Boulder cosmogenic exposure ages as constraints for glacial chronologies

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Introduction

Cosmogenic exposure dating greatly enhances our ability to define glacial chronologies. However, two principal geological factors yield erroneous inferred ages (Fig. 1):

1. **Prior exposure (inheritance)** yields exposure ages that are too old
2. **Post-glacial shielding** yields exposure ages that are too young

Here we evaluate these two options with the aim of helping interpretation strategies for datasets with wide exposure age disparity.

Methodology

We have compiled three extensive boulder ^{10}Be exposure age datasets (Fig. 2) for meta analysis:

- Tibetan Plateau (1123 boulders)
- Northern Hemisphere palaeo-ice sheets (615 boulders)
- Recent glaciers (186 boulders)

All exposure ages have been re-calculated using the CRONUS online calculator (Balco et al. 2008) version 2.2, reconciling measurements performed using various ^{10}Be standards (Nishiizumi et al. 2007). The exposure ages presented here are derived from the CRONUS Lm production rate scaling scheme.

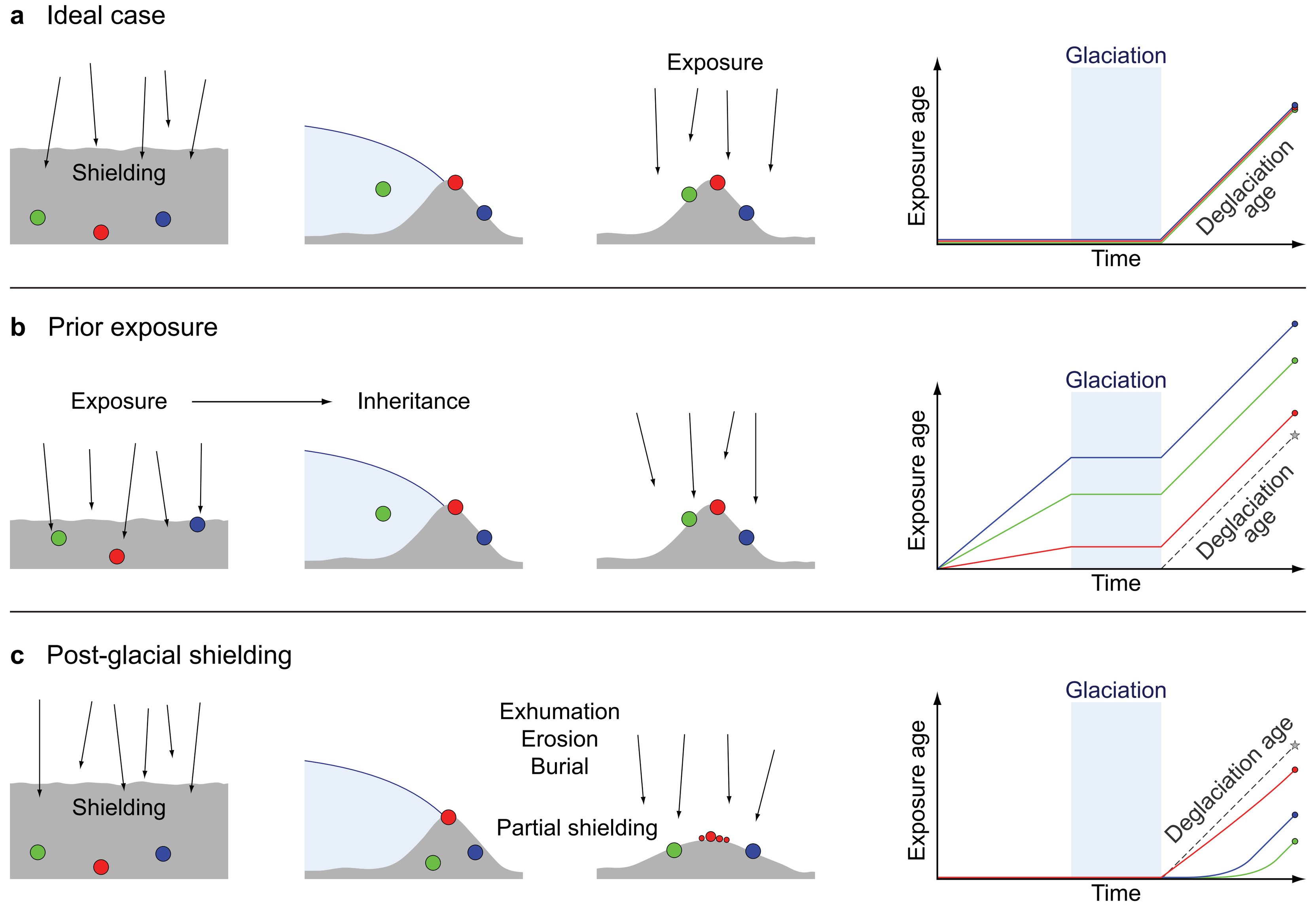

Fig. 1. Principle of prior exposure and post-glacial shielding and resulting apparent exposure ages. (a) In the ideal case the sample is completely shielded prior to glaciation and continuously exposed following deglaciation. (b) Prior exposure yields exposure ages exceeding the deglaciation age. (c) Post-glacial shielding yields exposure ages younger than the deglaciation age.

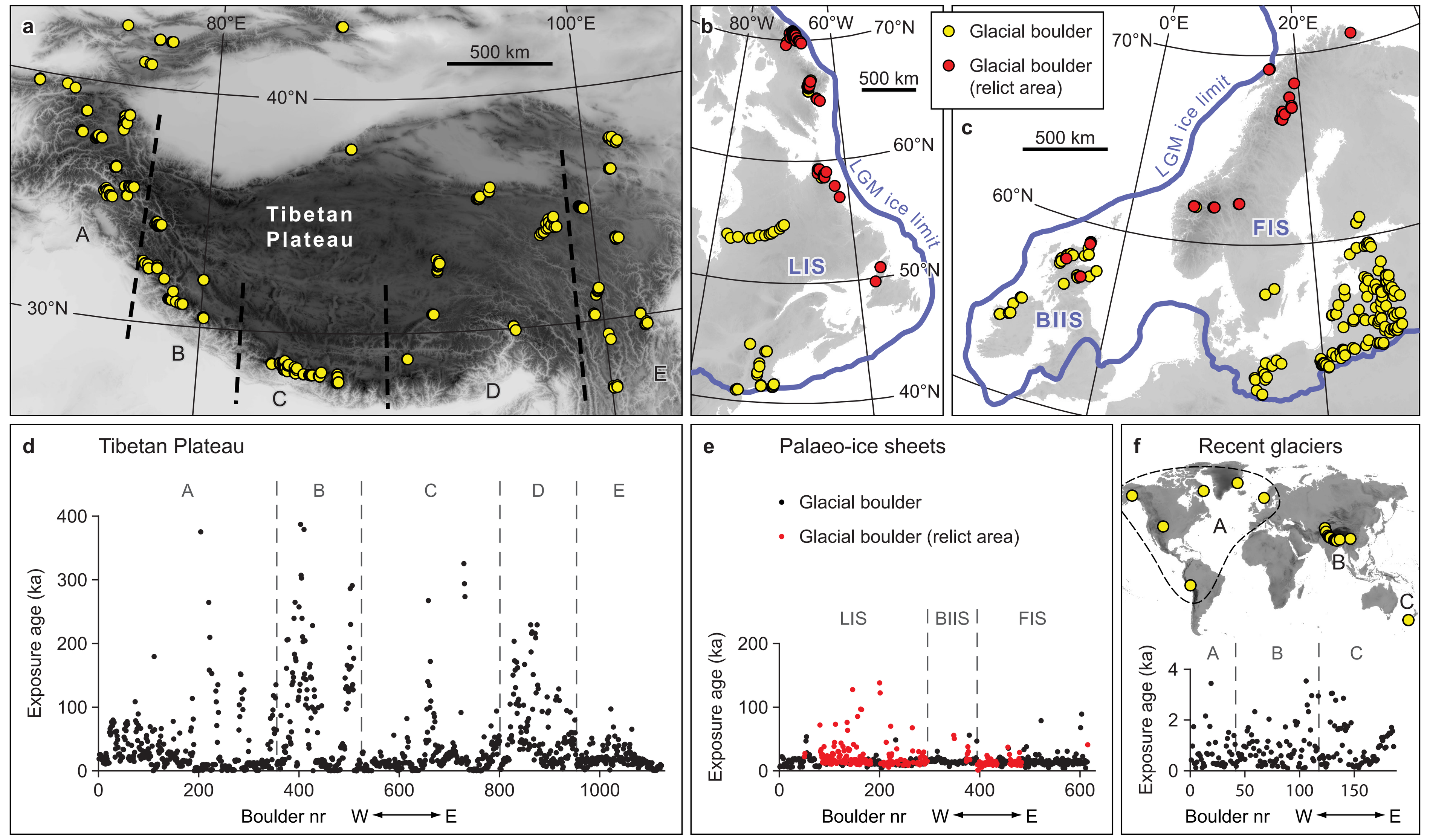

Fig. 2. Distribution and apparent exposure ages of the glacial boulder exposure age datasets from the Tibetan Plateau (a,d), the northern Hemisphere palaeo-ice sheets (b,c,e), and recent glaciers (f).

Inheritance evaluation

All boulders from recent glaciers have exposure ages <4 ka (Fig. 2f) indicating that none of these boulders experienced significant prior exposure.

For the palaeo-ice sheet exposure ages we have quantified the geological uncertainty by subtracting independent deglaciation reconstruction ages (Fig. 3) based primarily on ^{14}C ages (Dyke et al. 2003; Gyllencreutz et al. 2007; Kleman et al. 2008). The palaeo-ice sheet dataset was split into boulders from relict areas preserved under non-erosive ice and boulders from glacially modified landscapes (based on geomorphology). Only 4% of the boulders from glacially modified landscapes have exposure ages >10 ka older than the deglacial age of the surface indicating limited prior exposure.

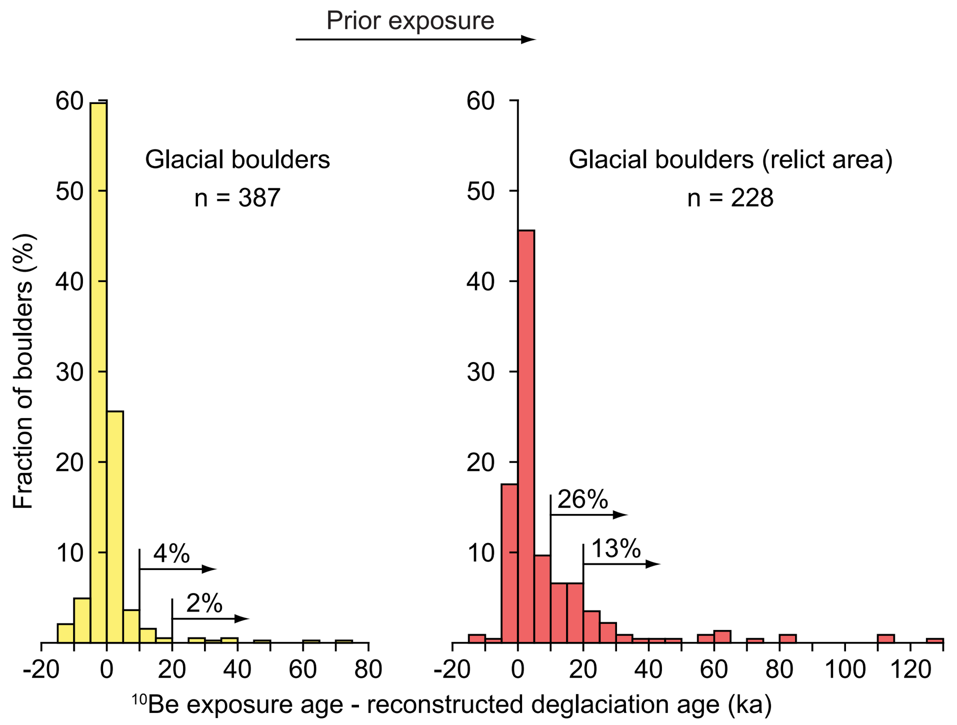

Fig. 3. Quantification of geological uncertainty for the palaeo-ice sheet dataset (Fig. 2b,c,e). Most of the boulders, in particular from non-relict areas, have exposure ages fairly close to the corresponding reconstructed deglaciation age.

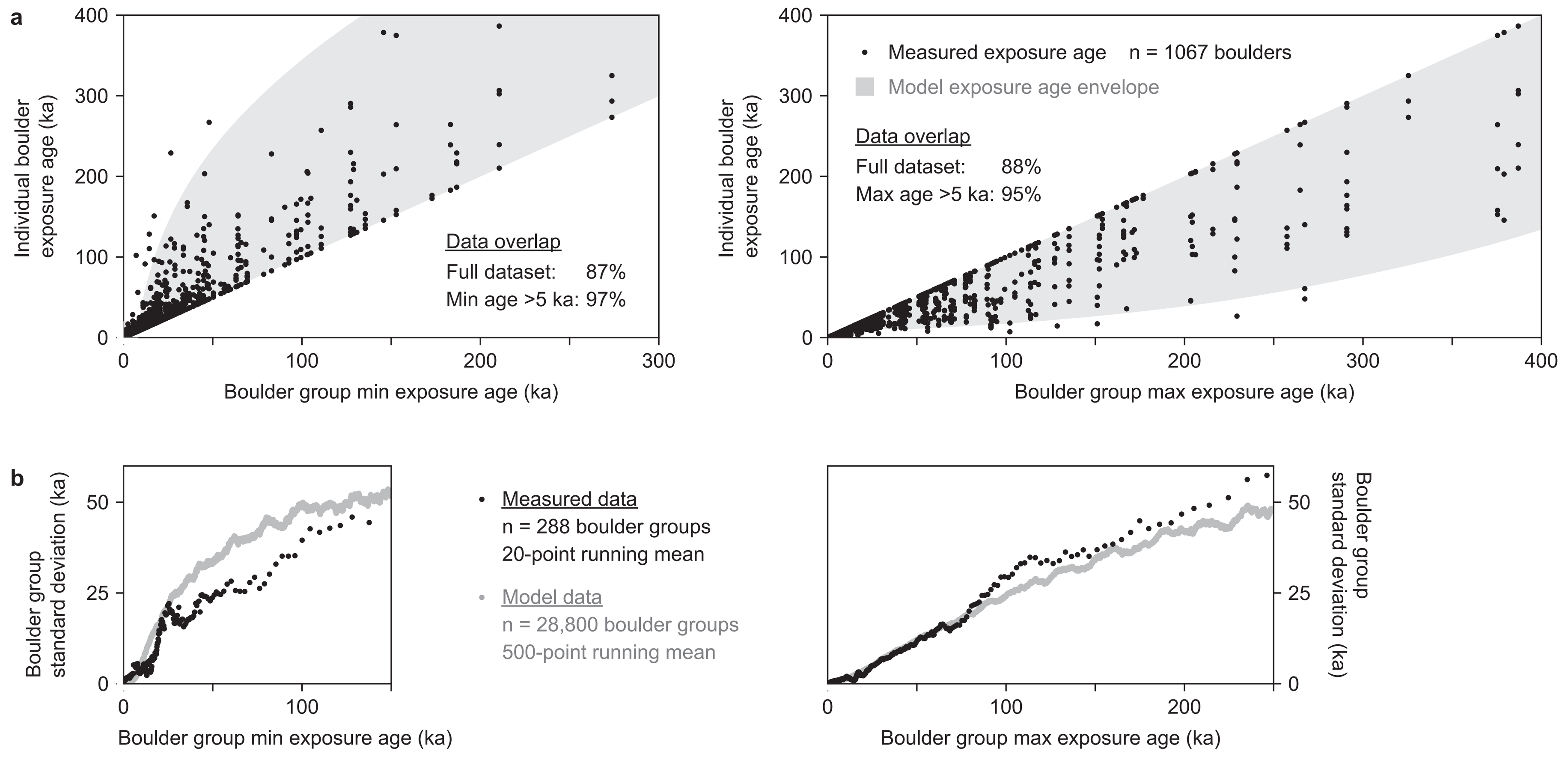

Fig. 4. Measured and simulated Tibetan Plateau exposure age data from multiple-boulder groups (≥2 boulders per group). (a) Individual boulder exposure age data. (b) Boulder group exposure age spread. Increasing age spread with group minimum and maximum exposure age indicate an increasing uncertainty with deglaciation age.

Shielding evaluation

The Tibetan Plateau boulders were organized in groups representing discrete glacial deposits (mostly single moraines). To simulate post-glacial shielding we used a simple surface degradation Monte Carlo model with one time-dependent exponential boulder exhumation rate for all boulders. The degradation model captures the main characteristics of the measured data remarkably well (Fig. 4) indicating that post-glacial shielding is an important factor for the apparent exposure age.

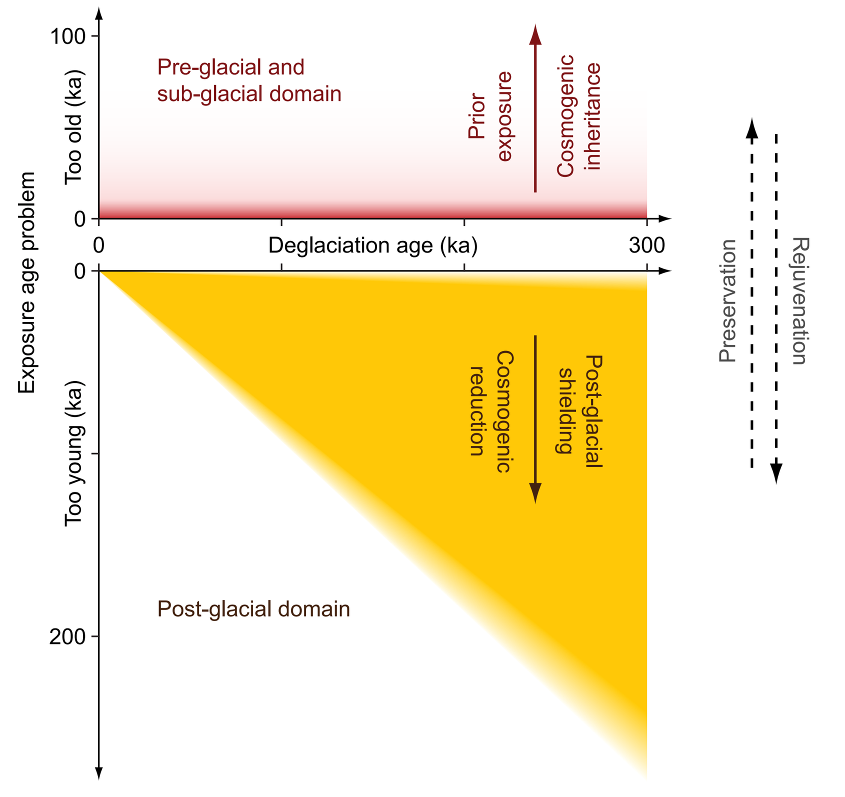

Fig. 5. Cosmogenic exposure age duality related to deglaciation age.

Summary

- **Quantification of cosmogenic inheritance** indicate limited importance of prior exposure.
- **Boulder exhumation simulation** indicate that post-glacial shielding is an important factor. The relative importance of post-glacial shielding increases with deglaciation age (Fig. 5).
- **Glacial boulder exposure ages should, in the absence of other evidence, be viewed as minimum limiting deglaciation ages.**

References

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