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Figure 1 | A glacier at Mount Robson Provincial Park, British Columbia, Canada. An analysis by Schildgen and colleagues[3] confirms that the rate of mountain erosion by glaciers has increased during the past few million years in certain places (such as in British Columbia) in response to climate cooling, but casts doubt on the idea that this was a global effect.

EARTH SCIENCE

Global erosion by glaciers revisited

Mountain erosion is thought to have sped up globally over the past few million years as the climate cooled and glaciers grew. A reassessment of the data suggests that this acceleration was limited to just a few regions. SEE LETTER P.89

ERIC KIRBY

A long-standing question in Earth sciences has been whether the climatic cooling that has occurred over the past 4 million to 6 million years — and the consequent growth of glaciers in temperate mountain ranges — accelerated the global rate at which Earth's surface has eroded. The answer has important implications for our understanding of the interplay between climate, landscape topography and plate tectonics[1]. In a 2013 paper in *Nature*, Herman *et al.*[2] evaluated the thermal histories of thousands of rocks sampled from dozens of mountain ranges, and concluded that rapid cooling of these samples heralded an acceleration in erosion driven by mountain glaciers. On page 89, Schildgen and colleagues[3] report that the apparent changes in erosion rates over time calculated in that study were largely the result of data being combined from samples that had separate erosion histories and that took different times to reach Earth's surface.

Mountainous landscapes are the manifestation of the competition between forces that arise from the collision of tectonic plates, which thicken the crust and build high-altitude topographical features, and the destructive action of erosion by wind, water and ice, which transforms bedrock into sediment and transports rock detritus into sedimentary and ocean basins. The rate at which erosion occurs globally is a key factor in the climate system over geological timescales. Volcanic activity supplies the atmosphere with carbon dioxide, but the chemical weathering of silicate minerals consumes CO_2; the balance between these two processes affects atmospheric CO_2 levels, which in turn regulate temperatures over millions of years[4]. If the supply of silicates at the surface grows, an increase in weathering might effectively scrub the atmosphere of CO_2, leading to a decrease in global temperatures[5].

Earth's climate began to cool about 15 million years ago[6], a trend that intensified approximately 6 million years ago and led to the expansion of both continental ice sheets and mountain glaciers. Apparent increases in the global accumulation of sediment in oceanic and continental basins during the same period[7–9] has often been cited as evidence that sediment production, sediment transport and the erosive action of glaciers became more effective as the climate cooled.

However, stratigraphic records also reveal episodes when no sedimentary deposition occurred. These hiatuses impart a statistical bias that causes sediment accumulation rates to seem greater when calculated from measurements taken at shorter time intervals[10]. Indeed, geochemical studies suggest that the delivery of continent-derived sediment to the global ocean has essentially remained constant over the past approximately 10 million years[11].

This statistical pitfall can be overcome by directly assessing the thermal history of rocks. Rocks in the crust cool as overlying material is removed by erosion at the surface (a process referred to as exhumation), because they are brought nearer to the surface. Several minerals in bedrock contain trace amounts of radioactive isotopes, whose decay generates daughter products. The ability of minerals to retain these products in their crystal lattices depends on temperature, and so the amount of a daughter product that has accumulated in a mineral can be used to work out the time passed since the mineral was at a specific temperature (the blocking temperature). This forms the basis of a technique known as thermochronology. By analysing mineral systems that have different retentivities, the rate at which rock cooled can be estimated.

Herman and colleagues took this idea a step further by developing a method that works out the temperature and exhumation histories that best fit thermochronologic data obtained for multiple rock samples collected within close proximity. This approach assumes that nearby samples have similar exhumation histories, and thus that any differences in thermochronologic age between mineral systems with different blocking temperatures are explained by the systems having different cooling rates over time. For the past five years, this work has stood as the most compelling evidence that the cooling of global climates drove synchronous increases in erosion rate as a direct consequence of the growth of mountain glaciers.

Schildgen *et al.* now demonstrate that the assumption that nearby samples have similar exhumation histories is often not appropriate. In nearly all of the regions that were thought to exhibit an increased exhumation rate over time[2], samples that have been recently exhumed are juxtaposed with older samples at geological boundaries. In the Western Alps, for instance, an abrupt difference in thermochronometer age for samples collected across a fault system reflects the different erosional histories for rocks on either side of the fault. Yet when these data are combined using Herman and colleagues' data-analysis method, the age difference is transformed into an apparent increase in average erosion rate through time for the entire region. Perhaps even more convincingly, Schildgen and colleagues used artificial data sets constructed to represent known geological scenarios to demonstrate that spurious results can occur when data are combined from samples subjected to erosion that was constant in time, but non-uniform in space.

The authors evaluated the other 29 examples of apparent accelerated erosion presented by Herman *et al.*, and found that nearly three-quarters could have resulted from the combination of data from samples that have different erosion histories. They argue that a few of the remaining cases reflect changes in tectonic boundary conditions (changes in fault activity). Only three of the original study sites seem to have experienced climatically driven acceleration in cooling, and each of these was associated with the formation of deep valleys by glaciers (Fig. 1). This re-evaluation suggests that, although glaciers can be an effective agent of landscape erosion, the thermochronology methods used by Herman *et al.* don't have the resolution required to assess whether global increases in glacial erosion occurred during the past few million years.

The finding that some sites do seem to reflect enhanced erosion by glacial ice, however, suggests that the story is not yet complete. As the precision and sensitivity to lower temperatures (shallower depths in Earth's crust) of thermochronology continue to improve, the method might be able to constrain estimates of changes in erosion over relatively short timescales[12]. Similar improvements in the precision with which the age of coarse sediments derived from glacial erosion can be determined[13] might also help to resolve questions of how rapidly such deposits accumulated.

Schildgen and colleagues' analysis reminds us that deformation of Earth's rigid outer shell matters: it deforms in a brittle way, breaking along geological faults that, in turn, produce boundaries between regions that have different rates of uplift. The resulting mountain ranges are subject to localized differences in exhumation. The authors' findings also teach us a broader lesson: as we use increasingly sophisticated analyses of 'big data' to gain insight into global trends in geology, we must not lose sight of the physical processes that operate locally. Incorporating site-specific geological constraints into analyses of global data sets will be essential in future studies.

Knowledge of how Earth responded to past climate change continues to be relevant to our future. Schildgen and colleagues' work removes one of the remaining pillars that supported the hypothesis that cooling climates were responsible for a global acceleration in erosion. The idea that erosion rates over the past few million years might have been less sensitive to cooling than was thought challenges us to re-examine our long-held notions of how erosion and climate systems interact. ■

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1. Raymo, M. E. & Ruddiman, W. F. *Nature* **359**, 117–122 (1992).
2. Herman, F. *et al. Nature* **504**, 423–426 (2013).
3. Schildgen, T. F., van der Beek, P. A., Sinclair, H. D. & Thiede, R. C. *Nature* **559**, 89–93 (2018).
4. Berner, R. A., Lasaga, A. C. & Garrels, R. M. *Am. J. Sci.* **283**, 641–683 (1983).
5. Raymo, M. E., Ruddiman, W. F. & Froelich, P. N. *Geology* **16**, 649–653 (1988).
6. Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K. *Science* **292**, 686–693 (2001).
7. Hay, W. W., Sloan, J. L. II & Wold, C. N. *J. Geophys. Res.* **93**, 14933–14940 (1988).
8. Peizhen, Z., Molnar, P. & Downs, W. R. *Nature* **410**, 891–897 (2001).
9. Willett, S. D. *Annu. Rev. Earth Planet. Sci.* **38**, 411–437 (2010).
10. Schumer, R. & Jerolmack, D. J. *J. Geophys. Res. Earth Surf.* **114**, F00A06 (2009).
11. Willenbring, J. K. & von Blanckenburg, F. *Nature* **465**, 211–214 (2010).
12. King, G. E., Herman, F. & Guralnik, B. *Science* **353**, 800–804 (2016).
13. Balco, G. & Shuster, D. L. *Earth Planet. Sci. Lett.* **286**, 570–575 (2009).

CELL BIOLOGY

Actin proteins assemble to protect the genome

The assembly of polymerized actin with motor proteins at DNA breaks in the nucleus supports the mobility and repair of DNA. This finding reveals a layer of regulation that helps to preserve genome integrity. SEE ARTICLES P.54 & P.61

VASSILIS ROUKOS

The protein actin polymerizes to produce filaments that form crosslinked networks in the cytoplasm of cells. These networks support many fundamental biological processes — such as cell movement and division and the intracellular trafficking of molecules. Reports that actin also has functions in the cell nucleus remain controversial[1,2], partly because of the challenges of performing experiments that exclusively perturb the nuclear actin pool without also perturbing actin in the cytoplasm. Two studies[3,4] in this issue now provide the most compelling evidence so far that polymerized actin has roles in cell nuclei in which DNA has been damaged, and that it could be essential for maintaining genome stability.

In cell nuclei, DNA is packaged with