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Contrasting styles of convergence in the Arabia-Eurasia collision: Why escape tectonics does not occur in Iran

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ABSTRACT

The westward motion of Turkey relative to Eurasia between the North and East Anatolian faults has been cited as one of the best examples of lateral transport of continental crust from a collision zone, in this case the Arabia-Eurasia collision. This process is variously called "escape" or "extrusion" tectonics. Range-parallel strike-slip faults within the Alborz (e.g., the Mosha fault) and Zagros Mountains (the Main Recent fault) of Iran have been regarded as playing roles similar to those of the North and East Anatolian faults in that they are responsible for the eastward transport of intervening Iranian crust away from the northward motion of the Arabia plate relative to Eurasia. However, both seismicity and GPS data show that there is no net eastward transport of Iranian crust with respect to Eurasia. Here we summarize how the tectonically active mountain ranges of Iran deform by combinations of thrusting and strike-slip movement oblique to the overall convergence vector across each region, without requiring net eastward movement with respect to Eurasia. A general conclusion is that strike-slip faults in collision zones can have different roles. These include not only the lateral transport of crustal material demonstrated in Turkey, but also the partitioning of strain into shortening and strike-slip components shown by the Alborz and Zagros structures and the accommodation of crustal shortening by strike-slip faults that rotate about a vertical axis.

Keywords: collision, escape tectonics, Arabia, Eurasia

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INTRODUCTION

This article shows that apparently similar patterns of strike-slip faulting in Turkey and Iran are likely to perform very different roles in absorbing convergence caused by the Arabia-Eurasia continental collision. In particular, the well-known "escape" of Turkey between the North and East Anatolian faults (Fig. 1) is not mirrored by an eastward escape of Iranian crust. Large strike-slip faults are observed across much of Iran, including in the Alborz and Zagros ranges. At first sight, these faults appear to have the same role as the Anatolian structures, and yet this hypothesis is not supported by the distribution of active faulting, the seismicity, and the GPS constraints on the deformation of Iran and surrounding regions (Figs. 2 and 3).

We first summarize the overall kinematics of the Arabia-Eurasia collision as revealed by published GPS, seismicity, and geologic data. We briefly describe the North and East Anatolian faults and their implications for the kinematics of the intervening crust of Turkey. We then review the geology of the Zagros, Alborz, and Kopeh Dagh ranges and the strike-slip faults of eastern Iran, focusing on the way that thrust and strike-slip faults oblique to the overall convergence vector may act together to take up that convergence rather than simply allowing relative lateral movements of crustal material across the faults. The data are summarized in the Discussion section to make the case that there is no "escape" for Iran at the present time, nor has there been in the last few million years. This argument is not new, given that it is clearly shown in the velocity field for Iran derived by Jackson et al. (1995; Fig. 4). However, the recent availability of GPS data for Iran and new studies of Iranian fault systems make it worthwhile to review the issue at this time. We stress that our review does not cover all of the many aspects of the Arabia-Eurasia collision, but focuses on the roles of strike-slip faults.

REGIONAL TECTONICS

Deformation across southwestern Asia arises from the continental collision of the Arabia and Eurasia plates (e.g., McKenzie, 1972; Jackson and McKenzie, 1984; Dewey et al., 1986; Hempton, 1987). This is an active process, as shown by (1) plate circuit studies (e.g., DeMets et al., 1994; McQuarrie et al., 2003); (2) GPS data on both regional and local scales (e.g., McClusky et al., 2000; Sella et al., 2002; Vernant et al., 2004a); and (3) the high seismicity of many fault zones in the region (e.g., Fig. 2).

Overall, Arabia moves roughly northward with respect to the stable interior of Eurasia. The GPS-derived velocity for the northern margin of the Arabia plate is 18 ± 2 mm/yr relative to Eurasia at longitude 48°E (McClusky et al., 2000). The convergence rate increases eastward because the Arabia-Eurasia Euler pole lies in the northeast Africa region (at ~27.4°N, 18.4°E based on GPS data in McClusky et al., 2003) and is roughly 10 mm/yr higher in eastern Iran than in the west (Fig. 1). The results of GPS networks within Iran and surrounding regions give lower estimates of the Arabia-Eurasia convergence rate than earlier plate circuit studies (DeMets et al., 1990, 1994), e.g., 22 ± 2 mm/yr instead of 30.5 mm/yr at the longitude of Bahrain (~51°E) (Vernant et al., 2004a).

Jackson et al. (1995) used earthquake moment tensors to construct a velocity field for Iran and adjacent areas (Fig. 4). Their study used values for the total Arabia-Eurasia convergence based on earlier NUVEL-1A plate circuit values (DeMets et al., 1990, 1994), which are now known to be too high (Sella et al., 2002; McClusky et al., 2003; Vernant et al., 2004a). However, although the velocity fields computed from seismicity and measured by GPS give different magnitudes of displacement, they both show very similar patterns (Masson et al., 2005), with distributed shortening across the active mountain belts of Iran that drops to nearly zero at the northern and eastern borders of the country (Figs. 3 and 4).

Active deformation in Turkey shows that individual regions within a collision zone can have kinematics that are not immediately obvious from the overall plate convergence vector. McKenzie (1972) demonstrated that right-lateral slip on the North Anatolian fault and left-lateral slip on the East Anatolian fault combine to produce westward movement of the intervening Turkish crust with respect to Eurasia. This model is confirmed by GPS studies (McClusky et al., 2000) that show coherent, platelike motion of the crust of Turkey between these faults, involving little internal deformation (<2 mm/yr) and counterclockwise rotation relative to Eurasia. In the west, the westward motion of Turkey is accommodated in the Hellenic subduction zone, above which rapid back-arc extension occurs in the Aegean (Fig. 2); continental collision has yet to happen in this region.

A prominent geographical feature of the Arabia-Eurasia collision zone is the Turkish-Iranian plateau (Fig. 1), which forms roughly half the area of the entire collision zone and lies between regions of active faulting to the north and the south (Fig. 2). Plateau altitudes are typically 1.5–2 km. These altitudes may result from crustal thickening or mantle support (Kadinsky-Cade et al., 1981; Pearce et al., 1990; Dilek and Moores, 1999; Şengör et al., 2003; Maggi and Priestley, 2005). Crustal thickness estimates vary from up to ~65 km in the region of the Zagros suture to ~40–50 km in eastern Anatolia and central Iran (Snyder and Barazangi, 1986; Sandvol et al., 1998; Hatzfeld et al., 2003; Zor et al., 2003). At present, there is little sign of active crustal thickening within the internal part of the plateau region, based on the low GPS-derived values of internal deformation and the scarcity of seismogenic thrusts (Figs. 2 and 3). The high ground of eastern Anatolia forms both part of the plateau and part of the zone undergoing transport to the west with respect to stable Eurasia.

At the southern and northern margins of the collision zone in Iran, crustal shortening builds mountain ranges such as the Zagros Mountains of Iran and Iraq, the Greater and Lesser Caucasus, and the Alborz and Kopeh Dagh ranges (Figs. 1 and 5).

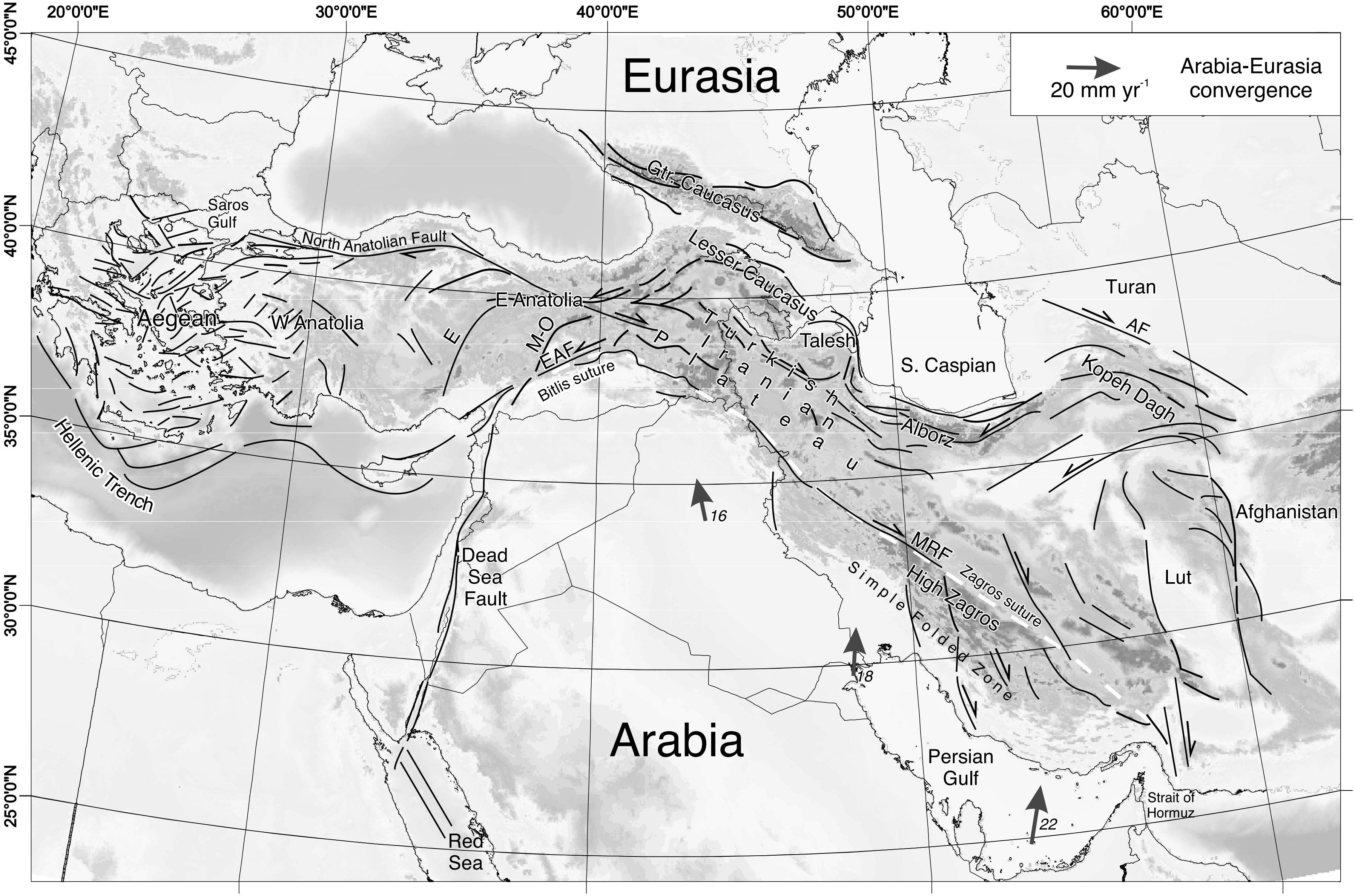

Figure 1. Location map and major structures of the Arabia-Eurasia collision. AF—Ashgabat (Ashkabad) fault; E—Ecemiş fault; EAF—East Anatolian fault; M-O—Malatya-Ovacik fault; MRF—Main Recent fault. Present Arabia-Eurasia convergence rates from Sella et al. (2002).

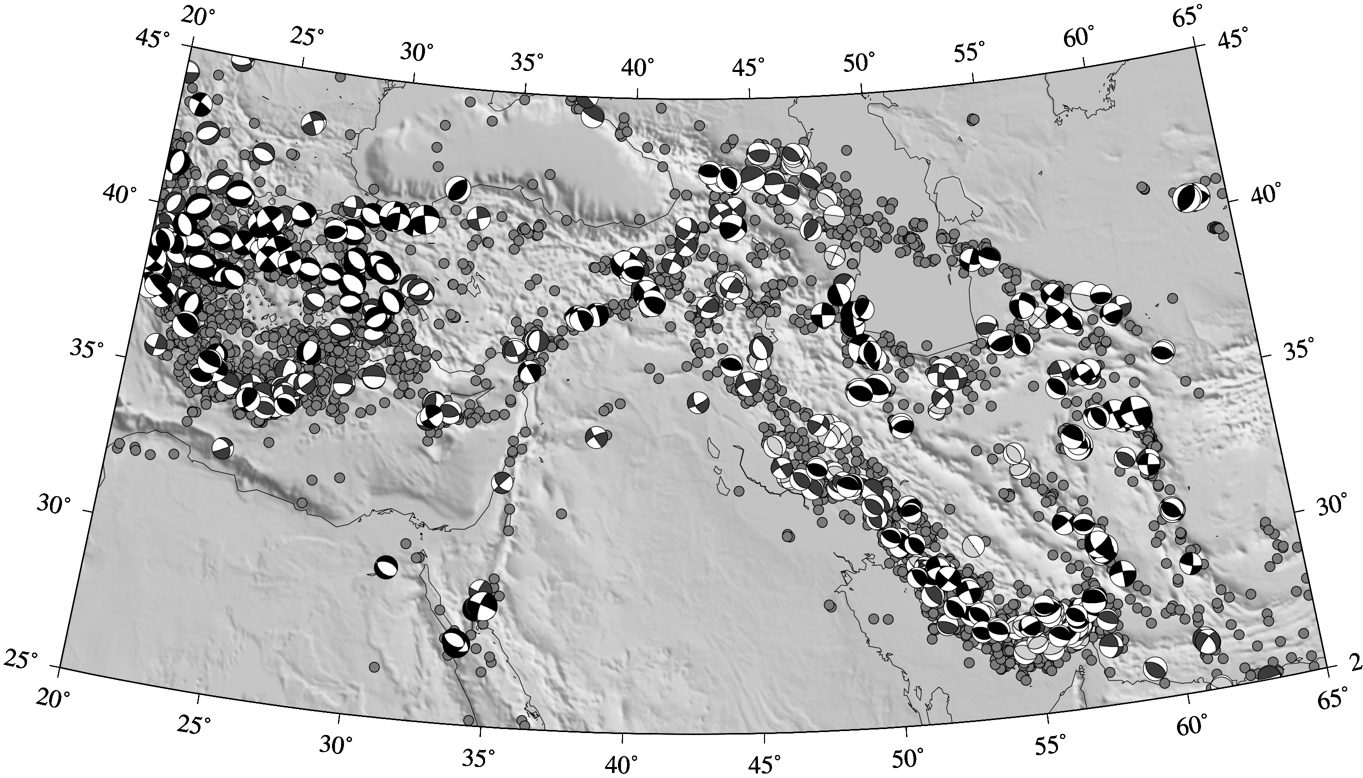

Figure 2. Seismicity of the Arabia-Eurasia collision zone. The small dots represent epicenters from the catalogue of Engdahl et al. (1998). The focal mechanisms are from the following sources: black—waveform modeled, from Jackson (2001) and references therein, with additional events from Talebian et al. (2004) and Walker et al. (2005); dark gray—best double-couple centroid moment tensor solutions from the Harvard catalogue (http://www.seismology/harvard.edu/CMTsearch.html) for earthquakes with depth ≤ 35 km, Mw ≥5.5, and double-couple component ≥70%, in the interval 1977–2002; light gray—first motion solutions from Jackson and McKenzie (1984). Earthquakes deeper than 35 km associated with the subduction zones in the Makran, south Caspian, and Hellenic trench have been omitted.

These ranges lie at the margins of the Turkish-Iranian plateau. Both the Alborz and the Zagros ranges are also deformed by a variety of strike-slip faults. Along the northeast side of the Zagros, the original suture between Arabia and the Iranian sector of Eurasia is partially reactivated as a right lateral strike-slip fault, the Main Recent fault (e.g., Tchalenko and Braud, 1974; Berberian, 1995; Talebian and Jackson, 2002). Within the Alborz, a series of discontinuous left lateral strike-slip faults trend parallel to the main thrust faults (e.g., Berberian and Yeats, 1999; Allen et al., 2003). The presence of these large strike-slip faults has led several authors to indicate that the part of Iran between the Zagros and the south Caspian basin moves eastward with respect to Eurasia, in an apparent mirror image of the escape tectonics of Turkey at the western side of the collision zone (Philip et al., 1989; Axen et al., 2001; Bachmanov et al., 2004; Karakhanian et al., 2004).

In the following sections, we first summarize the active faulting and kinematics of deformation in Anatolia. We then review some of the major fault systems in Iran. Finally, we reconcile the geologic and geodetic data for Iran to show that active tectonic escape does not occur along the eastern margin of the Arabia-Eurasia collision zone and that the prominent strike-slip faults within the mountain ranges of Iran instead act to accommodate crustal shortening.

THE NORTH AND EAST ANATOLIAN FAULTS

A key feature of the Arabia-Eurasia collision is the westward transport, with respect to Eurasia, of the part of Turkey that lies between the right lateral North Anatolian fault and the left lateral East Anatolian fault (Fig. 1). This motion is at a high angle to the overall plate convergence, and most of the affected region lies to the west of the Arabian promontory. The North and East Anatolian faults are highly active seismically (Fig. 2), and GPS studies have revealed their active slip rates as up to 24 ± 1 mm/yr and 9 ± 1 mm/yr, respectively (Fig. 3; McClusky et al., 2000).

The left lateral East Anatolian fault trends for ~400 km southwest of its intersection with the North Anatolian fault at Karliova, at ~39.5°N, 41°E (Fig. 1). There are several strands to

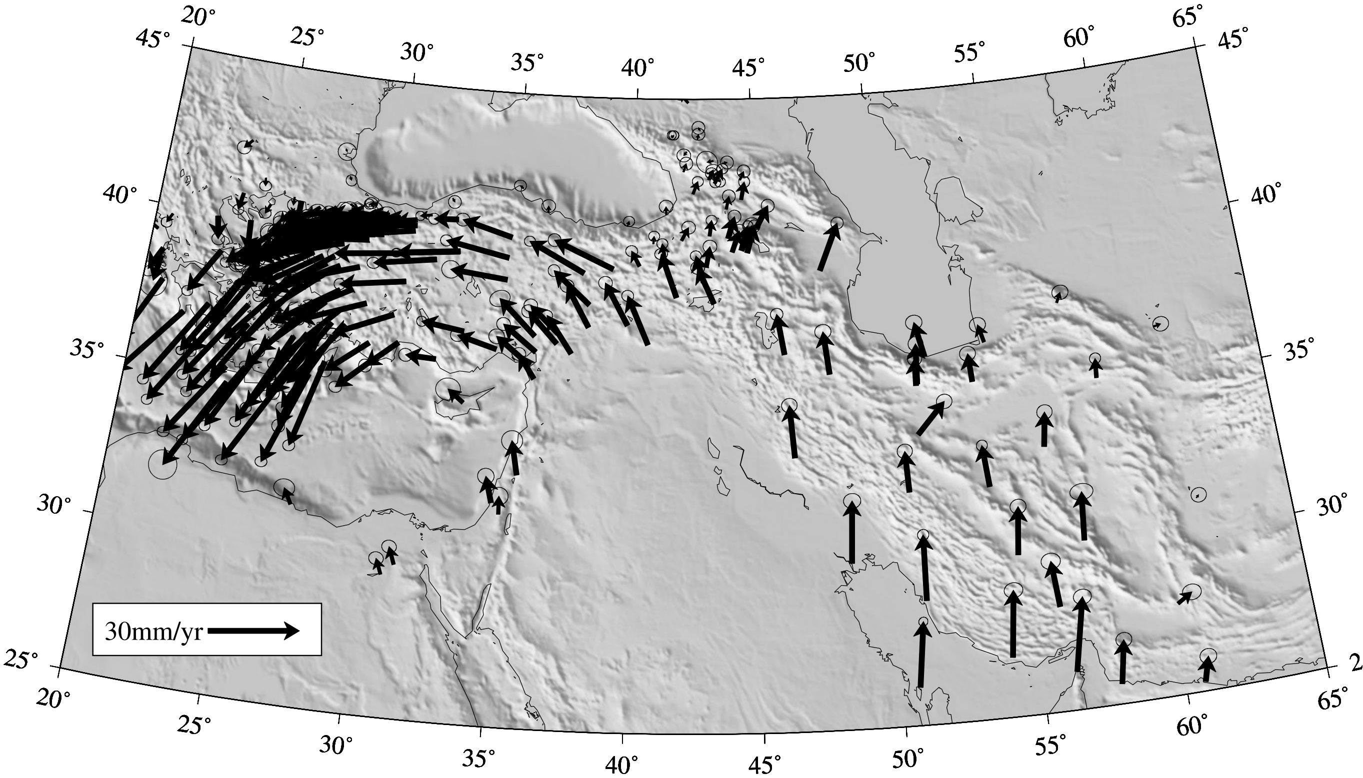

Figure 3. GPS-derived velocity field of the Arabia-Eurasia collision with respect to stable Eurasia. Compiled from McClusky et al. (2000) and Vernant et al. (2004a). Note that this does not include the left lateral motion in the Alborz region identified by Vernant et al. (2004b).

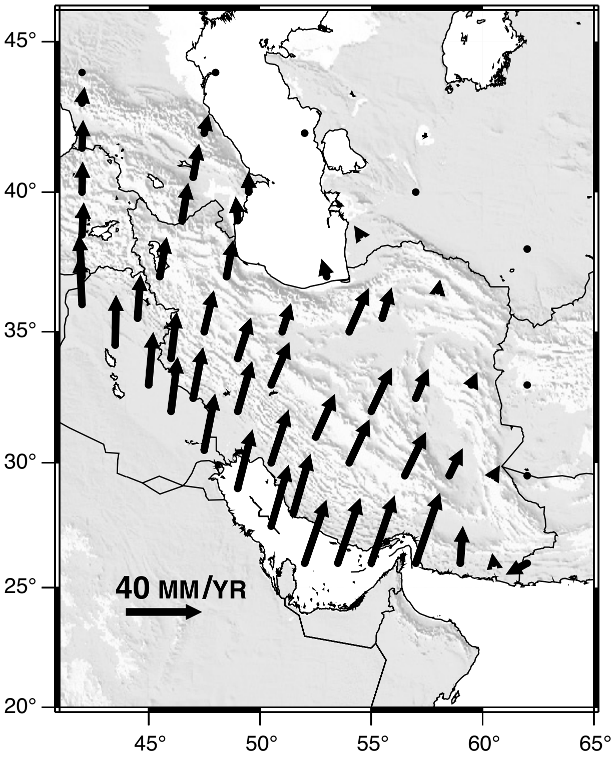

Figure 4. Velocity field for the Arabia-Eurasia collision within Iran, estimated from the spatial variation in the style of strain rates indicated by earthquakes (Jackson et al., 1995). This study used values for the total Arabia-Eurasia convergence based on earlier NUVEL-1A plate circuit values of DeMets et al. (1990, 1994), which are now known to be too high (Sella et al., 2002). However, the velocity field is very similar in pattern to that derived from GPS studies (Fig. 3). See also Masson et al. (2005).

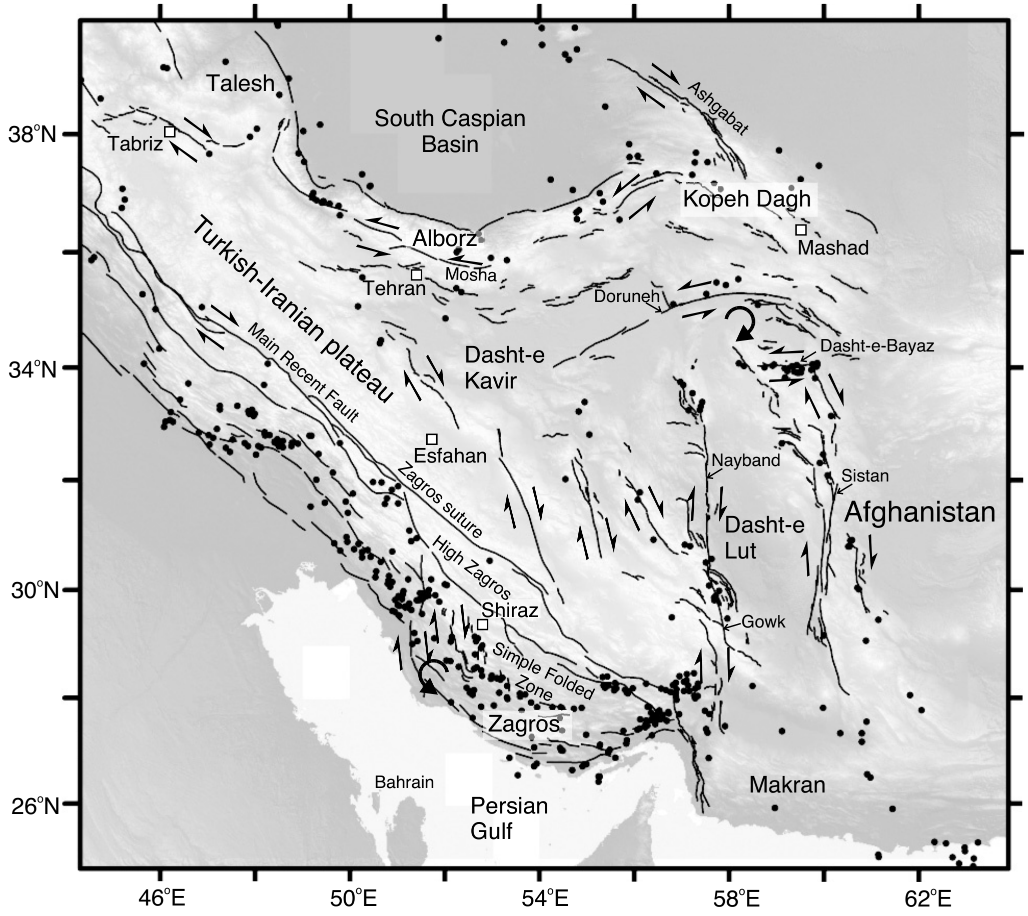

Figure 5. The distribution of active faults and earthquakes (Mw >5) in Iran. Seismicity is broadly confined to the Zagros, Alborz, and Kopeh Dagh mountain belts and to narrow north-south zones surrounding the Dasht-e Lut desert in eastern Iran. Vertical axis rotation of fault-bounded blocks is likely to occur within northeast Iran and the Zagros, and possibly also in central Iran. The south Caspian basin appears to be moving west relative to Iran. Black circles indicate epicenters, squares cities, half-arrows sense of strike-slip motion.

the fault zone, with localized pull-apart basins and push-up zones (Lyberis et al., 1992; Westaway, 1994). The finite offset is likely to be ~30 km (Westaway and Arger, 1996), constrained by offset geological markers. The fault is likely to have been active since the Pliocene (e.g., Şaroğlu et al., 1992).

Other left lateral faults in eastern Turkey have offsets on the order of tens of kilometers, but may not be active at present (Fig. 1). These include the Malatya-Ovacik Fault (Westaway and Arger, 2001), with ~29 km offset between 5 and 3 Ma, and the Ecemiş fault (Jaffey and Robertson, 2001), with ~60 km offset since the late Eocene.

The right lateral North Anatolian fault accommodates slip between the Eurasia and Anatolia plates over a length of >1200 km (Fig. 1). Its eastern limit lies at the Karliova triple junction. Displacement in the western part of the North Anatolian fault (in the Saros Gulf) has been constrained by offset folds at ~85 km since ca. 5 Ma (Armijo et al., 1999). This is within the range of 80–100 km given by drainage offsets between 30°E and 38°E, reported by Westaway (1994), and very close to the 85 ± 5 km offset of a Tethyan suture, reported at 38°E by Seymen (1975). An estimate of 80- to 85-km offset is emerging as a consensus figure for most of the length of the fault zone (Barka et al., 2000).

There is evidence for distributed strike-slip or extension within regions now cut through by the North Anatolian fault (e.g., Tüysüz et al., 1998; Coskun, 2000). Barka and Hancock (1984) suggested that a broad right lateral shear zone operated toward the end of the Tortonian (ca. 7 Ma), replaced by activity along the present main strand of the North Anatolian fault in the early Pliocene. Bozkurt (2001) also concluded that faulting began at ca. 5 Ma, based on a review of studies of individual sections of the fault zone. One place where there is a precise age for the onset of deformation is the Adapazarı pull-apart basin, along the western part of the fault zone at ~40.7°N, 30.5°E: rodent fossils date the onset of sedimentation in this fault-related basin as latest Pliocene (Unay et al., 2001).

ACTIVE FAULTING IN IRAN

The Zagros

The Zagros Mountains extend for ~1800 km from the northern tip of the Arabia plate to the Strait of Hormuz (Fig. 1). The mountain range results from late Cenozoic deformation of the northeastern side of the Arabia plate. The exposed deformed sediments were originally deposited on the precollision passive continental margin or the syncollision foreland basin that evolved on top of it. The northeast shoreline of the Persian Gulf is roughly coincident with the limit of major seismicity and also with the present southern limit of major active faulting and folding within the Arabia plate.

Exposed folds in the Zagros match the orientations of underlying blind thrusts (e.g., Berberian, 1995), which are apparent in the regional seismicity (Maggi et al., 2000; Talebian and Jackson, 2004). The majority of earthquake fault plane solutions indicate reverse faulting on relatively steep planes (>30°). The hypocentral depths are up to ~20 km, and the majority are presumed to involve slip on basement faults beneath the thick sedimentary cover (Talebian and Jackson, 2004); but see McQuarrie (2004) for a contrary view. The active faults may be reactivations of pre-Cenozoic normal faults inherited from the previously extended Arabia plate margin (Jackson, 1980; Berberian, 1995), but this has not been proved conclusively. Seismogenic thrusts are concentrated in the less exhumed, less elevated parts of the Simple Folded zone rather than the High Zagros, which is the part of the range adjacent to the original suture (Fig. 2). In the northwestern part of the Simple Folded zone, the onset of syntectonic sedimentation in one growth synform has been dated by magnetostratigraphy at 8.1–7.2 Ma (Homke et al., 2004).

The orientation of exposed folds and underlying blind thrusts in the northwestern part of the Zagros is roughly northwest-southeast, implying northeast-southwest shortening. However, the northwest-southeast-trending right lateral Main Recent fault bounds the northeastern margin of this part of the Zagros (Fig. 5) and indicates a spatial separation (or "partitioning") of oblique convergence into strike-slip and dip-slip components. In the southeastern part of the range, both folds and seismogenic thrusts trend roughly east-west (Fig. 5). The central part of the Zagros is cut by several right lateral faults that strike roughly north-south. These strike-slip faults accommodate along-strike extension within the Zagros (Talebian and Jackson, 2004) and connect the region with strain partitioning in the northwest to the zone of orthogonal convergence in the east (Blanc et al., 2003).

The total northeast-southwest shortening across the Zagros has recently been estimated from cross-section balancing as 70 ± 20 km for the whole range (McQuarrie, 2004) and ~50 km for the Simple Folded zone (Blanc et al., 2003). The Main Recent fault dies out to the southeast at ~51°E. Talebian and Jackson (2002) restored offset drainage and ophiolitic rocks along the fault zone to show that its right lateral offset is ~50 km.

The GPS-derived rate for active shortening across the Zagros is 6.5 ± 2 mm/yr at ~51°E according to Vernant et al. (2004a). Tatar et al. (2002) found a slightly higher value of 10 mm/yr of active shortening in the same general region, from a separate GPS study. The GPS-based rate of right lateral faulting along the Main Recent fault is 3 ± 2 mm/yr (Vernant et al., 2004a). This is much less than the long-term rate of 10–17 mm/yr rate proposed by Talebian and Jackson (2002), who assumed that 50 km of finite offset accumulated over the last 3–5 million years. If the fault has been active for as long as the deformation in the Simple Folded zone, which is now known to have begun deforming at least as early as 8.1–7.2 Ma (see earlier; Homke et al., 2004), the long-term slip rate falls to ~7 mm/yr. Regardless of the precise short-term or long-term slip rate, it is clear that the Main Recent fault has undergone major right lateral slip in the late Cenozoic and is an active structure.

The Alborz

The Alborz is an arcuate chain of mountains in northern Iran (Fig. 5) that wraps around the southern side of the south Caspian basin; the boundary is roughly the present shoreline of the Caspian Sea.

The range is actively deforming on range-parallel thrusts and left lateral strike-slip faults. The thrusts dip inward toward the interior of the range from both its northern and southern sides, and the GPS-derived shortening across the range is 5 ± 2 mm/yr at the longitude of Tehran (Vernant et al., 2004b). Strike-slip faults are present along the length of the range, at least as far west as 49°E, and the overall GPS-derived left lateral motion is 4 ± 2 mm/yr (Vernant et al., 2004b). The total late Cenozoic shortening and left lateral slip are estimated at ~30 km and ~30–35 km, respectively, based on a restored cross-section across the range and offset geological markers along the Mosha fault (Allen et al., 2003). Although the time of initial deformation is not well constrained across the range, major uplift since the late Miocene is documented by exhumation data (Axen et al., 2001). Left lateral slip may have begun at this time, reversing an earlier Tertiary right lateral slip within the range (Axen et al., 2001).

The Kopeh Dagh

The Kopeh (Kopet) Dagh range represents the product of late Cenozoic deformation in northeast Iran (Fig. 5), and it forms the northeastern side of the Arabia-Eurasia collision zone. Like the Alborz and the Zagros, the Kopeh Dagh displays partitioning of the overall convergence into compressional and strike-slip components, with right lateral slip on the Ashgabat

(Ashkabad) fault on the northern side of the range and a series of shorter faults segments within it (Lyberis and Manby, 1999). The active slip rate on the Ashgabat fault is low (<1 mm/yr) if it is fully represented by the available GPS data from the site SHIR at ~57.3°E, 37.8°N (Vernant et al., 2004a). This value is markedly lower than previous estimates for the long-term rate of 3–8 mm/yr, which were based on the total offset (up to 35 km) and likely time of activity (Pliocene–Quaternary; Lyberis and Manby, 1999).

If the total shortening estimated for the range (75 km) took place in the Plio-Quaternary, which is the time at which deformation is estimated to have started or intensified (e.g., Lyberis and Manby, 1999), the long-term shortening rate is ~15 mm/yr. Only one GPS site constrains the active shortening rate of the Kopeh Dagh: the KASH site on the south side of the range has a rate of convergence with Eurasia of 6.5 ± 2 mm/yr in the direction N11°E ± 5° (Vernant et al., 2004a). Because this site is located at 58.4°E, it may underrepresent the shortening rate in the wider parts of the range to the west, or there may have been a change in the rate over time.

Both the Kopeh Dagh and the Alborz lie adjacent to the south Caspian basin (Fig. 5), which is underlain by rigid, possibly oceanic basement (Neprochnov, 1968; Mangino and Priestley, 1998). The seismicity and geology of surrounding regions suggest that this basement is in the early stages of subducting to its north and possibly west, under the Apsheron sill and the Talesh regions, respectively (Jackson et al., 2002). The south Caspian basin appears to be moving westward relative to adjacent parts of Iran, resulting in thrusting in the Talesh to the west, left-lateral strike-slip in the Alborz to the south, and right lateral faulting in the Kopeh Dagh.

Eastern Iran

The eastern boundary of the Arabia-Eurasia collision zone is formed by a series of north-south right lateral faults in eastern Iran (Walker and Jackson, 2004). These faults take up right lateral shear between the shortening zones of Iran and western Afghanistan, which does not appear to be deforming as a result of the collision (Fig. 5). The present-day right lateral strain across eastern Iran is measured by GPS at ~16 mm/yr (Fig. 3; Vernant et al., 2004a). There are few constraints on how the 16 mm/yr of shear is distributed on the various parallel strike-slip faults around the Dasht-e Lut. Walker and Jackson (2002) used offset Quaternary basalts to estimate a slip rate of ~1.5 mm/yr on the Nayband fault (Fig. 5), which suggests that the major part of the present-day strain is accommodated elsewhere. The late Cenozoic strain on the eastern Iranian faults appears to be focused on the eastern margin of the Dasht-e Lut, where bedrock offsets of ~70 km occur along the Sistan shear zone (Walker and Jackson, 2004). If the distribution of cumulative right lateral shear is indicative of the present-day situation, the strike-slip faults to the east of the Dasht-e Lut may accommodate the major part of the relative motion between central Iran and Afghanistan.

North of ~34° N, the right lateral shear is achieved on left lateral faults that are thought to rotate clockwise about vertical axes (Fig. 5; Jackson and McKenzie, 1984; Walker and Jackson, 2004; Walker et al., 2004). It is likely that the transition from north-south right lateral faulting in the south to east-west left lateral faults in the north is influenced by pre-existing structural weaknesses. The change in style of faulting also highlights how slip on strike-slip faults may accommodate crustal shortening in ways that may not have an obviously direct relationship with the overall convergence vector. Both right lateral and left lateral sets of faults in eastern Iran perform the same job in facilitating crustal shortening in Iran by accommodating right lateral shear along the eastern border of the country.

DISCUSSION

There is clear evidence from GPS data, from the distribution of seismicity, and from the source parameters of instrumentally recorded earthquakes that there is no net transport of Iranian crust eastward with respect to stable Eurasia. This is in spite of the occurrence of large strike-slip faults within the Zagros and Alborz ranges that have attracted this interpretation repeatedly over the past 30 yr or so. There is no paradox. The range-parallel strike-slip faults of Iran instead accommodate Arabia-Eurasia convergence and crustal shortening directly rather than simply transporting crustal material laterally away from the collision zone. The faults achieve this crustal shortening either by a spatial separation ("partitioning") of oblique convergence onto separate structures (as in the northwest Zagros, for instance) or by vertical axis rotation of the faults themselves (as is proposed to be the case at the northern margin of the Dasht-e Lut in eastern Iran). That crustal shortening is accommodated in these relatively complex ways is likely to result from the orientation of inherited structures and weaknesses in the crust. For instance, the Main Recent fault of the Zagros follows the old Arabia-Eurasia suture.

In the case of the Zagros, the right lateral Main Recent fault acts with the active northwest-southeast-trending fold and thrust belt of the Simple Folded zone to produce roughly north-south convergence across the entire Zagros, with an azimuth to the overall Arabia-Eurasia convergence in this region. Around the south Caspian basin, fold and thrust belts developed in continental crust wrap around this aseismic basement block, which is in the early stages of subduction under its northern and possibly western boundaries. Left lateral strike-slip faults in the Alborz are part of this system and reflect the motion of the south Caspian basement relative to the northern side of the Alborz rather than that of central Iran to its south, as the GPS and focal mechanisms make clear.

It is also possible to make inferences about the dynamics involved in the tectonics. The westward motion of Turkey with respect to Eurasia is consistent with a buoyancy force arising from the high crustal thickness and elevation of the Turkish-Iranian plateau with respect to the Aegean region (McKenzie, 1972). Thrust surfaces at the Hellenic Trench allow the Aegean crust to move easily over the seafloor of the eastern Mediterranean (Jackson, 1994). Additionally, there is the possible effect of the downgoing slab at the Hellenic trench itself; this will provide a south-directed force contributing to Aegean extension if it sinks with a component of velocity out of its plane (Le Pichon and Angelier, 1979). The exact contribution from each mechanism is debatable. It is interesting to see how relevant each of these potential mechanisms is to the eastern side of the collision zone, in eastern Iran. There is little or no elevation contrast between regions such as the Dasht-e Lut and western Afghanistan, and presumably little contrast in crustal thickness. However, a topographic gradient of 1500+ m exists between the main part of the Turkish-Iranian plateau and the Makran coast. An active subduction zone exists in the Makran region, equivalent to the thrust zone at the Hellenic trench. A major difference between eastern Iran and the Aegean is that the Makran subduction zone is not associated with extension in the overriding crust. In the jargon of escape tectonics, there is no "free face" in the system to allow the eastern or southeastern motion of Iranian crust.

It is not certain that there has never been eastward motion of crust with respect to Eurasia. There was a major reorganization of the collision at roughly 3–7 Ma (Westaway, 1994; Axen et al., 2001); many active fault systems require only this amount of time to achieve their total slip at present deformation rates (Allen et al., 2004). The nature and location of deformation before this time are less clear.

Two key aims of studies of continental tectonics are to determine the nature of the velocity field that describes large-scale lithospheric deformation (because this has implications for the dynamics of crustal deformation) and to unravel the ways in which discontinuous faulting achieves this in the upper crust (because this has implications for the role that the brittle upper crust plays in the overall deformation of the lithosphere). Because geodetic data sets across the entire Arabia-Eurasia collision can now be added to the seismological record and the geological data, it becomes possible to see the full range of ways the overall plate convergence is accommodated. The model of "tectonic escape," as demonstrated by Turkey, is one of the more important aspects of this, and one that has been applied to other orogenic belts throughout the world, active and ancient alike. One example is eastern Tibet, where east-west left lateral strike-slip faults have been interpreted variously as allowing the eastward escape of crustal material away from the India-Eurasia collision zone (Tapponnier et al., 1986) and also as accommodating the northward indentation of India into Eurasia by clockwise vertical axis rotation (e.g., England and Molnar, 1990). Obviously, the correct interpretation has major implications for understanding the tectonics of the region.

The strike-slip and thrust fault systems across Iran demonstrate the roles of oblique convergence, strain partitioning, and vertical axis rotation of faults in continental deformation, with a further lesson that apparent cases of "escape tectonics" may be nothing of the kind. Whereas this is relatively easy to interpret in an active system, where seismicity and geodetic data are available, it could lead to serious and long-term misunderstanding of ancient, inactive systems for which such data are not available. We stress that large strike-slip faults are a commonly observed feature in regions of continental collision, but can perform several very different kinematic roles, with very different implications for the regional tectonics.

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