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Late Cenozoic Exhumation of the Alps

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The latest phases of exhumation of the Alps are complicated by the onset of glaciation and the consequent glacial erosion over the last 1 to 2 million years. We attempt to unravel the glacial component of erosion by calculating erosion rates using three independent techniques that estimate erosion rates over different timescales. Each technique is based on independent observations. First, we use a compilation of low-temperature thermochronometric data and a thermal-exhumation model to estimate exhumation rates over the last 30 million years. Using formal inversion methods we estimate the resolving capabilities of these data and our model and demonstrate that exhumation rates can be resolved for time intervals of 1 to 2 Ma , at least for the parts of the Alps with good data coverage. This provides a good estimate of the absolute rates of exhumation for the pre-glacial Alps. Second, we use cosmogenic isotope concentrations in modern sediments to calibrate a morphometric proxy for post-glacial erosion rates. The proxy is based on establishing channel head locations and drainage density obtained from high-resolution DEMs. Third, by assuming that glacial erosion results primarily in valley deepening with little erosion of mountain peaks, we can reconstruct pre-glacial topography by maintaining the drainage network, but forcing the channel concavity to have a constant value consistent with fluvial processes. This analysis is complicated by differential channel steepness induced by spatial variations in rock uplift and rock erodibility, but we have established an inverse method to resolve this spatial variability. We cannot, however, decompose rock uplift and erodibility, so obtain only an estimate of their ratio. This analysis does provide an estimate of glacial erosion, integrated over the last 1 to 2 Ma as well as the spatial distribution of the rock uplift, erodibility ratio.

Combining these 3 methods allows us to interpret the various components of erosion. We find that the valley deepening by glacial incision removes mass that produces an isostatic response that explains the pattern, but not the magnitude of the geodetic uplift data. All three methods show similar spatial patterns of erosion with higher rates in the Western Alps, the crystalline massifs of the Central Alps and isolated areas around the lower alpine Rhine. Using the exhumation rates from methods one and two, we can estimate rock erodibility from method three, and this correlates well with general geology. However, the thermochronometry-based estimate shows an acceleration of exhumation in the western Alps over the last two Ma that appears not to be the response to glaciation.