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Bedrock erosion by ice – how efficient is it really?

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The erosive capacity of glaciers is an inductively reasoned conclusion based on observational evidence of characteristic glacial landforms such as U-shaped valleys and over-deepened fjords. While theoretical models have provided valuable information on the potential mechanisms of glacial erosion, they cannot, as yet, prove their predictions because boundary conditions are not well enough known. Testing the models by direct field observations is difficult, and rates of glacial erosion have as yet not been directly measured. Nonetheless, the view that glaciers are very erosive is generally accepted within the earth sciences.

Quantification of average glacial erosion rates has been made possible with the advent of reliable measurements of in situ cosmogenic nuclide concentrations in glacially abraded bedrock surfaces. For glaciers to remove inherited cosmogenic nuclides, accumulated in bedrock as a result of exposure to cosmic rays during an earlier ice-free period, requires roughly 2 metres of erosion.

Measurement of cosmogenic nuclide concentrations in bedrock surfaces of formerly glaciated areas has shown that glacial erosion is spatially restricted at ice sheet and valley scales. In East Antarctica, striated bedrock surfaces yield nuclide concentrations in excess of what would be expected if the overriding ice had eroded sufficient bedrock. Similarly, apparent cosmogenic surface exposure ages of bedrock at the centre of the Scandinavian ice sheet are often well in excess of the deglaciation age expected if the ice had been erosive. This is not only manifested on interfluves, away from areas of former ice discharge, but also locally in major trunk valleys. Low bedrock weathering and erosion rates in regions formerly occupied by ice sheets are probably due to frozen bed conditions at the base of ice sheets.

Results from transects across U-shaped valleys in mid-latitude mountains indicate that glacial bedrock erosion in excess of 2 metres is confined to the valley base and decreases significantly up the valley sides. Hence glacial bedrock erosion deepens but does not necessarily widen valleys. Low bedrock erosion rates along U-shaped valley sides of temperate alpine glaciers may reflect optimisation of the valley form during earlier glaciations.

The broad implication of these cosmogenic nuclide measurements is that contrary to popular opinion, glaciological processes, at least during the last glacial cycle, have not generally been efficient agents of bedrock weathering and erosion. The low glacial erosion rates discussed here are derived from tectonically stable areas, including those occupied by the last great ice sheets, and do not support the idea that glacial erosion has the potential to influence climate by accelerating silicate weathering and hence the sequestration of atmospheric CO2. To explore if there is such a causative relationship between glacial erosion and climate change requires quantification of glacial erosion rates in tectonically active but spatially much more restricted glaciated regions.