Stable Isotope Paleoaltimetry of the Tibetan-Himalayan System

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The Himalayan chain and Tibet represent a key region where combined tectonic, geodynamic, and paleoclimatic records provide insight into the dynamics of an evolving orogenic system. Similarly important, the topography of the region is a key element in controlling global-scale atmosphere-lithosphere interactions. Yet, the topographic history of both, the Tibetan plateau and the Himalayas is still poorly constrained for most of its Cenozoic history [e.g. 1, 2, 3]. Stable isotope paleoaltimetry as a tool to recovering elevation histories of (eroded) mountain ranges has gained significant momentum over the past decade mainly because such topographic histories of high elevation regions are otherwise largely elusive from the geologic record.

Stable isotope paleoaltimetry estimates based on oxygen or hydrogen isotopes in precipitation rely on the systematic decrease in the heavy isotope (^{18}O or D) due to cooling of air parcels and associated condensation of water vapor during uplift. The resulting (empirically determined) isotope-elevation relationships seem to be robust and hence permit to relate surface uplift histories to changes in the isotopic composition of past rainfall. For a variety of reasons, however, single-site records of oxygen and/or hydrogen isotopes in precipitation can be affected by 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 particularly troublesome in high-elevation plateau regions that have reached threshold dimensions such that atmospheric circulation patterns change through topographic forcing.

Another common challenge are the different timescales involved in atmospheric circulation and rainfall patterns and recovery of isotope “signals” in mineral proxies. Climate modeling approaches are therefore extremely useful when interpreting 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.

Especially for regionally extensive high-elevation areas such as the Tibetan-Himalayan system, 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 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.

One challenge in recovering paleotopography and addressing pitfalls (1) through (4) mentioned above is that commonly used stable isotope proxy materials have low preservation potential in rapidly eroding orogens. In the absence of near-surface deposits 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 points [e.g. 4, 5]. This approach of determining relative changes in the isotopic composition of rainfall between low and high elevation sites eliminates some of the pitfalls typically encountered in stable isotope paleoaltimetry.

As one example, we could document that Miocene meteoric water infiltrated extensional detachment fabrics associated with the Southern Tibetan Detachment (STD) in the Mt. Everest region [6]. Hydrogen isotope ratios of 15-17 Ma synkinematic muscovite from individual structural levels of the STD are strongly D-depleted indicative of interaction with high elevation meteoric water. When compared to oxygen isotope records from the Himalayan foreland, these hydrogen isotope data require elevations similar or higher than today for the Everest region.

Here, I would like to review current results on changes in surface elevation of the Tibetan plateau over time and contrast these with stable isotope paleoaltimetry results from the Himalayan chain, in particular the Mt. Everest region.

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