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Stable isotopes reveal high southeast Tibetan Plateau margin since the Paleogene

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ABSTRACT

The evolution of the topography of eastern Tibet reflects the dynamic interaction between processes at Earth's surface and the lower crust. Reconstruction of its spatio-temporal development provides constraints for our understanding of the geodynamics of continental deformation. This study examines the topographic evolution of the southeast margin of the Tibetan Plateau throughout the Cenozoic using stable isotope paleoaltimetry of pedogenic carbonates preserved in Cenozoic basins extending from the northern to the southern portions of the SE margin of the Tibetan Plateau (Yunnan Province, China). Paleoelevations are calculated using a Monte Carlo simulation of the normally distributed uncertainties in each parameter used to calculate elevations from the isotopic value of pedogenic carbonate. Isotope–elevation relationships are determined from a modern sampling transect along the modern Lancang (Mekong) River and an estimated Eocene Rayleigh fractionation model that was randomly resampled. Calculated elevations indicate the SE margin of Tibet was at its present elevation as early as the late Eocene, with elevations of 3.3 km as far south as the northern third of China's Yunnan Province. This result expands the extent of the Eocene Tibetan Plateau more than 1000 km east of that previously known and precludes surface uplift via lower crustal flow in the area of SW Sichuan and Northern Yunnan as a driver for drainage reorganization and an observed middle to late Miocene pulse of rapid exhumation. Elevation estimates from the southern two thirds of the study area parallel to the Red River Fault suggest approximately 1 km of post late Miocene surface uplift, consistent with estimates from previous studies.

1. Introduction

The SE margin of the Tibetan Plateau is characterized by long-wavelength, low-gradient topography spanning 5 km of relief over ∼1500 km and contrasts with the steep northern, southern and eastern margins. A portion of the plateau margin is interpreted to be a low-relief, relict landscape of at least early to middle Miocene age (Clark et al., 2005) that is incised by the present-day Red, Yangtze and Lancang Rivers (Clark et al., 2004; Schoenbohm et al., 2004). The tectonic and topographic evolution of the SE margin of the Tibetan Plateau has been the subject of controversy that is generally cast in terms of the two end-member models of extruded lithospheric-scale blocks (Tapponnier et al., 1982) or surface uplift via flow of a weak middle to lower crust (Clark and Royden, 2000; Royden et al., 1997); however, a combination of both processes is possible (Akciz et al., 2008; Wang and Burchfiel, 1997). Ductile flow of the lower crust from the regions of high lithostatic pressure in the central Tibetan Plateau toward the SE margin has been the preferred mechanism to reconcile numerous geologic and geophysical observations of the SE margin of Tibet (Clark and Royden, 2000) including: the low topographic gradient, the gradual decrease in both surface elevation and crustal thickness from plateau to foreland, and a limited amount of Cenozoic shortening (Akciz et al., 2008; Studnicki-Gizbert et al., 2008; Wang and Burchfiel, 1997; Wang et al., 1998). The principal age constraints for lower crustal flow are derived from geomorphic estimates of an increase in topographic relief based on river incision (Schoenbohm et al., 2004), in conjunction with low temperature thermochronometric constraints on the timing of river incision (Clark et al., 2005; Ouimet et al., 2010). Together, these studies suggest 1.5 to 2 km

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of post-middle Miocene incision of eastern and SE Tibet (Clark et al., 2005; Ouimet et al., 2010; Schoenbohm et al., 2004). One modeling study suggests that it is difficult for lower crustal flow to propagate into thinner crust adjacent to a plateau and may require ∼20 Ma for any thickened crust to achieve the thermal state favoring flow (Beaumont et al., 2004). Other studies suggest a continuous (Clark and Royden, 2000) and potentially rapid propagation (Cook and Royden, 2008) of the lower crust towards the adjacent lowlands. Prior paleoelevation studies of the central Tibetan Plateau constrain near-modern elevations, and thus a thickened crust, as early as 35–26 Ma (DeCelles et al., 2007; Rowley and Currie, 2006), which could be consistent with middle or late Miocene lower crustal flow towards the SE margin.

The elevation history of the SE Tibetan Plateau constitutes the critical missing information necessary to evaluate the lower crustal flow hypothesis for generating late Miocene–Pliocene surface uplift of this region. This study presents new Eocene to Quaternary pedogenic carbonate stable isotope data from a string of NW–SE oriented Cenozoic sedimentary basins in China's Yunnan Province (Fig. 1). These basins span nearly 700 km distance and 1.3 km of modern relief, enabling us to determine the regional paleotopographic gradient of the SE margin of the plateau and how that gradient has changed over time. We determine the long-term elevation history in locations where Paleogene and Neogene deposits are in close geographic proximity (<100 km) using pedogenic carbonate based stable isotope paleoaltimetry (Quade et al., 2007; Rowley, 2007).

2. Geologic background

The SE margin of the Tibetan plateau is composed of several lithospheric fragments, including the Indochina, Simao-Lanping, Songpan Garze and South China Blocks (Fig. 1) (Burchfiel and Chen, 2012; Wang et al., 1998). This region has experienced a complex and protracted deformation history that spans the Mesozoic and Cenozoic. Triassic and Jurassic sedimentary basins are a mix of marine and non-marine rocks, while Cretaceous sediments are dominated by non-marine red bed sequences (Burchfiel and Chen, 2012). Early Cenozoic deposits are thinner and less extensive than the Mesozoic. The most extensive early Cenozoic deposits are found on the Simao-Lanping block and the South China blocks with minor deposits on the Qiangtang block (Fig. 1; Studnicki-Gizbert et al., 2008). Paleogene sediments are dominated by sandstone and conglomerate, including eolian deposits, that suggest more arid conditions than the late Cenozoic. Neogene deposits largely consist of sandstone, mudstone, and coal (Ge and Li, 1999; Xia et al., 2009; Xu et al., 2008), reflecting lower energy and in some cases, wetter depositional environments. Cenozoic contraction, constrained largely by deformation of early Cenozoic sediments, is restricted to the Longmenshan thrust belt, South China fold belt and the Three Rivers fold belt (Burchfiel et al., 1995; Wang et al., 1998). Late Cenozoic to Modern deformation across the SE portion of the Plateau is localized on a regional network of large strike-slip faults, including the Xianshuihe-Xiaojiang fault system, the Red River fault, and the Dien Bien Phu Fault, that accommodate the clockwise rotation of the SE Tibetan Plateau around the Eastern Himalayan Syntaxis (Fig. 1; Burchfiel et al., 1995; Wang et al., 1998). The Ailao-Shan-Red River shear zone experienced major sinistral motion in the Oligocene and today shows dextral motion (Leloup et al., 1995). There has been limited crustal shortening in the SE margin of the Plateau since the middle Miocene (Wang et al., 1998). Miocene to present extension is widespread across the region (Allen et al., 1984) and Pliocene to Quaternary deposits are generally undeformed, except near active faults (Wang et al., 1998).

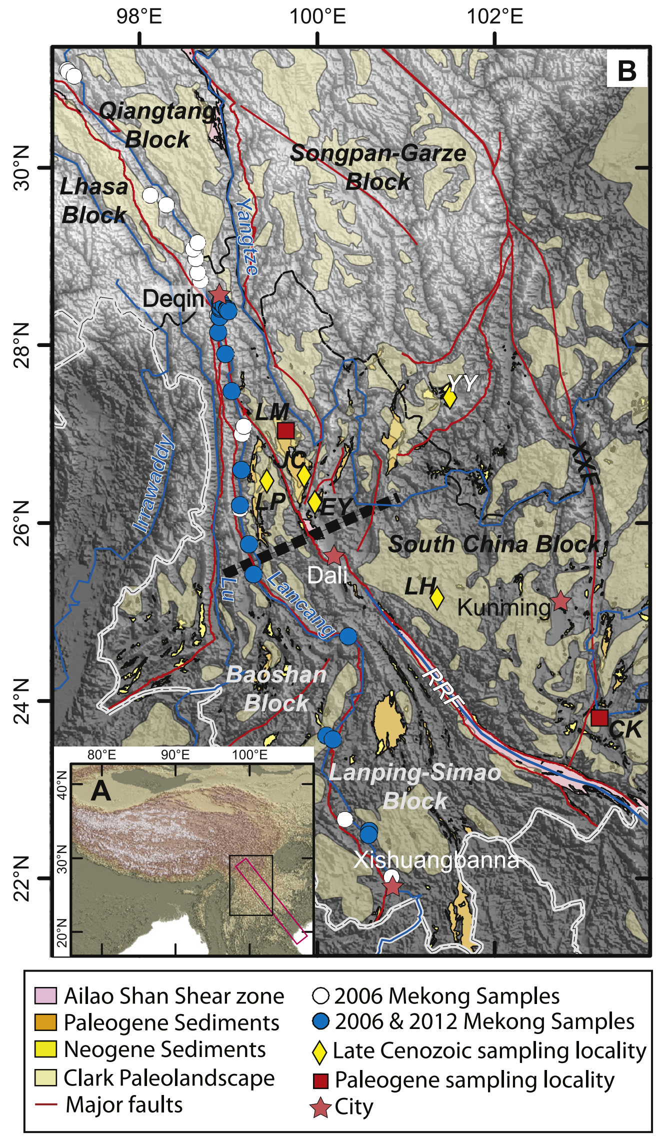

Fig. 1. Sampling localities, geographic features and selected geologic units of the SE Tibetan Plateau margin. (A) Topographic map showing the location of detailed map in (B) and the swath profile in Fig. 2D. (B) Topographic map of the SE Tibetan margin with the location of water samples (blue and white circles), Eocene (red squares) and late Cenozoic (yellow diamonds) sampling localities. Major tectonic boundaries are shown in crimson and labeled in bold italic text. The extent of the pre-Miocene paleolandscape mapped by Clark et al. (2004) is shown in transparent light green. Key terrane boundaries from Burchfiel and Chen (2012) are shown for reference (see key). Abbreviations: LM = Liming Basin, JC = Jianchuan Basin, YY = Yanyuan Basin, LH = Lühe Basin, LP = Lanping Basin, CK = Chake Basin, RRF = Red River Fault and XXF = Xianshuihe-Xiaojiang Fault. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Sampling and analysis

Rock samples for carbonate analyses were collected from measured stratigraphic sections at seven localities throughout the Yunnan Province (see supplementary material for sections and section locations). Age constraints at each locality are derived from Chinese geologic maps (biostratigraphic correlations), published magnetostratigraphic sections or geochronology from tuffaceous sandstones. The Neogene basins are the middle Miocene Jianchuan Basin (Shuanghe Formation; BGMRY, 1990; Burchfiel and Chen, 2012) late Miocene Lanping (Sanying Formation; BGMRY, 1990) and late Miocene Lühe (Xiaolongtan (formerly Shihuiba) Formation; Xu et al., 2008) Basins (Fig. 1). The Eryuan Basin