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Late-Cainozoic climate change, erosion, and relief of mountain belts: 20 years of chickens and eggs (Ralph Alger Bagnold Medal Lecture)

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Over the last two decades, the geoscience community has realized that surface erosion, considered for over a century to respond passively to tectonic forcing, in fact strongly interacts with tectonic processes to produce the variety of deformation styles and relief forms observed in nature. Multiple feedbacks between tectonics, climate and erosion have been identified. In particular, it has been proposed that Cainozoic uplift of mountain belts such as the Himalaya led to global cooling due to CO_2 drawdown from the atmosphere by efficient silicate weathering and organic carbon burial. At the same time, however, late-Cainozoic climate change, characterized by overall cooling and increased climatic variability, has been suggested to be responsible for increased erosion rates as well as uplift of mountain peaks through the isostatic response to erosion. Some active mountain belts have even been argued to respond to late-Cainozoic climate change by tectonic reorganisation. Thus, the relative strengths of the tectonic and climatic controls on mountain-belt relief and erosion rates, and how to discriminate between these, have arisen as central questions in tectonic geomorphology since the start of this century.

Pliocene-Pleistocene (post-5 Ma) increases in sediment flux have been reported from many major mountain belts such as the Himalaya and the European Alps. It has been suggested this is a global signal in response to increased climatic instability since the Pliocene, although recent work suggests that at least part of the signal may be intrinsic to the nature of the sedimentary record. Analysis of in-situ thermochronology data from the Alps appeared to support the Pliocene increase in erosion rates, which have been linked to increased precipitation subsequent to the Messinian Salinity Crisis and/or the onset of Gulf-Stream circulation. However, recent more detailed work, based on numerical inverse modelling and the use of new high-resolution thermochronometers, suggests locally decreasing erosion rates during that time, while detrital thermochronology from the basins surrounding the Alps suggests little change in erosion rates on the orogen scale. Thus, the imprint of Pliocene climatic variations on mountain-belt erosion and tectonic development may have been overstated and the sediment-flux data that suggested a strong link may require re-examination.

In contrast, the new data imply a significant increase in relief through focussed valley incision since mid-Pleistocene times ($\sim$1 Ma), which can be related to efficient but highly localised glacial erosion, due to extensive glaciation of the Alps triggered by the mid-Pleistocene climate transition. The isostatic response to a significant increase in Alpine relief due to glacial valley carving may explain part of the surprisingly high geodetic uplift rates measured in the western Alps and may also contribute to the current extensional deformation regime observed within the core of the mountain belt. Thus, it appears that this recent climatic change had a significant impact on mountain belts by enabling more focussed and efficient glacial erosion of topography. Confirmation of this hypothesis awaits more detailed analyses of the recent erosion, relief and tectonic history of glaciated mountain belts worldwide.