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New geodynamical model for the regional Tertiary extension during the Zagros orogeny: A transtensional arc?

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Abstract

The Zagros orogeny in Iran is associated with two successive geodynamic events during the Tertiary period, a Paleogene NE-directed regional crustal extension followed by a Miocene NW-directed regional crustal extension and a magmatic flare-up. The current study was undertaken to reanalyze previous structural work developed on the extensional Chapedony metamorphic core complex in Central Iran exhumed during Paleogene times. A new strain framework based on progressive dextral transtensional tectonics is proposed to explain the recorded structures. Its regional significance with other extensional areas in Iran is examined and an improved tectonic model is proposed to explain the southwestward drift of extension. This study emphasizes the key role of strain partitioning on the overriding plate as it relates to the increase in convergence obliquity during the Tertiary period. It is proposed that the regional extension is related to development of transtensional tectonics.

Keywords: *Zagros orogeny, transtensional tectonics, metamorphic core complex, partitioning*

1. Introduction

Transtension (oblique divergence) is common, perhaps prevalent, in extensional arcs and rift complexes, during continental breakup, in pull-apart basins along strike-slip faults and during the late history of orogens (Dewey 2002). Strain modeling and experimental analogue studies have begun to shed new light on the deformation patterns of transtensional zones but, compared to transpressional zones, fewer detailed studies of natural examples have been carried out (see De Paola 2005 and references therein).

The Zagros mountain belt is a NW-trending orogen stretching 2000 km from the East Anatolian fault in eastern Turkey (36°N, 45°E) to the Makran subduction in southeastern Iran (26°N, 58°E). The Zagros orogen flanks the Turkish–Iranian plateau to the south and its elevation reaches a maximum of 4548 m in Khuzestan province in the SW Zagros (Fig 1). In Iran, the Mesozoic and Cenozoic convergence between Africa/Arabia and Eurasia resulted in parallel NW-SE trending tectono-metamorphic and magmatic belts. These form the Zagros (or Simply) Folded Belt, the Imbricate Zone (including the Kermanshah and Neyriz ophiolitic complexes), the Sanandaj–Sirjan zone and the Urumieh–Dokhtar volcanic arc and Central Iran (see Agard et al. 2011 for further descriptions of these domains).

It is known that the Paleogene epoch was a time of NE-directed regional crustal extension (arc-orthogonal extension) in Iran with the recognition of Paleogene metamorphic core complexes, brittle normal-faults and basin formation coeval with a magmatic flare-up similar to the mid-Tertiary event in the western United States (Fig 1) (Verdel et al. 2011 and references therein; Verdel et al. 2013; Kargaranbafghi et al. 2015). The Zagros orogen was also affected by a regional Miocene NW-directed extension (arc-parallel extension), notably described in the Miocene Takab-Zanjan metamorphic core complex area (Stockli et al. 2004; Verdel et al. 2007), the Oligo-Miocene Golpayegan basin area (Nadimi and Nadimi 2008) and the Oligo-Miocene Qom-Saveh basin (Morley et al. 2009). Furthermore, this regional Oligo-Miocene extension was also coeval with a magmatic pulse (Chu et al. 2013).

Different geodynamical models have been proposed to explain the Tertiary extension and this coeval magmatic pulse, including slab break-off (Agard et al. 2011) and ablative subduction (Agard et al. 2011). Recent studies employing coupled structural, thermochronological, geochronological and petrological analyses propose a slab roll-back model involving lithospheric removal associated with extension and upwelling of the hot asthenosphere (Verdel et al. 2007, 2011; Kargaranbafghi et al. 2015). Based on geochemical analysis, it has also been proposed that the magmatic flare-up could have been caused by transtensional tectonics (Moncef et al. 2009).

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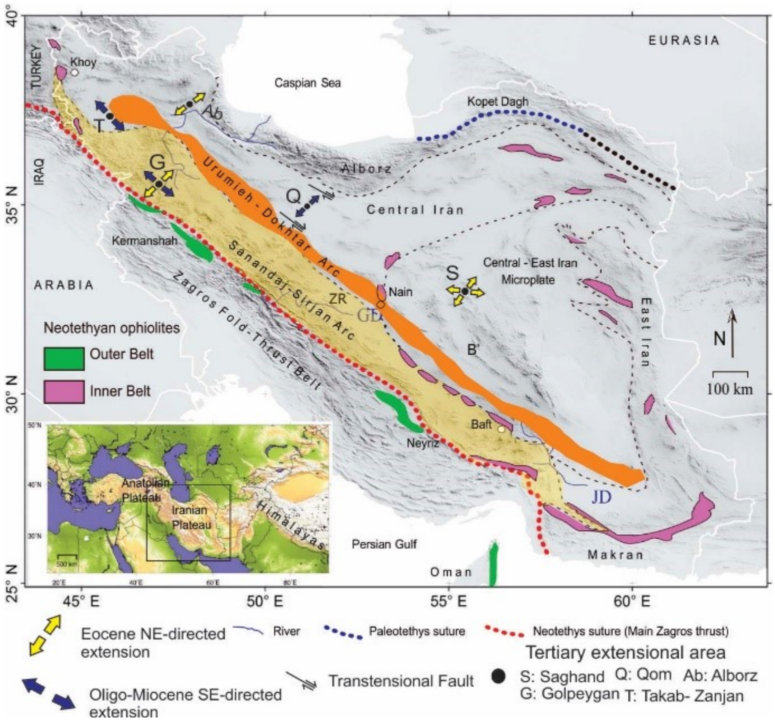

Fig 1. Map of Iran highlighting Tertiary extensional areas (modified from Verdel et al. 2007, 2011). Extensional area and related extension trending: Saghand (Verdel et al. 2007, 2013; Kargaranbafghi et al. 2015), Golpayegan (Moritz et al. 2006; Nadimi and Nadimi 2008), Takab-Zanjan (Stockli et al. 2004), Qom area (Morley et al. 2009) and Alborz (Guest et al. 2006; Shahidi et al. 2011).

The Chapedony metamorphic core complex occurs in Central Iran and was exhumed during the Paleogene (Ramezani and Tucker 2003; Verdel et al. 2007; Kargaranbafghi et al. 2015). The extensional regime remains in debate and different models exist, including the E-W-directed extension (Verdel et al. 2007, 2013), NE-SW extensional regime (Faghih et al. 2015) and the progressive ductile NNE then brittle E-directed extension (Kargaranbafghi et al. 2015). At regional scale, although the previous model explains the triggering of the NE-directed regional extension, no explanation has been provided to explain the shift from the NE to NW trend of the regional extension during the Tertiary. The current study firstly reanalyzes the previously recorded structural data on the Eocene-Oligocene Chapedony metamorphic core complex in Central Iran for transtensional tectonics. The regional significance of other extensional areas in Iran is investigated and an improved tectonic model is proposed to explain the regional Tertiary extension during the Zagros orogeny, including the effect of convergence obliquity.

2. Background: Chapedony metamorphic core complex

The Chapedony metamorphic core complex (CMCC) is located in the Saghand area in the southwestern Central Iranian block. The CMCC has an ESE-WNW extent of ~20 km and a NNE-SSW extent of ~100 km. Concerning the architecture, a NNE-trending migmatitic gneiss dome exposes high-grade metamorphic rock, primarily of migmatite intruded by less deformed granite and granodiorite. The eastern and western margin of the CMCC are bounded by the NNE-trending Chapedony and Neybaz-Chatak detachment faults. It is considered that the northeast-trending morphology is due to corrugations in the range-bounding detachment faults. The exhumation of the gneiss dome was accommodated by detachment faults that tilted toward the NE, a hanging-wall that includes Mesozoic metamorphic and sedimentary units and Eocene volcano-sedimentary deposits (Fig 2; Kargaranbafghi et al. 2015). Geochronological and thermochronological dating indicate that the HT metamorphic event and the unroofing of a gneiss dome occurs at between 49 and 30 Ma (Ramezani and Tucker 2003; Verdel et al. 2007; Kargaranbafghi et al. 2015).

Detailed structural analysis has recently been performed and proposes that the main deformation regime occurring in the footwall is a pure shear regime. The second pattern of ductile strain is a NE-directed stretching lineation associated with NE-directed ductile low-angle detachment faults. It is considered that the measured dispersion of stretching lineation is due to late-stage NW–SE shortening of the Chapedony complex (Kargaranbafghi et al. 2015; Faghih et al. 2015). However, other structural analyses record a different pattern of structures, including a northward lineation trending inside the footwall near Khoushoumi and Neybaz Mountain and a east-southeast tilt in the direction of the supradetachment basin at Khoshoumi. The authors express some issues concerning the north-northeast trend of the belt of core complexes and the lack of antiform criteria inside the footwall (Verdel et al. 2007). Based on paleostress tensor group analysis, it has been considered that the compressional phase occurred from the Late Oligocene during dextral transpressional tectonics possibly related to block rotation (Kargaranbafghi et al. 2011).

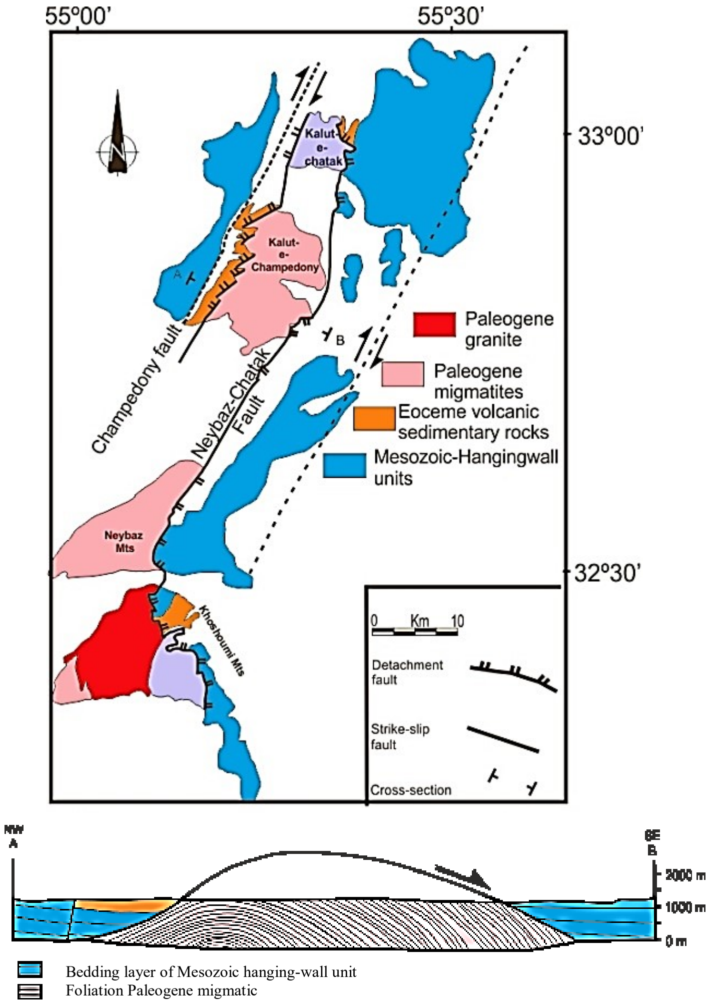

Fig 2. Structural map of Chapedony metamorphic core complex and overlying units (modified from Kargaranbafghi et al. 2015).

3. Strain framework and structural interpretation

We have analyzed the previous structural analyses and clearly identified (1) the presence of the ENE-to-E axis km folds of the foliation inside the metamorphic core and (2) the folding of N-trending detachments faults at Kalut-e-Chatak in the northern part and near Khoshoumi and Neybaz Mountain in the southern part (Figs 2 and 3). To explain this strain framework, we propose to use the 3D strain models developed for transtensional tectonics (see Teyssier and Tikoff 1999; Dewey 2001; Fohsen et al. 2013 for development discussion).

It has been inferred that these models can tentatively be applied to the Chapedony area to explain the recorded structural architecture by progressive dextral transtensional tectonics (Fig 4). It is proposed that during the first stage of exhumation, dated to the Eocene by previous geochronological and thermochronological dating, is related to a NE/NNE-directed extension that developed a NE/N-trending stretching lineation coinciding with a NNW/NW-directed detachment fault, exhuming the metamorphic core.

The end of the exhumation proposed at the Oligocene occurs with ductile N/NNE-directed to ESE-directed drift. The extensional drift is related to a transtensional tectonic that developed E-directed axis transtensional folds in the foliation, explaining the notable lack of a single antiform. During these transtensional tectonics, NNE-directed detachment faults developed while and the N-directed detachment fault was folded by constriction. Further support for the view of progressive transtensional tectonics is the pure shear regime recorded in previous studies inside the metamorphic core (Kargaranbafghi et al. 2015; Faghih et al. 2015), which is a major structural feature of transtensional tectonics.

4. Discussion and conclusion

In Iran, numerous Tertiary extensional areas have been recognized and have provided strong evidence for large-magnitude crustal extension in Iran during the Tertiary period (Verdel et al. 2011).

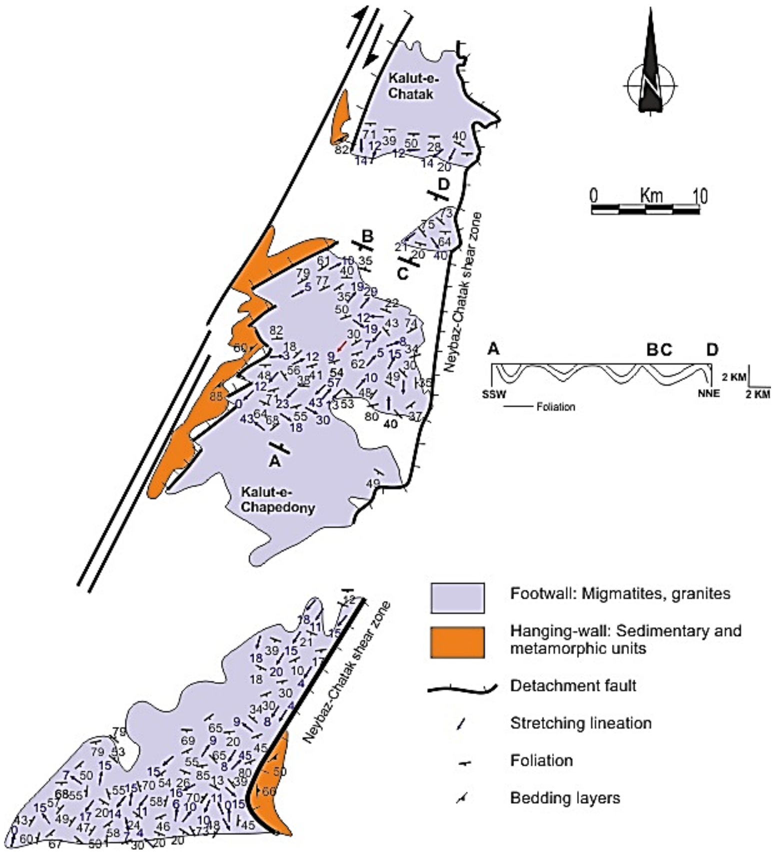

Fig 3. Structural map of Chapedony metamorphic complex (modified from Kargaranbafghi et al. 2011). SSW-NNE cross-section in Kalut-e-Chapedony area highlighting the presence of km fold with ENE-to-E axis for foliation.

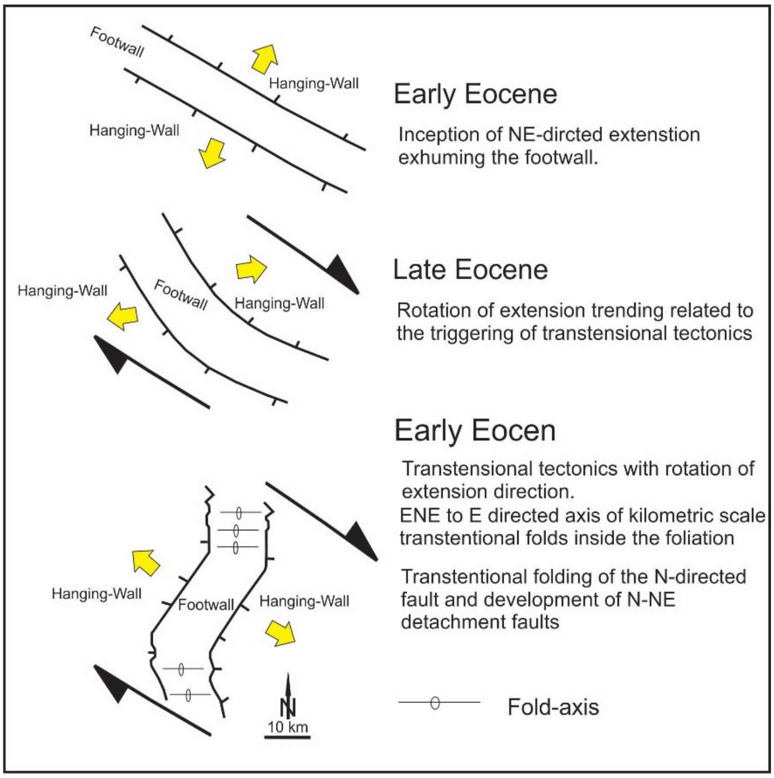

Fig 4. Cartoon model showing possible tectonic evolution for Saghand area with development of transtensional tectonics.

In addition to the Saghand area, these extensional areas include the Golpayegan area in the central Sanandaj-Sirjan zone (Nadimi and Nadimi 2008; Verdel et al. 2013; Moosavi and Mohajjel. 2014), the Takab-Zanjan area in the north Sanandaj-Sirjan zone (Stockli et al. 2004; Verdel et al. 2007), the Qom-Saveh area (Morley et al. 2009) and the Alborz mountains (Guest et al. 2006; Shahidi et al. 2011), an Eocene NE-directed extension recorded in the Golpayegan area or Alborz mountains (Shahidi et al. 2011) and an Oligo-Miocene NW-directed extension recorded in the Golpayegan area (Nadimi and Nadimi 2008) and Takab-Zanjan (Stockli et al. 2004; Verdel et al. 2007), which indicates a regional drift of extension between the Eocene and Oligo-Miocene. Toward the northeast, there are also Tertiary extensional areas in Turkey, for example, the Late Oligocene metamorphic core complex in northwest Turkey (Okay and Satir 2000) and the Early–Middle Miocene Kazdag complex in western Anatolia (Cavazza et al. 2009).

We now discuss the regional significance of the progressive Eocene to Oligocene transtensional tectonic regime highlighted in the Saghand area and the regional drift of the regional extension during Tertiary times. From this perspective, we propose a new tectonic model linking a regional extension and strain partitioning on the overriding plate related to an oblique convergence (Fig 5). Our new idiom is based on the geodynamical view that an oblique convergence is far more common than an orthogonal convergence during subduction and, at most continental arcs, an obliquity of only 10° off the orthogonal results in the formation of strike-slip faults in the upper plate (Busby 2013). During the Zagros orogeny, the previous paleo-obliquity reconstructions outline a convergence obliquity during Tertiary times at 10° between 55 and 35 Ma, followed by an increase in the obliquity of 20° between 35 to 20 Ma and 40° between 20 and 10 Ma (Agard et al. 2011). Consequently, it can be expected that the increase of the convergence obliquity has developed strain partitioning on the overriding plate and, consequently, regional wrench tectonics.

Thus, we emphasize that partitioning during the Paleogene must correlate with the local transtensional tectonics proposed for the Saghand area and, at regional scale, the shifting of the regional extension in the overriding plate from a Paleogene NE-directed extension (arc-orthogonal-extension) to a Miocene NE-directed extension (arc-parallel extension). This geodynamical model based on a review of the regional strain framework, indicates that, from Oligocene times, the Zagros orogen has become a transtensional arc as suggested by Moncef et al. (2009). Additional research on the structural analysis based on this new geodynamical model is required on all the described extensional areas and must be correlated with petrological analysis of coeval magmatic and metamorphic rocks to develop a well-constrained thermo-mechanical model of the tectonic evolution for Zagros orogeny during Tertiary times.

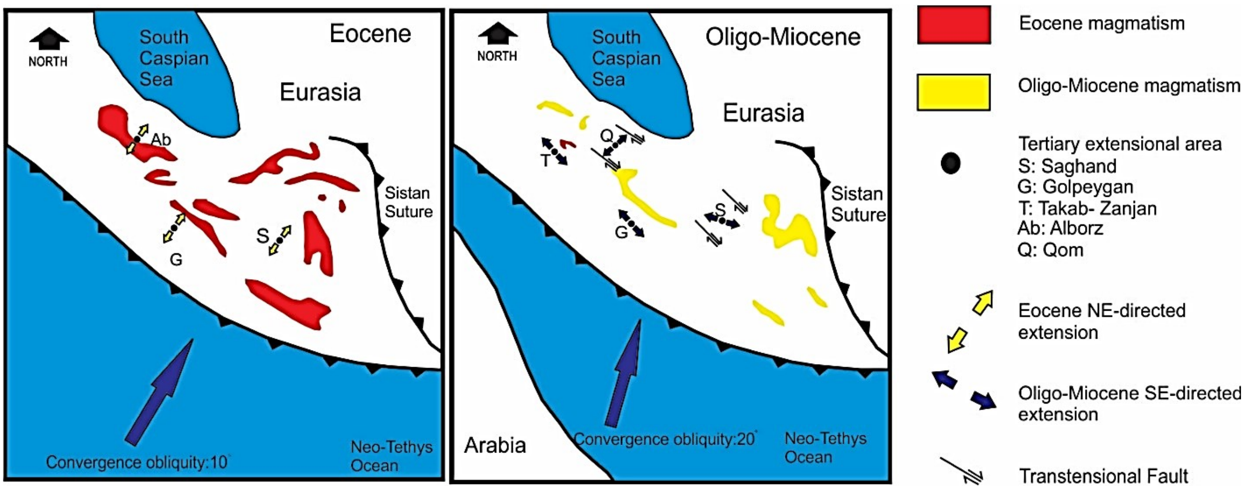

Fig 5. 2D regional geodynamical model showing the relationship between the increase in convergence obliquity and NE-to-SW drift of the regional direction extension during the Tertiary. The paleogeographical maps and magmatic events are modified from Agard et al. (2011). Extensional areas and related extension trending: Saghand (Verdel et al. 2007, 2013; Kargaranbafghi et al. 2015), Golpayegan (Nadimi and Nadimi 2008), Takab-Zanjan (Stockli et al. 2004), Qom area (Morley et al. 2009), Alborz (Shahidi and Shahidi 2008).

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