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Monsoonal vs. glacial control on erosion and sediment storage in the Himalayan rain shadow, Zanskar River, northwest India

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Summer monsoon precipitation strongly controls erosion and sediment storage in the frontal Himalaya but the relationship between monsoonal variability and erosion is less well-constrained beyond the High Himalayan topographic divide in the rain shadow. Here we establish a Quaternary erosional history for a rain shadow tributary of the upper Indus River system, the Zanskar River, by applying several sediment provenance techniques to modern and dated terrace river sediments. We evaluate if there are temporal links between sediment storage and moisture supply to the rain shadow and if regions like the Zanskar River basin play a significant role in controlling total sediment flux to the Indus River.

We compile bulk sediment petrography and Sr and Nd isotope geochemistry, detrital U-Pb zircon and apatite fission track dating with *in-situ* ^{10}Be cosmogenic radionuclide techniques to identify patterns of erosion and sediment production across Zanskar. Bulk petrography, Sr and Nd isotope geochemistry, and U-Pb detrital zircon spectra of modern and older terrace sediments indicate high rates of erosion along the Greater Himalaya in the Zanskar River basin. We find that the wettest and most glaciated subcatchment dominates the bulk sediment provenance signal, with only moderate input from other tributaries, and that other basin parameters cannot explain our observations. Catchment-averaged *in-situ* ^{10}Be cosmogenic nuclide concentrations of modern sediments indicate erosion rates up to $\sim$1.2 mm y^{-1} but show strong dilution attributed to glacial sediment recycling into the modern river, suggesting rates nearer 0.4–0.6 mm•y^{-1}. These rates are consistent with longer-term rates of incision (0.3–0.7 mm•y^{-1}) calculated from detrital apatite fission track ages, and incision rates inferred from Late Glacial and Holocene terraces near the Zanskar-Indus confluence. Our findings suggest that sediment production in glaciated Himalayan rain shadow environments like Zanskar is largely controlled by internal glacial fluctuations coupled with periodic dissection and reworking of terrace material during strong monsoonal precipitation phases.