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Age uncertainties, topography, exhumation pathway, and the interpretation of erosion rates and exhumation kinematics from thermochronometer age-elevation data

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Two- and three-dimensional thermal modeling studies suggest that 1D interpretations of erosion rates from thermochronometer age-elevation profiles can be compromised by topography, erosion, and non-vertical exhumation pathways. However, relatively few studies have evaluated the magnitude of error introduced by using a simple, 1D model. We addressed this question using 3D thermal models to predict cooling ages at the surface for a variety of steady-state erosion rates and exhumation geometries. Free parameters in the model include exhumation rate and pathway and sample profile orientation. The models assume surface topography based on the central Nepalese Himalaya, but the results are generally applicable to other active orogenic landscapes.

We find that profiles oriented orthogonal to the long-wavelength topography and orogenic transport direction are relatively insensitive to topography and exhumation pathway, and that simple 1D interpretations of age-elevation data (i.e., the average erosion rate equals the slope of a linear fit to a plot of sample elevation vs. cooling age) provide reasonable rate estimates if samples are collected along steep hillslopes. For profiles oriented parallel to the transport direction, horizontal transport during exhumation partly counteracts the tendency of age-elevation gradients to overestimate erosion rates due to topographic effects. Because closure isotherms for low-temperature thermochronometers (e.g., apatite (U-Th)/He) are more strongly influenced by topography than are those of many higher-temperature thermochronometers, the error introduced by the 1D assumption is greater for erosion rate calculations made using low-temperature data. The magnitude of this error is greatest when the exhumation kinematics are dominated by vertical movement, but in the Himalaya, as in other convergent orogenic systems, this is rarely the case.

Although 1D erosion rate estimates can be unreliable when samples are collected along gentle slopes and transects oriented parallel to the orogenic transport direction, much of the error introduced by the 1D assumption is within the noise of the errors associated with the linear regression analysis of age-elevation data - if those errors are formally propagated. To address this issue, we determined the probability that the true erosion rate will be recovered as a function of sample uncertainties of different magnitudes. We find that the magnitude of error in 1D erosion rate estimates varies dramatically as a function of sample uncertainty, particularly when erosion is rapid. The nature of this variation can be used to design sampling strategies for which 1D interpretations of age-elevation gradients are likely to provide accurate estimates of the true erosion rate. If sample uncertainties can be reduced, studies that combine thermal modeling with age-elevation data for samples collected in a range of profile orientations will have the potential to provide important constraints on thermal and kinematic fields at depth.