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Paleoaltimetry of the Tibetan Plateau from *D*/*H* ratios of lipid biomarkers

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ABSTRACT

The past elevation of the land surface provides a unique constraint on the underlying lithospheric structure during mountain and plateau formation. Development of new paleoaltimetry techniques that can be applied to a wide variety of sample types is therefore of continuing importance. This study evaluates organic substrates that preserve the δD ratio of surface waters as a new approach to reconstruct paleoaltimetry. We measured the hydrogen isotope composition of *n*-alkanes from epicuticular plant waxes preserved in lacustrine deposits to reconstruct the δD of precipitation in Cenozoic basins that have been elevated as part of the Tibetan Plateau. *n*-Alkane δD- and carbonate $\delta^{18}O$-inferred water compositions from the Eocene–Miocene Lunpola Basin and Miocene Hoh-Xil Basin plot near or at enriched values relative to the global meteoric water line, as expected for evaporative lakewater and leafwater systems that have the same precipitation source. *n*-Alkane δD-based water compositions are nearly identical to the minimum carbonate $\delta^{18}O$-based values, demonstrating that plant-wax δD is minimally affected by evaporation compared to lacustrine calcite $\delta^{18}O$. This agreement strongly supports the presence of similar precipitation isotopic compositions in both archives despite different isotope systems, source water reservoirs, archive materials, modes of incorporation, and diagenetic processes.

Paleoelevations for each basin and time period were calculated from precipitation isotope ratios using the isotope–altitude relationship derived from both a simple thermodynamic model and modern precipitation sampling from the Plateau region. Our new results from the Hoh-Xil Basin suggest 1700 to 2600 m of uplift may have occurred some time between the late Eocene and early Miocene. The timing of this uplift is consistent with late-Oligocene compressional deformation of the Hoh-Xil Basin and northward growth of the Tibetan Plateau however, the calculated uplift is not a unique solution from the paleoisotope data because of uncertainties in Eocene and Miocene moisture sources and isotope gradients for the northern plateau. Our results demonstrate the utility of lipid-based estimates of paleoelevation and expand the types of deposits amenable to paleoaltimetry analysis.

1. Introduction

The elevation of the Earth's surface reflects the balance between buoyant and gravitational forces on crust and mantle rock. The balance of these forces depends to a first approximation upon the thickness and density of the Earth's crust and underlying lithospheric mantle, together with contributions in some places from vertical stresses arising from mantle flow. Therefore, the elevation history of a point on the Earth's surface follows the time-evolution of the underlying lithospheric structure and provides a tool for understanding how crustal thickening, crustal flow, mantle dynamics and surface erosion contribute to mountain building. The relative importance of these processes during orogenesis is strongly debated, perhaps most strongly in conjunction with the evolution of the Tibetan Plateau.

Different models for the Cenozoic evolution of the Himalayan–Tibetan orogen yield contrasting area and elevation histories for the Tibetan Plateau and consequent forcing of the monsoon system. In particular, thickening and northward expansion of the Tibetan Plateau as a function of India–Asia convergence (Rowley and Currie, 2006) predicts a time-transgressive history of uplift, with regions near the Himalayan front experiencing uplift to current elevations earlier than regions farther to the north. In contrast, models that invoke convective removal of the mantle lithosphere augment crustal thickening-related uplift with rapid uplift of large regions at discrete time intervals (e.g. Molnar, 2005). Numerous alternatives have been proposed that blend concepts from each of these end-member models. This active debate is fueled by conflicting evidence for both rapid, punctuated uplift and for gradual uplift and expansion of the

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plateau following the collision of India and Asia (e.g. Harrison et al., 1992; Molnar, 2005; Tapponnier et al., 2001). Estimates of past elevations are one of the few means to test different models for the uplift history of the Tibetan Plateau.

Current approaches to quantitative reconstructions of past elevations (paleoaltimetry) largely rely upon variations with altitude of temperature (e.g. Ghosh et al., 2006), enthalpy (e.g. Spicer et al., 2003), atmospheric pressure (Sahagian et al., 2002), p_{CO2} (e.g. McElwain, 2004) and the stable isotopic composition of precipitation (Chamberlain and Poage, 2000; Garzione et al., 2000b; Rowley et al., 2001). Each approach has inherent strengths and weaknesses, therefore combined estimates based upon independent techniques are desired. Unfortunately, it is not always possible to apply more than one technique to a particular suite of samples due to differing sample requirements. Development of new paleoaltimetry techniques that can be applied to a wide variety of sample types is therefore of continuing importance.

This study evaluates organic substrates that preserve the δD ratio of surface waters as a new approach to reconstructing paleoaltimetry. In modern plants, the δD of leaf waxes reflects the δD of their growth water (Bi et al., 2005; Chikaraishi and Naraoka, 2003; Liu et al., 2006; Sachse et al., 2006), therefore δD measurements on ancient molecules are a potential means to estimate past water δD values and, ultimately, paleoelevation. We test this approach with Eocene and Miocene samples from the Lunpola Basin (Tibetan Plateau, Fig. 1), where we compare our results with existing carbonate mineral-based paleoprecipitation $\delta^{18}O$ and paleoaltimetry estimates. We then apply this method to Miocene deposits of the Hoh-Xil Basin, allowing us to evaluate the elevation predictions of different models for uplift of the central Tibetan Plateau. Our results on ancient samples complement an ongoing calibration study of paleoaltimetry from modern plant-wax δD that will be published elsewhere (Polissar and Freeman, in preparation).

1.1. Precipitation and plant-wax δD

The waxy epicuticular coating on plant leaves contains a variety of biochemicals, such as linear alkanes (*n*-alkanes) and esterified fatty acids and alcohols. Among these compounds, *n*-alkanes are ubiquitous components of ancient sedimentary organic matter because they are the least reactive during transport and burial. Further, the carbon-bound hydrogen of *n*-alkanes does not readily exchange at low temperatures (Schimmelmann et al., 2006), preserving the original isotopic composition after burial. These traits make sedimentary *n*-alkanes an attractive substrate for reconstructing paleoprecipitation and paleoelevation.

The δD value of plant-wax *n*-alkanes reflects that of precipitation, modified by soil evaporation, plant transpiration and biosynthesis (shown conceptually in Fig. 2). Soil evaporation and plant transpiration increase the deuterium content of soil and leafwater, respectively, while biosynthesis results in plant-wax *n*-alkanes more negative than leafwater. It is difficult to experimentally separate biosynthetic from evaporative effects on plant-wax δD, and current approaches use an apparent fractionation factor that is the fractionation between

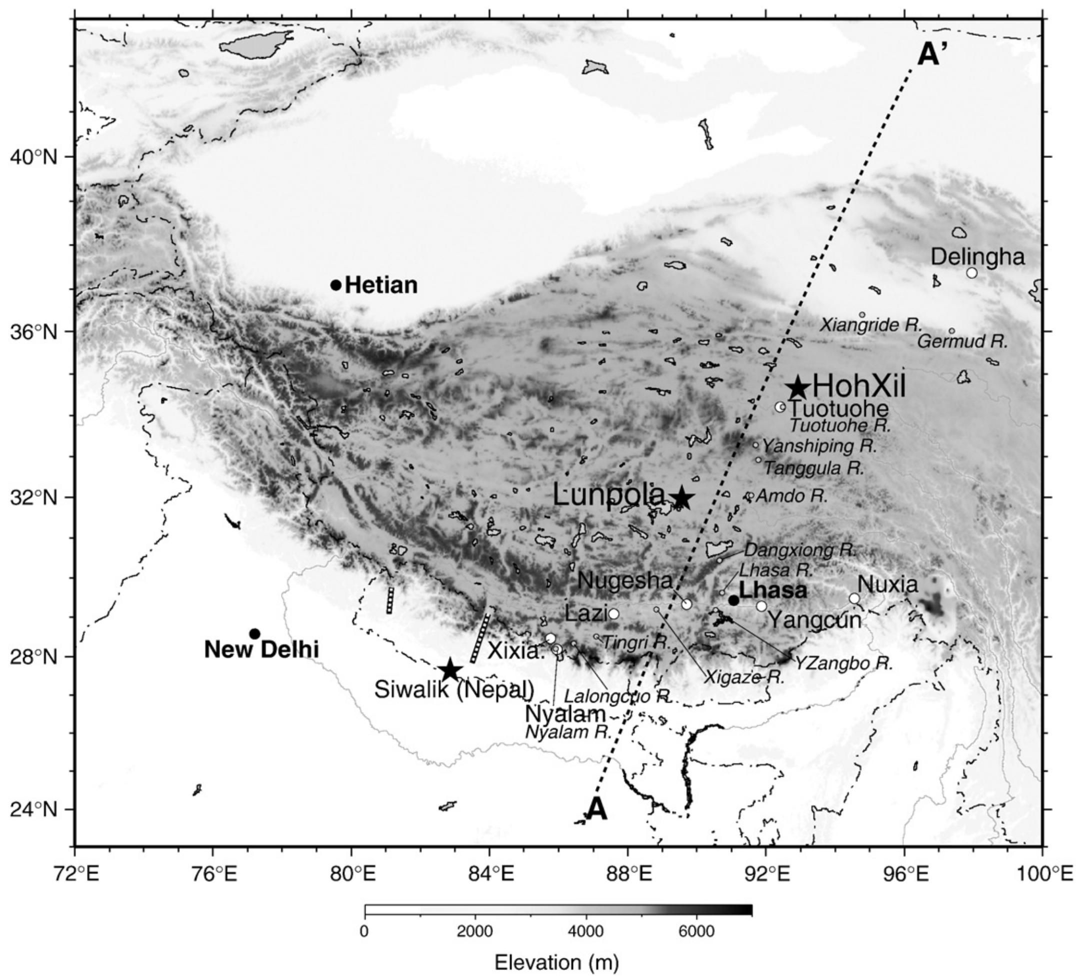

Fig. 1. Map showing locations of rock samples and modern water isotopic compositions. See Fig. 7 caption for interpretation of symbols. White–black dashed lines show location of river water samples in Garzione et al. (2000b).