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Eocene onset and late Miocene acceleration of Cenozoic intracontinental extension in the North Qinling range–Weihe graben: Insights from apatite fission track thermochronology

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ABSTRACT

Intracontinental extension in central China is accommodated by Cenozoic grabens flanking the Ordos Block, such as the Weihe graben, which accommodate 5–6 mm/yr of extension. To define the onset and evolution of major Cenozoic extension, we examine the cooling history of exhumed footwall rocks in the North Qinling range adjacent to the Weihe graben. We present results from 47 new apatite fission track (AFT) samples—primarily from two vertical transects of 1.5–2.5 km relief located on the northern flank of the North Qinling footwall. AFT ages that get progressively older with increasing distance from the active, range bounding, normal fault suggest that Cenozoic uplift and southward tilting was a response to range-parallel extension. Correlations between AFT ages and both elevation and track lengths, combined with thermal modeling of representative samples, reveal that the North Qinling experienced two major stages of Cenozoic exhumation: (1) relatively slow exhumation in response to a small magnitude of extension that initiated at ~50 Ma; (2) relatively rapid exhumation in response to a large magnitude of accelerated extension that initiated at ~10 Ma. In addition, small changes in cooling rate at ~35 Ma and ~25 Ma may reflect minor changes in faulting rate. We interpret initial extensional at ~50 Ma to be a far-field effect of initial India–Asia continental collision. In contrast, accelerated extension after ~10 Ma along the Qinling is likely linked to the upward and outward growth of the Tibetan Plateau. Alternatively, lower crustal flow beneath the Qinling may have progressively accelerated exhumation in late Miocene time.

1. Introduction

Central China has been host to widespread normal faulting in Cenozoic time (Fig. 1) (Kusky et al., 2007; Ma et al., 1982; State Seismological Bureau (SSB), 1988). In the North Qinling Range, intracontinental, range-parallel extension is dominated by high-angle normal and strike–slip faulting along the northern margin of the range (Fig. 2). Extension has resulted in rapid exhumation and uplift of the North Qinling Range as the footwalls of the North Qinling Margin Fault (NQMF) and the Huashan Front Fault (HFF) have uplifted and created a major boundary between the Weihe basin to the north and the North Qinling Range to the south (Fig. 2). The onset and evolution of Cenozoic extension in the North Qinling – Weihe, however, remains poorly constrained. Exhumed and exposed North Qinling footwall rocks provide an opportunity to study the thermal history of the fault block to illuminate the onset, magnitude and duration of major extension (Stockli, 2005). AFT thermochronology is a powerful approach to directly date the exhumation and cooling of footwall rocks that result from major normal fault slip in the upper crust during extension. Footwall rocks undergo relative uplift during slip on a normal fault, leading to exhumation and cooling of the footwall such that the timing of fault slip can be estimated from the age of this cooling (Ehlers et al., 2001; Stockli, 2005). AFT thermochronology has been widely and successfully applied to investigate the timing, spatial distribution and duration of extensional tectonic exhumation, rates and rate variations of fault slip, and magnitude of exhumation and crustal tilting (Armstrong et al., 2003; Colgan et al., 2006; Ehlers and Chapman, 1999; Ehlers et al., 2001, 2003; Fosdick and Colgan, 2008; Jolivet et al., 2009; Liu et al., 2010; Stockli et al., 2002, 2003). Therefore, AFT thermochronology of the North Qinling Range should provide useful information on the cooling and exhumation history of the range related to range-parallel extension.

Several studies have been performed on the exhumation/cooling history of the Qinling using fission track and (U–Th)/He thermochronologies (Chen et al., 2001; Enkelmann et al., 2006; Hu et al., 2006; Yin et al., 2001). Results of these previous studies provide useful constraints on the Late Mesozoic and early Cenozoic thermotectonic

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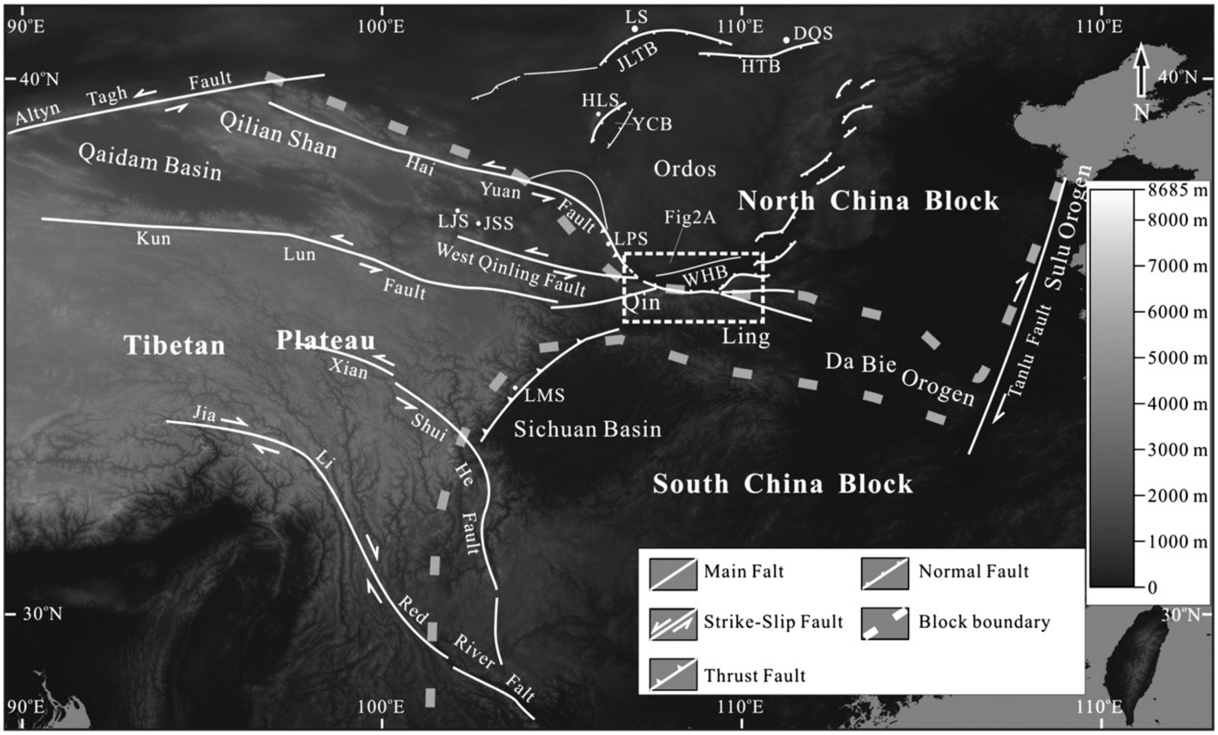

Fig. 1. Regional topographic map of the Qinling, which lies between the Tibetan Plateau, North China Block, and South China Block. LJS—Laji Shan; JSS—Jishi Shan; LS—Lang Shan; DQS—Daqing Shan; HLS—Helan Shan; LPS—Liupan Shan; LMS—Longmen Shan; JLTB—Jilantai Basin; HTB—Hetao Basin; YCB—Yinchuan Basin; WHB—Weihe Basin.

evolution of the Qinling region. However, most of the existing low-temperature thermochronologic data are from the south flank of the North Qinling Range. There are only a limited number of studies on the north flank of the North Qinling Range (the footwall of the NQMF): extant low-temperature thermochronologic data consist of only six zircon and AFT ages without track-length measurements, plus two AFT ages with track-length measurements at Huashan Mountain in the north flank of the North Qinling Range (or Lesser Qinling) (Hu et al., 2006; Yin et al., 2001), and six apatite AFT ages without track-length measurements at Taibaishan Mountain in the north flank of the North Qinling Range (Chen et al., 2001). Thus, the timing, patterns and history of range cooling and uplift related to the range-parallel extension in Cenozoic time are poorly constrained; in particular, little is known about the late Cenozoic history of extensional exhumation.

In this study, we present new AFT data from two transects from the northern flank of the North Qinling Range and from one longer transect across the entire North Qinling Range (Fig. 3A). When combined with published AFT data from the Qinling region, the data show that the spatial distribution of exhumation was controlled by Cenozoic extensional deformation. The AFT data thermal models reveal that the North Qinling Range has experienced at least two stages of differential exhumation/cooling and uplift in response to range-parallel extension, initiating at ~50 Ma and ~10 Ma. Our new constraints on the timing, stages, and magnitude of exhumation in the North Qinling Range help in understanding the mechanisms of extensional tectonics and mountain building in the Qinling as well as in other extensional regions in northern and eastern China.

2. Geological setting

The E–W trending Qinling orogen is the western portion of the Qinling-Dabie orogenic belt, which formed by the collision of the North China Block (NCB) with the South China (or Yangtze) Block in Triassic time (Fig. 1) (Ames et al., 1996; Hacker et al., 2004; Meng and Zhang, 2000; Ratschbacher et al., 2003; Roger et al., 2011; Zhang et al., 1989). After the Triassic collision, The Qinling-Dabie orogenic belt was subject to post-collision intracontinental mountain building, characterized by granitic pluton intrusion and large-scale extensional deformation (Peltzer et al., 1985; Ratschbacher et al., 2003; Xing et al., 2005; Zhang et al., 2001). The Qinling-Dabie belt constitutes an important regional geologic and climatic boundary in central China. To the west, numerous active strike–slip and thrust faults constitute the northeastern margin of the Tibetan Plateau, and continues to the Kunlun and Qilian orogens (Burchfiel et al., 1991; Gaudemer et al., 1995; Harkins et al., 2010; Jolivet et al., 2001; Lasserre et al., 1999; Li et al., 2009; Yin et al., 2007, 2008; Zhang et al., 1991). To the east lies the Dabie orogen and the Sulu terrane (Hacker et al., 1998, 2004, 2006; Yin and Nie, 1993). To the north lies the Ordos block, bounded by Cenozoic rift basins, which has been tectonically stable with very little Cenozoic or Recent deformation (Fig. 1) (Deng and You, 1985; Deng et al., 1984).

The geologic framework and tectonic evolution of the Qinling orogen have been investigated extensively during the last several decades (Meng and Zhang, 1999, 2000; Ratschbacher et al., 2003; Zhang et al., 1995a, 1995b, 1996, 2001). The Qinling orogen is a multiple-system orogenic belt with two mountain chains: the North Qinling Range and the South Qinling Range, which are separated by the strike–slip Shangdan fault (Fig. 2). Bedrock units exposed in the Qinling orogen include Archean crystalline basement, overlain by a series of Precambrian metamorphic rocks and Mesozoic-Paleozoic sedimentary strata, which have been intruded by widespread granitoid plutons which are of 152–135 Ma ages (Zhang et al., 2001). Cenozoic sedimentary strata are preserved in late Cretaceous–Cenozoic intermountain basins and rifted graben basins that resulted from normal and strike–slip faulting in the Qinling orogen (Fig. 2).

Our study area is limited to the North Qinling, a range with asymmetric topography of moderate relief on its southern flank, and steep relief up to 3000 m on its northern flank (Fig. 3). The North Qinling Range is bounded on its northern flank by the North Qinling Margin Fault (NQMF) and the Huashan Front Fault (HFF). These faults constitute a major boundary between the exhumed and southward-tilted