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Conceptual proof, current application, and lab procedures to quantify crustal thickness variations with muon paleotopometry

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Measuring the topographic relief evolution over hundreds of thousands to million-year timescales remains challenging. Current approaches use a mix of basin stratigraphy, numerical modelling of terrestrial cosmogenic nuclide (TCN) exposure ages on strath terraces, and exhumation histories based on thermochronology or drainage basin evolution. Yet, even a combined mix of these methods is incapable of quantifying the rate changes with precisions needed to differentiate climate from tectonic drivers over multiple glacial cycles and longer timescales.

The recently conceived muon-paleotopometry (MPT) approach is tailored to close the methodological gap of determining relief generation. MPT exploits the dependence of cosmic ray muon flux on crustal shielding depth. The spatial concentration pattern of multiple muon-induced TCN measured along a near-horizontal transect under valleys and peaks relates directly to the history of changes (positive or negative) in crustal thickness. MPT allows paleotopometry measurements above the sample datum over an isotope-specific monitoring duration. By sampling at depths of hectametres, long-lived TCN (e.g., ^{10}Be, ^{26}Al) are not sensitive to minor short-term (<10^5-yr) changes owing to cut and fill terraces or transgressions. For instance, the horizontal samples will have similar muon production histories. At this depth, only fast muon interactions and radiogenic or nucleogenic pathways are likely, and only high-energy cosmic ray particles can penetrate, dodging variations in geomagnetic and solar effects and simplifying the interpretation of concentrations along the transect.

We provide an overview of this new method, starting with the theoretical concept, the encouraging proof-of-concept results by Dalhousie (M. Soukup, Hon. Thesis, 2017), the laboratory needs for measuring low TCN concentrations at great depths (>150 m) and update on the progress for the current large-scale relief investigation of the European Alps.