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Differential exhumation at eastern margin of the Tibetan Plateau, from apatite fission-track thermochronology

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ABSTRACT

New apatite fission-track (AFT) ages from Mesozoic sediments in the Sichuan basin, combined with previous fission-track data, demonstrate differential uplift and exhumation across the basin. Particularly significant change in exhumation (at least ~2000 m) was found across the Huaying Mts. Modeled temperature–time histories and the Boomerang plot of AFT dataset across the basin suggest rapid cooling and exhumation events during 120–80 Ma and at 20–10 Ma. They reflect the start of the basin-scale differential uplift and exhumation which effected the eastern growth of Tibetan Plateau. In particular, nested old-age center separated by Huaying Mts. was found in the center-to-northwest part of the Sichuan basin. A simplified one-dimensional, steady-state solution model was developed to calculate the mean exhumation rate, which is 0.05–0.2 mm/yr in most parts of the basin. It suggests a slow exhumation across much of the basin. The regional pattern of AFT age, length and erosion rate supports a progressive change from the nested old-age center towards the southwest. This pattern supports the idea of a prolonged, steady-state uplift and exhumation process across the basin, controlled by cratonic basin structure. The eastern growth of the Tibetan Plateau has exerted a significant effect on the rapid exhumation of the southwestern part of the Sichuan basin, but not on all of the basin during the Late Cenozoic.

1. Introduction

The Sichuan basin and its peripheral mountains located on the eastern margin of the Tibetan Plateau (Fig. 1), have long been a field laboratory for studies of Tibetan Plateau uplift and its eastward growth (Bai et al., 2010; Burchfiel et al., 1995, 2008; Fu et al., 2011; Hubbard and Shaw, 2009; Royden et al., 2008; Zhang et al., 2004). Thermochronometric data provide an important constraint on the long-term erosion and thermo-mechanical processes here (Arne et al., 1997; Clark et al., 2005; Godard et al., 2009a; Kirby et al., 2002; Li et al., 2010). The rheologically strong basement and lithosphere of the Sichuan basin (Bai et al., 2010; Clark and Royden, 2000; Copley, 2008; Decelles et al., 2002; Royden et al., 1997; Shen et al., 2005), constrict the eastward growth of the Tibet Plateau. The crustal flow is impeded and diverted around the basin, causing regional rapid cooling and uplift (with the rate of >0.5–2 mm/yr) in the orogen located around the basin during the Late Cenozoic (Clark et al., 2005; Enkelmann et al., 2006; Godard et al., 2009a; Kirby et al., 2002; Ouimet et al., 2010; Schoenbohm et al., 2006). However, the rapid cooling and uplift show contrasting behavior between the periphery of the basin and the basin interior (Li et al., 2010; Liu et al., 2008; Richardson et al., 2008).

Cenozoic uplift and the exhumation processes in the Sichuan basin are poorly constraint due to the lack of Cenozoic depositional records, although thermochronometric data has recently revealed that the episodic uplift and exhumation played a key role in shaping of the present Sichuan basin (An et al., 2008; Arne et al., 1997; Chang et al., 2010; Deng et al., 2008, 2009; Liu et al., 1996; Qiu et al., 2008; Richardson et al., 2008; Shen et al., 2007, 2009; Tian et al., 2010). In an effort to better understand to large-scale exhumation processes in the Sichuan basin and its mechanism, new apatite fission-track (AFT) data were collected along the Huaying Mts. located in the basin center and are presented in this paper. The data provides new information on tectonic structure inside the basin, as well as about the cooling and exhumation history on the basin-scale, which allows testing the coupled geodynamic and exhumation process at the eastern margin of the Tibetan Plateau.

2. Geological setting

The Sichuan basin is located at the western margin of the Yangtze Block. Its northwest area is separated from the Songpan-Ganzi Fold Belt by the Longmen-Daliang Mts.; its northeast area is separated from the Qinling orogen by the Daba-Micang Mts., and its southeast area is separated from the Hubei–Hunan–Guizhou fold belt by the Qiyue-Dalou Mts. (Fig. 1).

The Sichuan basin was subjected to multi-phase tectonic movements during different time periods. To the north of the Sichuan basin, the Qinling orogen experienced a protracted orogenic history and is considered to have undergone a two-phase collision along

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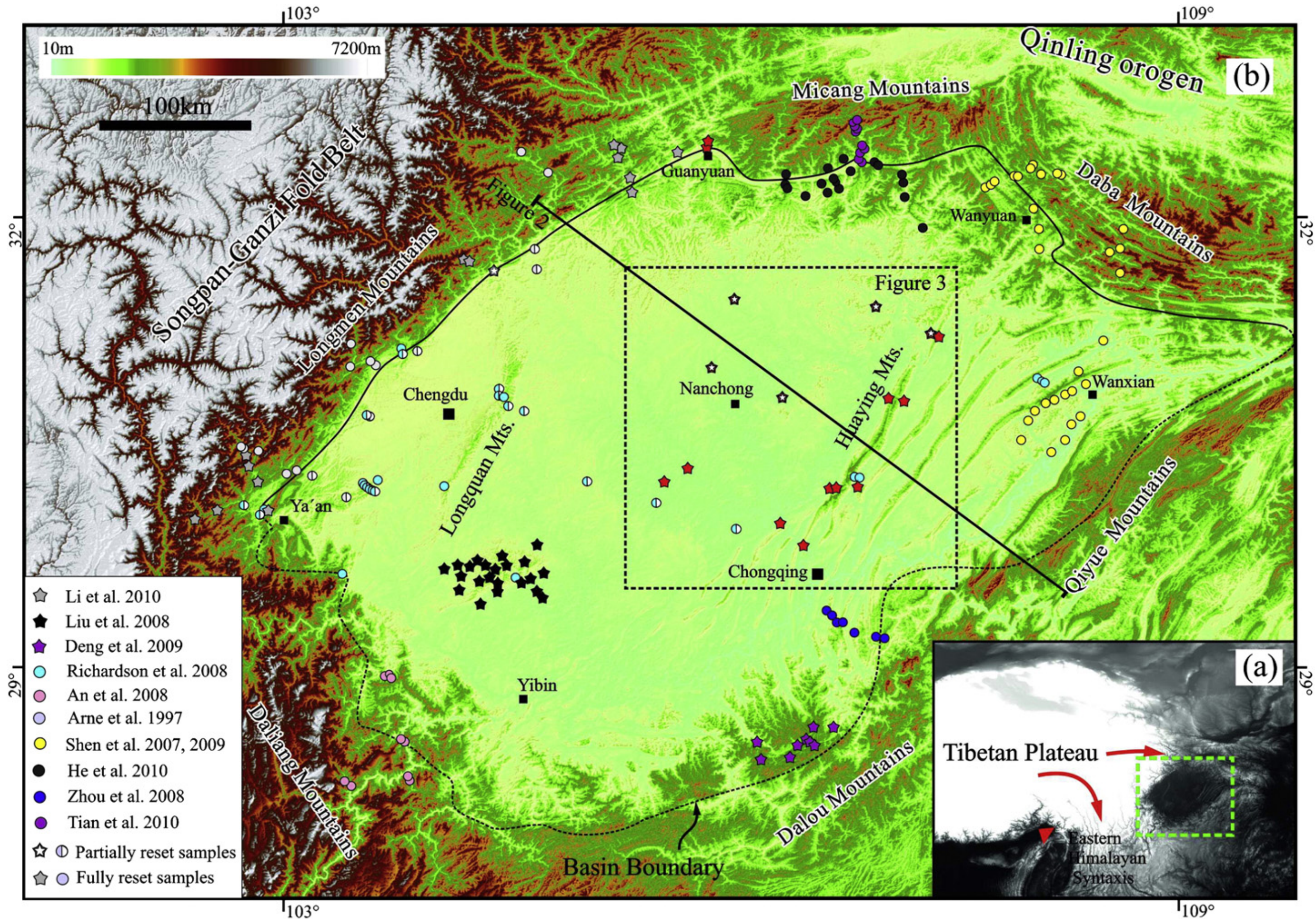

Fig. 1. (a) Geographical setting of the Sichuan basin showing the location of (b), red arrows indicate the eastern growth model of the Tibetan Plateau. (b) Topography from SRTM digital elevation model and tectonic map of the Sichuan basin; it shows most of the apatite fission-track data in the basin and its periphery.

the Shangdan and Mianlue suture zones in the middle Paleozoic and during mid-to-late Triassic periods (Mattauer et al., 1985; Meng and Zhang, 2000; Zhang et al., 2001). In particular, the later diachronous collision of the North and South China blocks along the Mianlue suture zone had profound impact on the evolution of the Sichuan basin (Li et al., 2007a; Liu et al., 2005; Yin and Nie, 1993; Zhao and Coe, 1987), even on the whole Yangtze Block. During the Middle Jurassic, a typical foreland basin developed in the northern part of the basin. It is a result of basin-ward thrusting of the Dabashan thrust–fold belt (Li et al., 2007b; Liu et al., 2005, 2006). In the northwest, the Longmen Shan thrust–fold belt experienced southeastward piggyback thrusting during the Late Triassic (Fig. 2) (Chen et al., 1995; Harrowfield and Wilson, 2005; Liu et al., 2009; Roger et al., 2010; Worley and Wilson, 1996), giving origin to the Western Sichuan foreland basin with sedimentary deposits of synorogenic Xujiahe Formation up to 4 km thick (Deng et al., 2012b; Li et al., 2003; Meng et al., 2005). Rapid uplift and exhumation and dextral neo-tectonics characterize the Late Cenozoic Longmen Shan due to the far-field effect of the India–Asia continental collision (Arne et al., 1997; Fu et al., 2011; Godard et al., 2009a; Kirby et al., 2002; Shen et al., 2005; Zhang et al., 2010). However, only minor studies were devoted to unraveling detailed influence of Tibetan plate expansion on the adjacent Sichuan basin. In contrast to a strong deformation around the basin, there is only a weak deformation with the horizontal, or low-angle inclined rocks in the Sichuan basin to the west of the Huaying Mts. (Fig. 2). In particular, slight deformations expressed by the "Rotating or radial structures" occur in the basin center (e.g. Mianyang and Bazhong radial structures) (BGMRSP, 1991; Burchfiel et al., 1995; Liu et al., 2012; Luo, 1998). To the east of the Huaying Mts., the tectonic framework is characterized by the NE-trending chevron anticlines and northwestward thrust faults (Fig. 2). It is believed that they are the result of progressive northwestward propagation of intra-continental deformation in South China, from the Late Triassic to the Cretaceous (Burchfiel et al., 1995; Yan et al., 2009). Southwest of the Sichuan basin, sinistral strike-slip faults and horizontal or low-angle inclined blocks characterize the geology of the Daliang Shan. It was formed by outward extrusions of the crust from the growing Tibetan Plateau interior during the Late Cenozoic (Burchfiel et al., 1995; Wang and Burchfiel, 2000; Wang et al., 2007). Some of the faults remain active till present (Densmore et al., 2007; Ouimet et al., 2007; Shen et al., 2005; Zhang et al., 2004).

Up to 10 km of sediments overlies the Proterozoic crystalline and metamorphic basement in the Sichuan basin (Fig. 2). According to stratigraphy and petrology, the geological evolution of the Sichuan basin can be divided into two major stages: (1) a continental-margin stage, dominated by deposition of a platform carbonate succession from the Late Sinian to Middle Triassic, (2) a terrestrial basin stage characterized by different thrust-loading foreland basins in front of the peripheral thrust–fold belts, with a deposition of up to 5 km thick terrestrial sediments from the Upper Triassic Xujiahe Formation up to the Quaternary. However, multi-phase tectonic movements, such as Caledonian, Dongwu, Indosinian, Yanshanian and Himalayan movements gave rise to a complicated tectonic evolution and sedimentary history of the basin. The tectonic events are distinctively identifiable by regional unconformities. During