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Modelling long-term landscape evolution by subglacial quarrying

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Glacial landscape-evolution models are useful tools when studying the mechanisms and long-term effects of glacial erosion. However, the difficulty of implementing the small-scale physics of abrasion and quarrying in large-scale landscape models has necessitated use of semi-empirical erosion laws, where sliding speed or total ice flux are the main parameters scaling the rate of erosion. Factors such as bed slope, effective pressure, and pre-existing fracture-density are known to also be of importance, however, especially for the mechanics of quarrying (Iverson, 2012).

The objective of our study was to improve links between large-scale landscape models and the physics of subglacial quarrying. We used the quarrying model presented by Iverson (2012) to calculate the average efficiency of quarrying across many topographic steps. The computations were repeated for one million combinations of bed slope, effective pressure, and basal sliding speed. We then performed a power-law fit to the many resulting erosion rates in order to quantify the overall influence of the regional parameters (effective pressure, bed slope, and sliding rate). Based on these results we suggest a quarrying rule where, in addition to the strong influence of bedrock fracture-density, erosion rate scales with sliding speed to a power of 1, with bed slope to a power of 2, and with effective pressure to a power of 3.

The high sensitivity to effective pressure implies a strong influence of meltwater hydrology on subglacial landscape evolution. To study this influence we implemented the new quarrying rule in a higher-order ice-sheet model coupled to a cavity-channel model for glacial hydrology. Computational experiments using steady-state hydrology predict that a well-drained glacier focuses quarrying in the upper parts of the glaciated catchment where water flux is small and slopes are steep, and in areas where ice is thick and the effective pressure high.

Decreasing the hydraulic conductivity of cavities and channels allows water pressure to build up and results in lower effective pressures and thereby smaller erosion rates, in spite of faster sliding. However, this simple picture is highly sensitive to melt supply variability, and quarrying rates increase markedly when water input is affected by seasonal and daily variations. Quarrying is then most effective in autumn when melt production starts to decay, but the drainage system is still adapted to the higher water flux of the summer. Our computational experiments hence suggest that quarrying is enhanced by glacial systems where water flux is highly variable throughout the year.

Iverson, N. R. A theory of glacial quarrying for landscape evolution models. Geology, v. 40, no. 8, 679-682 (2012).