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Coupled Geochemical and Environmental Magnetic Constraints on Late Quaternary Indian Summer Monsoon Variability

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Understanding Indian Summer Monsoon (ISM) variability regulates continental weathering and sediment transport is critical for defining low-latitude climate–surface process feedbacks. We present a high-resolution ~25.3 ka multiproxy lacustrine record from Bakhira Lake, Central Ganga Plain, India, supported by AMS ^{14}C dates and a Bayesian age–depth model for high resolution climate reconstruction. Bulk sediment geochemistry (major, trace and rare earth elements), clay mineral assemblages, grain-size distributions and environmental magnetic parameters were integrated to reconstruct hydroclimatic variability and weathering intensity. Provenance indicators, including chondrite-normalized REE patterns with LREE enrichment and negative Eu anomalies, together with immobile trace-element ratios (Th/Sc, La/Th), indicate persistent derivation from felsic Higher Himalayan Crystalline sources. The systematic fluctuations in Chemical Index of Alteration (CIA), $\alpha^{Al}Na$, Rb/Sr, Th/U and smectite/(illite+chlorite) ratios document alternations between intensified silicate weathering and dominant physical erosion. Accordingly, the strengthened ISM phases (~18–16.8 ka, ~14.5–12.8 ka, ~9.2–4 ka, and last two millennia) representing 18 ka warming, Boiling Allerød and Holocene climate optimum, respectively, are marked by elevated weathering indices, enhanced smectite formation, finer magnetic grain sizes (higher χARM/SIRM, χfd%) and increased χlf and SIRM values, reflecting greater detrital flux and pedogenic enhancement under humid conditions. In contrast, weakened monsoon intervals (~25.3–18 ka, ~16.8–14.5 ka, ~12.8–9.2 ka, and ~4–2 ka) for the periods Last Glacial Maximum, Heinrich event 1, Younger Dryas and global drought, respectively show reduced chemical weathering, coarser magnetic assemblages and greater relative abundance of high-coercivity hematite (higher HIRM), consistent with cold–dry conditions and mechanically dominated erosion. The coherence between geochemical weathering proxies and magnetic mineral assemblages demonstrates strong coupling between ISM-driven hydrology, silicate weathering and sediment dynamics at millennial scales. This integrated dataset provides new avenues on monsoon weathering feedbacks in the Himalayan foreland basin during the Late Quaternary. Additionally, the comparison with regional terrestrial and marine records demonstrates coherent South Asian Monsoon variability driven by orbital-scale insolation changes and interhemispheric teleconnections.