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Cosmogenic exposure dating and the pristine boulder fallacy(?)

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Cosmogenic exposure dating of moraine boulders is a powerful method for learning about changes in glacier and ice sheet extents over time, but a commonly applied criterion for selecting samples in the field may yield incorrect results. In cosmogenic exposure dating, samples are collected from boulders resting on the crests of moraines. Under ideal conditions, the concentrations of rare nuclides in these samples will be proportional to the ages of the moraines, after correcting for nuclear decay. However, the estimated ages will be too young if the sampled boulders were originally covered by sediment, or if the boulders have lost material from their surfaces over time.

Field workers often choose boulders with smooth, pristine surfaces to avoid problems with boulder erosion. Here, we argue that this sampling criterion is misleading. Exposure dates from pristine boulders may underestimate the ages of moraines by thousands of years in some cases.

We have developed a model of nuclide production in eroding boulders on a degrading moraine, following prior examples from the literature. The model assumes that 1) moraine profiles evolve diffusively over time, 2) boulders do not erode while buried, and 3) boulders erode at a constant rate once exposed. The model is able to reproduce the statistical distributions of cosmogenic exposure dates from selected moraines. Thus, the model likely captures the first-order effects of geomorphic processes on exposure dating of moraines. The model does not apply where moraines do not lose material from their crests over time, or where there are significant concentrations of inherited nuclides in moraine boulders.

In the model, the least eroded boulders have been exhumed most recently, and therefore yield the youngest exposure dates. This result arises because till erodes much more rapidly than boulders in the model; thus, moraines lose several meters of till from their crests over a few tens of ka, whereas continuously exposed boulders lose only a few centimeters of rock from their surfaces over the same time period. However, the model confirms that tall boulders are more likely to yield exposure dates that are close to the true age of the moraine, as suggested by many previous workers. We therefore recommend sampling tall boulders, instead of pristine boulders. Where tall boulders are not available, boulders should be chosen randomly.

These results are preliminary. If detailed investigation confirms these results, paleoclimate interpretations and ice sheet model calibrations made on the basis of exposure dating of moraines will need to be reevaluated.