallization in the mid of Midland succession that increases gradually to high-temperature grain boundary migration (GBM) on moving to north and south while reaching adjacent to the boundary region of Karnali Klippe and Jajarkot Klippe respectively. The quartz grain microstructure in the Karnali Klippe shows the high-temperature grain boundary migration (GBM) of dynamic recrystallization to grain boundary area reduction (GBAR) of static recrystallization that indicates the temperature of recrystallization occurs above 600-700ºC. The Jajarkot Klippe is characterized by a similar type of recrystallization to that of Karnali Klippe.

**Keywords:** Jajarkot Klippe, Karnali Klippe, microtectonics, shear sense indicator, quartz grain microstructure

# Petrography and geochemistry of the clastic rocks of Pithoragarh region, Kumaun inner Lesser Himalaya, India: Implications to provenance and tectonic setting

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The Kumaun Lesser Himalaya defines the central part of the Indian Shield revealing Proterozoic sedimentary rocks. The sedimentary studies in the inner Lesser Himalaya, Kumaun region is delimited owing to its restricted exposures. The present studies focus on the petrography and geochemistry of the clastic rocks from the Pithoragarh region (Kumaun, iLH) to understand the depositional setting, provenance, and tectonic settings of the area. The clastics are classified as quartz arenites and sub lithic arenite. The sandstones reflect a cratonic interior field and recycled orogens for the sandstones deposited in a shallow marine system. The provenance is reflected as a granitic field.

Geochemically, the bivariate diagram of $TiO_2$/Zr, $Al_2O_3$/$TiO_2$, and Zr/$TiO_2$ suggests that the source rocks of studied sediments were of felsic and intermediate provenance. $Al_2O_3$/$TiO_2$ and Zr/$TiO_2$ plots also suggest that sediments were derived from felsic to intermediate igneous rocks. V–Ni–Th*10 ternary plot justifies a granitic and granodiorite field inclining towards the field of felsic rocks rather than the basaltic field. The Ni/Cr ratio indicates the post-Archean field whereas, Ni/$TiO_2$ shows an acidic source rock. The tectonic discriminant function diagrams ($K_2O/Na_2O$ vs $SiO_2$, $Fe_2O_3$+MgO vs $TiO_2$, and $Fe_2O_3$+MgO vs $Al_2O_3$/ $SiO_2$) of sandstone represent the deposition of sediments that took place from passive to island arc setting. Analysis of the source rock based on the geochemistry studies shows very close correspondence and overall felsic and intermediate igneous source rocks indicating deposition of sediments in passive marginal setting.

**Keywords**: Kumaun Himalaya, petrography, geochemistry, provenance

# Frequency and extent of rock-fall hazard along Mugling-Narayanghat and Dobata-Surainaka sections of East-West Highway

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Rock-fall on Nepalese highways is a serious risk to travelers. It occurs on cut slopes consisting of massive rocks, such as gneiss, quartzite, dolomite and sandstone. The Himalayan region experience frequent falls along road cut slopes due to various causes, such as daylighting joints, steep and long cut slopes, the presence of shear zones or the development of a high pore-water pressure. Slope instability issues have subsequent effects on the transportation system and socio-economic development of the region on a large scale. In the present study, rock fall frequency and extent was investigated along the road cut slopes of the Mugling-Narayanghat section in the Lesser Himalayan Zone and the Dobata-Surainaka section in the Siwalik Zone of the East-West Highway. The two sections were selected for study as they have a high frequency of vehicular movement and serve as the lifeline of national connectivity as well as the link to the capital city of Nepal. In the present study, we have carried out detailed field survey of cut slopes and the data were analysed using computer-based simulations for generating rock fall hazard maps. For this purpose, more than 70 sites from both road sections were studied. The rock mass structure determines the possible unstable blocks that can trigger falls on hill roads and their size may range from small to large failures. Measurement of rock mass parameters was carried out using the Rock Mass Rating, Slope Mass Rating, Continuous Slope Mass Rating, and Rock fall Hazard Rating systems. The outputs were then evaluated and mapped using the GIS. Kinematic analysis techniques were also employed to identify the different modes of failure (such as structurally controlled or otherwise) in jointed a rock mass using DIPS.

**Keywords**: Rock-fall hazard, road cut slopes, failure mechanism, Siwalik Zone, Lesser Himalayan Zone

# Geomorphological analysis of landslide and early warning system for landslide risk mitigation in Nepalese mid-hills

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The Nepalese Himalayas is one of the world's most active mountain belts, with widespread natural hazards of various types, including landslides, which claim numerous lives and properties in Nepal. Landslides occur due to the combined effects of seismic activity, monsoon rainfall, and improper land-use practices. The prevention and mitigation of landslides are challenging for countries like Nepal, however, low-cost techniques such as bioengineering with low-cost early warning systems have been implemented in recent decades. The Methum landslide near Lalitpur was selected as a case study to investigate the landscape dynamics along with triggering factors, and to evaluate the effectiveness of a landslide early warning system (LEWS). The study assessed aerial photos, satellite images, and precipitation records and conducted multiple field visits to analyze patterns of landslide evolution, landslide risk, and potential triggers. Heavy rainfall, sloped terrace farming, and earthquakes are identified as major landslide triggers. LEWS, installed, measures rainfall, soil moisture, and displacement activity and generates an alarm if any of these parameters exceed the threshold set. This monitoring system is a cost-effective technique and exemplifies the reduction of landslide risk at the community level in the landslide-prone mid-hills of Nepal.

**Keywords**: Landslide, triggering factor, monitoring system, risk reduction

# An approach of landslide susceptibility evaluation in central Nepal Himalaya

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Landslides occur in the Nepal Himalaya represent a major constraints on development planning and their impacts are increasing every year during summer monsoon season. The root cause for increasing trend in the frequency and effects of landslides may attributed to extreme weather events, human intervention etc. For this reason, it is important to evaluate landslide susceptibility which can include geomorphological mapping, qualitative (subjective) to quantitative (statistical and deterministic) approaches by using the landslides causative parameters. The selection of an approach is important because available data and the scale of analysis defines the methodology followed. For example, deterministic modelling is suitable with sufficient geotechnical and soil depth data whereas statistical modelling can provide better outcome if proper input data are used in computation. Spatial data sets can be obtained from low-cost satellite images, e.g. Google Earth and freely available SRTM, ASTER etc. images. Many researchers in Nepal are trying their efforts by linking between landslides and contributing factors that are suitable for the landslide susceptibility assessment. In this study, geospatial tools are utilized for evaluating the landslide susceptibility in a portion of central Nepal Lesser Himalaya. The analysis result is validated by success and prediction rates.

**Keywords**: Landslide, susceptibility, evaluation, Nepal Himalaya

# Limiting the extent of twentieth century surface faulting earthquake in the eastern Himalaya, India

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Quantitative evaluation of the relation between interseismic elastic strain accumulation and its release during seismic events is crucial to assess the magnitude and spatio-temporal variability of future large-to-great earthquakes along the Himalayan arc. The historical records and paleoseismological investigations confirm the surface rupture evidences of the great continental earthquakes (Mw $\geq$ 8.5) that are preserved in the geologic records as fault scarps along the Himalayan Frontal Thrust (HFT) or Main Frontal Thrust (MFT). These observations reveal the rupture of 3/4th of the arc's frontal thrust during great events since medieval time (1100 to 1600 C.E.) but with debatable opinions for the timing of events due to unclear evidences, ignorance of transverse segment boundaries, and lack of detailed studies. However, large segments of the Himalayan arc lack the rupture produced during any significant historical earthquake. Besides, the large blind earthquakes (e.g. 2015 Mw 7.8 Gorkha earthquake in Nepal) loaded greater strain in the adjacent segments, making a way for a potentially devastating future earthquake on the Main Himalayan Thrust in the instrumental seismic gap areas or a new area or revisit the past ruptures. In the eastern Himalaya, the western segment, including Sikkim, Bhutan, and Assam didn't witness any large-to-great earthquake activity over the past 300 yr. In order to fill the gap and confirm the substantive evidence of the twentieth-century event in the eastern segment of the eastern Himalaya, we conducted detailed paleoseismological investigations along the Himalayan front in Arunachal Pradesh. Our results, together with the previous paleoseismological studies, provide an assessment of the possibility for the future earthquake/s along the eastern segment of HFT/MFT.

**Keywords**: Paleoseismology, Assam Earthquake, surface rupture, eastern Himalaya

# *Bauhinia* L. (Fabaceae) leaf from the Upper Siwalik sediments of central Nepal and its climatic and phytogeographic significance

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The plant fossil records from the Siwalik sediments are important in understanding the relationship between the orogeny of the Himalaya vis-à-vis climate change. These Siwalik sediments were deposited between the Lesser Himalaya in the north and the Gangetic Plains in the south. These sediments accumulation took place all along the length of the Himalayan Foreland Basin in a coarsening upward succession known as the Siwalik Group. The Siwalik Group is divided into three sub-groups, namely Lower, Middle, and Upper Siwalik. Abundant plant fossils in the form of leaves, wood, fruits, seeds, and pollen have been recovered from the Lower and Middle Siwalik sediments. However, floral records from the Upper Siwalik sediments are still scarce. The flora of Upper Siwalik is known only known from the Arunachal Pradesh of India and the western part of Nepal. Here we report a *Bauhinia* L. (Fabaceae) fossil leaf from the Upper Siwalik sediments exposed along the Chepang Highway section in Central Nepal. The characteristic features of the fossil leaflets are asymmetrical lobed lamina, entire margin, primary vein basal acrodromous; secondary veins brochidodromous; tertiary veins percurrent. The earliest fossil record of *Bauhinia* is known from the late Eocene sediments of southwestern China. Moreover, the fossils are also known from the Oligocene sediments of China and Mexico and the Neogene sediments of China, India, Nepal, South America, and Africa. The fossil records of *Bauhinia* indicate that it might have originated and diversified in Asia and migrated to different parts of the world in the late Paleogene and Neogene.

**Keyword:** Fabaceae, megafossil, Upper Siwalik, central Nepal

# Slip transfer between overlapping fault segments of the Main Frontal Thrust (MFT) in central Nepal

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The MFT around Bardibas in Central Nepal has two overlapping strands, the Patu and Bardibas thrusts (Fig. 1). These have been the site of several paleoseismological studies that have been instrumental in characterizing the great earthquakes that have affected this region over the last millennia. Better understanding the transfer of slip between the Patu and Bardibas thrusts is necessary to place the results of these studies in an appropriate geological context and fully understand their implications. We present field observations, ten seismic reflection profiles, and high-resolution topography to show the effect of the slip transfer at several scales, from folding of landscape features such as alluvial fans and fluvial terraces, to fault related fold geometries. We show that the structural style of both faults is different in spite of their closeness and the fact that they are both deforming the same stratigraphic units (Miocene-Pliocene Siwalik Group). The Patu thrusts shows a well-defined fault-bend fold style of folding while the Bardibas thrust shows a shear fault bend fold geometry. Furthermore, the Patu thrust is emergent, while the Bardibas thrust is blind.

Further complicating the structural context, the surface expression of this deformation is strongly modulated by surface processes. The deformation associated to the Bardibas thrusts has been completely beveled by the ephemeral streams of the Siwaliks west of Bhabsi khola, even though the related folding is clear in the subsurface seismic reflection data. The complete tapering of slip of the Bardibas thrusts is reached at Khayaramaraha Khola, and is coincident with presence of a footwall shortcut thrust in the Patu thrusts that uplifts Upper Siwalik strata of the Bardibas thrusts sheet. Older, deeply weathered alluvial fans, in the area are gently folded, but younger, fresher ones are not, which could allow for dating of the last folding and fault slip in the area in future studies. Finally, the interaction of these faults raises the question of how does co-seismic slip partition between them, if at all? Published studies have shown evidence of daylighting slip related to the great 1934 earthquake in Sir Khola, on the Patu thrust, as well as Charnath Khola, on the Bardibas thrusts. In between these sites, at places such as Ratu khola, the Bardibas thrusts remains blind, which does not allow us to assess how far slip occurred on each strand. Currently the possibility exists that slip from the same earthquake that is partitioned among both strands may be interpreted as different smaller earthquakes, and thus misrepresent the seismic hazard in the region. Our detailed fault geometry, deformation style and timing of deformation could serve as inputs for dynamic rupture modelling studies that could help constrain this process and help shed light on this issue.

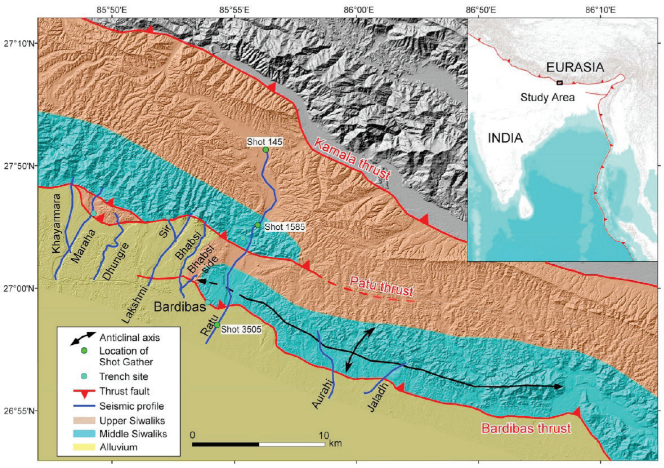


**Fig. 1: Map of the study area in central Nepal, showing the location of the Patu and Bardibas thrusts, the 10 seismic transects used in this study, and the surface geology. The inset shows location of map (Liu et al., 2020).**

**Keywords:** Main Frontal Thrust, overlapping faults, paleoseismology, reflection seismic

# Geology of Pokhara Valley

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Pokhara valley about 50 km in length and an average width of 5 km is a unique intermountain basin developed almost at the center of Nepal. It is elongated in the NW-SE direction. The detailed conceptualization of the Quaternary stratigraphy, geological structures, and tectonic setting of the valley can help to interpret the evolution of such intermountain basins throughout the Himalayas. The present objective of the study is to map both the basement hard rocks as well as valley sediments and prepare a geological map on the scale of 1:25,000. The main aim of the research is to establish the stratigraphy of the region. To fulfill the objective, an extensive field mapping was carried out and many columnar sections were prepared to show the contact relations of the rocks and other textural and structural variations within the rock successions. A preliminary study shows that the Pokhara valley sediments have several mappable geological units, and a few new geological units are also found in this investigation.

The basement rock succession can be divided into six geological units as the Kuncha Formation, Fagfog Quartzite, Dandagaon Phyllite, Norpul Formation, Dhading Dolomite, and the Benighat Slates from older to younger stratigraphy. Similarly, the Quaternary sediments can be mapped into the Begnas Formation, Siswa Formation, Ghachok Formation, Pokhara Formation, and several levels of the Pokhara terrace deposits. These stratigraphic names are adopted from the previous researchers who worked at and adjacent regions. Several sedimentary structures include ripple marks, cross and parallel laminations, graded bedding, and stratification in such compacted sediments. The final part of the correlation of such geological units with the adjacent successions is under the process.

**Keywords:** Stratigraphy, sedimentary structures, terrace deposits, Pokhara valley

# Hot springs of Darchula (far-west Nepal) and perspectives for the monitoring of earthquake-induced geothermal unrest

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Hot springs are found in Nepal especially along the Main Central Thrust (MCT), branching at depth to the subhorizontal Main Himalayan Thrust (MHT) where large Himalayan earthquakes nucleate. During the last decade, one substantial novel result obtained in Nepal was the observation at several sites of geothermal unrest, namely the sudden changes, at the time of the $M_w$7.9 2015 Gorkha earthquake, of the properties of hot springs and associated dry $CO_2$ degassing (Girault et al., 2018). While most changes occurred during and after the earthquake, highly interesting precursory changes were also recorded. Given the fact that the next Himalayan megaquake could happen in the seismic gap between Far-West Nepal and West-Central Nepal, it is important to investigate the poorly known hot springs of Far-West Nepal, where this megaquake could nucleate.

Two important hot springs of Darchula district, Sribagar and Tapoban, were studied in June 2022. The Sribagar hot spring is located a few kilometres to the north of the Darchula district headquarters, on the left bank of the Mahakali River, with various hot water springs observed over a 50-m long zone. The peak temperature (64 °C) is one of the highest so far recorded in Nepal. Significant bubbling of $CO_2$ is observed over the whole hot spring zone. The Tapoban hot spring is located about 27 km from Gokuleshwar in the Chamaliya valley on the right bank of the Chamaliya River. Numerous hot water springs are spread over more than 200 m, with temperature ranging from 31 to almost 44 °C. No $CO_2$ emission was observed at this site.

Both sites, located at critical locations for the next Himalayan megaquake, offer interesting assets for future monitoring of geothermal unrest. However, they are located near a large river with frequent destructive flood episodes. Strategies to address this difficulty will be discussed.

**Keywords:** Hot spring, Main Central Thrust, geothermal unrest, degassing, earthquake cycle

# Fossils of Nepal Himalaya as implications to establish the stratigraphy and correlation of eastern Tethys with western Tethys

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In this study, the fossils so far recorded in Nepal Himalayas till now are summarized. An attempt is made to describe the important fossil records from Nepal Himalaya with their significance for the establishment of stratigraphy. A rich assemblage of invertebrate fossils has been identified from Nepal's Tethys, Lesser, and Sub-Himalayan zones. However, vertebrate fossils have been recorded only from the Sub-Himalaya and the Lesser Himalayan zones. Only the footprints of tetrapod have been reported from the Permian sediments of the Dolpo areas of the Tethys zone. Recently, this abstract's first and second authors have prepared a book entitled "Fossils of Nepal" where all the available paleontological research carried out in Nepal by national and international researchers are gathered. The research gaps in paleontological studies in Nepal are also highlighted. Another attempt is made to correlate the eastern Tethys with western Tethys based on the index fossils.

**Keywords:** Invertebrate fossils, vertebrate fossils, eastern Tethys, western Tethys, Nepal Himalaya

# Are the Naudanda Quartzite and Fagfog Quartzite Similar Geological Units?

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There is still some debate about whether the Naudada Quartzite in western Nepal and the Fagfog Quartzite in central Nepal are geologically similar units or not. The name Fagfog Quartzite was first used by Hashimoto et al. (1973) and it is derived from the village of Fagfog in Dhading district in central Nepal. This name is later well-followed by Stőcklin and Bhattarai (1977), Stőcklin (1980), Paudyal and Paudel (2013) and Paudyal (2014). Similarly, the Naudada Quartzite was first used by Sakai (1985, followed by Hirayama et. al. 1980, and Paudel and Dhital 1996 described from western Nepal). The autochthonous succession of the Lesser Himalaya in Nepal is scanty of fossils and lacks geochronological data for the biostratigraphical correlation as well as the chronostratigraphic correlation of rocks in the region. This has created problems in geological mapping. The carbonate succession and quartzite successions, in such cases, act as a marker bed for the stratigraphy. However, quartzites are mapped in several stratigraphic positions. It has also created another problem to distinguish the stratigraphic position of such quartzite succession. It is mainly due to the repetition of beds by folds and faults and thrusts. The objective of the present research is to assess the stratigraphic position of the Fagfog Quartzite in central Nepal and the Naudada Quartzite in western Nepal. An attempt was made to work out the stratigraphy of an underlying and overlying succession of quartzite beds in both areas. Additionally, the quartzite succession was studied in terms of bed thickness, texture, mineral assemblages, sedimentary structures, and other important depositional environmental characteristics as well as contact relations at the bottom and top of both quartzite succession. The present preliminary study shows that the stratigraphic position of this quartzite succession is similar. However, there is remarkable variation in succession characteristics and thickness of individual beds.

**Keywords:** Naudada Quartzite, Fagfog Quartzite, stratigraphy, sedimentary structures

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Stőcklin, J; Bhattarai, K. D., 1977, Geology of Kathmandu Area and Central Mahabharat Range Nepal. Department of Mines and Geology Kathmandu, Nepal, 86p.

# Movement monitoring of Dutti Landslide, Kavre district, central Nepal

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Dutti Landslide is a large-scale landslide that is situated in the Chauri Deurali Rural Municipality of Kavrepalanchok District in central Nepal. The landslide has an approximate length of 2.345 km and a width of 1.713 km. The landslide has been damaging fertile lands as well as settlement areas for more than 30 years. Therefore, the research aimed to measure the slip rate of the landslide together with engineering geological investigation in order to get recommendations for mitigation measures. The DGPS technique is used to monitor the slip rate of the landslide by installing 14 monuments on the landslide areas and one monument on the stable ground surface outside of the landslide area to obtain relative movement of the slide mass with respect to the stable surrounding zone (Figure 1). Additionally, geotechnical characteristics of the landslide mass, including both soil and rocks, have been determined in the laboratory of the university. The average maximum slip rate of the landslide obtained from 9 months' campaign measurement in the field is 4 cm/month. Rainfall data for the surrounding area indicates the maximum value at 485 mm during July for the years 2021–2022 (DHM, 2022). The landslide area's rocks are dominated by phyllite, with sandstone as a subordinate. This landslide is monitored using the DGPS technique from December 2021 to August 2022. The point load test, i.e., the strength of the rock sampled from the landslide area, ranges from 4 to 34 kN on the pressure gauge. The dominant fine micaceous content in the rocks of the landslide area with an unfavorable scar slope, i.e., more than 39°, as well as bad agriculture practice on the surrounding slopes of the landslide area are the major triggering factors for causing continuous mass movement.

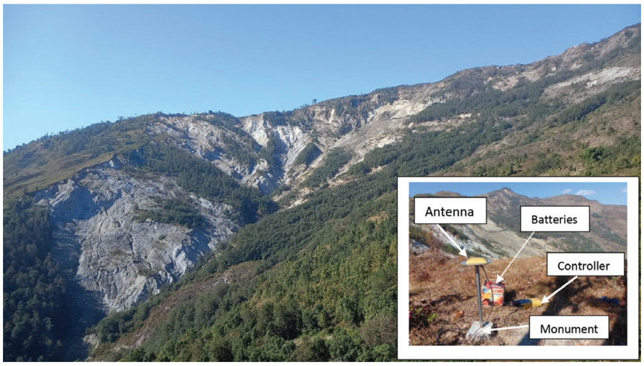


**Figure 1: Viewing the Dutti Landslide from East to North-West, the inset photograph shows the DGPS measurement in the landslide zone.**

**Keywords:** Hazard, landslide slip rate, movement monitoring, DGPS, point load test

# Spatial-temporal variation on river and shallow aquifer interconnection in the Kathmandu valley, central Nepal

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Naturally exchanging of water between river and aquifer is common process in interconnected hydrological systems. The exchange direction of water dependent on hydraulic headwhich can change with alteration of head by seasonal and diverse precipitation pattern, evapotranspiration and over-extraction of groundwater. This study attempts to present interconnection of the Bagmati River and its tributaries with shallow aquifer, and their spatial and temporal variation within the Kathmandu Valley. Chemical analyses: and hydrogen (δD) and oxygen ($\delta^{18}O$) isotopes were performed on shallow groundwater and river samples, collected from August 2017 (wet) and Feb 2018 (dry). Similarity between river and groundwater samples was determined by Hierarchical Cluster Analysis (HCA) on the basis of chemical ($Na^+$ and $Cl^-$) and isotopic value to specify interconnected areas.

Grouping of river and groundwater samples into clusters indicate presence of interconnection. Around 68% of groundwater sites from the wet season and 11% in the dry season shows absence of interconnection. Dominant sites from urbanized area changed exchange process from non-connected to influent condition in the dry season. The influent condition as dominant exchange process (54%) during the dry season signify recharging capacity of low discharge river to peripheral shallow groundwater. Meanwhile, rivers of the valley indicate increment of contamination changing water type from Ca-$HCO_3$ in the wet season to Na-K-$HCO_3$, Ca-$SO_4$, and Na-Cl-$SO_4$ type in the dry season. Presence of significant positive correlation between chemical ions indicates influence of anthropogenic activities.HCA of dry season river water indicates the Godawari Kholaas least polluted and the Hanumante Kholaas seriously contaminated river. Percentage of groundwater sites exceeding NDWQS limits of $NH_4^+$-N and EC becomes double (60.9% and 8.5% respectively) in the dry season comparing to the wet season (30.6% and 4.7%). These outcomes signify that increased contamination in shallow groundwater is the effects of recharge from contaminated river water during the dry season.

**Keywords**: Stable isotopes, chemical ions, HCA, groundwater-river water interconnection, Kathmandu valley

# Identifying crystal cumulation and melt extraction during formation of high-silica granite (Gangdese batholith belt, Tibet)

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High-silica (>70 wt.% $SiO_2$) granites are usually interpreted to form via shallow crustal-level fractional crystallization of silicic parental magmas, yet the predicted cumulate residues have so far escaped widespread identification within granitic plutons. The Nyemo composite pluton (Southern Tibet), which comprises intrusive rocks with intermediate to high-silica (65–78 wt.%) compositions, offers an excellent opportunity to identify processes of crystal cumulation and melt extraction from crystal mush reservoirs. The results of *in situ* zircon U–Pb dating revealed that the different plutonic rocks of the Nyemo pluton were emplaced contemporaneously between 50.0 and 48.9 Ma. Both intermediate and high-silica rocks exhibit consistent zircon Hf isotopic compositional ranges (εHf($t$) = +3.6 to +11.4 and *TDMC* = 0.87–0.37 Ga), suggesting that they were derived from the same primitive, non-radiogenic magma of a depleted mantle wedge source with crustal assimilations in the deep crust. However, these rocks have distinct geochemical characteristics. High-silica rapakivi and miarolitic granites are strongly depleted in Ba, Sr, and Eu, and their zircon trace elements show extremely low Eu/Eu* and Dy/Yb. In contrast, intermediate-silica monzogranite and granodiorite are relatively enriched in Ba and Sr with minor Eu anomalies, while zircon trace elements are characterized by relatively high Eu/Eu* and Dy/Yb. On the basis of these geochemical characteristics we suggest that the high-silica granites represent highly fractionated melt extracted from a mush reservoir at unusually low storage pressure (~0.99-1.19 kbar), the intermediate-silica monzogranites constitute the complementary residual silicic cumulates, and the granodiorites are close to the composition of the mush reservoir. Therefore, crystal-melt segregation as identified in the Nyemo pluton illustrates the formation process of highly fractionated high-silica rocks and complementary large silicic cumulates in magmatic arcs of the upper continental crust. The occurrences of mafic microgranular enclaves in the lower part of the monzogranite and the miarolitic cavities in the high-silica granites suggest that crystal-melt separation was enhanced by gas filter-pressing.

**Keywords**: High-silica granites, crystal-melt separation, silicic cumulates, zircon trace element compositions, Nyemo composite pluton, Gangdese batholith belt, southern Tibet

# Rift propagation in south Tibet controlled by underthrusting of India: A case study at the Tangra Yumco graben (south Tibet)

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Active graben systems in south Tibet and the Himalaya are the surface expression of ongoing E-W extension, however, the cause and spatio-temporal evolution of normal faulting remain debated. Here, we reconstruct the exhumation history driven by normal faulting at the southern Tangra Yumco graben using new thermochronological data. The Miocene cooling history of the footwall of the main graben-bounding fault is constrained by zircon (U-Th)/He ages (16.7±1.0 to 13.3±0.6 Ma), apatite fission track ages (15.9±2.1 to 13.0±2.1 Ma), and apatite (U-Th)/He ages (7.9±0.4 to 5.3±0.3 Ma). Thermo-kinematic modelling of the data indicates that normal faulting began 19.0±1.1 Ma ago at a rate of ~0.2 km/Myr and accelerated to ~0.4 km/Myr at ~5 Ma. In the northern Tangra Yumco rift, re-modelling of published data shows that faulting started ~5 Ma later at 13.9±0.8 Ma. The age difference and the distance of 130 km between the two sites indicates that rifting and normal faulting propagated northward at an average rate of ~25 km/Myr. As this rate is similar to the Miocene convergence rate between India and south Tibet, we argue that the underthrusting of India beneath Tibet has exerted an important control on the propagation of rifts in south Tibet.

**Keywords**: Tibet, Tangra Yumco rift, northward propagation of rifting, thermochronology, thermokinematik modeling

# Preliminary findings of the mineral resources of Dolalghat – Kodari section of Sindhupalchok district, central Nepal

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Preliminary geological prospecting for the mineral resources has been done along the Dolalghat-Kodari section of the Sindhupachok district, Central Nepal. The main objective of this research work is to define and delineate the metallic and non-metallic mineral resources of the area. Further, it is aimed to define the nature, localization, and distributions of mineralization with identification of geological control and analysis of future prospect. Preliminary research has shown that dolomite, slate, phyllite, metasandstone, gneiss, schist and quartzite are the dominating rock types of the area. Stratigraphically, the Lesser Himalayan rock sequences from the Kunchha Formation to the Robang Formation are distributed within the region and the Main Central Thrust is the major structural unit of the area. Copper and iron are the major metallic mineral resources and magnesite, talc, ocher, slate, quartzite and dolomite are the major non-metallic mineral resources. The metallic ore are found to confine within the rock unit of Nourpul Fomation. Iron and copper are considered to be syngenetic and hydrothermal in origin respectively. Initially grab sampling has been done. For the detail study, chemical analysis along with polished sections will be prepared for metallic minerals. There are ongoing mining work on the slate belonging to the Benighat Slate and is found to be mineable. Also, there is well distribution of talc and magnesite in the Dhading Dolomite. Columnar sections and route mapping has been prepared for the volume calculation of these deposits.

# Documenting the Western Nepal fault system - a regional-scale splay fault system within the Himalayan thrust wedge

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The Western Nepal Fault System (WNFS) is an active fault zone that traverses the structural grain of the Himalayan orogen, for greater than 300 km. This fault system extends from the High Himalaya in northwestern Nepal towards the range front in west-central Nepal and accommodates oblique-dextral slip resulting from oblique convergence between India and the Himalayan thrust wedge. The WNFS is composed of multiple fault segments, including three NW-striking faults that follow a right-stepping pattern. The NW-striking segments are partially connected by three N-striking extensional stepover faults. As a subaerial subduction zone system, the occurrence of the WNFS within the Himalayan orogen provides a unique opportunity to investigate the kinematics of splay fault systems and their interaction with the underlying megathrust. We undertook team-based mapping and site investigations along >150 km of the fault system, to integrate bedrock, neotectonic, and paleoseismic constraints on the displacement and earthquake behaviour of the WNFS. Correlating bedrock units across the Talphi segment suggest a minimum of ~2 km of dextral offset. Kinematic indicators observed at the outcrop and micro-scale elucidate key evidence for NW-SE directed brittle faulting. The orogen-oblique, NW-strike of the active WNFS dextral segments and the subparallel orientation of the foliation within the bedrock suggests these active fault segments may root into the megathrust at depth along pre-existing shear zones. Geomorphic evidence of active structures occurs at multiple scales and our neotectonic mapping of offset geomorphic features, such as fluvial terrace risers and moraines, indicates dextral-oblique slip on multiple structures during the Quaternary, consistent with an orogen-oblique fault splay. We anticipate our mapping and geochronology will yield ten independent Quaternary slip rate sites along the length of the WNFS. Paleoearthquake excavations at sites along each of the major segments of the fault system document evidence for multiple late Holocene surface-rupturing earthquakes. Our ongoing research will integrate the new observations into an updated probabilistic seismic hazard analysis for western Nepal.

**Keywords**: Splay fault, megathrust, seismic hazard, Himalaya, active fault

# Design and optimization of proposed road tunnel on Siddhartha Highway from upper Siddhababa to Dobhan

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The road section of Siddhartha Highway from Upper Siddhababa to Dobhan is prone to rock fall and landslide owing to its steep topographic condition, differential weathering pattern and activation of the Main Frontal Thrust (MFT). A lot of work and capital has been invested in stabilizing the rock mass along this section albeit promising solutions are yet to be found. Being one of the most strategic highways of Nepal, the provision of roadway type tunnel would be a abiding solution in saving lives and increasing commute along the highway. This work proposes a suitable alignment, design and optimization of support system, and check the suitability of the tunnel owing to structural safety. After carrying out preliminary investigation, selection of the most suitable alignment is carried out. The widely preferred RMR and Q-system of rock mass classification is carried out along the selected tunnel alignment. Shape and size of the tunnel is designed in accordance with the guidelines given by AASTHO. For the design of support system in the underground opening Finite Element Method (FEM) is used which helps to simulate physical phenomena and thereby reduce the need for physical prototype while allowing for the optimization of support system. To examine the suitability of the initial support system and to determine whether the proposed support system would provide the tunnel with enough structural safety might to withstand the stresses induced in the tunnel face, finite element analysis of the rock mass along with the collected data is carried out. Finally, the dimension and type of various optimized support system for safe operation of tunnel is determined.

**Keywords**: RMR, Q-System, FEM, road tunnel

# Dolomite-and magnesite-bearing lithologies from the Upper Lesser Himalayan Sequences: A petrological perspective in the framework of $CO_2$ degassing during collisional orogeny

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The Lesser Himalayan Sequence (LHS) is a thick Proterozoic sedimentary sequence originally deposited on the northern margin of the Indian plate, and metamorphosed during the Himalayan orogeny. Abundant carbonatic lithologies occur in the Upper-LHS, in the Dhading Dolomite and Benighat Slates Formations. The lithostratigraphic features of these formations are relatively well-known; however, these lithologies have been rarely investigated from a petrologic point of view, and their metamorphic reaction history is fundamentally unknown.

Here we present the results of a detailed petrologic study on different carbonatic lithologies from the Upper-LHS, whose protoliths can be grouped in: (1) a dolomitic series (dolostones, dolomitic marls, dolomitic pelites), and (2) a magnesitic series (sparry magnesite ores, magnesitic pelites). In the dolomitic series: (a) impure dolomitic marbles contain variable amounts of quartz, phlogopite, and/or muscovite; (b) calcschists derived from dolomitic marls consist of carbonates (dolomite ± calcite), phlogopite, quartz and variable types of silicates among which hornblende or kyanite; (c) schists derived from dolomitic pelites show mineral assemblages similar to those of normal metapelites, but with significant amounts of Ca-rich minerals (e.g. plagioclase) and with biotite anomalously enriched in Mg. In the magnesitic series: (a) magnesite-rich rocks consist of coarse-grained magnesite partially replaced by talc + Mg-chlorite; (b) schists derived from magnesitic pelites are characterized by uncommon assemblages, such as orthoamphibole + kyanite + garnet + phlogopite.

Thermodynamic forward modelling ($P/T$-$X(CO_2)$ pseudosections) applied to selected samples from each series allowed to: (1) understand the nature of the main decarbonation reactions; (2) constrain the P-T conditions at which these reactions occurred, and (3) estimate the amounts of carbonates consumed during prograde metamorphism, and the correspondent amounts of released $CO_2$.

The results of this study suggest that carbonatic lithologies from the Upper-LHS: (1) could have produced relevant amounts of $CO_2$ in the past, through metamorphic decarbonation reactions, and (2) they can still be an efficient source of $CO_2$, thus contributing to the diffuse Himalayan $CO_2$ degassing observed at present along the most important tectonic discontinuities.

**Keywords:** Collisional orogeny, dolomitic pelites, magnesitic rocks, decarbonation, $P/T$-$XCO_2$ pseudosections

# Aluminous metapelites as a key to constraining the P-T evolution of the Upper Lesser Himalayan Sequence (Central Nepal)

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The Lesser Himalayan Sequence (LHS) of the Nepal Himalaya is a classic example of an inverted metamorphic sequence, which experienced Barrovian metamorphism during the Himalayan orogenic cycle. Although the LHS represents, in terms of volumes, the bulk of the Himalayan thrust-belt, its metamorphic evolution has been much less constrained than that of the overlying Greater Himalayan Sequence (GHS), the general belief being that it experienced low-to-medium grade metamorphism, limited to the biotite and garnet zones. However, previous studies showed that the upper structural level of the LHS experienced peak temperatures up to 630-650 °C, consistent with the sporadic occurrence of staurolite and/or kyanite-bearing lithologies. Moreover, the overall Upper-LHS metamorphic evolution is still poorly defined because the correspondent P-T paths have been rarely reconstructed in detail. As a contribution to a better understanding of the LHS metamorphic evolution, this study aims at constraining the P-T path of the Upper-LHS, mostly on aluminous metapelites because these lithologies are more prone to developing low-variant assemblages than other lithologies. Detailed petrographic, microstructural, and compositional data are presented for six phyllitic schists, containing porphyroblasts of one or more of the following aluminous minerals: garnet, staurolite and kyanite. Their P-T evolution is constrained through thermodynamic forward modelling (i.e., isochemical phase diagrams combined with isopleth thermobarometry).

Overall, the P-T evolution of the studied Upper-LHS aluminous metapelites is characterized by a prograde moderate increase in both P and T, up to peak-P conditions of 9.5-10.5 kbar, 580-590°C, followed by a heating decompression, up to peak-T conditions of 8.2-8.9 kbar, 610-630 °C. The P-T path constrained for the Upper-LHS differs from the typical “hairpin” paths (i.e. prograde lithostatic loading followed by cooling decompression) registered in the Lower-LHS, and supports those thermo-mechanical models that predict a period of slowdown (or quiescence) of the Main Central Thrust activity.

The results of forward thermodynamic modelling additionally suggest that the studied samples could have experienced different degrees of thermal (ΔT) and/or baric (ΔP) overstepping of garnet nucleation, whereas kinetic factors seem much less critical in controlling the growth of garnet rim at peak P-T conditions.

**Keywords**: Aluminous metapelites, forward thermodynamic modelling, isopleths, P-T evolution, overstepping of garnet nucleation

# Geo-conservation and geo-toursim of Pokhara-Ghandruk section of Gandaki Province, Nepal

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Geo-conservation deals with interpretive and service facilities to enable tourists to acquire knowledge and understanding of the geology and geomorphology of a site beyond the level of a mere aesthetic appreciation. Similarly, geo-tourism deals with natural area tourism that focuses on geology and landscape. It enables to the conservation of geodiversity and geo-heritage. This is achieved through independent visits to geological features, use of geo-trails and viewpoints, guided tours, geo-activities, and patronage of geo-sitevisitor centers. Pokhara-Ghandruk section of Gandaki province is famous for tourism. However, from the viewpoint of geo-tourism, this area has not been explored yet. The present study is aimed to assess the important geo-conservation and geo-touristic sites valuable for the economic development of the nation through geo-conservation and geo-tourism. For this purpose, a systematic geological survey was carried out and a geological map was prepared in 1: 12500 scales showing all the geologically interesting sites. Each of these proposed sites have unique geological as well as geomorphic features. The most important sites are the Pokhara valley, Lumle region, Naudata region, Bantakura temple, Poonhill, Mardi and Annapurna base camp trek route, and Ghandruk-Dhampus areas. Pokhara is famous for caves, deep gorge of the Seti River and several mountain lakes. Naudada section can be proposed as a site specific to see the view of Pokhara valley. Lumle can be proposed for the geo-park development. The Mardi and Annapurna trekking route has several geologically important sites especially outcrops with unique features. The Bantakura temple and Poonhill areas act as view tower for the observation of the snow-capped mountain ranges. Similarly, Ghandruk-Dhampus section is proposed for geo-heritage sites. The upper section of the Modi Khola is the most appropriate site for observation of semi-precious gemstones like garnet, kyanite, and rock crystal.

**Keywords**: geo-conservation, geo-tourism, gemstone, Pokhara, Ghandruk

# A case study of slope stability issues of hydropower project (Bukula Landslide)

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The slope stability issues are highly concerning to researchers, professionals and academicians. There have been different researches, geological investigations and geotechnical investigations on landslides globally. However, proper study of landslide hazard, accurate data acquisition and monitoring is still lacking in case of Nepal. The objective of the present study is to identify the type of failure, cause and effect of landslide and mitigation measures of the Bukula Landslide which lies on Raghuganga Hydropower Project of Myagdi. The Landslide is large scale landslide extended up to more than 500 m of length and of relief more than 300 m. The wedge type failure, toppling and buckling types of failure are observed based on visual inspection. The bedrock is thinly foliated and moderately jointed. The tension cracks (of length 3 m) are observed along the foot trail of landslide area. Hence the slope is not stable. The buckling type failure is common in highly jointed bedrock with low RQD. Sheared zone / weak zones were observed within the landslide area. By analyzing the engineering geological condition, the numerical simulation of unstable hillslope was conducted. The result revealed that Bukula landslide was triggered by sheared rockmass and river toe cutting. The problem due to landslide should be mitigated by proper support installment and proper design of drainage system.

**Keywords**: Landslide hazard, wedge failure, toppling failure, buckling failure, numerical simulation analysis

# An Application of optical and acoustic Televiewer Borehole Logging in geotechnical site investigation

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Drilling and logging of boreholes play an important role in geotechnical site investigation for the sectors of hydropower, mining, construction sites, and research in Himalayan rock. Using an Optical and Acoustic Borehole Imager provides valuable information in addition to cores. By analysing optical image logs with advance software, optical image logs provide detailed structural information, fracture analysis, cased hole images, lithological interpretation, and shear zone identification in boreholes above the water table or with clear water environments. Besides that, the Acoustic Borehole Imager gives extra breakout analysis and works only in a water-filled environment. Very thin fractures and joints – hardly visible on the core – can be detected, as well as bedding planes. Dip, strike, aperture, and type of these structural elements can be determined and displayed in rose, polar, and histograms.

This paper is focused on the study of the geotechnical characteristics of rock at hydropower sites using Optical and Acoustic Borehole logger to scan the boreholes and obtain the geotechnical parameters, which are most essential for the design of underground excavation.

**Keywords**: Optical televiewer, Acoustic televiewer, Geotechnical Investigation

# The role of the tephra layer in the landslides caused by the 2018 Hokkaido Eastern Iburi Earthquake

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The "2018 Hokkaido Eastern Iburi Earthquake," which measured an average magnitude of M6.7 and a maximum seismic intensity of 7, occurred on September 6, 2018, in northern Japan's Hokkaido region. Major damages observed after the earthquake were multiple slope failures with huge debris flow, destruction of vegetation, agricultural lands, physical properties, and human casualties in the region (Fig. 1A). For this, we compared the properties of soil layers to understand the age of landslides, conditions causing landslides, and failure boundary locations of landslides in the 2018 earthquake-affected areas namely Atsuma town in southern Hokkaido and Mizuho district of Abira Town in northern Hokkaido. This study explored that the surface soil layer (2-3 m thick) was mainly composed of pumice and volcanic ash layers (tephra) that had erupted in the past from Mt. Tarumae and deposited in this region.

In the Atsuma region, the landslide collapse occurred in the central part of the damaged area, many of the topsoil collapsed at the boundary of the clay layer below the thick weathered pumice layer (Ta-d layer, which erupted about 9,000 years ago)(Fig. 1B). However, in Abira Town the landslide occurred at the boundary of the lower clay layer of the En-a layer (En-a layer erupted about 20,000 years ago from the volcanic eruption of Mt. Eniwa), which has an older age. The difference between the two is the thickness of the fallen pumice layer, with the central axis of pyroclastic deposits in the north for En-a and in the south for Ta-d. Landslides were more pronounced where the layer thickness was 1 m or greater in both studied sites.

These tephra layers became unstable materials on the slope and fell due to earthquake-induced vibrations, but at the same time, they show a landform development as time indicators. Ta-d layers are nearly 10000years younger than En-a layers. Based on the age of the collapsed tephra, this landslide disaster can be regarded to be an extremely rare event on a time scale of tens of thousands of years, since the mountain slope, which had maintained stability for more than tens of thousands of years since the end of the last glacial period, collapsed due to a recent earthquake that occurred in 2018.


**Fig. 1: (A) Massive landslide caused by the earthquake in 2018, (B) tephra layers exposed in the collapsed slope.**

**Keywords:** Landslide, Tephra, Earthquake, Hokkaido

# SEISMICA: A new diamond open-access journal built for seismology, earthquakes, and related disciplines

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The journal Seismica launched in July 2022 with a call for scientists to submit their research in seismology, earthquake science, and related disciplines. Seismica began in 2020 when a group of seismologists wanted to change scientific publishing in light of recent technological advances and rising publication costs. This initiative continues a movement that started with other journals specializing in volcanoes, tectonics and sediments that promote open science and data for the global research community. More than 100 scientists from around the world have contributed their considerable expertise, skills, and time to develop Seismica to deliver novel peer-reviewed research globally that is free-to-publish and free-to-read. These volunteers cover traditional editorial roles as well as the journal's full-time operation (including technical support, copy editing, branding and communications, and promotion of equity, diversity and inclusion). Seismica values their labor and service by crediting reviewers, authors, and contributors of published works. Beyond traditional research articles, Seismica publishes an innovative set of peer-reviewed reports including fast reports, null results/failed experiments, software reports, and instrument deployment/field campaign reports, null results. Seismica accepts papers within a very broad scope of fault slip and earthquake source phenomena, earthquake records, imaging the Earth, theoretical and computational seismology, beyond Earth-tectonic applications, techniques and instrumentation, earthquake engineering and engineering seismology, and community engagement, communication, and outreach.

Seismica has an ongoing call for scientists to submit their research or to serve as reviewers, and for volunteers to help run the journal. As of August 2022, 247 people have joined the Seismica community, 228 signed up as Seismica reviewers, and ~140 responded to the call for editors. Since the launch date, Seismica has received manuscripts from authors in Germany, US, UK, France, and Japan. This autumn, Seismica will launch the Ambassadors Program to engage volunteers across the world to promote open science and data globally. This program is a unique opportunity that will give participants an extensive and international network of scientists and the tools and support from the Seismica editorial board to promote our diamond open-access journal within their own networks. For more information about how to join Seismica, visit http://www.seismica.org/

**Keywords**: Seismica, seismology, diamond journal, open-access, citizen science

# Bringing geoscience education to Nepali schools for earthquake risk reduction

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To close the gap between research results in Geosciences and the Nepali population living in a high seismic risk zone, we have developed a local educational seismology program starting in 2017 [ref.1]. The program currently involves thirty-three secondary schools, and focuses on two, connected pillars: (1) an operational low-cost seismic network installed in schools, (2) training teachers and providing all the material to teach earthquake-related topics in classrooms. Since spring 2019, the seismometers have been used to record earthquakes, and allowed various 'learning-by-doing' classroom activities. Individuals outside the schools are invited to observe earthquake records on their smartphones, and to access the program's fully open website, which motivates them for better earthquake preparation. Beyond our funding efforts and crowdfunding, the program convinced local governments to co-fund school's participation. The network operation is monitored online, and repairs feasible on site are carried out by Nepali people with remote advice and sometimes autonomously.

We prepared and adapted several materials to the Nepali education system, and also trained the teachers for their new challenges in the classroom. The knowledge learnt by students is transferred to their personal environment, which helps building earthquake-safer communities including the older generations. Our approach was very well received and we could already measure a positive impact of our program. This is encouraging and we continue the efforts to expand the program across Nepal. Finally, our program has developed outreach beyond the schools, by composing the Earthquake Awareness Song [ref.2] which has already been seen by >118'000 visitors online, and the recent development of a card game to increase earthquake awareness. Lessons learned in Nepal could be applied for developing educational seismic networks in other countries with high and moderate seismic hazard.

**Keywords:** Geoscience, education, seismic risk zone, learning-by-doing, awareness

**Notes:**
[ref.1] http://www.seismoschoolnp.org/, Subedi et al. 2020 doi:10.3389/feart.2020.00073
[ref.2] https://youtu.be/ymE-lrAK0TI

# Cement industry in Nepal

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Nepal's Domestic cement industry had an installed production capacity of 10.20 million tonnes for clinker and 17 million tonnes for cement grinding as of 2018-19. Out of 17 million tonnes, 10.20 million tonnes are Integrated Units and remaining 6.80 million tonnes are Grinding Units.

The stabilizing political environment, coupled with vital construction projects in the aftermath of the 2015 earthquake, as well as transportation and energy infrastructure project, it is expected that it will accelerate the upward trend in domestic cement consumption. As the country pushes forward with infrastructure development projects such as the building of road networks, hydropower projects, the rise in the construction of houses and apartments in urban areas and development in rural areas, it is expected that demand growth will be in the range of 15-20% over next 5 years, i.e., demand of cement is expected to reach 20 million tonnes by 2023-24. There are more than 60 cement factories operating in Nepal, out of which 13 are Integrated Units, 38 nos. are Grinding Units and remaining are Vertical Shaft Kilns (VSKs).

The Lesser Himalaya and Tethys Sediment are geological provenience for limestone deposit. Out of total 147, 516 sq. km. of nation's area, limestone occupies about 7000 sq. km. About 985 million tons of limestone reserves of different categories including 139 million tons of proved reserve are identified. However, many limestone resources have a marginal quality for cement production especially with high magnesia content. There are 87 opening licenses and 213 prospecting licenses issued by Department of Mines and Geology as of fiscal year 2078/79.

At present, there is surplus production of cement in Nepal and a high demand of PCC cement in India. So it is expected that the export of cement to India along with the government grant would help boost the country's economy.

**Keywords:** Cement industry, limestone deposit, Nepal

# Seismic microzonation of Banepa valley using microtremor survey method

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Close to the country's capital, Banepa is a rapidly growingintermontane valley filled with fluvio-lacustrine sedimentson the basement rocks ofthe Lesser Himalayan rock sequence. Haphazard and unplanned urbanization in a soft fluvio-lacustrine deposit, the risk of an overdue earthquake event has been accelerating rapidly. This study intends to conduct seismic microzonation based on fundamental frequency obtained from Nakamura's Horizontal to Vertical Spectral Ratio (HVSR) method. The microtremor survey was conducted in evenly spaced grids of 500 m×500 m for estimating fundamental frequency ($f_o$) and amplification factor (A) along with array microtremor measurement to establish shear wave velocity (Vs) model of the subsurface within the Banepa valley. The study has found fundamental frequency ranging from 0.12 Hz to 12.49 Hz and average shear wave velocity at 30m depth ($Vs_{30}$) of 256 m/s. The thickness of the sediments varies from 34m to 56m, which reveals heterogeneity in sediment distribution and its basement topography. This study is expected to give quantifiable outputs into geotechnical properties, ground response and seismic characterization of Banepa valley, which is useful fordevelopingearthquake-resilient infrastructures.

**Keywords:** Surface wave, HVSR, basin, site characterization

# Palynological records and their climatic implications from the Sunakhoti Formation during Last glacial age

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The palynological and sedimentological research is one of the best archives to reveal past environment of the Palaeo-Kathmandu Lake sediments which holds immense knowledge of past climate and vegetation change along with its tectonic history and depositional environment. The 14m thick sequence of the Sunakhoti Formation exposed in the southern part of the Kathmandu basin is composed of gravel, silty clay and clay sequence with plant remnants. Altogether eight samples from clay and silty clay layer were collected for palynological study to disclose the climate and vegetation change since late glacial period. The two pollen zones SK1 and SK2 are divided according to the CONISS cluster analysis. The pollen assemblages show high frequency of tree pollen exceeding 70% then herbs and shrub plant about 20%. *Pinus* and *Quercus* are dominant tree taxa followed by *Abies*, *Picea* and *Tsuga* species. The Poaceae is major herb gradually increasing in frequency (<20%) in upward section. The other herbs such as Brassicaceae, *Artemisia*, Cyperaceae and Compositae occupy less than 10% frequency in both zones. The Pteridophytes spore such as *Lygodium*, *Lycopodium*, Polypodiaceae, are major recorded from the section. The Coexistence Approach analysis shows Mean annual temperature ranges from 9.3 °C to 17.5 °C and Mean annual precipitation ranges from 1122-1146 mm. These average temperature and precipitation are lower than the present day average annual temperature and precipitation of the Kathmandu valley indicating relatively colder climatic condition during deposition of the Sunakhoti Formation. The climate and precipitation suggest favorable conditions for the expansion of vegetation throughout the deposition period. The SK2 zone suggest dominance of gymnosperm trees over angiosperm indicating sub temperate to temperate forest with cold and humid climate during the period. The forest floor was dominated by compositae, poaceae and fern plants.

**Keywords**: Lake sediments, depositional environment, late glacial, Kathmandu basin

# Landslide investigation using 2D-electrical resistivity tomography along the Araniko Highway

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Nepal Himalaya being the youngest and most fragile experience various natural disasters. Landslide, one of the main hazard that causes the damage of infrastructures and loss of human life. This study focuses on the landslides along the Araniko Highway. This highway is the main connection route to neighboring nation China and has the economic and strategic value. The 2015 A.D Gorkha Earthquake triggered several landslides along the highway and left the several hillslope in critically stable state. The landslide were frequent in the following years after the 2015 Gorkha Earthquake mostly in the rainy season. This study combines the geology and the geophysical survey to understand the subsurface geology of landslide. All together 7 different landslides (Kothe, Mahavir, Bulkot, Himdi, Koplang, Kodari and Lipling) along the Araniko Highway were considered based on the severity of obstruction.

The application of 2D- Electrical Resistivity Tomography (ERT) has been increasing day by day for landslide studies to find out the depth of the slip surface and thickness of overburden masses (Drahor et al. 2006, Coskun et al., 2015). The depth of the layer depends on the lateral distance of the profile such as the increase in the spacing increasing in the depth of investigation. Normally, one third to one fifth of the depth can be taken for data processing (Winghtman et al., 2003). The ERT was applied along the different parts of landslide in the field. The ERT survey was carried out in the unstable mass of colluvium in each slide with the aim of finding the thickness of mobile colluvium mass, to delineate the slip surface and the groundwater condition. The representative profile (Dipole-Dipole array) of Koplang landslide as shown in Figure 1. Since, the landslides along this highway were more frequent in the rainy season, the degree of groundwater saturation in colluvium and nearby springs were mapped in the field. The resistivity inversion image shows the different patches of high resistivity and the low resistivity. The low resistivity zone overlies with the saturated landmass observed in the field. Similarly, the high resistivity zone corresponds to the bedrock and dry colluvium consisting boulders and cobbles. Hence, using this method, the distribution of dry colluvium, wet colluvium and bed-rock along each ERT profile is mapped. The volume of the loose mass and depth of slip surface in each landslide were estimated.

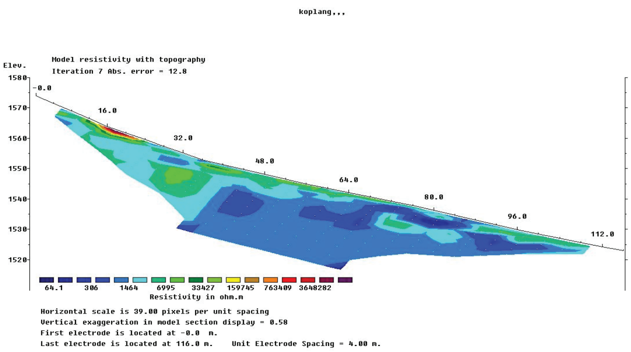


**Fig. 1: Electrical Resistivity Tomography profile in the uphill direction of road in Koplang landslide.**

**Keyword:** Highway, landslide, slip surface, overburden, dipole-dipole array

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# Kinematic analysis and rock mass classifications for rock slope failure along access road of upper Trishuli-1 hydroelectric project in Rasuwa district, central Nepal

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The first to fifth kilometers of the Upper Trishuli-1 Hydroelectric Project (216 MW) in Rasuwa District, Central Nepal, are subjected to rock slope kinematic analysis and rock mass classification. The road alignment follows on the right bank of the Trishuli River. In particular, rock slope kinematic analysis and rock mass classification provide the criteria of a mode of failure and overall quality of rock slope. The purpose of this research is to investigate the kinds of rock slope failures that occur as well as the quality of the rock mass. The rock mass quality and rock slope stability have been investigated based on Rock Mass Rating (RMR) system and Kinematic analysis is performed to identify the failure mechanism. The rock's strength data was further checked and verified in the field by the Schmidt hammer test and in the laboratory by the point load test, which also verify the rock mass strength data, collected during the field excursion. Thirteen slopes are studied and the result of the kinematic analysis revealed that plane failure may occur in slopes 1, 2, and 6, while wedge failure may see in slopes 2, 4, and 6, and toppling failure is likely to occur in slopes 1, 2, 5, 6, 7, 10 and 11. The adverse orientation of joints concerning slope, slope geometry, and basic friction angle depending on the roughness of joints are contributing to the failures. The RMR on the investigated slopes seems to be the same. The slopes studied have similar RMR because of their similar lithological and geotechnical characteristics.

**Keywords:** Rock slope stability, rock mass rating, kinematic analysis

# Analysis of size, shape and textural maturity of sands from the Kaligandaki River

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Large number of sands gets transported via the rivers of the Himalaya. Despite of their high economic significance, the nature of sands is still unknown. The Gandaki River System is one of the major river basins of the Himalaya originating from China and flows through Nepal and eventually mixes with the Ganga River in India. The study aims to analyze the textural properties (size and shape) and maturity of the Kaligandaki River sands, and their downstream variation. Sand samples were collected along the river from the Tethys Himalayan region up to the Indo-Gangetic Plain of Nepal. The sands are classified as slightly muddy sand, in which mean and median sizes and sorting increase with distance downstream from the upstream segment to the downstream segment. The results indicate that coarsely skewed and platy to mesokurtic sands become nearly symmetrical to finely skewed and leptokurtic suggesting increase in fine-grained sands and enhancement of sorting with distance downstream. The percent fines (mud) ranges from 0 to 5% and shows no distinct downstream variation trend. Mean roundness of quartz is generally subangular (2 to 3 ρ), and downstream variation does not reflect change in roundness category. However, there occurs slight diminish of roundness with distance downstream. Inclusive graphic standard deviation ($\sigma_I$) varies from 0.30 to 1.38 φ. After 100 km downstream, $\sigma_I$ decreases reflecting improvement of sorting. Sediments are immature to mature and are submature in upstream and midstream segments except for few sites where they are immature not due to flux, but probably due to local contribution of fines. With distance downstream, sediments tend to be more mature owing to enhancement of sorting.

**Keywords**: Kaligandaki River, roundness, sorting, textural maturity, sands

# Regional geological structures of Tamghas-Burtibang section of the Lesser Himalaya, western Nepal

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The Tamghas-Burtibang section, which lies in the Lesser Himalaya of western Nepal covers mostly the allochthonous units with some part of the autochthonous zone. This study mainly focused to determine the structural setups by lithological and structural evidences with support of petrographic analysis. Detailed field geology was studied to prepare structural-geological map along with petrographic study is used to verify the field evidence in lab.

The present study area comprises the Darling Carbonates correlable with the Malekhu Formation of the Nawakot Group. Birbas Slate is equivalent to Benighat slate of Nawakot group. Followed by the Gwaslung Formation, the Musimorang Formation and the Shivapur Schist of the Jajarkot Nappe. Lithologically, the Kathmandu Nappe, the Kahun Klippe and Jajarkot Klippe are a part of a single crystalline thrust sheet and the basal thrust of the Kahun Klippe (the Dubung Thrust) and that of the Kathmandu Nappe (the Mahabharat Thrust) are equivalent to the Khurpa Khola Thrust from the study area.

Structurally a thrust equivalent to the Mahabharat Thrust had transported these rocks of nappe, and hence it bounds the Jajarkot Nappe from all sides. The Badigad-Kaligandaki Fault, a strike-slip fault passed close to the Mahabharat Thrust in the North. A number of local deformation structures are present throughout the region. A large unnamed NW-SE trending synclinorium passes through the core of younger strata of the Jajarkot Nappe. Numbers of anticlines and synclines are developed in the north and south flank of this synclinorium.

**Keywords**: Structure, Badighad Fault, Mahabharat Thrust, Jajarkot Nappe, Western Nepal, Lesser Himalaya

# Stability analysis and evaluation of rock support in headrace tunnel of Khimti-2 Hydroelectric Project

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The tunneling activities have increased considerably in Nepal with the development of many hydropower projects. During the design phase, tunnel alignment selection and rock mass quality prediction along with rock support requirements have a direct impact on overall cost and time requirements to the project. The major decisions that must be made in planning, designing and constructing a tunnel is mainly influenced by the geology along the tunnel alignment. An assessment on the stability of the Headrace Tunnel (HRT) of Khimti-2 HEP has been done. Ten excavated sections of headrace tunnel have been selected for the study at the critical zones. Squeezing and spalling phenomena have been assessed by empirical and semi-analytical method. The wedge block stability analysis has been done using UNWEDGE software. Further, rock support estimation from Q-method as well as support optimization have been done from numerical method with phase$^2$ software developed by Rocscience. From the numerical analysis the support has been optimized based on the Q values.

**Keywords**: Stability analysis, support optimization

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# Geology and structural setting at the boundary between Jajarkot Nappe and Karnali Nappe in western Nepal, Lesser Himalaya

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Among four tectono-stratigraphic units of the Himalayan orogeny, the Lesser Himalaya also known as the thrust-and-fold belt is geologically very complex due to folding and thrusting of crystalline sequences. The Lesser Himalayan sequencethe Nepal Himalaya, especially the western and central parts comprises of numerous metamorphic crystalline thrust sheets which are core of either large-scale great Himalayan syncline or anticline. This study aims to explore the boundary between two less explored, large crystalline thrust sheets of western Nepal; the Jajarkot Nappe and the Karnali Nappe along Chhedachaur- Archhani section, southern section of Jajarkot district with emphasis on lithostratigraphy, structural setting, metamorphism, and magmatism. After taking several traverses during field observation, primary data collection, and microstructural analysis, the area revealed two allochthonous units, the Jajarkot nappe or the Lesser Himalayan thrust sheet and Karnali nape or the Higher Himalayan thrust sheet along with the Lesser Himalayan meta-sediments in between them. The lithological succession of the Jajarkot nappe is further subdivided into five units; Marka Formation consisting of the meta-diamictite member named as the Chhera Diamictite, Badakada Formation, Thalaha Quatzite, Karkigaun Schist and Bhoor Carbonate Unit from south to north. The Karnali nappe comprises two types of the rock succession: orthogneiss or granitic augen gneiss and paragneiss. The thrust that carried out the Higher Himalayan crystalline rocks of the Karnali nappe, the Tapuchaur Thrust is equivalent to MCT and that thrusted over the rocks of the Jajarkot nappe; the Thalaha Thrust is apparently equivalent to the Mahabharat Thrust and the Dubung Thrust.Except these two structural discontinuities, there are two large a plunging non-cylindrical fold Suwa Gad anticline and Bhoor syncline.The area also displays inversion of metamorphism, supporting the development and existence of thrust with metamorphic grade ranging from chlorite grade to kyanite grade with metamorphic facies assemblage of zeolite amphibolite facies. The granitoid intrusion reported within theKarkigaun Formation has deformed and metamorphosed to the blasto-mylonitic augen gneiss indicating the passage of the thrust and extreme shearing.

**Keywords**: Nappe, thrust, stratigraphy, metamorphism, magmatism, metamorphic facies

# Textural division of aquamarine-bearing Yamrang Pegmatite: A case study of rare-metal pegmatite from Nepal Himalaya

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Rare metals or critical metals, e.g., Li, Be, Nb, Ta, Rb, Cs, Zr, Hf, etc., are of the highest economic importance due to their unique physical and chemical properties, which make them essential in low carbon energy systems, electronics, automotive, aerospace, military, and medical industry. Rare-element (REL) pegmatites are the primary sources of rare metal minerals. Pegmatites are identified by their extremely coarse grain size compared to ordinary igneous rocks of similar composition and the unique graphic texture resulting from the skeletal intergrowth of quartz and alkali feldspars. Most pegmatites are common pegmatites with granitic eutectic compositions, containing quartz, feldspar, muscovite, biotite, accessory tourmaline, garnet, and apatite. Pegmatites that host appreciable beryl, lithium aluminosilicates, phosphates other than apatite, oxides other than magnetite or ilmenite, and other rarer minerals are regarded as rare-element pegmatites. Two phases of field investigation confirmed the beryl-bearing pegmatites at the Ikhabu area at 1800 m elevation in the Tamor-Kanchenjunga region of Eastern Nepal. We named Ikhabu Pegmatite Field for the Ikhabu area consisting of beryl-bearing pegmatites and the largest aquamarine-bearing Yamrang pegmatite was chosen for the detailed study and characterization of REL mineralization from the region. Yamrang Pegmatite is intruded on kyanite grade Precambrian schistose gneiss at the middle part of Junbesi Formation. The Yamrang Pegmatite shows axial-symmetric internal zonation and can be differentiated into five mineralogical–textural zones based on mineral evolution, composition, texture, and location within the pegmatite body; zone 1: saccharoidal albite zone (marginal zone); zone 2: blocky perthitic microcline zone (outer intermediate zone); zone 3: muscovite–microcline–quartz zone (inner intermediate zone); zone 4: beryl-quartz zone (core zone); and zone 5: miarolitic zone (miaroles). Beryl mineralization was found in zones 3-5, with spectacular aquamarines recovered from miarolitic zone 5. The extensive manual mining observed at the exposure confirms that Yamrang Pegmatite is the primary source of elusive aquamarines traded to the global market from Nepal for decades. The Yamrang Pegmatite intruded into amphibolite facies Ky grade schistose gneiss, containing beryl, columbite-tantalite in inner zones (3-5) is classified as the rare-element (REL) class, beryl type, beryl-columbite subtype pegmatite.

**Keywords**: Aquamarine, Yamrang Pegmatite, textural division, rare metals, Ikhabu pegmatite field, eastern Nepal Himalaya

# The role of landslides on the sediment budget in upper Phewa Lake watershed, western Nepal

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Phewa Lake at the outlet of its draining valley has been forced to receive sediment load from the upstream part of the watershed. Siltation in this lake by normal water erosion process is an issue that has been raised for years. Additionally, the mass movement event that occurred on 31 July 2015 added considerably high sediment turning the lake murky.

This study mainly concentrates on the question of how - landslides contribute to the total sediment budget in the upper Phewa Lake watershed, taking a case of the upper north-western Andherikhola sub-basin, which provides recent examples of large debris flows, and landslides that fed the river system in 2015.

Two main methodological approaches: estimation of baseline erosion and assessment of sediment delivery by landsides, were considered. The research has estimated the normal sedimentation rate in prelandslide situations (for the year 2014) and also for the year of disaster 2015 by applying the Revised Morgan Morgan Finney daily erosion model in the PCRater GIS platform. Four different approaches: 'planar areal segment', 'triangular prism', 'parabolic segment', and 'rectangular prism' were applied to reconstruct landslide volume and the added deposit into the river system.

With some adaptations such as the application of separate equations for sand, silt, and clay, the introduction of a new code to enhance the role of saturated hydraulic conductivity - initial infiltration base followed by runoff calculation as a rainfall fraction, increment of effective hydrologic height, slope correction for terraced cultivation areas, and cloud correction in NDVI images, the sediment flux for 2014 and 2015 were estimated as 51013 and 66383 tons with the average rate of 16 and 17 tons/ha/y. The volume reconstruction by a triangular prism and parabolic segment has provided a better estimation of debris flows with long runouts. The planar areal segment has given a relatively good estimation for shallow and complex landslides. The total volume of debris directly deposited into the river was estimated between 871858 and 1119792 m3 with 337731 m3 finer constituents. These finer constituents of sediment are 5 times and 6 times higher than sediment yield by the RMMF-D erosion model for 2014 and 2015, respectively. The net contribution by landslides and incremental volume of erosional sediment yield in 2015 was estimated at 341721 cubic meters.

**Keywords:** Erosion, PCRaster, sediment yield, debris flow, RMMF erosion model, and debris volume

# Elucidating the tectonometamorphic history of the Nepalese Himalaya using monazite petrochronology

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The Himalaya, the archetypical continent-continent collisional orogeny, is often simply described by two major tectonostratigraphic units, the Greater Himalayan Sequence (GHS) and the Lesser Himalayan Sequence (LHS), juxtaposed by the Main Central Thrust (MCT). The GHS, in the hanging wall of the MCT, primarily composes Neoproterozoic-early Paleozoic amphibolite grade metasedimentary and metaigneous rocks whereas the LHS, in the MCT footwall, comprises Paleoproterozoic-Mesoproterozoic greenschist grade metasedimentary rocks. Development of the Himalayan fold-thrust belt is often attributed to deformation in the GHS because of abundant evidence of Eocene-Miocene GHS metamorphism. However, recent studies also highlight the importance of deformation in LHS since Mid-Late Miocene. If that is the case, GHS and LHS samples should have distinctive tectonometamorphic 'fingerprints' that vary spatially and temporally due to differences in timing of involvement in deformation. To assess whether monazite petrochronology datasets can document such tectonometamorphic 'fingerprints' of GHS and LHS samples consistently along strike, we analyze samples in the central and eastern Nepalese Himalaya.

GHS samples host both Paleozoic and Cenozoic (Eocene-Miocene) monazite whereas LHS samples exclusively host late Cenozoic (mid-late Miocene) monazite. Monazite Th-Pb ages and corresponding trace and rare earth element chemistry (TREE) from GHS samples show increase in Y and decrease in Gd/Yb, Dy/Yb as Th-Pb ages get younger from Eocene-Oligocene to Miocene. LHS samples show similar increase in Y and decrease in Gd/Yb, Dy/Yb during Middle to Late Miocene. We interpret an increase in Y with a decrease in Gd/Yb, Dy/Yb to reflect cogenetic garnet growth and the reverse to reflect garnet resorption. Eu* trends for both GHS and LHS samples are variable but generally decrease with younger Th-Pb ages, possibly indicating consumption of Eu due to crystallization of plagioclase feldspar. Consequently, we see a systematic difference in timing of monazite TREE patterns between GHS and LHS where a change from low Y and high Gd/Yb, Dy/Yb to high Y and low Gd/Yb, Dy/Yb reflects transition from crustal thickening and prograde conditions to cooling and retrograde conditions.

Our new monazite petrochronology dataset indicates that most GHS samples record an earlier phase of tectonism during the Paleozoic followed by Eocene-Oligocene post-collisional crustal thickening. Late Miocene cooling in GHS samples was likely caused by tectonic transport to upper crustal levels by the MCT. In contrast, LHS samples do not document any evidence of Paleozoic or Eocene metamorphism. Furthermore, LHS samples were still undergoing tectonic burial during Early Miocene and began cooling during Mid-Late Miocene, consistent with independently constrained timings of Ramgarh thrust and growth of the Lesser Himalayan Duplex. Thus, monazite petrochronology can differentiate distinct tectonometamorphic histories for GHS and LHS samples consistently along strike. Miocene metamorphic monazites in our LHS samples also add to the growing body of evidence that the establishment of the Nepalese fold-thrust belt has been dominated by deformation in the Lesser Himalaya since the Middle Miocene.

# Causes and effect of cut-slope failure in the road passing through the granitic terrain of central Nepal Himalaya

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Slope failures due to cutting and excavation of slopes for road construction are an important issue in mountainous areas of Nepal. Slope stability is affected by internal factors such as rock types, weathering, internal behaviour of soil and rock, geological structure, etc. and external factors such as rainfall, melting, earthquake, blasting, surcharging of external loads etc. Granite is the hard rock but due to excessive joints and chemical behaviour of minerals of granite, granitic terrain is vulnerable to slope failure issues. In granites of Central Nepal different structures and texture of the granite are found, e.g. porphyritic, graphic, blocky and gneissic granite was observed in the area. Kaolinisation and alteration is intensively active in potash feldspar and muscovite bearing granites.

Granite soils are widely recognized to be very sensitive to weathering and vulnerable to Landslides. Along the Kanti Rajpath many disasters have occurred in granite soil areas following heavy rains. Huge rock slides have also occurred in the granitic terrain. Rainfall slope instability tends to occur more frequently in granite soil formation compared to the other meta-sediments. Weathered granite landslides are initiated when the sandy residual soils of the granitic terrains are saturated. Slope Stability Analysis of a Weathered Granitic Hillslope as Effects of Soil Thickness depend on the slope angles, vertical depth of the soil, and saturation of water in soil. Thickness of soil is also controlling factor of slope stability. In this study, relation of rock mineralogy, discontinuity of rock, rainwater infiltration into an unsaturated slope are related for the change in slope stability and analysis is carried out for occurrence of slope failure in granitic terrain.

**Keywords**: Cut-slope, slope failure, granitic terrain

# Subsurface investigation using resonance acoustic profiling and Geo-electrical method

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Subsurface information plays a crucial role for the successful planning and implementation of any projects from construction to repair and renovations. Integration of Resonance Acoustic Profiling (RAP) and Geo-electrical method has been used in the present study for shallow to deep investigations. Data acquisition of acoustic signal was conducted using RAP-G and resistivity using GD-10 Supreme Resistivity/IP meter. Filtering and computation of the spectral characteristics of the signal using fast Fourier transformation is conducted in RAP software and resistivity values using inversion modelling in Res2Dinv software.

Case studies were conducted in different natural and artificial condition for subsurface investigation of groundwater, landslide and RCC structures of bridges.

Integration of RAP and Geo-electrical methods has been useful in detection of subsurface features like loose/compact sediments, water bearing zones, depositional sequence, fractured to competent bedrock and mechanical properties of subsurface material. This study shows that integration of RAP and Geo-electrical method can be successfully used to enhance subsurface investigation in natural and artificial condition.

**Keywords**: Acoustic profiling, geo-electric method, resistivity, subsurface investigation

# Geological prospecting of iron from Jelban-Seram section of Rolpa district, western Nepal

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The iron deposits primarily of sedimentary origin is distributed along the Lesser Himalaya region of Nepal. The Jelban-Seram section of the Rolpa District has been reported as a prospect for iron but lacks detailed study to determine quantity, quality, association and its distribution. The detailed geological setting of iron mineralization within the area based on stratigraphy and prospecting in terms of geological control, genesis, and gross reserve were the primary objectives of the present study. Petrographic and chemical analysis of the rock samples collected from various lithological units including ones from the old iron mines were conducted to understand the geology and grade of iron mineralization respectively.

The study area composed of low-high grade metamorphic rocks of the Jajarkot Nappe and the Upper Nawakot Group. The rocks of the Lesser Himalayan autochthonous succession include the Benighat Slates and the Jhiku Calcareous beds. The rocks of the Rankot Formation, the Kasala Schist with the Poban Quartzite and Gneiss body, and the Ghusban Marble are all found in the allochthonous sequence, or the Jajarkot Nappe, which extends from south to north. The Badachaur Thrust which is a low angle reverse fault, divides these two tectonic units. The stratiform type iron mineralized band is confined within the sedimentary metamorphosed quartzite and schist rock succession of Poban Quartzite unit of Kasala Schist. The average grade of iron is 40.99% with an estimated gross reserve is 12.318 million metric tons. The reserve is sub-economic and it is feasible for the further detail prospecting and exploration.

**Keywords**: Western Nepal, Jajarkot Nappe, iron mineralization, sedimentary metamorphosed rocks

# Plio-Pleistocene metamorphism, partial melting, and ultra-fast exhumation in the Nanga Parbat Massif: petrochronology of the youngest migmatites in the Himalaya

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The syntaxial massifs of the Himalaya – Nanga Parbat and Namche Barwa – are currently the sites of the fastest rock uplift and exhumation in the entire orogen. These massifs expose the youngest migmatitic and magmatic rocks in the Himalaya, which give Plio-Pleistocene U-Pb dates that are interpreted to mark the timing of melt crystallization. Various mechanisms have been proposed to be the dominant drivers of anomalously rapid exhumation at the syntaxes: 1) a 'top-down' mechanism in which extreme fluvial and glacial erosion induce localized rapid uplift, exhumation, and decompression melting, or 2) 'bottom-up' mechanisms that include viscosity reduction due to partial melting in the mid-lower crust, or larger-scale tectonic processes that drive mass input into the massifs. Detailed metamorphic pressure-temperature-time (P-T-t) histories from are necessary to evaluate these proposed mechanisms. We present a petrochronological study of migmatitic rocks from the core of the Nanga Parbat Massif (NPM), in which we link isotopic dates (derived from U-Pb accessory mineral dates and trace element chemistries), thermobarometry, and diffusion modelling of major element zonation in garnet, in order to reconstruct their P-T-t histories, with particular focus on reconstructing exhumation rates, as well as the timing and duration of melting and melt crystallization reactions.

Our data indicate a substantial acceleration of exhumation rate at ~1 Ma, from ~2-4 mm/yr to 9-13 mm/yr. The data also reveal diachronous partial melting/melt crystallization amongst different lithologies prior to the 1 Ma exhumation pulse: one sample records melt crystallization as early as ~4 Ma, whilst another sample records partial melting beginning at ~2.2 Ma, with both samples recording melt crystallization at ~1 Ma. Diffusion modelling of major element zonation in garnet shows that maximum timescales of peritectic garnet growth are consistent with interpretations made from the U-Pb data. These data are inconsistent with massif-wide partial melting in the mid-crust as a mechanism for inducing ultrafast exhumation.

Recent studies suggest the Namche Barwa Massif experienced a similar acceleration of exhumation at ~1 Ma. This 'pulse' of exhumation appears to be restricted to the syntaxes (rather than affecting the entire orogen), which precludes the role of enhanced surface erosion driven by Pleistocene climatic changes in initiating ultrafast exhumation. We interpret our results – in concert with those of recent studies - to suggest that the current loci and tempo of rapid exhumation in the Himalayan syntaxes are largely dictated by larger-scale tectonic and/or structural forcing.

**Keywords**: Nanga Parbat Massif, exhumation, metamorphism, petrochronology

# The role of brittle fault zones in triggering landslides in the Himalaya: Examples from the Darjeeling Himalaya

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Landslides are a major global natural hazard typically triggered by earthquakes and rainfall. Structurally weak fault zone rocks along slopes located within fault core and damage zones may also trigger landslides (Fig. 1). Two, out-of-sequence, fault zones in the Darjeeling Himalaya clearly illustrate this as their intersection with the national highway NH10, the primary highway in the region, has been the site of multiple debilitating landslides. Therefore, brittle fault zones must be studied systematically as part of slope stability assessment during all infrastructure development in the Himalaya.

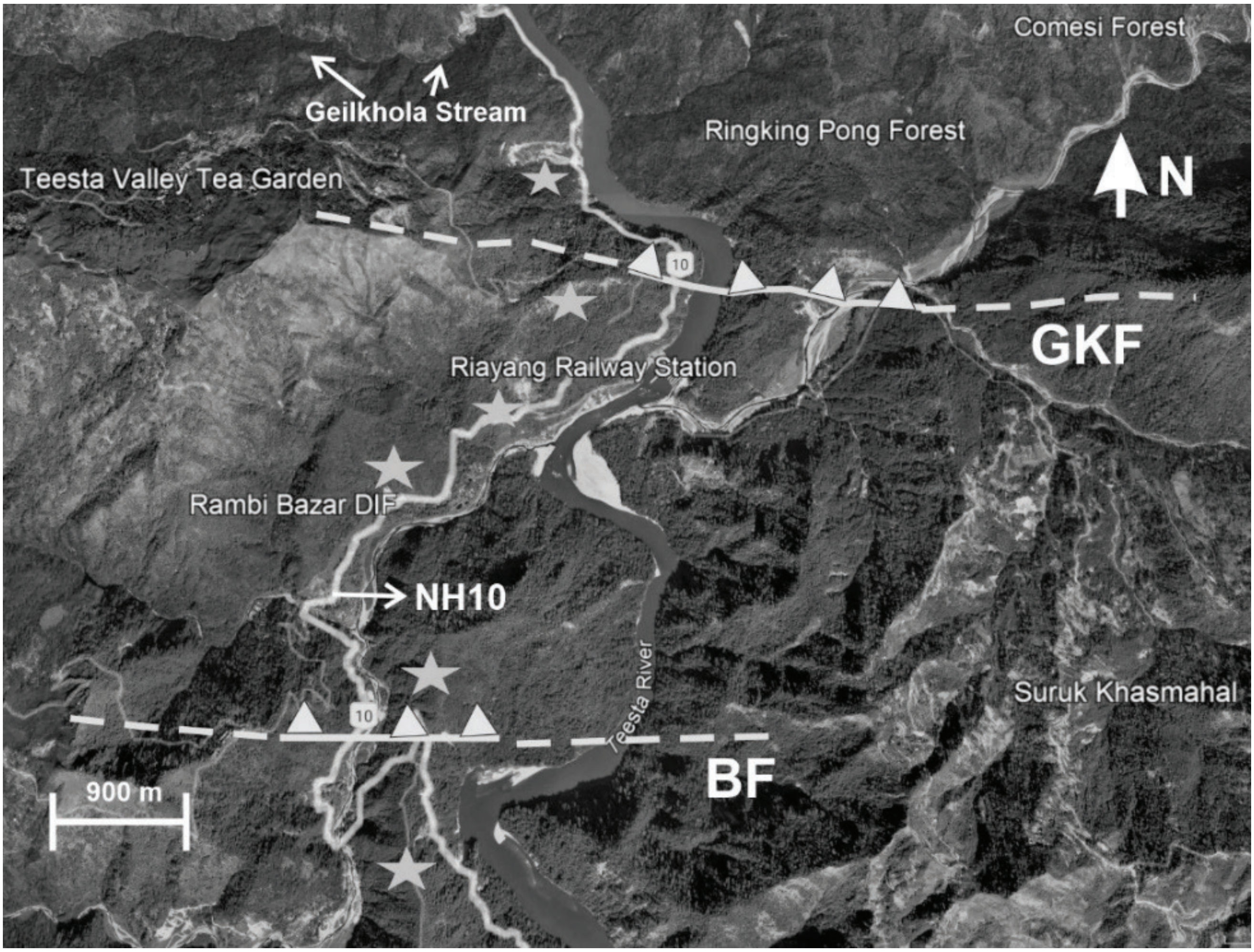


**Fig. 1: Google Earth image of the area near the intersection of National Highway 10 (NH 10) with the Geil-Khola (GKF) and Birik (BF) faults. NH 10 is shown as grey shaded line and landslides as stars.**

**Keywords:** Landslides, Brittle-Fault zone, Darjeeling Himalaya

# Larger benthic foraminiferal–Algal biodiversity in the eastern Tethys, Meghalaya, NE India and their paleobiogeographic significance

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The larger benthic foraminifera and coralline algae show a wide biotic diversity in the Paleocene-Eocene eastern Tethyan carbonates of Meghalaya, east India and have been used in the paleobiogeographic reconstructions. Global correlation and paleobiogeography of the eastern Meghalayan and western Tethyansea has been compared on the basis of SBZ of Paleocene- Eocene foraminifera assemblage. The similarities between NE India, NW Himalaya and Southern Tibet suggest that all these regions belonged to a single faunal province during Paleocene – Eocene period. Tethyan Himalaya persisted at the northernmost Indian plate, representing a passive continental margin until the end of the Paleocene. Paleozoic to Cretaceous marine sedimentary strata is widely exposed within the Tethyan Himalaya, whereas the Paleocene-Lower Eocene shallow-water limestones developed mainly in the southern Tethyan Himalaya and Shillong Plateau, Meghalaya. The paleobiogeographic reconstruction during Paleocene – Eocene times in the Western region shows its extension in the Eastern region.

The Late Paleocene – Middle Eocene Tethyan foraminiferal – algal carbonate biofacies are well developed after Late Cretaceous – Paleogene mass extinction event in the eastern Tethys, Meghalaya, east India. Tethyan Foraminiferal – algal biotic diversity is recorded from the Lakadong and Umlatodoh Limestones of the Sylhet Group well exposed in East Khasi and Jaintiahills, Shillong Plateau Meghalaya. These Tethyan benthic orthophragmine foraminiferal – algallimestones were deposited in the passive continental margin setting of a shallow marine carbonate shelf in eastern Tethys and Standard Benthic Zones (SBZ) of the Alpine-Adriatic western Tethys are recorded from Meghalaya. These sedimentary basins were developed after the separation and anti-clock wise northward movement of India from Australia and Antarctica in Late Cretaceous times. The Cretaceous – Tertiary boundary is well marked in these basins by biotic mass extinction. Late Cretaceous mega ammonoid fossils and Sauropod dinosaur bones are abundantly found in the Maastrichtian Mahadek Formation.

The global extinction event is also substantiated by Carbon, oxygen and Mercury isotope chemostratigraphy. The larger benthic orthophragmine foraminifera assemblage of Lakadong Limestone is compared with Alpine- Adriatic - Himalayan –MeghalayanTethyan and Tibetan zones. The algal assemblage of Lakadong Limestone include Sporolithon sp., Lithophyllum sp., Jania sp., Corallina sp., and Distichoplaxbiserialis. The overlying Umlatodoh Limestone is characterised by larger benthic foraminifera of Thanetian –Ilerdian age. Calcareous algae include species of Helimeda sp., Sporolithon sp., Ovulites sp. and Spongites sp., the index fossils of the Lakadong Limestone in Mawmluh Quarry section define the standard Paleogene biozones SBZ 3 and SBZ 5-6 respectively of Serra – Kiel et al. (1998). The biozones SBZ 3 and SBZ 4 present *Distichoplaxbiserialis* Dietrich, Miscellanea. The SBZ 5 and SBZ 6 contain Alveolin Hottinger, *Nummulites* sp. And Discocyclina sp. The biozones SBZ 5 SBZ 6 show *Ranikothalia nuttalli* Davies).The mixed association nummulitids/assilinid and shell fragments encrusted by corallinacean algae are also found.

# A new balanced cross-section for the Pakistan fold-thrust belt: implications for the stratigraphy and structural framework of the Pakistan Himalaya

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Fold-thrust belts are critical laboratories for understanding crustal shortening during collisional orogenesis. Over the past 20 years, our understanding of the Himalayan thrust belt has increased dramatically between the eastern and western syntaxes. However, the structural framework of the fold-thrust belt in Pakistan is not well-understood, particularly to the north of the Main Boundary thrust (MBT). The Potwar Plateau, south of the MBT, is characterized by broad, open folding and the presence of Neoproterozoic salt acting as a ductile décollement that controls the structural style of the plateau. Previous studies estimate shortening in the Potwar Plateau between the Main Frontal thrust and MBT of ~65 km (Baker et al., 1988; Jaswal et al., 1997; Ghani et al., 2018); additionally, a schematic minimum shortening estimate of the entire fold-thrust belt is 470 km (Coward & Butler, 1985). North of the MBT, determining the deformation style and unraveling the structural history of the rocks is complicated by multiple phases of metamorphism and deformation, and a lack of surface and subsurface data. This leads to uncertainties about the true stratigraphic thickness of many of the units that record multiple phases of deformation as well as those that are not exposed at the surface. As such, shortening estimates north of the MBT are not well-defined. We address these stratigraphic relationships, provide an alternative tectonostratigraphic classification, and illustrate the areas where data collection needs to be improved. Finally, we present a new balanced cross-section for the Pakistan Himalaya that illustrates the regional structural geometry and kinematic evolution, and provides a minimum shortening estimate across the entire fold-thrust belt, from the Main Frontal thrust to the Main Mantle thrust.

**Keywords**: Pakistan; cross-section; fold-thrust belt; Potwar Plateau; tectonostratigraphy

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# Duplex kinematics reduces both frontal advance and seismic moment deficit in the Himalaya

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Duplexing plays important roles in the evolution of fold-and-thrust belts and accretionary wedges, and causes internal shortening of the system, which then impacts both rates of frontal advance and seismic-moment deficit. Nevertheless, the significance of this internal shortening has not yet been highlighted in previous studies in the Himalaya or elsewhere. We invoke geometric solutions to constrain the ratio of transferred slip (R; i.e., the ratio of updip slip to downdip slip) for the midcrustal ramp–the most active ramp within the midcrustal duplex–in the Himalayan wedge. We find that R is ~0.9, and then used this ratio to calculate the accumulating seismic moment. The reduction in seismic-moment accumulation over the past 1000 yr along the entire Himalayan arc (~2200 km) is equivalent to at least one ~Mw 8.72 earthquake, and potentially reduces the seismic moment deficit by ~23%–54%, which may reconcile the long-term unbalanced seismic moment in the Himalaya.

**Keywords**: Duplexing, seismic moment, Himalaya

# The evolution of the Indus River drainage basin, and its influence on the Indus Fan sediment archive

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In order for deep sea sedimentary archives to be used effectively as records of hinterland evolution, the external influences on their contributing drainage basin need to be understood. The Indus Fan is the second largest sediment repository of the erosional products of Earth's largest orogen, the Himalayas. The fan is fed by the Indus River which drains the mountain belt, with a subordinate contribution from peninsular India. Changes in the sedimentary signature of the fan over time have been variously interpreted as resulting from tectonic, drainage and / or climatic changes affecting the source regions' drainage basin. A significant geochemical change near the Mio-Pliocene boundary has been previously ascribed to either a change in exhumation in the Indus River's catchment, or a major palaeo-drainage re-organisation in the lower Indus, whereby the Punjab tributaries previously draining into the Ganges and ultimately the Bengal Fan to the east, were diverted to drain into the Indus River to the west. We compared our new and published Sr-Nd, zircon U-Pb and mica Ar-Ar data from the Himalayan peripheral foreland basin with similar data from coeval sediments downstream of the Punjab tributary input and conclude that the lower Indus River drainage has maintained its current configuration since the Eocene-Oligocene boundary and developed with the evolving orogen. Comparison of our new foreland basin with modern river data indicates increased Lesser Himalayan material to the foreland basin occurred sometime between Late Miocene times and present day. This supports the view that the Punjab tributaries joined the Indus trunk river early in the history of the orogen, and that changes in exhumation in the hinterland, namely increased Lesser Himalayan +/- Karakorum input, resulted in the geochemical shift we see in the Indus Fan at 5-6 Ma.

**Keywords:** Indus River, geochemistry, exhumation, Himalaya

# Comparison between two bivariate methods of landslide susceptibility mapping at the junction of Jajarkot and Karnali Nappe, western Nepal

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Landslide susceptibility mapping helps researchers to understand spatial distribution of landslides within the region and can greatly be useful in reducing landslide hazards. This study aims to carry out two bivariate statistical approaches; frequency ratio (FR) and weight of evidence (WOE) to explore and predict the probability distribution of future landslides in the area of great risk: boundary between two nappes, a tectonically deformed zone. High resolution Google Earth images, field study and topographic maps were used to make database representing spatial distribution of pre-existing landslides. Database for landslide conditioning factors is prepared and exported with pixel size of 20 m × 20 m in GIS (ArcGIS, 10.4.1) environment. Weightage calculations using both techniques shows that lithology, slope, stream power index, aspect, road, thrust, distance to major folds are the most important conditioning factors in the mountainous study area. The susceptibility models prepared using the FR and the WOE methods were divided into five susceptibility zones; very low, low, moderate, high and very high susceptibility classes; which accounts for 16.22%, 22.77%, 29.16%, 21.06% and 10.79% of the total landslides for the WOE method and 3.57%, 12.31%, 28.29%, 31.54% and 24.29% of the total landslides for the FR method respectively. These classes cover 16.83%, 30.22%, 28.93%, 18.61%, 5.41% for FR technique and 45.35%, 29.31%, 16.59%, 7.17% and 1.60% of the total area for the WOE methods from very low to very high susceptible zones respectively. Results of the susceptibility modeling were validated by calculating landslide density and also graphically by preparing area under (AUC); AUC for the WOE is 0.7132 and that for the FR is 0.7503, translating to an overall success rate of 71.32 % and 75.03%, which validates with pre-existing slope instability site conditions. The outcome will be useful to authorities concerning landslide susceptibility and possible improvements for disaster management activities and designation of cautionary development program and environmental planning.

**Keywords**: Landslides, debris flows, susceptibility, frequency ratio, weight of evidence

# Orogenic collapse and stress adjustments revealed by an intense seismic swarm Following the 2015 Gorkha Earthquake in Nepal

**Lok Bijaya Adhikari[1,2]*, Laurent Bollinger[3], Jérôme Vergne[4], Sophie Lambotte[4], Kristel Chanard[2], Marine Laporte[3], Lily Li [5], Bharat P. Koirala[1], Mukunda Bhattarai[1], Chintan Timsina[1], Nabina Bishwokarma[1], Nicolas Wendling-Vazquez[3], Frédéric Girault[2], Frédéric Perrier[2]**

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The April 25, 2015 Mw 7.9 Gorkha earthquake in Nepal was characterized by a peak slip of several meters and persisting aftershocks. We report here that, in addition, a dense seismic swarm initiated abruptly in August 2017 at the western edge of the afterslip region, below the high Himalchuli-Manaslu range culminating at 8156 m, a region seismically inactive during the past 35 years. Over 6500 events were recorded by the Nepal National Seismological Network with local magnitude ranging between 1.8 and 3.7 until November 2017. This swarm was reactivated between April and July 2018, with about 10 times less events than in 2017, and in 2019 with only sporadic events. The relocation of swarm earthquakes using proximal temporary stations ascertains a shallow depth of hypocenters between the surface and 20 km depth in the High Himalayan Crystalline slab. This swarm reveals an intriguing localized interplay between orogenic collapse and stress adjustments, involving possibly CO2-rich fluid migration, more likely post-seismic slip and seasonal enhancements.

**Keywords:** Gorkha earthquake, aftershock, seismic swarm, seismicity and tectonics, relocation, Himalaya

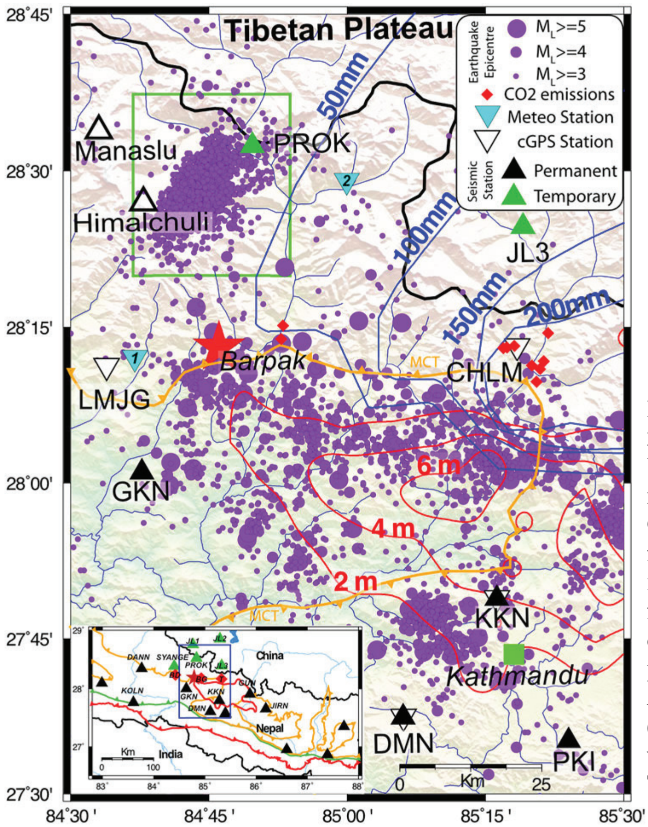


**Fig. 1: Seismicity after the Mw 7.8 Gorkha earthquake of April 25, 2015. Earthquakes with local magnitude ML ≥ 3.0 are recorded by the permanent NSC network (stations shown in inset) plotted in purple circles. Red star represents the Gorkha mainshock. Green triangles represent the temporary seismic stations installed following the activation of Himalchuli swarm. Light blue triangles represent the meteorological stations (numbers 1 and 2 respectively for Gharedhunga and Chhekampar). Red contours correspond to coseismic slip (Grandin et al., 2015). Blue contours correspond to post-seismic slip deduced from cGPS stations (Zhao et al., 2017). At a larger spatial scale, the inset presents the seismic stations (black triangle), and three $CO_2$ emission sites (red diamond), where BD, BG, and T stand for Bahundanda, Budhi Gandaki, and Trisuli sites, respectively.**

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ISSN 0259-1316

**Journal of Nepal Geological Society**
Registration No. 1/042/043
US Library of Congress Catalogue Card No.: N-E-81-91064

**Published by:** **Nepal Geological Society**
PO Box 231, Kathmandu, Nepal
Email: info@ngs.org.np
Website: https://www.ngs.org.np