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5.4.13 Cosmogenic Radionuclide dating of glacial deposits of Thajiwas valley of Kashmir Himalaya

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In the present study, samples of boulders from the four moraine stage were analyzed for exposure age dating to estimate the past glacial advance and retreat episodes of Thajwas glacier of the great Himalaya range. The samples were collected during the field visit using the already prepared glacial geomorphic map of the Thajwas glacial valley (Dar et al.,2017). The samples collected from the field were pulverized using jaw crusher, Ball Mill and were preprocessed using Frantz isodynamic magnetic separator to extract the pure quartz for chemical analysis.

Sample preparation and processing:

Samples were crushed, sieved and homogenized by cone and quartering method. The diagonally opposite parts were mixed and the same method was followed for complete homogenization. Out of the homogenized sample 80-120 ASTM size fraction were separated for further processing. This fraction was cleaned by deionized water and dried. Sample was passed through Franz isodynamic separator at different current and slope to remove different mineral to extract pure quartz. Pure quartz was separated at a higher current (1.4 Amp) at a reverse slope of 5. Quartz grains were leached with 2% HF and 5% HNO_3 to remove the meteoric ^{10}Be contribution and also other inclusions. The leaching of the samples was carried out for 48 hours and repeated for three times. We examined the quartz grains under microscope for checking the purity. Approximately 0.5 g of quartz was digested for checking the elemental composition in extracted quartz. We checked Al, Na, K, Ti, Fe using the digested sample for purity checking. Other samples were considered for further leaching and physical abrasion. Then the samples were treated with concentrated HF and HNO_3 for complete digestion. Digested sample was made to 10 ml out of which 1 ml was kept for ^{9}Be measurement. Remaining part was spiked with approximately 0.1 g of 1071 ppm ^{9}Be spike. Digested samples were passed through anion and cation columns to extract Be isotope. We collected Be in 45 ml of 1.2 N calibrated HCl. Collected aliquot were dried followed by $NH_4(OH)$ treatment for converting the Be to $Be(OH)_2$ in centrifuge tube. $Be(OH)_2$ were carefully transferred to quartz vials. Samples were converted to BeO by a stepwise heating and finally at 900 °C for 8 hours. BeO was mixed with Nb Powder at a ratio 3:1 and loaded into the cathodes for AMS measurement. Using 500 kV XCAMS system ^{10}Be/^{9}Be ratios were measured at IUAC, New Delhi. ^{9}Be was measured using ICP-MS (Model: i-Cap-Q) at IUAC New Delhi.

Results

Geomorphological mapping when coupled with the dating technique can be used to reconstruct the style cum extent and timing of past glacial episodes. The geomorphological setup of the Thajwas glacial valley have preserved well distinguishable moraine ridges in the form of lateral and terminal moraines and thus provides smooth ground for exposure age dating. Four stages of the advances and retreat of the Thajwas glacier were reconstructed using ^{10}Be analysis along with the relative age dating technique. Both the absolute age ^{10}Be dating and Schmidt Hammer Exposure age relative dating shows very high correlation with each other. The stages correspond to Marine isotope stage-1, Younger Dryas, Early Holocene and Neoglaciation. The MIS-1 is the oldest and massive advance stage of the Thajwas glacier during which the glacier advances about 10 km down valley from the present day glacier snout. The Neoglaciation is the most recent advance of the glacier with the areal coverage of about 19.35 km^2 which is about 16.59 km^2 more than the present glacier area.

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5.4.14 Paleomonsoon study using multi-proxy data from marine and lake archives

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The Indian Summer Monsoon (ISM) is a complex atmospheric phenomenon that depends on insolation, ocean circulation and wind movements. In order to understand the variability and intensity of the ISM in the past, two sediment cores (SK291/GC17 and SK291/GC08) from the outer continental shelf of the eastern Arabian Sea, which were collected during the Sagar Kanya Cruise expedition of NCAOR, Goa in 2011, were chosen to study marine proxies. The marine proxies include relative abundance of benthic foraminifera and pteropods, and total organic carbon (TOC) content of the sediment. Moreover, lake sediment samples were collected from four lakes in northern India. A total of six cores of length 3.25 m, 48.5 cm, 60 cm, 70 cm and 1.84 m, respectively, were obtained from Tadag Taal, Tikkar Taal and Sherla lakes, located in the Almora and Panchkula districts of Uttarakhand and Haryana, respectively, using a piston corer. Similarly, samples were collected from two trenches of depth 1.14 m and 1.9 m in the Chandrika Taal lake near Lucknow, Uttar Pradesh. It is a seasonal lake located near the Gomti River in the Lucknow district of Uttar Pradesh.

In the case of marine sedimentary cores, planktic foraminifera specimens were picked and ultrasonicated (Majumder et al., 2022) before analysing for AMS dates following standard procedure (reported in Sharma et al, 2019) at Inter-University Accelerator Center (IUAC), New Delhi. On the other hand, the ages of the lake samples were determined by AMS radiocarbon dating at IUAC, New Delhi, and Optically Stimulated Luminescence (OSL) dating at Indian Institute of Science Education and Research (IISER), Kolkata. Prior to AMS radiocarbon dating, lake sediment samples had been finely crushed using mortar and pestle and sieved in order to remove the detrital materials and plant roots. Afterwards, sediment samples were pre-treated in the Graphitization laboratory of IUAC using Acid- Base- Acid treatment (Sharma et al, 2019).

Radiocarbon dates of marine sedimentary cores have provided an age-range of late Quaternary to late Holocene. During the early Holocene, the study area experienced relatively higher primary productivity due to intensified ISM, as compared to the Younger Dryas (YD) interval. The bottom water environment became more deoxygenated after the rise of sea level and onset of the middle Holocene, as the summer monsoon intensified and Oxygen Minimum Zone (OMZ) shoaled. The shoaling and intensification of the OMZ caused major change in the abundance of pteropods in the water column. Our data bears signatures of cold Bond events as well as the 8.2 ka event. Moreover, oceanographic changes in the study area were driven by solar influence aligned with North Atlantic climatic oscillations, as seen in the time series analysis of oxic group of benthic foraminifera and *Uvigerina peregrina*. The late Holocene phase is marked by a weak OMZ, coinciding with the 4.2 ka dry event (Majumder et al., 2022).

The radiocarbon ages and OSL dates of the lake sediments indicate that the Chandrika Taal Lake is primarily formed during the middle Holocene and prospered during the late Holocene. The presence of sand at the base of the Chandrika Taal lake at 6.6 calibrated kiloyear before present (cal kyr BP) indicate very high energy fluvial environment. The lake formation took place probably in an intense and arid environment during the 4.2 kyr event shown by the drop in the sand percentage and increase in finer grain size fraction. A few of the paleo-flood and paleo-drought layers have also been identified from this lake. In Tikkar Taal lake we have recorded several pulses of Little Ice Age (LIA).

Multi proxy study from Tadag Taal and Sherla Lake aims at understanding precipitation changes during the late Holocene encompassing the Dark Ages Cold Period (DACP), Medieval Climate Anomaly (MCA) and LIA. At present Tadag Taal is an open crescent shaped lake which receives water from a seasonal freshwater stream. On the other hand, Sherla lake is a closed lake which is fed by surface runoff when monsoonal precipitation happens. Grain size record from Tadag Taal indicates weak energy conditions and reduced precipitation from about ~540-1000 AD (DACP). During the MCA (~1000-1440 AD), high percentage of sand-size and coarse silt particles reflects a wet phase with multi annual dry events at ~1240-1280 AD and ~1380-1400 AD. Onset of the LIA (~1450-1800 AD) is marked by sudden decrease in sand-size fractions in the Tadag Taal lake. A more rigorous analysis is required to better reconstruct past geochemical and hydroclimatic scenario of the lake.

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5.4.15 Paleomonsoon study using multi-proxy data from marine and lake archives

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5.4.16 Radiocarbon dating using AMS of samples from Vaigai River Civilization Site

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The present work was carried out with active support from the IUAC facility at New Delhi. Sediment samples were collected in excavated pit dug in a paleochannel-natural levee-point bar complex wherein human habitation surfaces were presumed to be located. A total of 28 sediment samples together with bone remains, artifacts, pottery were collected from the site. Establishing chronological relationship between the sediment samples in stratigraphy and the artifacts collected is crucial in interpreting of ancient civilizational development, timing of habitation and stages of cultural advancements. In addition, accurate dating of the site and samples will advance our understanding on the paleoclimatic extremes that led to occurrence, shifting and abandonment of civilizational surfaces during Neolithic in the Vaigai Basin.

The samples were subjected to pretreatment in IUAC Graphitization laboratory. A total of 15 samples (charcoal, charred bone clast, bone, and organic carbon-rich sediment) were measured for total organic carbon using the standard methods, and 14 of them were considered for radiocarbon dating on the basis of available organic carbon contents. These have provided a chronological control partly over the excavated site and with which a manuscript entitled ***Episodic habitation and abandonment of Neolithic civilization sites in the Vaigai River Basin, Southern India*** has been published in Geosystems and Geoenvironment.

5.4.17 Comparison of luminescence and radiocarbon ages of trans-Himalayan palaeo-lake sediments (Ladakh)

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Lacustrine sediments from Trans-Himalaya face a specific problem that hinder the application of luminescence dating method on them to reconstruct the past climate. Luminescence ages from this region suffers from poor sensitivity of quartz to ionizing radiation (χ; cts.Gy^{-1}.mg^{-1}) and poor resetting of luminescence signal prior to the deposition (during transportation). Poor sensitivity of quartz does make this material undatable due to signal to noise ratio, and hence researchers use larger sample size aliquots (~ 1000 quartz grains as sub-sample in a disc) to overcome this issue. But a more number of grains in a sub-sample, would include a greater number of un-reset grains and, results in over-estimated luminescence ages. We compared these over-estimated luminescence ages to radiocarbon ages for the same samples which have already been published (Phartiyal et al, 2005 and Sangode at el., 2013). Our preliminary results have suggested that a reduction in aliquot size (~ few 10s of grains) may give correct luminescence ages that is comparable to radiocarbon ages. We wanted to confirm this observation by comparing luminescence ages measured using large aliquot and small aliquot with radiocarbon ages of same set of samples.

With that objective, we collected samples for luminescence dating and radiocarbon from the same strata from two palaeo-lakes in Ladakh region. We collected 9 samples from Spituk and 5 samples from Saspol palaeo-lakes. Reliably dated (by luminescence) 6 sediment samples and 2 known age foraminifer shells were used as control samples. We, recently, got the radiocarbon ages of all the samples except 4 due to low carbon content. Obtained radiocarbon ages are apparently older and stratigraphically inconsistent. However, we can work around the obtained ages and interpret them once the ongoing luminescence measurements are completed, and luminescence ages are finalized.

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5.4.18 Southwest monsoon response to Surface Hydrographic variations in western Arabian Sea through the last 172 kyr

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The carbon and oxygen isotopic ratio of planktonic foraminiferal records from Western Arabian Sea (WAS) sediments core shows significant hydrographic variation over the last ~172 kyr. Besides geochemical proxy, we have also used faunal assemblage of *Globigerina bulloides* from marine sediment core (VM3504-PC). The comparison between $\delta^{18}O$ records of studied core (VM3504-PC) to five $\delta^{18}O$ records from a different region of the Indian Ocean; namely those in South Western Indian Ocean (SWIO) (WIND 28K- 10°10'S, 51°46'E), Eastern Indian Ocean (EIO) (GeoB10038- 5°56'S, 103°15'E and SO139-74KL- 6°32'S, 103°50'E), Equatorial Indian Ocean (EIO) (SK157-04- 02°40'N, 78°00'E) and Bay of Bengal (BoB) (U1446- 19°5.01'N, 85°44.08'E). In all these cores, the $\delta^{18}O$ record of planktonic foraminifera shows marked similarities during the last ~172 kyr except mid-MIS 4 shows coherency except mid-MIS 4. The chronology of the core is established by using five radiocarbon ^{14}C dates and nine tie points between $\delta^{18}O_{G.ruber}$ and global stack LR04 (Lisiecki and Raymo, 2005). Four radiocarbon dates were obtained from the Accelerator Mass Spectrometry (AMS) from the Inter-University Accelerator Centre (IUAC), New Delhi, India. The error in radiocarbon age estimates ranges from ± 48 to ± 164 years. The $\delta^{18}O_{G.ruber}$ marked the glacial-interglacial variation. The significant variation in $\delta^{18}O_{G.ruber}$ mostly towards positive excursion which shows the cooler period during MIS 6, 4 & 2. In contrast, MIS 5, mid-MIS 4 (~65.6 - ~60.3 kyr), MIS 3 & MIS 1 marks negative excursion in $\delta^{18}O_{G.ruber}$ representing the warmer period. During MIS 5, $\delta^{18}O_{G.ruber}$ signatures suggested significant changes in the surface hydrography of the WAS due to Southwest monsoon (SWM) intensification. The $\delta^{18}O_{G.ruber}$ values ~ -0.74 (‰) at ~12.5 kyr, marking the MIS 2 shift towards the onset of MIS 1, attributed to intensified monsoonal precipitation. Simultaneously, *G. bulloides* is an important species of the faunal assemblages with minimum and maximum abundance ranges from 2 to 45 %, respectively. *G. bulloides* abundance usually associated with temperate to sub-polar water masses as well as upwelling region. It is most abundant in monsoon driven upwelling region which is related to cold, nutrient rich upwelled water in WAS and changes in their relative abundance has been commonly used to infer the past variation in SWM intensity and productivity. The relative abundance of *G. bulloides* is higher during warmer period (MIS 5 & MIS 3 & MIS 1) while lowest relative abundance of *G. bulloides* was during MIS 6. It is suggested that increased upwelling and high nutrient availability due to strong SWM during MIS 5, MIS 3 & MIS 1. Significantly reduced upwelling occurred during MIS 6 & 2, as evident from low relative abundance of *G. bulloides*. Based on $\delta^{18}O_{G.ruber}$ and *G. bulloides* relative abundance, the mid-MIS 4 are warmer due to SWM superimposed the Northeast monsoon (NEM). The mid- MIS 4 warming is not coherent with palaeoclimate record from the WAS.

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5.4.19 AMS dating of the Archaeological sites of Digaru – Kolong River Valley

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The present work was carried out as a part of Ph.D. work by Jitendra Kumar under the supervision of Prof. Sukanya Sharma of the Indian Institute of Technology Guwahati in collaboration with Inter University Accelerator Centre,