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Lake overspill and onset of fluvial incision in the Iranian Plateau: Insights from the Mianeh Basin

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ABSTRACT

Orogenic plateaus represent a prime example of the interplay between surface processes, climate, and tectonics. This kind of an interplay is thought to be responsible for the formation, preservation, and, ultimately, the destruction of a typical elevated, low-internal relief plateau landscape. Here, we document the timing of intermontane basin filling associated with the formation of a low-relief plateau morphology, followed by basin opening and plateau-flank incision in the northwestern Iranian Plateau of the Arabia–Eurasia collision zone. Our new U–Pb zircon ages from intercalated volcanic ashes in exposed plateau basin-fill sediments from the most external plateau basin (Mianeh Basin) document that the basin was internally drained at least between ∼7 and 4 Ma, and that from ∼5 to 4 Ma it was characterized by an ∼2-km-high and ∼0.5-km-deep lake (Mianeh paleolake), most likely as a result of wetter climatic conditions. At the same time, the eastern margin of the Mianeh Basin (and, therefore, of the Iranian Plateau) experienced limited tectonic activity, as documented by onlapping sediments and smoothed topography. The combination of high lake level and subdued topography at the plateau margin led to lake overspill, which resulted in the cutting of an ∼1-km-deep bedrock gorge (Amardos) by the Qezel-Owzan River (QOR) beginning at ∼4 Ma. This was associated with the incision of the plateau landscape and the establishment of fluvial connectivity with the Caspian Sea. Overall, our study emphasizes the interplay between surface and tectonic processes in forming, maintaining, and destroying orogenic plateau morphology, the transitional nature of orogenic plateau landscapes on timescales of 10^6 yr, and, finally, the role played by overspilling in integrating endorheic basins.

1. Introduction

Orogenic plateaus are extensive and elevated regions with a subdued internal relief, steep and highly dissected margins, and a thick, approximately isostatically compensated crust (e.g., Dewey et al., 1988; Isacks, 1988). Plateau interiors are generally located on the leeward side of major orographic barriers, and are therefore characterized by an arid to semi-arid climate, which tends to favor the development of endorheic (internally drained) sedimentary basins (Sobel et al., 2003; Garcia-Castellanos, 2007). The sedimentary infills of these basins constitute a unique record of the uplift and erosion of nearby ranges, thereby representing a valuable long-term environmental archive (Burbank and Johnson, 1982; Sobel et al., 2003; Hilley and Strecker, 2005; Garcia-Castellanos, 2007; Strecker et al., 2009; Carroll et al., 2010). Importantly, the fate of these sedimentary basins is linked to the complex interplay between surface processes, which are primarily controlled by climate, and tectonic activity along the plateau margins. In particular, tectonic activity is needed to not only create an elevated and efficient orographic barrier, but also to maintain it, and to thereby preserve the typical plateau morphology (Sobel et al., 2003; Garcia-Castellanos, 2007). At the same time, the lack of tectonic activity within the basin interior can lead to the development of larger coalescent basins in association with shifts in basin depocenters and sediment redistribution within the plateau area (e.g., Metivier et al., 1998; Sobel et al., 2003). Prime examples of such processes exist in Tibet and in the Puna-Altiplano Plateau, where protracted endorheic conditions have lasted for timescales

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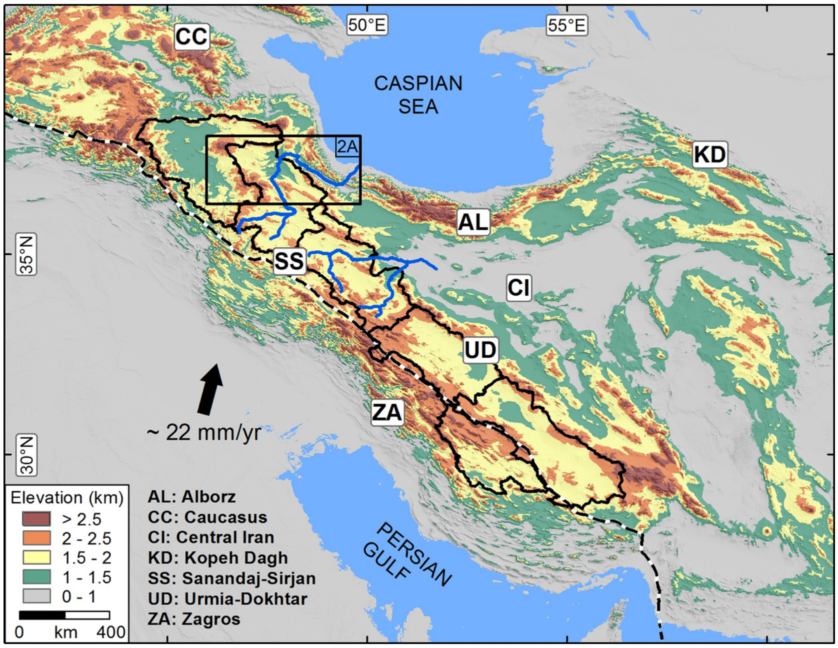

Fig. 1. Digital elevation model of the Arabia–Eurasia collision zone and the Iranian Plateau. The black dashed line represents the approximate location of the Arabia–Eurasian plate boundary, while the arrow indicates the direction of the relative motion of Arabia with respect to Eurasia (Vernant et al., 2004). Black polygons denote the extent of the Iranian Plateau and its drainage basins. The blue lines depict the main rivers of two externally drained basins. The black rectangle indicates the location of Figs. 2A and 2B. Abbreviations: AL: Alborz Mountains, CC: Caucasus Mountains, CI: Central Iran, KD: Kopeh Dagh, SS: Sanandaj–Sirjan belt, UD: Urmia-Dokhtar belt, ZA: Zagros orogen. (For the references to color in the figures, the reader is referred to the web version of the article.)

of 10^7 yr (Allmendinger et al., 1997; Metivier et al., 1998). Overall, this interplay between tectonics and climate appears to play a critical role in maintaining the typical low-relief plateau morphology. This implies that the perturbation of such a delicate system, which can occur either during changes in climate or in the locus of tectonic activity, can lead to disequilibrium conditions, which trigger the rapid destruction of the plateau morphology via fluvial incision (Meek and Douglass, 2001; House et al., 2008; Craddock et al., 2010).

Numerous studies have been conducted to date on the formation of orogenic plateaus in different geodynamic environments (e.g., England and McKenzie, 1982; Isacks, 1988; Molnar et al., 1993; Royden et al., 1997; Sobel et al., 2003; Garcia-Castellanos, 2007; Ballato et al., in press), but our knowledge concerning the demise of plateaus is limited. Gravitational collapse and tectonic denudation are tectonically controlled mechanisms that have been inferred to ultimately lower topography in these environments (e.g., Dewey, 1988; Rey et al., 2001; Jadamec et al., 2007). Alternatively, fluvial incision of plateau landscapes by rivers draining their steep flanks can occur while surface uplift is still happening. For instance, field-based studies have documented basin incision and excavation of plateaus and their marginal basins in Eastern Tibet (e.g., Brookfield, 1998; Clark et al., 2006; Liu-Zeng et al., 2008; Craddock et al., 2010), in the Puna-Altiplano Plateau (Hilley and Strecker, 2005; Montero-Lopez et al., 2014), and in the Colorado plateaus (e.g., Blackwelder, 1934; Meek and Douglass, 2001; Dickinson, 2012). However, the timing and mechanisms of incision, as well as the role of the possible interplay between surface and tectonic processes, are a matter of debate in most of these cases. Typical suggested mechanisms are basin overspill (top-down) and headward erosion (bottom-up) (e.g., Spencer and Pearthree, 2001; Douglass et al., 2009 and references therein), but the lack of unequivocal diagnostic criteria for distinguishing such mechanisms often hampers our understanding of these processes as well as the rates at which they occur.

The orogenic Iranian Plateau is part of the Cenozoic Arabia–Eurasia continental collision zone (e.g., Ballato et al., 2011 and references therein) and comprises the northwest–southeast-oriented Sanandaj–Sirjan metamorphic zone, the Urmia (Urumieh)–Dokhtar volcanic belt, and part of the High Zagros Mountains (Ballato et al., 2013; Ballato et al., in press) (Fig. 1). The plateau consists of six endorheic basins filled by sediments sourced from the ranges within and at the margins of the plateau. Two of these basins, however, are now externally drained and characterized by a fluvial network that is adjusting to lower base levels outside of the plateau, including playa lakes in Central Iran and the Caspian Sea (Fig. 1). Overall, the sedimentary basins of the Iranian Plateau are characterized by high aridity (several hundred mm/yr of rainfall decreasing southeastward) due to the presence of orographic barriers such as the Alborz and the Zagros-Bitlis Mountains, which intercept moist air masses sourced from the Caspian Sea and the Mediterranean–Atlantic regions, respectively (Ballato et al., 2010). In this study, we focused on the sedimentary basin evolution of the Mianeh Basin (northwestern Iranian Plateau), which is currently connected to the Caspian Sea by the Qezel-Owzan River (QOR) via a narrow bedrock gorge (Amardos gorge) at the plateau margin (Fig. 2A). There, fluvial incision provides exposure of a rich sedimentary archive that recorded the plateau growth and therefore provides opportunities to understand the basin-fill processes as well as to explore timing and mechanisms that led to the development of an external drainage system. Furthermore, we analyzed the characteristics of the drainage network along the Amardos gorge in order to document ongoing incision processes and gain insights into the mechanisms that may have led to the establishment of fluvial connectivity between the Iranian Plateau and the Caspian Sea. Overall, our study documented that lake overspill, the importance of which may have been overlooked in other plateau regions, represents an efficient and rapid process in triggering the destruction of a typical plateau morphology.

2. Background

2.1. Geology of the Mianeh Basin

The Mianeh Basin is bounded by a series of mountain ranges that formed through the combined effects of tectonic shortening