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Boulder cosmogenic exposure ages as constraints for glacial chronologies

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Cosmogenic exposure dating greatly enhances our ability to define glacial chronologies spanning several global cold periods, and glacial boulder exposure ages are now routinely used to constrain deglaciation ages. However, calculating an exposure age from a measured cosmogenic nuclide concentration involves assumptions about the geological history of the sample that are difficult to test and yet have a profound effect on the inferred age. Two principal geological factors yield erroneous inferred ages: pre-depositional exposure (yielding exposure ages that are too old) and post-depositional shielding (yielding exposure ages that are too young). To evaluate the importance of these two problems we have compiled datasets of glacial boulder ^{10}Be exposure ages from the Tibetan Plateau (1099 boulders), the Northern Hemisphere palaeo-ice sheets (613 boulders), and present-day glaciers (141 boulders). All exposure ages have been recalculated with the CRONUS online calculator version 2.2 (http://hess.ess.washington.edu/) using the new ^{10}Be half-life of 1.36 Ma. All boulders from present-day glaciers have exposure ages $<$3.5 ka indicating that none of these boulders experienced significant pre-depositional exposure. The palaeo-ice sheet boulders in the dataset were deposited during the last deglaciation c. 25-8 ka. By subtracting independently-derived, primarily radiocarbon-based, deglaciation ages we have quantified the inheritance of cosmogenic nuclides from pre-depositional exposure. Only 4% of the boulders from glacially modified landscapes (n = 385; dated to constrain the glacial chronology) have exposure ages $>$10 ka older than the deglacial age of the surface. Boulders from the Tibetan Plateau have mainly been collected from moraine ridges. We have organized them into boulder groups, each of which has one deglacial age. The age spread of the Tibetan Plateau boulder group dataset is significantly higher than the inheritance observed in the palaeo-ice sheet boulders. If this spread is attributed to inheritance we would conclude that on the Tibetan Plateau inheritance plays a much more prominent role than is seen in the palaeo-ice sheet areas. Alternatively, a simple exponential post-glacial landform degradation model produces exposure age distributions remarkably similar to the measured data, indicating that post-depositional shielding is likely the dominant process producing spread among boulder age distributions. Our analysis lends strong support to the argument that post-depositional shielding is the most important geological process leading to potential errors in cosmogenic exposure ages for glacial boulders older than a few thousand years. The strong recommendation emerging from this analysis of global ^{10}Be exposure ages is to interpret sets of dates from glacial settings in terms of post-depositional shielding: i.e., that exposure ages represent minimum ages of deglaciation.