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Multiple episodes of fast exhumation since Cretaceous in southeast Tibet, revealed by low-temperature thermochronology

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ABSTRACT

The southeast margin of the Tibetan plateau is characterized by deeply incised river valleys separated by a perched low relief landscape that gently descends from the high Tibetan plateau towards the southeast. When and how this unique landscape formed is debated. The onset of increased river incision is often interpreted as a proxy for the timing of surface uplift. Here, apatite and zircon (U–Th)/He and apatite fission track thermochronometries are employed to map the spatial and temporal pattern of exhumation in the region. Vertical profiles of granitic rocks were collected near Deqin (∼28.5°N) and Weixi (∼27.5°N). The two transects share a similar exhumation history, with two episodes of relatively fast exhumation (∼100–300 m/Myr) in the Cenozoic: during the Paleocene to Eocene (60–40 Ma) and Miocene to present (20–0 Ma), separated by an intervening period of slow exhumation. A pulse of moderate to high exhumation (70–300 m/Myr) during the mid- to late-Cretaceous (120–80 Ma) is also present in the data. However, the rate and total amount of exhumation near Deqin is larger than at Weixi and is especially pronounced in the interval between 20 Ma to present. We interpret this difference as possibly related to differences in erosion rates between the Lancang (Deqin) and the Jinsha (Weixi) rivers. The Paleocene to Eocene episode of fast exhumation is likely in response to early Cenozoic deformation along tectonic boundary structures, related to the transpressional collision of the Indian plate with this region. Pre-Miocene episodes of fast exhumation corroborate recent paleoaltimetric studies, which show that the southeast margin of the Tibetan plateau was elevated prior to the Oligocene.

1. Introduction

While much of the high-elevation, low-relief and internally-drained Tibetan Plateau is bounded by steep mountains, its southeast margin is characterized by a gradual topographic gradient where elevations descend from 4–5 km to 1–2 km over 1000–1500 km. Three of the largest Asian rivers, the Nu (Salween), Lancang (Mekong), and Jinsha (Yangtze) rivers traverse the southeast margin, flowing roughly parallel to each other for hundreds of kilometers as they flow out of Tibet (Fig. 1). This area, the Three Rivers region, is characterized by deep incision separated by patches of relatively low relief highlands, which gradually become more continuous upstream and merge into the extensive low relief surfaces of the plateau interior.

Understanding the evolution of the Tibetan Plateau has great implications for both exploring the geodynamic processes of plateau growth and its potential link to changes in global climate (i.e., An et al., 2001; Roe et al., 2016; Royden et al., 1997; Tapponnier et al., 2001). The genesis of southeast margin's unique landscape and its geodynamic implications are debated, and two leading hypotheses have emerged (Clark et al., 2005; Liu-Zeng et al., 2008). One idea suggests that the gradual slope of Southeast Tibet is the result of ongoing crustal thickening due to lower crustal channel flow that initiated in the late Miocene (Clark and Royden, 2000; Royden et al., 1997). The other idea suggests that southeast Tibet attained its present height well before the mid-Miocene, was extruded along large strike-slip faults

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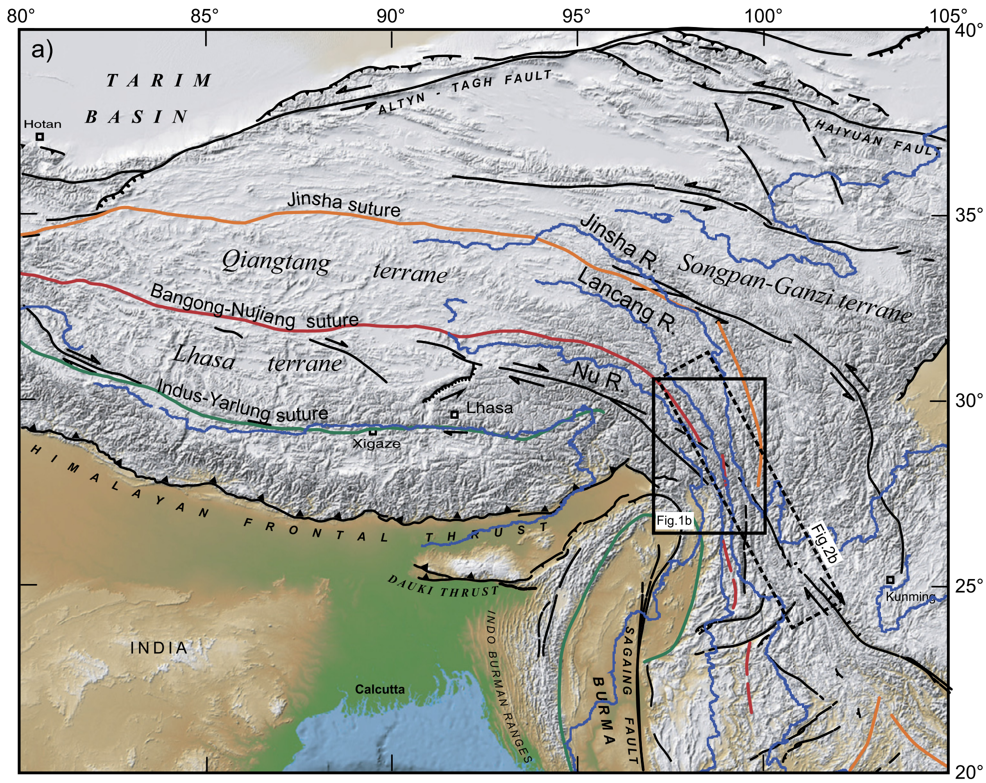

Fig. 1. Geological and tectonic settings of the Three Rivers region. (a) Topography, active faults, and major suture zones in the Tibetan Plateau. (b) Simplified geological map of Three Rivers region, superimposed on shaded relief. Sample locations in Deqin (DQ) and Weixi (WX) transects in this study are indicated by filled circles. Also shown are sample transects in previous publications, except those by Wilson and Fowler (2011) and Yang et al. (2016), whose samples are scattered, rather than in vertical transects. 1. Zhang et al. (2015); 2. Tian et al. (2014); 3. Ouimet et al. (2010); 4. Zhang et al. (2016); 5. Li and Zhang (2013); 6. Clark et al. (2005); 7. Tian et al. (2015); 8. Shen et al. (2016).

active during the early to mid-Cenozoic (Leloup et al., 1995; Lacassin et al., 1996; Tapponnier et al., 2001), and since then the plateau margin has undergone relief reduction and the retreat of the plateau margin via landscape lowering (e.g., Liu-Zeng et al., 2008). Yet another mechanism, autogenic stream piracy, was recently put forward as a means for building the unique topography of the southeast margin of Tibet during or after the plateau uplift (Yang et al., 2015). While each hypothesis is supported by a set of observations, a multiple low-temperature thermochronometer explanation of exhumation through time will help discriminating between them.

A low-temperature thermochronometer records when a section of crust cooled through a closure temperature as it was exhumed towards the surface. A closely spaced vertical profile of cooling ages is commonly used to determine rates of exhumation. Because of their relatively low closure temperatures, apatite and zircon (U–Th)/He (AHe and ZHe) and apatite fission track (AFT) analyses are the best tools in documenting the latest stages of the evolution of topography and cooling within the uppermost kilometers of the crust (Ehlers and Farley, 2003; Reiners and Brandon, 2006; Willett and Brandon, 2013).

Much of the support for the Miocene lower crustal flow hypothesis comes from previous low-temperature thermochronological studies in southeast Tibet (along the Yalong and Dadu rivers; Fig. 1b) that conclude that rapid exhumation since the late Miocene is reflected by increased river incision which began no earlier than 8–13 Ma (Clark et al., 2005; Ouimet et al., 2010). However, subsequent low-temperature thermochronometric data indicate Oligocene to early Miocene initiation of river incision (Shen et al., 2016; Tian et al., 2014), while Oligocene rapid exhumation has been identified in the Longmen Shan (Wang et al., 2012). In contrast, stable isotope paleoelevation studies suggest that the Three Rivers region has been at or near its present elevation since the Eocene (Hoke et al., 2014; Li et al., 2015; Tang et al., 2017), which lends supports to the extrusion and subsequent erosion hypothesis (Liu-Zeng et al., 2008). The apparent discrepancy between the rock uplift histories gleaned through low-temperature thermochronometry and paleoaltimetry highlights the need for additional data.

Earlier thermochronological studies typically applied AHe in the region east of the Three Rivers (Fig. 1b) and extended their findings across the entire southeast plateau margin. Extrapolation of an exhumation history from a few localities to an entire region with a complex set of large strike-slip fault systems can be problematic because important regional differences and the potential for heterogeneities in exhumation history are not considered. Previous work in the Three Rivers region only sampled near the valley bottom (e.g., Yang et al., 2016); however, vertical transects that analyze multiple thermochronometers, are crucial to develop a comprehensive understanding of the regional uplift history.

In this study, we apply low-temperature thermochronometric methods to 23 granitic samples collected at two nearly vertical profiles along the Lancang River at Deqin and Weixi (Figs. 2 and 3). Both profiles are composed of samples collected in close horizontal proximity to each other, and span a total relief of 2500 m for the Deqin transect (∼28.5°N) and 1100 m for the Weixi transect (∼27.5°N) (Fig. 2). We combine three thermochronometric systems (AHe, AFT, and ZHe) with closure temperatures ranging at ∼60–200 °C (Farley, 2002; Laslett et al., 1987; Reiners et al., 2004). Together, these systems allow us to reconstruct a continuous exhumation history from the mid-Cretaceous to present.