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Timing and climatic drivers for glaciation across semi-arid western Himalayan-Tibetan orogen

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Analysis of cosmogenic radionuclide ages usually involves quantitatively describing the clustering of ages on a particular surface (i.e. moraine, landslide, etc). Statistical methods vary by study and commonly include reduced chi-squared or mean square weighted deviates, probability density functions (PDFs), 2σ tests, etc. We separate Gaussians from the cumulative PDFs using the "ksdensity" kernal in MATLAB 2011a in a model that runs 1000 iterations to obtain the best fit. Typically, there is more than one Gaussian to choose from after analysis due to post-depositional alteration of glacial landforms. Denudation and inheritance have been shown to have significant affect on the clustering of ages on old and young moraines, respectively. Thus, we adapt separate interpretation schemes for old (>gLGM) and young moraines ($\leq$gLGM) to address these issues. We apply these age analysis methods to a new set of 10Be ages and reanalyze cosmogenic ages on a regional scale to better understand the timing of glaciation in the Northwest Himalaya.

Mapping and forty-seven 10Be ages help define the timing of glaciation in the Ladakh and Pangong Ranges in Northwest India. Five new local glacial stages are defined in the Ladakh Range. From oldest to youngest these include: the Ladakh-4 glacial stage at 81$\pm$20 ka; the Ladakh-3 glacial stage (not dated); the Ladakh-2 glacial stage at 22$\pm$3 ka; the Ladakh-1 glacial stage (not dated); and the Ladakh Cirque glacial stage at 1.8$\pm$0.4 ka. Three local glacial stages are defined in the Pangong Range, which include: the Pangong-2 glacial stage at 85$\pm$15 ka; the Pangong-1 glacial stage at 40$\pm$3 ka; and the Pangong Cirque glacial stage at 0.4$\pm$0.3 ka.

The new 10Be ages are combined with 494 recalculated 10Be ages from previous studies to develop the first regional framework of glaciation across the dryland regions of the Greater Himalaya, Transhimalaya and Pamir. Sixteen regional glacial stages are recognized, which we call Northwest Himalayan Stages (NHTS). These include: NHTS 9 at 316$\pm$38 ka; NHTS 7 at 234$\pm$44 ka [tentative]; NHTS 6 at 146+17/-15 ka; NHTS 5E at 124 +7/-9 ka; NHTS 5A at 80+7/-4 ka; NHTS 5A- at 73+4/-7 ka; NHTS 4 at 61+5/-10 ka; NHTS 3 at 46$\pm$5 ka; NHTS 2E at 30$\pm$3 ka; NHTS 2D at 21$\pm$3 ka; NHTS 2C at 16.8$\pm$0.4 ka; NHTS 2B at 13.9$\pm$0.9 ka; NHTS 2A at 12.2$\pm$0.9 ka; NHTS 1C at 3.7$\pm$0.6 ka; NHTS 1B at 1.6$\pm$0.3 ka; and NHTS 1A at 0.4$\pm$0.1 ka. Regional glacial stages older than 21 ka are broadly correlated with strong monsoons and Heinrich events. NHTS 2D (21 ka) and younger, have smaller uncertainties and are broadly correlate with global ice volume given by marine oxygen isotope stages, and northern hemisphere climatic events (Oldest Dryas and HeinrichEvent 1, Older Dryas, Younger Dryas, Roman Humid Period, and Little Ice Age).