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Synchronous deformation on orogenic plateau margins: Insights from the Arabia–Eurasia collision

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ABSTRACT

The temporal and spatial distribution of deformation during the early phases of Plateau formation is poorly known. The Iranian Plateau is developing in response to Arabia–Eurasia convergence and is a potential analog to the early phases of Tibetan Plateau deformation. Previous studies document the onset of the Iranian Plateau growth based on the kinematic history of the Zagros to the south and the Alborz Mountains to the north. Here we present new detrital apatite fission track (AFT) data from 13 modern rivers of the Talesh Mountains, northwestern Iranian Plateau. These mountains lie immediately south west of the rigid South Caspian Block. A total of 1233 single grain cooling ages were measured and range between 185 and 4 Ma. Deconvolution of grain-age data documents three main phases of exhumation including: the Oligocene (30–23 Ma), early to middle Miocene (18–12 Ma), and early Pliocene (~5 Ma). Comparison between cooling ages from the Talesh Mountains and elsewhere across the Iranian Plateau indicates widespread plateau formation in the Oligocene, earlier than previously suggested for the northwestern plateau margin. These results highlight deformation on both the northern and southern margins of the plateau over almost the entire history of Iranian Plateau formation. A similar pattern of synchronous deformation on the north-northeastern and southern margins of the Tibetan Plateau has recently been documented and highlights the significance of rigid basement blocks focusing far field deformation for both plateaus.

1. Introduction

The Iranian Plateau with a mean elevation of ~2000 m is centrally located in the Arabia–Eurasia continental collision zone (Fig. 1). Previous estimates of the temporal pattern of deformation within and around the Iranian Plateau were controversial for decades and range from the Cretaceous to Late Cenozoic (e.g., Allen et al., 2004; Axen et al., 2001; Ballato et al., 2010; Berberian and King, 1981; Guest et al., 2007; Mouthereau, 2011; Rezaeian et al., 2012; Ritz et al., 2006). Previous studies have investigated the geologic evolution of this collision, but the initiation of plateau formation within the evolutionary succession of Arabia–Eurasia collision is poorly known. Like the Tibetan Plateau, the Iranian Plateau developed in response to continent–continent collision, but with the difference that the magnitude and rate of convergence are estimated to be smaller for the Arabia–Eurasia collision (Hatzfeld and Molnar, 2010). The Iranian Plateau therefore provides an alternative setting for understanding the rates and style of orogenic plateau growth. The later onset time of deformation and slower rate of convergence relative to the Himalaya–Tibet systems make the Iranian Plateau an intriguing analog for a better understanding what could have been earlier stages of the Tibetan Plateau formation. This comparison has previously been highlighted with respect to geophysical and present day kinematic studies (e.g., Allen et al., 2004; Hatzfeld and Molnar, 2010).

Different mechanisms have been proposed for Tibetan and Iranian Plateau formation, the collision of the continental blocks is the major driving force for forming a high elevated and low relief plateau. In collisional tectonic settings, plateaus are hypothesized to start forming near the colliding plate boundary and then propagate away from the collision zone into the interior (England and Houseman, 1986; Molnar et al., 1993; Tapponnier et al., 1982, 2001). An alternative model suggests plateau development initiating not only near the boundary of the collision zone but also more distal from the collision zone in the plate interior (Clark, 2007; Clark and Royden, 2000). The later model is recently suggested for the Tibetan Plateau from a variety of data demonstrating synchronous deformation at its northern and southern margins rather than isolated near the plate boundary (Clark, 2007; Clark and Royden, 2000; Royden, 1996; Royden et al., 1997). Integration of new and existing data along the southern and northern margins of the Iranian Plateau can provide insights into the previous models of plateau growth (e.g., Allen et al., 2004; Mouthereau et al., 2012). The timing of

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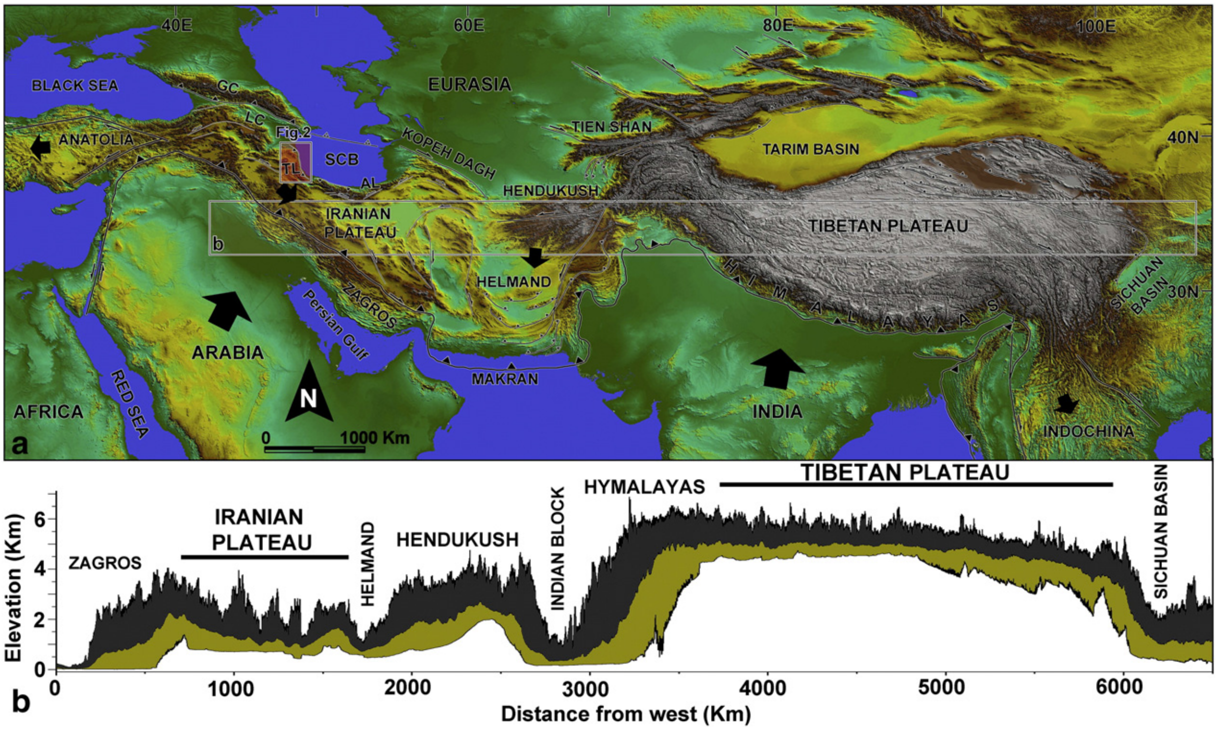

Fig. 1. a) General structural features in the Arabia–Eurasia and India–Asia continental collision zones. Solid arrows represent the plate and micro-plates' movement direction. SCB = the South Caspian Basin, LC: Lesser Caucasus, GC: Greater Caucasus. b) Swath profile across the India–Asia and Arabia–Eurasia collision zones. Swath topography was selected by extracting a narrow rectangular patch of topography with the long axis passing from the Tibetan Plateau at east to the Iranian Plateau at west. The topographic values of the swath are projected onto a vertical plane parallel to the long axis of the swath rectangle, and maximum, mean, and minimum topographic curves are calculated. The width of our swath profiles was ~200 km, a range that was narrow enough to avoid averaging in the large-scale along-strike variations in geologic structure.

deformation associated with the Iranian Plateau is partially inferred from the Alborz and Zagros Mountains (e.g., Allen et al., 2003; Axen et al., 2001; Ballato et al., 2013; Gavillot et al., 2010; Guest et al., 2007; Homke et al., 2004, 2010; Khadivi et al., 2012; Okay et al., 2010; Rezaeian et al., 2012). Low-temperature thermochronometer data are widely used to resolve the upper crustal deformation and exhumation histories of orogens (e.g., Clark et al., 2005; Ketcham et al., 2007; Kirby et al., 2002; Zeitler, 1985). Previous thermochronometer data from the Talesh Mountains and the neighboring Greater Caucasus Mountains include Ar–Ar technique from basaltic lava flows in the Paleocene–Eocene volcano-sedimentary sequences in the most northern part of the Talesh Mountains in Azerbaijan by Vincent et al. (2005) and the low temperature thermochronometer data from the central Great Caucasus Mountains by Avdeev and Niemi (2011). We present new detrital apatite fission track (AFT) data from the Talesh Mountains in the northwestern Iranian Plateau. Comparison of these data with other thermochronometer data from different parts of the Iranian Plateau (Avdeev and Niemi, 2011; Axen et al., 2001; Ballato et al., 2013; Gavillot et al., 2010; Guest et al., 2007; Homke et al., 2004; Karagaranbafghi et al., 2011; Okay et al., 2010; Rezaeian et al., 2012; Vincent et al., 2007, 2011) constrains the chronology of exhumation across the northern plateau margin and the history of the plateau growth. Here we complement previous work in the northern margin of the Iranian Plateau with new thermochronometer ages from the Talesh Mountains. We conclude with a discussion of the similarities and differences between models of Iranian and Tibetan Plateaus and the potential influence of rigid basement blocks in the evolution of the northern margin of these settings.

2. Geologic background

The Iranian Plateau comprises an amalgamation of continental blocks that are bounded by a series of high relief mountain ranges including the Kopeh Dagh, Alborz, Talesh and Caucasus Mountains to the north, and the Zagros Mountains and Makran active subduction related complex to the south (Fig. 1). The continental collision between Arabia and Eurasian continental fragments acts as the main driving force in the Cenozoic deformation history of the Iranian Plateau and adjacent areas (e.g., Alavi, 1994; Berberian and King, 1981). As a result of this collision the overlying sedimentary cover was deformed and shortened ~200–300 km during Cenozoic time (e.g., Allen et al., 2004; McQuarrie et al., 2003; Morley et al., 2009). The South Caspian Block, located at the southern margin of the Eurasian Plate (Fig. 1) influenced the pattern of deformation at the northern margin of the Iranian Plateau(e.g., Allen et al., 2003; Berberian, 1983; Berberian and King, 1981; Jackson et al., 2002).

The rigid basement of the South Caspian Basin is one of the thickest basins in the world and is covered by ~20 km of Cenozoic sediments, which overlie in the crystalline basement (e.g., Berberian, 1983; Zonenshain and Le pichon, 1986). The crystalline rigid basement of the basin is slightly thicker than that observed in ocean basins, with a mean thickness of ~10 km and seismic characteristics similar to oceanic crust (e.g., Berberian, 1983; Knapp and Connor, 2004). This oceanic lithosphere subducts below the Eurasian Plate along the Apsheron–Balkhan sill (e.g., Allen et al., 2003; Berberian, 1983; Jackson et al., 2002). A small component of underthrusting of this lithosphere beneath the continental crust of the Talesh Mountains is suggested by seismic and gravity data (e.g., Allen et al., 2003; Berberian, 1983; Granath et al., 2007; Jackson et al., 2002).

The Talesh Mountains at the northwestern border of the Iranian Plateau (Figs. 1, 2) have a curved geometry that wraps around the western side of the South Caspian Basin (e.g., Allen et al., 2003; Berberian, 1983; Jackson et al., 2002). Present day NE directed oblique convergence between the Arabia and Eurasia plates is accommodated through a combination of strike-slip (~5 mm/yr in the central part of the Talesh Mountains) and thrust faulting