Tectonophysics 694 (2017) 332–355

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Neogene shortening and exhumation of the Zagros fold-thrust belt and foreland basin in the Kurdistan region of northern Iraq

Renas I. Koshnaw [a,*], Brian K. Horton [a,b], Daniel F. Stockli [a], Douglas E. Barber [a], Mazin Y. Tamar-Agha [c], Jerome J. Kendall [d]

[a] Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78712, USA
[b] Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78712, USA
[c] Department of Earth Sciences, College of Science, University of Baghdad, Jadiriya, Iraq
[d] Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA

ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form 25 October 2016
Accepted 13 November 2016
Available online 16 November 2016

Keywords:
Zagros
Fold-thrust belt
Foreland basin
Shortening
Out-of-sequence thrusting
Critical taper
Detrital zircon
Thermochronology

ABSTRACT

The Zagros fold-thrust belt in the Kurdistan region of Iraq encroached southward toward a rapidly subsiding Neogene foreland basin and was later partitioned by out-of-sequence shortening focused along the Mountain Front Flexure (MFF), as defined by new low-temperature thermochronologic, stratigraphic, and provenance results. Apatite (U-Th)/He ages document rapid deformation advance from the Main Zagros Fault to southern frontal structures (Kirkuk, Shakal, and Qamar thrusts) at ~10–8 Ma, followed by potential basement-involved out-of-sequence development of the MFF (Qaradagh anticline) by ~5 Ma. Distinct shifts in detrital zircon U-Pb provenance signatures for Neogene foreland basin fill provide evidence for drainage reorganization during fold-thrust belt advance. U-Pb age spectra and petrologic data from the Injana (Upper Fars) Formation indicate derivation from a variety of Eurasian, Pan-African, ophiolitic and Mesozoic-Cenozoic volcanic terranes, whereas the Mukdadiya (Lower Bakhtiari) and Bai-Hasan (Upper Bakhtiari) Formations show nearly exclusive derivation from the Paleogene Walash-Naopurdan volcanic complex near the Iraq-Iran border. Such a sharp cutoff in Eurasian, Pan-African, and ophiolitic sources is likely associated with drainage reorganization and tectonic development of the geomorphic barrier formed by the MFF. As a result of Zagros crustal shortening, thickening and loading, the Neogene foreland basin developed and accommodated an abrupt influx of fluvial clastic sediment that contains growth stratal evidence of synkinematic accumulation. The apparent out-of-sequence pattern of upper crustal shortening in the hinterland to foreland zone of Iraqi Kurdistan suggests that structural inheritance and the effects of synorogenic erosion and accumulation are important factors influencing the irregular and episodic nature of orogenic growth in the Zagros.

1. Introduction

Interactions between thrust belt exhumation and foreland basin accumulation have been investigated by numerical models (Beaumont et al., 1992; Avouac and Burov, 1996; Willett, 1999; Whipple and Meade, 2004; Stockmal et al., 2007; Fillon et al., 2013) and analog experiments (Storti and McClay, 1995; Barrier et al., 2002; Marques and Cobbold, 2002; Bonnet and Crave, 2003; Del Castello et al., 2004), but the linkages in natural systems have proven elusive (e.g., Horton, 1999; Simpson, 2006; Whipple, 2009). Previous studies suggest that surface processes such as erosion and deposition can influence the style and spatial distribution of fold-thrust deformation in an orogenic wedge (e.g., Bonnet et al., 2007; Berger et al., 2008; Barnes et al., 2012). Syntectonic mass accumulation in the wedge-top zone can promote deformation advance and generate a broader orogenic wedge (Horton, 1998; Sobel et al., 2003; Stockmal et al., 2007; Fillon et al., 2013). In the frontal segments of fold-thrust wedges, the length of the advancing thrust sheet may be controlled by the thickness of the stratigraphic overburden (Elliott, 1976a, b; Mitra and Boyer, 1986). Relatively modest sedimentary loads induce a lower ratio of vertical to horizontal stress, producing a frontal wedge less prone to forward advance, thereby influencing the locus of thrusting (Johnson, 1981; Willemin, 1984; Fillon et al., 2013). In foreland basins, thick sedimentary deposits could promote the activation of weak layers as décollements and generate wedge-top basins (Konstantinovskaya et al., 2009; Chapman and DeCelles, 2015). Numerous case studies have demonstrated that surface erosion not only places limits on the geometry, dimension, and rock-uplift patterns of orogenic wedges, but also localizes deformation and exhumation by regulating advance of the orogenic wedge (e.g., Masek et al., 1994; Pavlis et al., 1997; Horton, 1999; Willett, 1999; Montgomery et al., 2001; Whipple and Meade, 2004; Simpson, 2006). When erosion inhibits wedge

* Corresponding author.
E-mail address: renas.i.koshnaw@gmail.com (R.I. Koshnaw).

http://dx.doi.org/10.1016/j.tecto.2016.11.016
0040-1951/

advance, crustal thickening is necessary to maintain critical taper (Davis et al., 1983; Dahlen and Suppe, 1988; Dahlen, 1990), which can be achieved by out-of-sequence thrusting, backthrusting, duplexing, and underthrusting (Malavieille, 2010; Konstantinovskaya and Malavieille, 2011). In addition to surface processes, other factors such as mechanical stratigraphy and structural inheritance can influence growth of the fold-thrust belt and foreland basin (Lageson and Schmitt, 1994; Boyer, 1995). During regional compression, upper crustal shortening is more likely to be focused along zones of weakness such as preexisting, suitably oriented normal faults (White et al., 1986). This implies that variations in the predeformational framework may strongly influence thrust belt development (Tavarnelli et al., 2004; Mora et al., 2006; Perez et al., 2016).

Critically tapered fold-thrust wedges are strongly influenced by the mechanical properties of the deforming wedge and basal décollement. For a weak basal layer, the wedge is typically characterized by a low topographic slope, regularly spaced and symmetric décollement folds, high angle faulting, and no preferred vergence direction for major structures. In contrast, in the case of a strong frictional base, the wedge is characterized by high topographic slope, asymmetric folds, and enhanced internal deformation (Chapple, 1978; Davis and Engelder, 1985; Jaumé and Lillie, 1988; Letouzey et al., 1995; Braathen et al., 1999; Ford, 2004). For low-friction ductile surfaces promote faster and farther deformation advance and thus produce broader orogenic belts (e.g., Cotton and Koyi, 2000; Bahroudi and Koyi, 2003). Therefore, surface processes combined with internal wedge properties, structural inheritance, and foreland basin mechanical stratigraphy largely influence the position of the deformation front, structural style, and overall modes of thrust belt and foreland basin growth.

A prominent tectonomorphic feature of the Zagros orogenic belt is defined by the Mountain Front Flexure (MFF), a key structural boundary separating high anticlines of the Zagros mountains from the less-deformed foothills belt underlain by blind thrust faults (Berberian, 1995; McQuarrie, 2004). The architecture of this structural boundary relative to the Zagros foreland basin has produced the Fars salient, Lorestan salient (Pusht-E-Kuh arc) and intervening Dezful and Kirkuk embayments (Haynes and McQuillan, 1974; Berberian, 1995). Cross-section restorations outside of the Kirkuk embayment have shown diverse magnitudes of Zagros shortening (ranging from 50 to 84 km) and varying degrees of basement involvement (McQuarrie, 2004; Vergés et al., 2011; Mouthereau et al., 2012; Saura et al., 2015). The kinematic evolution of the Zagros fold-thrust belt in Iran has been proposed to have involved distributed basement shortening (Blanc et al., 2003; Sherkati and Letouzey, 2004; Farzipour-Saein et al., 2009; Agard et al., 2011) and out-of-sequence thrusting (Molinaro et al., 2005; Fard et al., 2006). Alternatively, other researchers have interpreted basement involvement to be restricted to the hinterland (northern) segment, near the Zagros-Bitlis suture and away from the MFF (McQuarrie, 2004; Jahani et al., 2009), with sequential propagation of shortening toward the foreland (Alavi, 2004; Hessami et al., 2001; Sarkarinejad and Ghanbarian, 2014).

Previous paleontological and stratigraphic suggest span a wide range of estimated ages for the Arabia-Eurasia collision, including the Late Cretaceous (Alavi and Mahdavi, 1994; Alavi, 2004), Eocene (Numan, 1997, 2001), Oligocene–early Miocene (Koop et al., 1982; Fakhari et al., 2010; Horton et al., 2008), middle to late Miocene (Axen et al., 2001; McQuarrie et al., 2003; Guest et al., 2007; Saura et al., 2015; Zhang et al., 2016), and Pliocene (James and Wynd, 1965; Falcon, 1974). Thermochronologic and magnetostratigraphic results for the Lorestan, Dezful, and Fars segments in the Zagros of Iran show a similarly broad range of bedrock cooling ages, with most-rapid cooling and accelerated sediment accumulation during Miocene shortening (Homke et al., 2004, 2009a, 2009b; Gavillot et al., 2010; Khadivi et al., 2010; François et al., 2014).

The purpose of this paper is to assess the timing, pattern, and potential controls on Cenozoic shortening and exhumation in the NW segment of the Zagros fold-thrust belt, and integrate results with the Neogene record of nonmarine clastic sedimentation in the adjacent foreland basin in the Kurdistan region of Iraq. In particular, we seek to evaluate whether the Zagros orogenic wedge: (i) advanced steadily through systematic forelandward propagation of the deformation front with minimal erosion or (ii) advanced intermittently through out-of-sequence thrusting and localized hinterland exhumation far from the deformation front (Morley, 1988; Woodward et al., 1989).

This study utilizes low-temperature thermochronometry for major thrust sheets—the Main Zagros Fault, MFF, and frontal thrust faults of Kirkuk, Shakal, and Qamar—and clastic units of the Neogene foreland basin, including the Injana (Upper Fars), Mukdadiya (Lower Bakhtiari), and Bai-Hasan (Upper Bakhtiari) Formations. Techniques employed in this study include low-temperature apatite (U-Th)/He thermochronometry, detrital zircon U-Pb geochronology, structural and stratigraphic syntheses, as well as sandstone petrography and conglomerate compositional analyses.

2. Geologic setting

2.1. Zagros fold-thrust belt and foreland basin

The Zagros orogenic belt represents the Middle Eastern segment of the Alpine-Himalayan orogenic system and one of the youngest continental collision zones on Earth (Falcon, 1974; Dercourt et al., 1986; Alavi, 1994; Hessami, 2002). The Zagros fold-thrust belt spans from the Oman Line in SE Iran for 2000 km along strike to the NW, across Iraqi Kurdistan into SE Turkey, where it meets the left-lateral East Anatolian Fault (Fig. 1) (Beydoun et al., 1992; Sharland et al., 2001; Alavi, 2007; Kent, 2010; Bretis et al., 2011). The SW-vergent fold-thrust belt (Alavi, 2007) and peripheral foreland basin formed as a consequence of the Arabia-Eurasia collision during final closure of the Neotethys ocean (Dercourt et al., 1986). In the Arabian plate, the Phanerozoic succession is divided into multiple tectonostratigraphic megasequences (Sharland et al., 2001). The Phanerozoic succession attains thicknesses of ~12 km in the Kirkuk and Dezful embayments and ~6 km in Fars and Lorestan arcs (Konert et al., 2001). The upper succession (34–0 Ma) represents the main phase of Zagros mountain building and includes up to 4 km of marine to nonmarine foreland basin deposits in Iraqi Kurdistan (Jasim and Goff, 2006).

Prior to the Cenozoic Arabia-Eurasia collision, northern Iraq underwent several geologic episodes that generated a thick Phanerozoic sedimentary cover. Depositional products are subdivided into six tectonostratigraphic units that reflect: (1) irregular late Neoproterozoic–Permian rifting along the northern passive margin of Gondwana; (2) Permian–Late Triassic rifting and breakup along the Gondwanan margin; (3) Triassic–Late Cretaceous tectonic quiescence and passive margin development; (4) Late Cretaceous (Berriasian–Maastrchtian) enhanced subduction of Neotethyan oceanic lithosphere beneath Eurasia and ultimately ophiolite obduction; (5) Paleogene flexural subsidence and marine foreland basin (flysch) sedimentation (Homke et al., 2009a; Saura et al., 2015) (6) Neogene Arabia-Eurasia collision and nonmarine foreland basin sedimentation (Beydoun et al., 1992; Sharland et al., 2001; Ziegler, 2001; Alsharhan and Nairn, 2003; Alavi, 2004; Saura et al., 2015).

The Zagros orogenic wedge and foreland basin are composed of five NW-trending tectonic zones representing different components of the Arabia-Eurasia collisional system (Fig. 2). (1) The Urumieh Dokhtar Magmatic Zone (UDMZ) contains an arc system formed by subduction of Neotethyan oceanic crust. (2) The Sanandaj-Sirjan Zone (SSZ) is the complex suture zone resulting from early arc collision and later continental collision. (3) The Zagros Imbricate Zone is characterized by tightly spaced imbricate thrust faults and related anticlines. (4) The Simply Folded Belt constitutes the youngest deformation zone and is expressed as regularly spaced, large-amplitude, fault-related folds affecting the Phanerozoic succession (Hessami, 2002). (5) Along the southern margin, the Zagros (or Mesopotamian) foreland basin consists of a foredeep depocenter adjacent to the deformation front (Stöcklin, 1968; Falcon,