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5.4.6 Development of Paleo-earthquake History in the western part of Central Seismic Gap along the Himalayan Frontal Thrust (HFT), Kumaun Himalaya: Multi-Dating approach

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Owing to the occurrence of large magnitude earthquakes for the last two centuries, recorded historically as well as instrumentally in the northwestern Himalaya (i.e., the segment of the Himalaya to the west of Nepal), a number of studies on active faults as well as paleoseismological investigations have been conducted over the last few decades (Jayangondaperumal et al., 2018 and references therein). The area extending from North-Central India to Western Nepal is referred to '*Central Seismic Gap*' (Khattri, 1987). This area seismically lies between the areas affected by 1905, Kangra, and 1934, Bihar-Nepal earthquakes. Due to the quiescence in earthquake occurrence, the area has been studied by several workers over the last decade, but the paleoearthquake scenario is not clear yet (e.g., Kumar et al. 2006; Jayangondaperumal et al. 2013; Rajendran et al. 2019). The present excavated trench at Chourgalia town, Uttrakhand, would provide the timing of paleoearthquake event(s). Primarily the age of paleoearthquake will be deduced based on radiocarbon dating of 20 charcoal fragments collected from the trench. A comparison of the concentration of cosmogenic radionuclides ^{10}Be and ^{26}Al from these pebbles collected from the hanging and footwall of the trench will help in matching both walls. This study will provide the multiple earthquake events as the multiple numbers of folding of the layer in trench hints at various fault events.

The collected 20 charcoal samples were firstly cleaned physically. Any contamination from the sediments or extra organic materials like roots was removed. The clean charcoal samples were chemically pre-treated using standard Acid-Base-Acid (ABA) pre-treatment (Sharma et al. 2019). Based on the quantity of available samples, the samples were divided into three groups as per their abundance. The first acid wash (0.5M HCl, 60° C) was carried out to remove carbonates. Batch 'A' weighing <3g was treated in 3ml 0.5M HCl for 10 minutes @ 60° C, batch 'B' weighing <5g was treated in 5ml 0.5M HCl for 15 minutes @ 60° C, and batch 'C' weighing >5mg was treated in 12ml 0.5M HCl for 2.5 hours @ 60° C. It was followed by neutralizing the samples with ultrapure water. After that, humic acid was removed by base wash (0.1N NaOH, 60° C). Batch 'A' and 'B' were treated for the same time as the previous, and the 'C' batch was treated for 2 hours. Again the samples were neutralized with ultrapure water. The second acid wash (0.5M HCl, 60° C) was carried out to remove absorbed atmospheric CO_2 during the base wash. Batch 'A' and 'B' were treated for the same time as previous, and the 'C' batch was treated for 1.5 hours. Again the samples were neutralized with ultrapure water. After that, the samples were freeze-dried in a vacuum for 6 hours. The dried samples were then packed in small tin boats and combusted in an Elemental Analyser (EA) to form CO_2. The Automated Graphitization Equipment (AGE) then reduces the CO_2 by reacting with H_2 in the presence of iron catalyst. Each sample was packed in tin boats weighing between 1.5mg to 2.0mg, producing ~1000 µg CO_2. The final processed samples are now in line to be dated in the AMS facility at IUAC. Furthermore, this study with be strengthened with the help of the cosmogenic nuclide dating method of ^{10}Be and ^{26}Al radionuclides that will be done in the subsequent months.

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5.4.7 Geomorphological and sedimentological evidences of palaeo-outburst flood events from TanglangLa- Gya catchment of River Indus, Ladakh, India

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The Gya river catchment in Ladakh is one of the susceptible areas with the problem of outburst flood events, due to potentially hazardous lakes in its headwaters, the most recent experienced in the year 2014. The chronology, genesis and spatiotemporal relationships of these scattered deposits can throw light to the regional and global climatic fluctuations and their implications for the evolution of the valley. This study is an attempt to understand the pattern of extreme events in one of the tributary valley of Indus *viz*. the Gya catchment by identifying the sedimentological expression of past extreme event and geomorphic implications of such event to valley morphology. Furthermore, the study would also try to ascertain the forcing factors associated with these extreme events. To achieve the above objectives, the conventional sedimentological and geomorphological criteria are used in conjunction with the ^{14}C Accelerator Mass Spectrometer dating from IUAC, New Delhi. The geomorphological, sedimentological and chronological study in this valley reveals multiple short-lived lake phases (damming) at 21–19.9 ka, 13 ka and 4.5 ka in the broader reach of the river during the transition periods when climate rapidly fluctuates between cold-dry and warm-wet. The damming in the valley is the result of the glacial lake outbursts in the headwaters of the Gya catchment blocking the narrow lower reaches of the main channel by massive sediment discharge. These dammed lakes contain ~10^8 m^3 of water which subsequently breach out causing significant geomorphic changes on reach scale along the Gya river channel. https://doi.org/10.1080/02723646.2021.2022339.

5.4.8 Climate variability since the Last Glacial Maxima from Khalsi palaeolake deposit in the cold arid mountain region of Ladakh: A multiproxy approach

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The Indus river valley hosts a number of archives attesting the climatic variations through time and provides one of the best laboratories to study past climate changes. Palaeolacustrine sediments are scattered along the entire river valley formed as a consequence of tectono-climatic disturbances. These palaeolake sequences record spatio-temporal climate variability and can be used to address palaeoclimatic changes of the region. The present study aims to establish palaeoclimate changes from the Ladakh region since Last Glacial Maxima (LGM). During the climate *warming interval* from the end of the *LGM* at approximately 19 ka, caused significant global changes with respect to mean sea level, glacial cover, terrestrial and marine ecosystem, atmosphere-ocean circulation. High resolution palaeoclimate reconstruction studies since this time period is completely absent from the Trans-Himalayan region of Ladakh that host numerous glaciers, thus the source of fresh water to life downstream and also forms the source for the development of early advanced civilization in the Indus valley. The present work is aimed to decipher the evolution of global climate since LGM. To achieve this objective multi proxy study (magnetic parameters, end member modeling for sediment grain size, stable isotope, LOI, TOC) will be conducted for the Khalsi palaeolake. This palaeolake deposit forms a part of major Saspol-Khalsi lake system [1]. The section is exposed along the Indus River located approximately 150 m above present river level at Khalsi village. Previous work [2] reveals that breaching of Lamayuru palaeolake during the deglaciation phase at ~ 19-20 ka generated huge amount of sediment that chocked the Indus River at a narrow gorge near Dumkar. Thus, the damming of the river led to the formation of the palaeolake. Further, with the rise in temperature and increased monsoonal activity, the lake level increased giving rise to the formation of the Saspol-Khalsi lake system. The chronology for the palaeolake sequence will be developed by ^{14}C Accelerator Mass Spectrometer (^{14}C-AMS) dating from IUAC, New Delhi.

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5.4.9 Chronology of the glacial lake deposits from the Ladakh Range, NW Trans Himalaya: Implications to palaeoclimate during the late Quaternary

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In order to establish the glacial lake chronologies in Ladakh range, climatic data coupled with [^{14}C AMS] (Accelerator Mass Spectrometry) dates provides a high-resolution climatic data of the Trans Himalayan region. These glacial lake deposits need attention as they hold in them an archive that has hinted for a record of a huge data bank on climatic episodes that have occurred in this region [1, 2]. A multi-proxy record provided with a reliable age constraint offer an important record of catchment and environmental changes. Therefore, a total of ten AMS dates were obtained from Inter University Accelerator Centre (IUAC), New Delhi using 500 kV Pelletron Accelerator. The measured results for all the samples were normalised to the standard sample OX II. AMS delta ^{13}C values were used for the isotopic fractionation correction and the background value during the measurement was (0.406±0.0129) pMC (Percentage modern carbon) that corresponds to $^{14}C/^{12}C$ ratio as (4.524± 0.1438) x 10^{-15}. Data quality was evenly monitored with secondary standard sample (IAEA-C7), with a measured value (pMC= 49.22 ± 0.17) close to its consensus value (pMC = 49.53±0.12) within the error was considered [3].

The results produced by upper deduced calibration techniques provided an age of 2115±27 to 4239 ±29, from the glacial lake of the Chang La pass region, which has few more dates, which brackets the section upto the last ~7020 cal yrs. While the glacial lake from the Hor La pass region ranges between 5744±25 to 9307 ±35, as such the linear regression of the calibrated age range provided and age constraint of ~11700 cal yrs. The age retrieved from Nyoma and Shey village, eastern Ladakh range provided an age constraint of 16178 ±52 and 21422 ±150, which can be traced upto the late Pleistocene. As such, very-high resolution climatic history of the Quaternary could be established, and that may serve as reference database for correlating major climatic events in the Ladakh region and elsewhere. Some well reported short lived damming caused by glacial lake outburst flood were reported from the Tanglang La Gya catchment using a chronology constraint to establish the global climatic fluctuations and their implications for the evolution of the Gya river valley [4]. Hence, similar such studies coupled with high resolution chronologies helps in delineating the climatic variability and address the queries about the climatic episodes that have occurred during the recent time scales. The manuscripts involving the described chronologies are under preparation and would be published soon to provide a reference for the climatic modelling and risk assessment of the Ladakh Himalayas.

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5.4.10 Late Quaternary Indian Summer Monsoon Records from Baspa Valley and Chakrata Region, Northwest Himalaya

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The Indian Summer Monsoon (ISM) records from Late Quaternary have been reconstructed based on the high-resolution environmental magnetism (EM), carbon isotope (δ^{13}C), and total organic carbon (TOC) data supported by radiocarbon dating. Chronology of the peat-sequence was carried out using ^{14}C Accelerator Mass Spectrometry (AMS) dating at the Inter-University Accelerator Centre, New Delhi. We selected six peat samples (top to bottom) for obtaining the chronology of the litho-section, and ages were calibrated by the online OxCal v4.42 program (Reimer et al., 2020), and post-bomb ^{14}C ages were calibrated by CALIBomb software using F^{14}C values with 95.4% accuracy (Reimer et al. 2004). The samples were pre-treated by the acid-base-acid (HCl-NaOH-HCl) standard method (Sharma et al., 2019).

Considering the sensitivity of the peat bog/lake sediments to climate change, we investigated a peat/lake deposit in Baspa valley and Chakrata from Northwest Himalaya, which is located close to the southern fringe of the Tibetan Plateau. The strategic location of the deposits would possibly provide an opportunity to understand the interplay between the two-weather system and their temporal changes as well as their causative mechanism. Therefore, the objective of the present study is to unravel the interplay between the ISM and westerlies as well as ascertain the processes responsible for the postglacial changes in these two weather systems.

The study from millennial to centennial-scale monsoon variability during the Late Quaternary using multi-proxy data from 100 cm thick peat deposit in the Baspa Valley, Northwest Himalaya (Khan et al., 2022, In Press). Four climatic phases of alternating strengthened and weakened ISM are identified for the last 20 kyr in the higher central Himalaya. Periods of strengthened ISM are dated to ~15 to ~14 ka, ~10 to ~7 ka, ~2.4 to ~1.3 ka, and 243 yr BP to Present, which is ascribed to the post-Older Dryas associated with an increase in solar insolation. The phases of weakened ISM are bracketed between ~20 to ~15 ka, ~14 to ~10 ka, ~7 to ~2.4 ka, and ~1300 to ~243 yr BP. These phases are attributed to global cooling events, i.e., the Last Glacial Maximum (LGM), Younger Dryas (YD), and the Middle to Late Holocene and governed by changes in the solar insolation (Khan et al., 2022, In Press).

Presently, we are working on the Holocene (last ~9.2 kyr) climatic records from the 146 cm sedimentary profile excavated from the Chakrata region. The four climatic phases of alternating strengthened and weekend ISM are identified for the last 9.2 ka and reconstructed using magnetism, carbon isotope, and total organic carbon multi-proxy analysis supported by five AMS ^{14}C dated samples. The multiple warming spells during Early to Late Holocene, i.e., Phase-2 (7.6 to 6.1 ka), Phase-4 (4.9 to 4.4 ka), Phase-6 (3.4 to 2.1 ka) and Phase-8 (1 ka to Present) exhibit strengthened in ISM. Phase-1 during 9.2 to 7.6 ka and Phase-5 from 4.4 to 3.4 ka indicated a decline in ISM hence correlated with the 8.2 ka ad 4.2 ka global cooling events. Also, Phase-7 from 2.1 to1 ka and Phase-3 from 6.1 to 4.9 ka demonstrates the reduction in the ISM precipitation which considered cold and dry climatic conditions. Phase-8 around 1 ka to Present indicated the strong southwest monsoon condition.

The present findings from Baspa Valley records have been revealed that wet and warm climate that indicates the Bølling-Allerød Interglacial period between ~15 to ~14 ka. The $\delta^{13}C$ increased with a decrease in TOC and EM during ~14 to ~10 ka, which shows a weakening in the ISM intensity. This decline in the ISM strength is associated with the YD cooling phase. The abrupt decrease in the ISM conditions between ~7 to ~2.4 ka correlates with the 4.2 ka global cooling event and that may cause diminish the Indus valley civilization. The I.S.M. was intensified during ~2.4 to ~1.3 ka, which associated with the Roman Warm Period (RWP). Similarly, an abrupt decrease in $\delta^{13}C$ values and increase in χlf values during 243 yr BP to Present exhibits the Current Warming Period resulted strengthening in the I.S.M. after the termination of LIA period. Whereas high-resolution EM, $\delta^{13}C$, and TOC data supported by radiocarbon dating from the Chakrata region indicated 8.2 and 4.2 ka cooling events as well as the RWP and Recent Warming. The study also reveals the cultural change in the Indus Valley Civilization, Valley vs. Monsoon front ISM variability, and Early to Middle Holocene cooling, which indicates a decrease in solar insolation.

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5.4.11 Investigating the rates and kinematics of bedrock lowering and soil production, spatially averaged catchment scale denudation rates and sediment redistribution within a small Himalayan River catchment

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Hillslopes are the prime units of soil and sediment production within a landscape [1]. It has been demonstrated by a number of workers that soil thickness varies spatially within a landscape [2][3][4][5][6][7] and that the rate of soil production is a function of this thickness [8]. This function itself varies spatially and is dependent on topographic parameters (slope, relief, curvature etc.) [9] and lithology [10].

In our study, we aim to answer the following questions:

1. Calculate the rates of soil production and lowering of the bedrock
2. Calculate spatially averaged catchment scale denudation rates
3. Map the redistribution of sediments within a catchment and identify potential zones of erosion and storage
4. Assess the weathering kinematics in the transformation of bedrock into soil

We selected Pranmati Basin in Uttarakhand to conduct this study. Pranmati Basin is a small river catchment in the Himalayas. The basin lies entirely within the Baijnath klippe and the bedrock lithology comprises of seicite schists, gneiss and quartzites [11].

For the first objective, we selected diffusive surfaces within the catchment. One of the surfaces had in-situ soil column overlying the bedrock while other surfaces were local topographic highs with no soil mantle. 2kg of bedrock from the top 1-3cm was chiselled and collected. A total of 6 samples were collected. The samples were ground and sieved to the desired range of particle size. The sample was put through magnetic separation and acid leaching to obtain pure quartz. The quartz was digested and column chromatography was performed to isolate Be and Al. The oxides of these metals were prepared and loaded in cathodes.

For the second objective, sand samples from the mouth of Pranmati basin and subcatchments of Pranmati basin were collected. In order to compare the denudation rates of these catchments with the catchments of tectonically dormant basins, we collected 2 samples from the catchments of Ken and Betwa in central india. A total of 8 samples were collected. The samples were sieved to the desired range of particle size. The sample was put through magnetic separation and acid leaching to obtain pure quartz. The quartz was digested and column chromatography was performed to isolate Be and Al. The oxides of these metals were prepared and loaded in cathodes.

For the third objective, we collected top soil sample from the top 1-3cm of surface. Samples were collected from various surfaces in the catchment over a range of land cover units and with varying surface gradients. A total of 28 samples were collected. The samples were dried, sieved and the fraction finer than 90 microns was taken. 1g of the sample was taken and leached to obtain the meteoric Be content along with the other adsorbed ions. Column chromatography was performed and Be was isolated. The oxide of Be was prepared and loaded in cathodes.

In order to assess the weathering kinematics, the mineralogy of the depth profile of the soil column needs to be looked at. For this purpose, soil was sampled along the depth profile in 4 trenches. A total of 17 samples were collected. To observe the transformation from the parent lithology, 7 bedrock samples were also collected. All 24 samples were ground to particle size finer than 90 microns. The samples were analysed in X-ray diffractometer to determine the mineralogy.

All samples for Be and Al have been prepared in IUAC. The samples are yet to be analysed in AMS. Analysis in the X-ray diffractometer has been completed. All results are awaited.

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5.4.12 Source apportionment of carbonaceous aerosols in Indo-Gangetic region Patna, Bihar using radiocarbon (^{14}C)

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Radiocarbon (^{14}C) is an important tracer that can be used to achieve source information on carbonaceous components in particulate matter [1, 2]. The concentration of ^{14}C has been applied to estimate the relative contributions of fossil and contemporary carbon in particulate matter. Fossil carbonaceous components are emitted from fossil fuel combustion and are generated by secondary formation reactions with fossil-derived volatile organic compounds (VOCs). Contemporary carbonaceous components originate from biomass burning, biological emissions such as pollen and fungal spores, and secondary formation reactions with biogenic volatile organic compounds (BVOCs). In this study, we determined the contribution of fossil and non-fossil carbon sources by measuring radiocarbon in Patna atmospheric aerosols using accelerator mass spectrometry (AMS) facility in Inter University Accelerator Centre (IUAC), New Delhi.

Based on ^{14}C results, it is obvious that the relative contribution of non-fossil carbon is significantly higher than fossil carbon in all samples. The non-fossil carbon fraction presents with an f_{NF} of 0.66, 0.62, 0.74, and 0.83 during month of August, September, October, and November respectively. The patter of f_{NF} estimated in this study is consistent with past studies reported in South Europe along the Mediterranean Sea, such as the Po Valley, Italy [2], and Barcelona, Spain [3] respectively. The high value of calculated non-fossil fraction (f_{NF}) indicate that the non-fossil component is more important in term of total carbon content of carbonaceous aerosol than the fossil component indicating towards the influence of stubble burning and biomass burning for domestic heating as the main source during September, October and November.

A significant contribution of fossil carbon was also quantified and was 34%, 38%, 26% and 17% for August, September, October and November months, respectively (Fig.1). Although the fossil carbons from industrial and vehicular sources are relatively higher in September than those in October and November, their absolute concentration is stable irrespective of sampling month. This is in fact true in case of urban area like Patna where intense activities are carried out throughout the year.

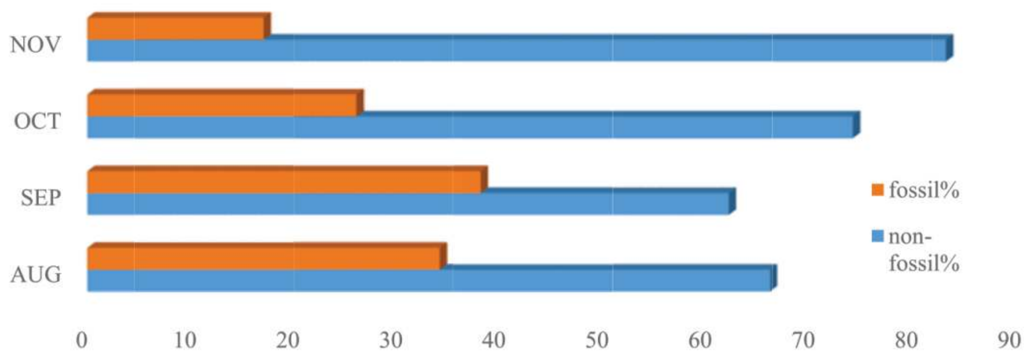

Fig.1 Emission level of fossil and non-fossil source of atmospheric aerosols in percentage

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