Early Tibetan Plateau uplift history eludes

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The elevation history of Tibet, the world’s highest and most extensive plateau, offers a testing ground for ideas concerning the geodynamics of continental collision, the effect of large orogens on climate, and the interactions between the two. Included in the understanding of the evolution of modern Tibet is the elevation of the proto-plateau, or Asian margin, prior to its collision with India ~50 m.y. ago. Although most assume that post-collision convergence created much of the current high topography and doubled the thickness of the crust, many studies document crustal shortening or rapid cooling histories during Jurassic and Cretaceous time across Tibet, which raises the possibility of elevated topography prior to continental collision with India.

The rock that comprises Tibet had amalgamated by late Jurassic to early Cretaceous time, and most believe that an elevated Lhasa Block represented a wide Andean-type margin that bound southern Asia prior to collision (Fig. 1). But quantifying the contribution of pre-Eocene deformation to the modern crustal thickness and elevation is difficult. Where estimates are made on the basis of surface shortening, assumptions regarding the mechanisms of lower crustal and mantle lithosphere shortening drastically affect predicted altitudes. Erosion, foundering of mantle lithosphere, and lateral flow of ductile lower crust also affect the longevity of topography, but are rarely quantifiable. So, whether or not high elevations accompanied pre-Eocene deformation in Tibet, and were sustained for tens of millions of years prior to India’s collision, remains an open question.

Hetzel et al. (2011, p. 983 in this issue of Geology) challenge a widely accepted view that the southern margin of Asia was at high elevation prior to collision with India (e.g., England and Searle, 1986; Kapp et al., 2007a, and references therein). Using low-temperature thermal histories from granitoids in the northern Lhasa block, Hetzel et al. documented rapid cooling between 65 and 48 Ma that occurred at rates of ~10 °C/m.y. (0.2–0.4 mm/yr) and exhumed up to 6 km of rock. They interpret rapid denudation rates to reflect planation by laterally migrating rivers that created the observed low-relief land surfaces. By relating these rivers to sea level, they propose that the landscape was reduced to low elevations prior to the continental collision of India. Slow erosion rates (0.006–0.016 mm/yr) averaged over the past 40–90 k.y. from 39Be ages, combined with extrapolation of the low-temperature histories to modern time, suggest little modification of these surfaces since collision and uplift to their modern altitude near 5300 m.

Hetzel et al.’s study highlights the use of low-relief surfaces as passive markers in continental tectonics, a practice that has regained momentum in the past decade (e.g., Clark et al., 2005, 2006; Bishop, 2007; Calvet and Gunnell, 2008; van der Beek et al., 2009). As ~70% of the Earth’s continental surfaces lie at altitudes of <1 km, most landscapes undergo very little relief change over long periods of time. Erosion surfaces, more aptly termed “relict landscapes,” represent low-relief remnants of fluvially sculpted, and sometimes glacially modified, landscapes that can develop at relatively low altitude where rivers are externally drained to or near sea level (plation surfaces) or alternatively, at high altitudes where rivers are internally drained to high-elevation basins (alitplanation surfaces). Once reduced to low relief, the stability of these landforms is demonstrated by long periods (more than tens of millions of years) of low erosion rates (e.g., Hetzel et al., 2011), which can be shown to be out of equilibrium with parts of the landscape responding to recent tectonic forcing, climate change, or drainage integration (e.g., Clark et al., 2005). These artifacts seem to be commonly preserved in active landscapes to greater or lesser degrees. Where base level can be determined, these planar landscape remnants present opportunities to measure local and regional surface elevation change, and the timing of their disruption can represent climate or tectonic forcing on the landscape.

The Eocene low-relief surfaces described by Hetzel et al. likely correlate with the basal unconformity of the Linzizong volcanics (magmatic flare-up between 68 and 49 Ma), a gently-dipping contact at similar elevations across the Lhasa terrane. This unconformity surface has been previously interpreted as a part of a high-elevation, Altiplano-like landscape (Kapp et al., 2007b), which would have formed by an isolated (internally drained) river system and would not necessitate a near-sea-level interpretation. A critical difference in Hetzel et al.’s argument is the formation of a low-relief landscape by a southward-flowing fluvial system that drained to sea level. While south-draining rivers are a likely inference, the connection to global base level (i.e., sea level) is a crucial part of the puzzle that awaits confirmation or rejection by provenance studies or fluvial reconstructions.

Rapid underthrusting and elevation increase following lithosphere removal from 90 to 50 Ma (Kapp et al., 2007b) are also consistent with the rapid erosion rates inferred by Hetzel et al. between 65 and 48 Ma. This period of erosion acted on potentially high-elevation topography created by thrust faulting associated with the accretion of the Lhasa Block between 125 and 118 Ma, continued convergence, and mantle foundering thereafter (e.g., Kapp et al., 2007a and 2007b, and references therein). An estimate of 50% shortening may account for 3–4 km of elevation gain if pure shear of the entire crust and Airy isostasy are assumed (Murphy et al., 1997). Preservation of Eocene age low-relief surfaces, if they drained southward to sea level, would suggest reduction of that topography prior to the time of collision (Hetzel et al., 2011).
Once collision commenced, the area over which crustal thickening began may have been much larger than previously thought. The development of the northeastern plateau, typically considered to be the youngest part of the orogen (e.g., Meyer et al., 1998), has been occurring since roughly collision time (e.g., Dupont-Nivet et al., 2004; Yin et al., 2008; Wang et al., 2008; Clark et al., 2010; Duvall et al., 2011). As such, a stable northern boundary would imply that the north-south extent of Tibet has grown narrower, not wider, since collision. While Eocene thrust faulting does not necessarily imply achievement of modern elevations at that time, it does suggest that the northern boundary of Tibet was established early and has not propagated despite >2000 km of subsequent convergence of India with Eurasia.

In the recent decade, quantitative paleo-elevation records for Tibet derived from light stable isotopes offer elevation constraints that are independent of deformation, erosion, and assumptions therein. Greater confidence exists in younger histories from southern Tibet where the isotopic composition of modern meteoric waters conforms to a simple thermodynamic model of isotopic fractionation of water vapor traveling over a high-elevation landmass. These records suggest that southern Tibet has been high since at least 26 Ma (e.g., Quade et al., 2007), but estimates from northern Tibet and older rocks are not definitive (e.g., Quade et al., 2011). Complexities in past moisture sources, evaporation, and surface-water recycling are thought to effect the isotopic composition of meteoric water from the interior of Tibet. Our current understanding of how these processes have interacted in the past limits the quantitative interpretation of paleo-elevation there (e.g., Polissar et al., 2009; Quade et al., 2011). A better understanding of the proxy record from climate simulations, that include the prediction of isotopic values in precipitation, is an area of active research.

Studies in Tibet illustrate the current need to reconcile conflicting views of paleo-elevation derived from erosion histories, reconstructions of surface shortening, and estimates from geochemical proxies in active orogens. As a clearer picture of widespread deformation prior to and overlapping with the beginning of continental collision emerges, the record of paleo-elevation remains critical to the dynamic understanding of how the world’s largest plateau came to be. Recognition of stable landforms and their connection to sea level may be an integral part of our overall understanding of plateau evolution. Where surfaces can be related to sea level through fluvial systems or their deposits, they become a useful passive marker to elevation change and long-wavelength deformation.

Surfaces of late Jurassic to Eocene age have been recognized across Tibet and within the Himalaya, and even north into Mongolia. It is interesting to speculate whether these surfaces may represent a vast, large-scale ancient surface that has been disrupted at different times, or may have formed independently at a range of altitudes. Advances in our ability to quantify the most recent history of these landforms through new lower-temperature methods in thermochronometry (<60 °C), and application of robust cosmogenic isotopes to dating of surfaces, promises to enhance interpretation of the origin, age, and geodynamic significance of these long-lived landscape relics. Why old landscapes are often preserved in tectonically active regions is enigmatic; but the fortunate preservation of these ancient remnants may be an important clue to the tectonic and climatic conditions that governed the plateau during and just prior to continental collision.

REFERENCES CITED


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