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Coupling of Tectonics and Climate as Seen Through the Topographic History of Orogens

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Stable isotope paleoaltimetry as a tool to recovering elevation histories of (eroded) mountain ranges has gained significant momentum over the past decade mainly because the topographic history of high elevation regions is otherwise largely elusive from the geologic record. Paleoelevation estimates based on oxygen or hydrogen isotopes in precipitation commonly envisage adiabatic cooling of air parcels and associated condensation and systematic isotopic fractionation during uplift. It is obvious, however, that single-site records of oxygen and/or hydrogen isotopes in precipitation can be affected by a multitude of climatic and topographic parameters some of which may have magnitudes much larger than can be accounted for by changes in regional surface uplift alone. This is especially troublesome in high-elevation plateau regions that have reached threshold dimensions such that atmospheric circulation patterns change through topographic forcing. Therefore, uncertainties in reconstructing past rainfall-topography relationships can arise with the interplay of climatic and/or topographic conditions such as (1) upstream changes in the source area of water vapor, (2) variable air parcel trajectories, (3) mixing of air masses or evaporation of meteoric waters under (semi-)arid climate regimes, or (4) changes in stable isotope in precipitation-elevation relationships ("isotopic lapse rate") over geologic time.

In the absence of near-surface deposits in a rapidly exhuming and eroding orogen such as paleosols, volcanic ashes, or lacustrine sediments that track the stable isotopic composition of precipitation through pedogenic or authigenic mineral growth we have pioneered approaches that exploit the hydrogen isotope record in fault and detachments zones and have coupled these to near-sea level reference sections. This approach of determining relative changes in the isotopic composition between low and high elevation sites eliminates some of the pitfalls typically encountered in stable isotope paleoaltimetry. Another common challenge are the different timescales involved in atmospheric circulation and rainfall patterns and recovery of isotope “signals” in mineral proxies. Climate modelling approaches are therefore extremely useful when relating atmospheric dynamics to the geologic proxy record and quantifying the rates associated with either the growth or hydration of proxy minerals. These rates can vary over several orders of magnitude but in general are much longer than seasonal variations in rainfall, or even individual storm events and thus integrate precipitation signals in the isotope record over relatively long time scales.

Here, we present examples from the European Alps, the Himalayas, and the western United States where reconstructions of paleoaltimetry were successful because sea-level reference sections were used as comparison or large spatial coverage of lacustrine or pedogenic stable isotope records allowed tracking changes in the oxygen isotope composition of precipitation through time.