Windows on erosion rates under polythermal ice in Fennoscandia via computational experiments with paired CNs

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Abstract

Cosmogenic nuclide (CN) abundances at Earth's surface reflect the balance of accumulation during intervals of cosmic-ray exposure and loss via erosion or radioactive decay. Yet for landscapes periodically covered by Quaternary ice masses this equation readily becomes complicated. Exploitation of CN inventories produced during exposure intervals prior to the last glaciation (viz, inheritance) has led to progress in understanding polythermal ice masses at high-latitudes. CN abundances on bedrock surfaces are a valuable clue to the spatial patterns and rates of subglacial erosion, and hence the history of subglacial thermal regimes. Bedrock surfaces with an exposure age that matches the timing of deglaciation are interpreted as having experienced >2-3 m of subglacial erosion. This implies the existence of warm-based ice with the capacity to remove all prior CN inheritance. Conversely, significant CN inheritance indicates minimal subglacial erosion and implies the development of frozen-bed patches beneath the ice sheet. Comparison of 310 'apparent ^{10}Be exposure ages' to a recently published deglaciation chronology of Fennoscandia reveals that 58 % of sampled bedrock surfaces contain appreciable (>2σ) CN inheritance.

With the aim of extracting deeper landscape history information from inherited CN inventories, we devised a Markov Chain Monte Carlo (MCMC) inverse approach that matches present-day CN (^{10}Be and ^{26}Al) abundances with the most probable permutation of exposure history and erosion rates over multiple glacial and interglacial periods. Shifts in ice cover over successive glacial cycles are simulated via a free parameter threshold applied to a benthic δ^{18}O record. The MCMC model yields two key outputs integrated over the last one million years: mean denudation rate and total exposure time. In addition, we propose a new quantitative measure of surface exposure and erosion termed the '^{10}Be-memory', defined as the time after which 95% of the present-day ^{10}Be atoms were produced. The ^{10}Be-memory is effectively year zero for landscape histories recorded by ^{10}Be. We apply the MCMC model to a subset (n=26) of Fennoscandian data for which ^{10}Be-^{26}Al paired measurements are available for five bedrock landform types: tors, mountain blockfields, ice-carved valleys, ice-carved lowlands, and fluvial channels.

Mean denudation rates (±1σ) on lowland tors (4.3±1.3 m/Myr, n=6) and mountain blockfields (5.8±2.8 m/Myr, n=5) are tightly clustered and overlap at 1-sigma. Erosion of ice-carved valleys, on the other hand, varies widely: one subgroup (5.9±3.4 m/Myr, n=4) is eroding equally slowly as tors and blockfields, and another includes more recently eroded troughs (20±7 m/Myr, n=5) plus one outlier (~105 m/Myr). Erosion rates on ice-carved lowlands fall roughly midway between the two subgroups of valley troughs (11.4±4.0, n=4), plus an outlier (~62 m/Myr) that matches the fluvial channel site (~68 m/Myr). The 10Be-memory predates the last deglaciation at all sites and reaches back nearly 3 million years for some tors, blockfields, and ice-carved landforms. Total exposure times are the least well constrained of the model outputs (262–424 kyr, Q1–3, n=26) and suggest that about one-third of the last one million years was ice-free in Fennoscandia.

Despite their clearly disparate origins, lowland tors, mountain blockfields, and several ice-carved valleys in our dataset have remarkably similar histories of exposure and erosion over the last one million years. This leads us to speculate that the erosion dynamics at these sites differed markedly prior to the Mid-Pleistocene transition. The MCMC inverse approach is a useful tool for extracting landscape histories from the inherited CNs that are ubiquitous in Fennoscandia. We reflect on the opportunities offered by this new tool and discuss implications of our findings for the interpretation of bedrock landscapes at high-latitudes.