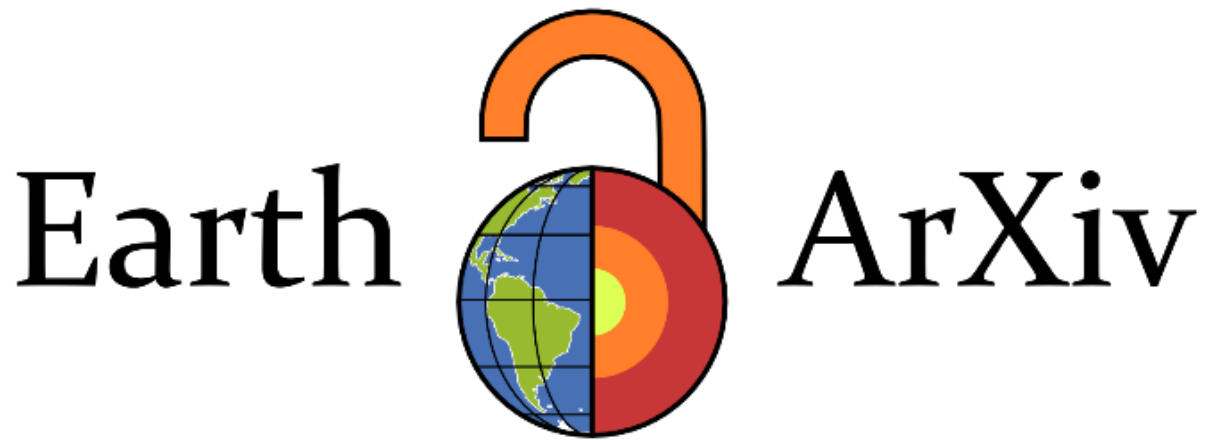




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Reconstructing extension, subduction, and lateral extrusion in the Central Tethysides (Iran, Afghanistan)

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Abstract

The supercontinent Pangea enclosed an internal Tethys ocean whose destruction by subduction formed the Tethysides orogenic belt, exposed in the Alpine-Himalayan mountain range. The Tethyan realm consisted of multiple oceanic basins separated by microcontinents, and their tectonic reconstruction has proved instrumental in understanding subduction geodynamics, back-arc basin evolution, and continental deformation. The Central Tethysides, mostly in Iran and Afghanistan, hosts remnants of distinct, non-parallel ocean basins, including the Jurassic South Caspian-Kopet Dagh basins in the north, the Jurassic Sabzevar-Nain-Baft basins in Central Iran, and the Early Cretaceous Sistan Basin in eastern Iran, whose opening and closure have not been kinematically reconstructed in detail. Here, we review geological constraints on Central Tethysides structure and provide a GPlates-based reconstruction of its tectonic history. Our reconstruction indicates that the South Caspian oceanic basin (pinching eastwards in the continental Kopet Dagh Basin) and the oceanic Sabzevar-Nain-Baft basins (pinching westwards in the continental Central Basin) together partitioned Late Jurassic-Early Cretaceous N-S back-arc extension behind the main Neo-Tethyan subduction zone. The Sistan Ocean formed at a long-lived plate boundary that accommodated final Eurasian amalgamation. In the Early Cretaceous, these continents shared a rotation pole at the junction of the closing Waser Suture leading to extensional reactivation of the southwestern part of the collision zone, where the Sistan Ocean opened. The Sabzevar-Nain-Baft basin subsequently closed in Late Cretaceous-Eocene time by westward extrusion of the Central-East Iranian Microcontinent and Farah-Rud Zone from western Tibet and the Pamirs. The Sistan Ocean closed simultaneously by westward extrusion of the Helmand Block, originally part of the Tibetan Qiangtang Block. Extrusion exceeded 1000 km, likely initiated by Cretaceous Tibetan Plateau shortening.

Highlights

- GPlates reconstruction of the Central Tethyan realm back to the Permian.
- Caspian and Sabzevar-Nain-Baft back-arc basins opened in Jurassic-Early Cretaceous time.
- Sistan Ocean opened in the Early Cretaceous at the suture that accommodated final Eurasian amalgamation.
- Iranian back-arc basins closed due to major westward extrusion from western Tibet/Pamir.

Keywords: Central Tethyan, Kinematic reconstruction, Plate tectonics, Orogenic belt, GPlates

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1. Introduction

Since the first reconstructions of Pangea of (Wegener, 1912) it has been clear that the opening of the Atlantic and Indian oceanic basins must have been accompanied by the closure of a major, eastward widening oceanic basin system conceptually known as the Tethyan Ocean. Analysis of the geology exposed in the Alpine-Himalayan Mountain belt later revealed that the Tethyan realm hosted several ~E-W trending and eastward widening oceanic basins intervened by continental fragments (Fig. 1; Stöcklin, 1968, 1974a; Schreiber et al., 1972; Şengör, 1979, 1984, 1990a; Berberian and King, 1981; Savostin et al., 1986; Boulin, 1988; Şengör et al., 1988; Abdullah and Chmyriov, 2008; Shafaii Moghadam and Stern, 2014, 2015). The orogen that resulted from the closure of the Tethys oceans is referred to as the Tethysides (Şengör, 1987), and the detailed tectonic and geological analysis of this orogenic belt has been, and still is, instrumental in our development of concepts of paleogeography, geodynamics, plate tectonics, and orogenesis (Şengör, 1987; Jolivet and Faccenna, 2000; Stampfli and Borel, 2002; Agard et al., 2011).

Based on the first-order along-strike heterogeneity in tectonic architecture and deformation patterns, the Tethysides is subdivided into the Mediterranean, Central (Iranian-Afghan-Pamir), and Tibetan segments (Fig.1). Their boundaries likely represent former transform plate boundaries that existed within the Tethyan oceans. The Tibetan and eastern Mediterranean segments of this orogenic system show dominantly E-W trending suture zones and continental fragments that are contiguous throughout each segment. Even though orogen-lateral motions in the eastern Mediterranean and Tibetan regions are well-known (e.g., Dewey and Şengör, 1979; Tapponnier et al., 1981; Şengör, 1984; Leloup et al., 1995; Şengör et al., 2005; Li et al., 2017; Whitney et al., 2026), these orogenic systems were predominantly deformed by overall north-south convergence and shortening that governed ocean closure and orogenesis (e.g., Kapp and DeCelles, 2019; van Hinsbergen et al., 2019, 2020). However, the Central Tethysides display Paleogene, non-parallel sutures that formed at high angles, or even orthogonal, to the east-west trending overall tectonic grain of the Tethysides (Fig. 2; Camp and Griffis, 1982; Tirrul et al., 1983; Bagheri and Stampfli, 2008; Bagheri and Damani Gol, 2020). These discontinuous sutures are puzzling, their opening and closure have so far only provisionally been placed in a kinematic framework (Fourcade et al., 1995; Van Der Voo, 1993; Dercourt et al., 2000; Stampfli, 2000; Golonka, 2004).

These sutures in the Central Tethysides are thought to represent closed back-arc basins that formed within the southern Eurasian margin during Mesozoic northward subduction of the Neo-Tethys Ocean (Stampfli and Borel, 2002). However, their opening and discontinuous nature as well as their closure history remains puzzling. An important implication of the orientation of these sutures is that a considerable amount of east-west, orogen-parallel shortening must be inferred to generate the modern pattern (e.g., Bagheri and Damani Gol, 2020). Although this shortening component has been realized in previous studies that focused on Iran (e.g., Tirrul et al., 1983; Bröcker et al., 2013; Jentzer et al., 2017), the kinematic implications that such orogen-parallel motions must have for the kinematic history of western Tibet and adjacent areas (e.g., Tapponnier et al., 1981) has not been accounted for in plate reconstructions.

Since the last comprehensive reconstruction of the tectonic evolution of the Tethyan basins of Stampfli and Borel (2002), a wealth of new data has been published on the geology of the suture zones of the Central Tethysides, and the intervening continental fragments. In addition, the advent of novel GPlates plate reconstruction software (Müller et al., 2018), and detailed reconstructions of the Mediterranean and Tibetan Tethysides following systematic reconstruction protocols (van Hinsbergen et al., 2011, 2019, 2020) invites a revisiting of the Central Tethysides tectonic evolution, focused on the opening and closure of Tethyan and back-arc basins. Our paper is structured to provide a comprehensive synthesis. We start by reviewing the available structural and stratigraphic constraints from sutures and intervening continental fragments in Iran and Afghanistan. Next, we analyse the available data of the opening and closure of the ocean basins. We attempt at restoring the deformation since the Jurassic in detail, focusing on resolving discrepancies in the Mesozoic record. Finally, we use these constraints to develop a revised kinematic model for the Central Tethysides, concluding with discussion on the role of back-arc systems and orogen-lateral tectonic extrusion in the context of the wider Tethyan closure.

2. Approach

The prime constraint on plate reconstructions is the restoration of the modern oceanic basins using marine magnetic anomalies and fracture zones/transform faults. Relative Arabia-Eurasia motion back to the times of Pangea are based on the Eurasia-North America-Africa-

Arabia plate circuit (e.g., Seton et al., 2012; McQuarrie and van Hinsbergen, 2013) - we use the latest rendition summarized in (Vaes et al., 2023; their Table 1). However, these reconstructions are only of limited use for the reconstruction of the Mesozoic-Paleogene deformation within Iran: The Eurasia-Arabia plate circuit only constrains the net area lost between Arabia and Eurasia but cannot account for area gained and lost by intra-Iranian extension and subsequent closure.

Our reconstruction thus relies on the restoration of the modern orogenic architecture of Iran and Afghanistan, starting from the present-day and kinematically reconstructing deformation from younger to older. For the Neogene, deformation is entirely intracontinental accommodated along strike-slip faults and fold-thrust belts, and occasionally extensional basins and metamorphic core complexes with quantified or estimated displacements (e.g., McQuarrie and van Hinsbergen, 2013). For the pre-Neogene, quantified fault displacements are restricted to a few major strike-slip faults, and deformation was mostly concentrated in subduction zones represented by the modern suture zones. Their convergence, and the preceding divergence that made the ocean floors, cannot be directly constrained. There, we estimate the timing of extension and convergence through stratigraphic data and correlations, particularly of ocean plate stratigraphy (OPS, Isozaki et al., 1990) that marks the relics of oceanic basalts, overlying radiolarian cherts, and continental clastics that typically mark trench fill deposits. Tectonic interpretations of magmatic geochemical data are restricted to ophiolites to infer whether they formed above a subduction zone or at a regular mid-ocean ridge. Where independent evidence for subduction exists from structural records, we use adjacent calc-alkalic magmatism to infer e.g., subduction polarity or timing of activity, but no plate boundaries are inferred based on geochemistry of magmatic rocks alone. Combined, geological data from suture zones and adjacent continental margins constrain timing, and general direction and location of spreading and subduction, as well as subduction polarity, but cannot directly quantify the associated horizontal motions.

An independent source of quantitative kinematic information comes from paleomagnetic data. Paleolatitudinal motions within Iran and Afghanistan after the Triassic were typically within typical paleomagnetic error bars of $\sim\pm 5-10^\circ$, but the first-order information of vertical axis rotations is valuable. We compiled the available paleomagnetic

constraints and adjust our reconstruction according to these within the constraints posed by geological data.

For the reconstruction, we used the free GPlates software to create polygons which define blocks that behave as coherent units (<http://www.gplates.org>; Boyden et al., 2011; Müller et al., 2018). During restoration of block rotations, the crustal domains were subdivided into smaller polygons that were internally deformed to prevent geometric gaps or overlaps. We used polylines that move relative to each other to be able to reshape the polygons (see e.g., van Hinsbergen and Schmid, 2012). Our final model is a best-fit kinematic scenario that obeys the constraints as we understand them. The rotation and shape files are provided in the appendix.

Below, we review the first-order orogenic features of the Iran–Afghan region, focused on the main oceanic and continental basin systems that opened and closed. We review these in chronological order, beginning with the Paleo-Tethys Suture in the north and ending with the Neo-Tethys Suture in the south. We illustrated our individual tectonic units on geological maps of the present-day and trace them on our paleogeographic maps. The kinematic constraints we used in our restoration and the timing of the emplacement or juxtapositions of key order units are shown in charts and tables.

3. Geological Setting

The Central Tethysides constitute deformed, Gondwana-Land-derived continental fragments separated from Eurasia by a Triassic suture zone adorned with Paleozoic oceanic rocks. This suture zone is interpreted as the remains of the subducted Paleo-Tethys Ocean. To the south, they are bounded by a Cenozoic suture with Mesozoic oceanic rocks, interpreted as the remains of the Neo-Tethys Ocean (Stöcklin, 1974a, 1989; Berberian and King, 1981; Tapponnier et al., 1981; Şengör, 1990a, 1990b; Stampfli, 2000; Torsvik and Cocks, 2017) (Fig. 3, Supplementary Data Fig. S1). The ages of these sutures and the remnants of the oceans they consumed show that the Paleo-Tethys Ocean that occupied the heart of Pangea in the late Paleozoic closed well before Arabia and Eurasia collided. This geometric problem was solved by recognizing that a ‘Cimmerian Continent’ detached from Gondwana-Land in the Permian and accreted to Laurasia in the Late Triassic, opening a Neo-Tethys Ocean in its wake

that closed in Jurassic to Cenozoic time (Şengör et al., 1988; Stampfli and Borel, 2002). Paleomagnetic data confirmed Permo-Triassic paleolatitudinal drift of the Cimmerian Continent to the Gondwana-Land to the Eurasian margin (Wensink et al., 1978; Van Der Voo, 1993; Muttoni et al., 2009).

The Cenozoic Neo-Tethyan Suture separates the Cimmerian blocks in the south from the Arabian continental margin-derived Zagros fold-thrust belt to the south (Fig. 3; Berberian and King, 1981; Şengör, 1990a). Closure of the Neo-Tethys was underway by Jurassic time and was finalized in Late Oligocene time (McQuarrie and van Hinsbergen, 2013; Koshnaw et al., 2019; Cai et al., 2021), after which convergence was accommodated by shortening and strike-slip deformation within Iran, and underthrusting of the Arabian continental margin (Vernant, 2004; Vernant et al., 2004; Agard et al., 2011; Mouthereau, 2011; McQuarrie and van Hinsbergen, 2013). To the east of Strait of Hormuz, in the Makran region, continental collision between Arabia and the Cimmerian blocks has not happened yet, and instead an active subduction zone is still consuming oceanic lithosphere of the Arabian Plate (Peyret et al., 2009).

To the west, the Cimmerian blocks of Iran are separated by a NE-SW trending fault zone from the orogenic collage of Anatolia. This boundary has acted as transform fault, oblique subduction zone, and in its latest motions since the Eocene, as the sinistral Araks Fault (Fig. 3). The ocean closure history to the west of the Araks Fault differs from the Iranian segment, owing to a much different paleogeographic and subduction zone configuration (see; van Hinsbergen et al., 2020, 2024). For instance, the Neo-Tethys Ocean in the Anatolian segment opened later (Late Triassic to Jurassic) than in the Iranian segment (Permian-Late Triassic) (Şengör, 1979; Barrier et al., 2018; van Der Boon et al., 2018; van Hinsbergen et al., 2020). The southeastern boundary of our study area is marked by the Chaman Fault and the Himalayas that bound Indian plate-derived units. To the northeast, the Paleo-Tethys Suture, and adjacent blocks, continues into the Pamir Mountains to the northeast that contains the transition to the Tibetan Tethysides (Fig. 3). A detailed review of the Pamir architecture is beyond the scope of our study, but we include a brief outline of the geological architecture to discuss implications of our findings for the paleogeography and tectonic evolution of this region.

In between the widely recognized Paleo-Tethys and Neo-Tethys sutures, the 'Cimmerian' continental units in Iran and Afghanistan were extended into continental and oceanic basins. Some still exist, such as the South Caspian Basin. Others were subsequently closed and now form ophiolite-bearing sutures, including the Sabzevar-Nain Baft and Sistan basins (Fig. 3). The opening of these basins broke the Cimmerian continent into smaller fragments. The fragment enclosed by the Sabzevar-Nain-Baft suture in the west and the Sistan Suture in the east is the Central-East Iranian Microcontinent (CEIM), which is broken into smaller blocks by intracontinental faults, from west to east the Yazd, Posht-e Badam, Tabas, and Lut blocks (Fig. 3, Supplementary Data Fig. S2; Takin, 1972; Berberian, 1981; Berberian and King, 1981; Davoudzadeh et al., 1997). In western Iran, the Cimmerian continent is not separated by sutures but remains contiguous. There, parts of the continent exposed in the Sanandaj-Sirjan Zone in the south is separated from the Talesh, Alborz and Kopet Dagh Mountains in the north by the Central Basin (Fig. 3).

4. Review

We provide a detailed review of the geological constraints that we use for our tectonic reconstruction. We focus our review on the sutures and basins, from old to young. We include a paleomagnetic database from the tectonic blocks of the Iranian-Afghan region (Supplementary Data Table S1).

4.1 The Paleo-Tethys Suture and adjacent tectonic units

The remnants of a Paleozoic ocean are exposed mostly in the north, from the Caucasus mountains through the Talesh, Alborz and Kopet Dagh mountains of Iran. It is offset by the dextral, N-S striking Hari-Rud Fault and continues in northern Afghanistan where its location is inferred from lenses of ultramafic rocks exposed along the Herat Fault, and abundant calc-alkaline magmatism to its north (Fig. 3; Natal'in and Şengör, 2005). In addition, relics of the suture zone were recognized in central Iran, in the western part of Yazd and the Posht-e Badam blocks (Fig. 3). These relics are strongly deformed and metamorphosed Paleozoic sedimentary rocks with tectonically interspersed serpentinized ultramafic rocks.

In the west, the Paleo-Tethys Suture curves around the South Caspian Basin from the Talesh Mountains in the west, where it connects to the younger Anatolian Paleo-Tethys Suture in the Caucasus mountains and Black Sea (Şengör and Yilmaz, 1981; Şengör et al., 1984, 2019; van Hinsbergen et al., 2020 and references therein). Eastward, the suture runs through the Alborz Mountains into the Kopet Dagh in the east (Fig. 3; Stöcklin, 1974a, b; Alavi, 1992; Ruh et al., 2019). In the Talesh Mountains, the Paleo-Tethys Suture is well-exposed in the Shanderman metamorphic complex, where it is marked by deformed OPS units, serpentized peridotite, and eclogite lenses within sheared phyllites, gneisses, and amphibolites (315±9 Ma, $^{40}\text{Ar}/^{39}\text{Ar}$ ages of white micas; Zanchetta et al., 2009; 350 Ma, Sm-Nd isochron in garnet; Pastor-Galán et al., 2025) (Sh in Fig. 4). This complex is considered as an allochthonous nappe of the subducted Turan Platform (Davies et al., 1972; Alavi, 1996; Zanchi et al., 2009; Rossetti et al., 2017).

In the northern Alborz Mountains, the suture is marked by ultramafic rocks and Lower Permian radiolarites intercalated with turbidites in Gorgan and southwest of Rasht (Stöcklin, 1974a, 1974b; Şengör, 1990a; Popkov, 1992; Ruttner, 1993; Sheikholeslami and Kouhpeyma, 2012; Rossetti et al., 2017) and Late Permian metamorphic rocks (greenschists, amphibolites, and gneisses) (Fig. 4). In the Kopet Dagh, OPS units are exposed comprising mafic lavas, and gabbros (282-288 Ma in Mashhad: Ghazi et al. (2001); 380-382 Ma at Darrehanjir Mountain: Alavi (1992), Zanchi et al. (2009)), Lower Permian radiolarites and Middle to Upper Triassic turbiditic sandstones are attributed to the Paleo-Tethys (Fig. 5; Hsü, 1977; Şengör, 1979; Ruttner et al., 1991; Balini et al., 2009, 2019; Mirnejad et al., 2013; Zanchi et al., 2016).

In the east of the Kopet Dagh, the Paleo-Tethys suture is offset southward by the right-lateral Hari-Rud Fault over ~50 km. In northern Afghanistan, the Paleo-Tethys Suture continues eastwards as the northern boundary of the Band-e Bayan Block, and the Turan Platform to the north (Fig. 3). The Band-e Bayan Block forms the northern part of the Farah-Rud Zone, exposes Middle Proterozoic amphibolite to greenschist facies metasedimentary and metavolcanic rocks unconformably overlain by a Paleozoic sequence that is considered typical of the Gondwana-Land-derived Cimmerian Continent (Boulin, 1988; Abdullah and Chmyriov, 2008; Montenat, 2009). The suture is expressed as a belt of ultrabasic rocks exposed along the Herat Fault, which are associated with Paleozoic to Triassic sedimentary and volcanic rocks (Montenat, 2009); best exposed in the Ghorband region (Fig. 6; Stöcklin, 1989; Tapponnier et

al., 1981). The southern margin of Eurasia hosts the Late Paleozoic-Triassic Silk-Road magmatic arc thought to have formed during Paleo-Tethys subduction (Natal'in and Şengör, 2005).

Remnants of the Paleozoic Paleo-Tethys Suture are also found on the western margin of the Central-East Iranian Microcontinent (Bagheri and Stampfli, 2008), in the Anarak region on the western Yazd Block, and the Bayazeh area to the east and west of Posht-e Badam city (Fig. 7). In the west and east of the Yazd Block, ophiolites and accretionary complexes are found of Late Paleozoic to Triassic age. In the west, in the Anarak region, a dismembered ophiolite consisting of serpentinite, harzburgite, hornblende gabbros (~387 Ma, zircon dating), and diabases are reported, as well as low-grade metapelites, metabasites, and marbles that record greenschist- to blueschist-facies metamorphism (Zanchi et al., 2015). On the eastern part of the Yazd Block lies the Bayazeh ophiolite that also consists of serpentinized peridotites and metagabbros (Fig.7; Nosouhian et al., 2019). These ophiolites are overlain by sedimentary rocks that became metamorphosed and yielded 333-320 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages (Bagheri and Stampfli, 2008; Buchs et al., 2013). In addition, Bagheri and Stampfli (2008) identified a thrust sequence of marble, phyllite, quartzite, and metavolcanics that they interpreted as remnants of an accretionary wedge. To the northeast of this sequence, in the Jandaq area, arc to collisional type granites (215±15 Ma) intrude into these metamorphic rocks. The Posht-e Badam Block is also overlain by Paleozoic ophiolitic mélange, consisting of peridotite, metagabbro, serpentinite and listwaenite, and associated with amphibolites, west of Posht-e Badam city (Fig. 7; the Posht-e Badam ophiolite, Khalili et al., 2016). This association of ophiolites and stacked oceanic and continental margin rocks of Triassic age are interpreted as remnants of the Paleo-Tethys Suture (Davoudzadeh et al., 1969; Davoudzadeh and Schmidt, 1984; Ruttner, 1984; Vaziri, 2001; Bagheri and Stampfli, 2008; Zanchi et al., 2009). These Paleo-Tethys remnants were far displaced into central Iran along the 900 km long, sinistral Doruneh Fault, also known as the Great Kavir Fault. That bounds the Central-East Iranian Microcontinent (CEIM) in the north and northwest (Fig. 3). It extends from the Paleo-Tethys Suture around the Iran-Afghanistan border in the east into Central Iran in the west (Fig. 3, Supplementary Data Fig. S1; Wellman, 1966; Fattahi et al., 2007; Farbod et al., 2011). The names of the fault are used interchangeably, although the eastern, transpressional portion of the fault zone is called Doruneh, and the near-linear NE-SW trending, purely sinistral western

portion is called Great Kavir Fault (Farbod et al., 2011; Pezzo et al., 2012; Bagheri et al., 2017). The fault is still active today (Farbod, 2012) and has been episodically active in the Mesozoic-Cenozoic (Javadi et al., 2013, 2015; Tadayon et al., 2019), with cumulative offsets of some 500 km. We will return to the role of this fault later in this review.

Following closure, the Paleo-Tethys Suture zone was intruded by Late Triassic granitoids (e.g., Mashhad in the Kopet Dag, ca. 217-200 Ma; Mirnejad et al. (2013), Esmailabad Granite in the Posht-e Badam Block, 218±3 Ma U-Pb zircon age, Ramezani and Tucker (2003), sealing the suture (Figs. 5 and 7; Alavi, 1992; Karimpour et al., 2010; Zanchetta et al., 2013). In addition, the Paleo-Tethys Suture zone is unconformably covered by the Upper Triassic–Lower Jurassic terrigenous clastic Shemshak Formation (Bagheri and Stampfli, 2008; Balini et al., 2009; Fürsich et al., 2009a; Taheri et al., 2009; Zanchetta et al., 2013; Berberian, 2014; Wilmsen et al., 2015). In Afghanistan, Upper Triassic plant-bearing continental deposits indicate emergence of the Cimmerian Continent and Jurassic unconformably cover deformed older rocks (Abdullah and Chmyriov, 2008; Montenat, 2009), consistent with a post-collisional setting following Paleo-Tethys closure.

4.2 South Caspian, Greater Caucasus, and Kopet Dag basins

To the north of the Paleo-Tethys Suture zone, and in places straddling it, an extensional basin system formed in the Jurassic to Early Cretaceous. The South Caspian Basin still remains of this system. Remains of the original basin are found to the west in the Greater Caucasus and to the east into the Kopet Dag (Fig. 3), where basin sediments were overprinted by Cenozoic shortening.

The South Caspian Basin likely has oceanic crust and a ~20-25 km thick sedimentary cover (Berberian, 1983; Khain and Bogdanov, 2005; Kaz'min and Verzhbitskii, 2011). The oldest drilled rocks in the South Caspian Basin are Cretaceous in age (Khain and Bogdanov, 2005). However, Mesozoic stratigraphy is well-exposed in the Alborz Mountains due to 53 ± 2 km of shortening since the Late Miocene (Guest et al., 2006a), and shows that the South Caspian Basin extension may have started as early as Toarcian-Bajocian, ~180-165 Ma, and continued into the Late Jurassic (Brunet et al., 2009; Fürsich et al., 2009b). The northern boundary of the modern South Caspian Basin is the Apsheron Sill, a fault zone that is thought to accommodate

incipient subduction of the South Caspian ocean floor below Eurasian continental crust that underlies the northern Caspian Sea (Fig. 3; Jackson et al., 2002). The estimated shortening orthogonal to the Apsheron Sill is minor, ~17-35 km alongside some dextral displacement parallel to Apsheron Sill of 22-45 km (Walker et al., 2021). Taking this shortening into account, the South Caspian Basin may have generated ~400 km of oceanic crust, in addition to extension accommodated in its continental margins.

Towards the west, the South Caspian Basin continued into the Greater Caucasus Basin (Saintot et al., 2006; McCann et al., 2010). Remains of this basin are folded up in the southern Greater Caucasus, which exposes a sedimentary sequence exceeding 15 km spanning the Jurassic to Cenozoic (Zonenshain and Pichon, 1986; Golonka, 2004; Saintot et al., 2006; Adamia et al., 2011). Like in the South Caspian Basin, rifting phase took place during the Aalenian to Bajocian (~174-168 Ma), which led to deposition of deep-marine clastic rocks, marls, and volcanic rocks (Robinson et al., 1996; Saintot et al., 2006; McCann et al., 2010; Adamia et al., 2011). Aalenian basalts (~174-170 Ma) exhibit MORB geochemistry (Saintot et al., 2006) indicating that crustal extension approached the threshold of continental breakup. However, there is no definitive evidence for complete oceanization within the Greater Caucasus Basin, which may have been underlain by hyperextended continental lithosphere rather than true oceanic crust (e.g., McCann et al., 2010). Tectonic reconstructions of an orocline that formed to the south of the Caucasus, and of balanced cross sections and seismological imaging suggests that the Greater Caucasus Basin may have been up to ~300 km wide (Cowgill et al., 2016; van Der Boon et al., 2018; Trexler et al., 2023) decreasing westwards. This shows that the South Caspian Basin pinched out westwards.

Extension also from the South Caspian Basin eastwards, into the continental Kopet Dagh Basin. Stratigraphic remains are found in the WNW-ESE trending Kopet Dagh fold-and-thrust belt (Stöcklin, 1968; Tchalenko, 1975). This belt formed by 60-75 km of N-S shortening since ~5 Ma (Lyberis et al., 1998; Lyberis and Manby, 1999; Hollingsworth et al., 2010), reactivating the Kopet Dagh Basin. Shortening ends abruptly against the Hari-Rud Fault in the east, and transfers south-westwards to the Alborz Mountains, through a zone of oblique shortening and rotation in the Binalud Mountains (Fig. 5; Ruh et al., 2019). The Kopet Dagh Basin formed mostly to the north of the Paleo-Tethys Suture. Extension and sedimentation occurred in Middle to Late Jurassic time, simultaneously with the South Caspian Basin, but of

smaller magnitude without oceanization or hyperextension (Fürsich et al., 2009b; Taheri et al., 2009; Berberian, 2014; Robert et al., 2014; Balini et al., 2019). The basin remained a depocenter into the Cenozoic (Moussavi-Harami and Brenner, 1992; Aghababaei et al., 2022). The thickness of the Mesozoic and Cenozoic strata of the basin exceeds 10 km (Lyberis et al., 1998).

4.3 The Sabzevar Zone

Between the Kopet Dagh and the CEIM is a belt of dismembered Cretaceous ophiolitic and OPS rocks known as the Sabzevar Zone (Fig. 5; Lensch and Davoudzadeh, 1982; Ohnenstetter, 1983; Baroz et al., 1984; Omrani et al., 2018). This zone is bounded by faults in linked to the Doruneh Fault Zone in the north and south. The Sabzevar Zone hosts complete ophiolitic sequences that appear as imbricated massifs (Ohnenstetter, 1983; Omrani et al., 2013; Bröcker et al., 2021). Lensch and Davoudzadeh (1982) subdivided the Sabzevar Zone in 3 groups: a) the Sabzevar ophiolite, with a well-developed Penrose-sequence (harzburgite, lherzolite, cumulate gabbro, diabase dikes, pillow lavas and well-bedded micritic limestones, (see also Khalatbari Jafari et al., 2013), b) ocean plate stratigraphy of Oryan-Bardaskan which contain thrust sequences of massive lava, siliceous shale, radiolarite and pyroclastics, and c) the coloured *mélange* of Torbat-e-Heydarieh; dismembered harzburgite, gabbro and sheeted diabase mixed in a serpentinite matrix (Fig. 5).

The Sabzevar Zone ophiolites are divided into two types based on their geochemical characteristics. A depleted mantle source indicating a supra-subduction zone (SSZ) setting, with U/Pb zircon ages of gabbros and plagiogranites clustering between 100 and 90 Ma (Khalatbari Jafari et al., 2013; Moghadam et al., 2014; Omrani et al., 2018; Kazemi et al., 2019) and *Globotruncana*-bearing limestones between the SSZ-series pillow lavas indicating Upper Campanian to Lower Maastrichtian ages (Table 1; Baroz et al., 1984; Moghadam et al., 2014; Jafari et al., 2017). There are also ophiolites with a MORB-type precursor with a sheeted dyke complex of island arc tholeiitic affinity thought to represent formation in a back-arc basin (Stöcklin, 1974a; Shojaat et al., 2003; Rossetti et al., 2010; Nasrabad et al., 2011; Moghadam et al., 2014; Rezaei et al., 2019).

Lower Cretaceous deep marine sediments in the OPS sequences below the ophiolites are interpreted as remains of subducted oceanic crust of the inferred back-arc basin, and extension is thought to have started in the Late Jurassic (Lindenberg et al., 1984). Dismembered NW-SE striking tectonic slivers of mafic granulites crop out to the northwest of Sabzevar city and Early Cretaceous (107 Ma c.) peak metamorphism may record subduction initiation (Rossetti et al., 2010). Lawsonite-bearing blueschists (Table 1; Baroz et al., 1984; Bröcker et al., 2021) along with amphibolite and greenschist were reported from the northern part of the accretionary complexes (Omrani et al., 2018). Bröcker et al. (2021) reported 57-55 Ma Rb-Sr ages (Table 1) from blueschists and interpreted ongoing burial or exhumation in the Sabzevar region around this time.

The Sabzevar Zone is unconformably covered by Lutetian nummulitic limestones and Eocene calc-alkaline basaltic, andesitic, and dacitic lavas and pyroclastics (Moghadam et al., 2014). Towards the west, the Sabzevar Zone disappears beneath the young deposits of the Central Basin. In the east, it is truncated by the N-S trending Hari-Rud Fault (Ulmishek, 2004).

4.4 The Nain-Baft Ophiolitic Belt and adjacent tectonic units

The Sabzevar Zone ophiolites are currently isolated in northern Iran but connect through the Doruneh Fault Zone to the Nain-Baft ophiolitic belt of south-central Iran (Fig. 3). This belt is bounded to the north by the CEIM, to the south by the Sanandaj-Sirjan Zone, and to west by the Central Basin.

The Nain-Baft ophiolitic belt (also known as the Coloured M $\acute{e}$ langes or the Inner Zagros Belt) is characterized by dismembered ophiolitic rock assemblages and m $\acute{e}$ langes including massifs such as the Ashin, Nain, Dehshir, Shahr-e Babak, Balvard, and Baft ophiolites (Fig. 7; Moghadam and Stern, 2011). The ophiolites contain mantle sequences of mainly depleted harzburgite with minor lherzolite, and crustal sequences with pegmatitic and isotropic gabbros whereas a well-developed layered cumulate sequence have not been reported (Ghazi and Hassanipak, 2000; Moghadam et al., 2013; Shafaii Moghadam and Stern, 2015). Sheeted dike complexes are poorly developed and dacitic and plagiogranite dikes are mostly found in tectonic slices or as separated dike swarms in mantle rock (Rahmani et al., 2007; Moghadam et al., 2009, 2010; Ghazi et al., 2012). U/Pb ages of plagiogranites and tonalites of the Nain

and Dehshir ophiolites yielded ages of 99-103 Ma (Table 2; Moghadam et al., 2013). The geochemistry of the Nain-Baft ophiolitic belt implies an arc-tholeiitic to calc-alkaline affinity as an indicator of a setting above a subduction zone (Rahmani et al., 2007; Moghadam et al., 2009). Pillow or massive lava flows are present in each section and radiolarites are often found as thin chert layers (Rahmani et al., 2007; Moghadam et al., 2009; Pirnia et al., 2020). The ophiolitic sections are covered by *Globotruncana*-bearing Cenomanian-Maastrichtian pelagic, shallow marine limestones and evaporites in some places extending into the Paleocene (Stöcklin, 1977; Moghadam et al., 2009; Shafaii Moghadam and Stern, 2015).

The Nain-Baft ophiolite belt continues eastwards into the North Makran Zone (Hunziker et al., 2015), which to the north of the Bajgan-Durkan Complex comprises a tectonic mélange containing exotic blocks with Albian limestones (McCall, 2002; Shahabpour, 2010). The north Makran mélanges also contain blueschists that yielded a 88 ± 5 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age from a sodic amphibole (Delaloye and Desmons, 1980) and 81-84 Ma Rb/Sr isochron ages (Fig. 8; Bröcker et al., 2021).

The Sanandaj-Sirjan Zone to the south of the Nain-Baft ophiolite belt consists of continental sequence that is bounded in the south by the Main Zagros Thrust (Fig. 3; i.e., the Neo-Tethys Suture) (Stöcklin, 1968). It runs from the western margin of the Iranian Cimmerian Continent around the Iranian-Turkish border to the North Makran Zone, where Paleozoic metamorphic rocks and Mesozoic carbonates of the Bajgan-Durkan Complex likely represent the easternmost parts of the Sanandaj-Sirjan Zone (Fig. 8; McCall, 2002; Hunziker et al., 2015; Dorani et al., 2017). Its Neoproterozoic-Cambrian basement is like that of the Talesh, Alborz, and Kopet Dag mountains, all characteristic of northern Gondwana-Land (Badr et al., 2018; Hassanzadeh et al., 2008; Nutman et al., 2014). The Sanandaj-Sirjan Zone hosts abundant Jurassic and Cretaceous plutons interpreted as a subduction-related arc (e.g. Berberian and Berberian, 1981; Khalaji et al., 2007; Shahbazi et al., 2010; Ahadnejad et al., 2011; Esna-Ashari et al., 2012; Fazlnia et al., 2013; Deevsalar et al., 2018; Sepahi et al., 2018). More recently, others found evidence that Jurassic magmatism occurred during rifting (Hunziker et al., 2015; Hassanzadeh and Wernicke, 2016; Azizi et al., 2017, 2020; Azizi and Stern, 2019). Interpretations of this extension vary, ranging from invoking that the Sanandaj-Sirjan Zone was a separate continental fragment from the Cimmerian Continent (e.g., Azizi and Stern, 2019), but rifting occurred simultaneously with the back-arc basin opening summarized above.

During the Late Cretaceous and Paleogene, arc magmatism shifted northwards and developed the ~150 km wide Urumieh-Dokhtar Magmatic Arc (UDMA) that partly overlies the Nain-Baft ophiolite belt (Verdel et al., 2011).

4.5 The Central Basin

A large, triangle-shaped area in west-central Iran with low topography, occupied by intracontinental sedimentary basins of Qom, Great Kavir, and Garmsar (Fig. 4; Jackson et al., 1990; Bin and Meiyin, 2010; Arian and Noroozpour, 2015). This region is loosely defined as the Central Basin (but also known as the Great Kavir Block), although its boundaries are not always faults (Jackson et al., 1990; Morley et al., 2009). It is bounded in the west by the Araks Fault, in the in the east by the Doruneh Fault, the Sabzevar Zone ophiolites and the CEIM, and to the north and south it straddles the Alborz and Sanandaj-Sirjan zones (Fig. 3).

Mostly on the periphery of the basin, continental pre-Cenozoic rocks of Gondwanan origin show that the basin is underlain by continental crust of the Cimmerian Continent (Jackson et al., 1990; Rahmati-Ilkhchi et al., 2011; Malekpour-Alamdari et al., 2017; Honarmand et al., 2020). The Central Basin hides horst-and-graben structures beneath its desert cover. It contains Turonian graben fill that shows that extension started in the Middle Jurassic, followed by of marls, calcarenites, shales, and radiolarites intercalated with tuffs that yielded a 140.7 ± 4.8 Ma, U-Pb zircon age (Jackson et al., 1990; Rahimpour-Bonab et al., 2007; Malekpour-Alamdari et al., 2017). The Central Basin was formed between the Alborz and Sanandaj–Sirjan zones, this separation supported by Mohammadi et al. (2023b) through detrital zircon analyses that indicate a shared sediment source in the Arabian–Nubian Shield. A large metamorphic complex that exhumed in Late Cretaceous–Early Tertiary time shows that extension in western Iran resumed around this time and may have accommodated as much as 135 km extension (Malekpour-Alamdari et al., 2017). The last deformation that affected the Central Basin was SW-NE shortening in the last 10 Ma with a cross-section reconstruction suggesting 38-40 km of shortening (Morley et al., 2009) (Table 3).

4.5 The Sistan Suture Zone

In eastern Iran, the Sistan Suture zone separates the CEIM in the west and the Farah-Rud Block in the north from the Helmand Block of Afghanistan in the east (Fig. 8; e.g., Stöcklin, 1977; Tirrul et al., 1983). The highest structural units are exposed in the east of the Sistan Suture zone, and comprise non-metamorphosed ophiolites with supra-subduction zone geochemical signatures (Delaloye and Desmons, 1980; Moslempour et al., 2012; Nikbakht et al., 2021). The boundary of the ophiolites with the Helmand Block is covered by alluvium and cannot be directly observed, but is widely assumed to have been reactivated by the Neogene Hari-Rud Fault, to the east of which no ophiolites and underlying OPS units are known and to the west of which no continental basement is exposed (Stöcklin, 1989). Direct age constraints on the Sistan ophiolites are sparse. Delaloye and Desmons (1980) reported a 92 ± 3 Ma K-Ar age from the Tchehel-Kureh ophiolite, and the oldest overlying sediments are Turonian in age (Tirrul et al., 1983). The intruding Mahi Rud Complex that was recently interpreted based on geochemistry as an arc-related sequence (Keshtgar et al., 2019) that yielded a U/Pb zircon age of 103.9 ± 2.9 Ma (Bagheri and Damani Gol, 2020). The ophiolites are thus thought to have formed during the Late Cretaceous spreading above a nascent subduction zone (Saccani et al., 2010), along the western active margin of the Helmand Block (Angiboust et al., 2013; Delavari, 2013; Hundee et al., 1995; Saccani et al., 2010; Zarrinkoub et al., 2012).

Structurally below the ophiolites is a series of accreted OPS units, with westward younging ages of accretion as inferred from the youngest trench-fill clastic deposits. The oldest, eastern units (the Ratuk Complex) include HP-LT metamorphic blocks in a serpentinite-dominated matrix, whereas the western units (the Neh Complex) are mostly unmetamorphosed and have a sediment-hosted matrix (Tirrul et al., 1983). The Ratuk Complex consists of metamorphosed elements of OPS sequences, including metabasalt, metachert, and quartzites and phyllites interpreted as trench fill, metamorphosed at blueschist, amphibolite, or eclogite facies (Fotoohi Rad et al., 2005, 2009; Kurzawa et al., 2017; Bonnet et al., 2018). The age of metamorphism is estimated from U/Pb dating of zircon in eclogite, and by Rb/Sr and $^{40}\text{Ar}/^{39}\text{Ar}$ ages of high-pressure rocks, and ranges from 86-75 Ma (Bröcker et al., 2013; Kurzawa et al., 2017; Bonnet et al., 2018). Protolith ages of the Ratuk Complex are at least Cenomanian-Campanian in age based on biostratigraphy of radiolarian cherts (Babazadeh and De Wever, 2004a, 2004b).

Structurally below the Ratuk Complex is the mostly non-metamorphic Neh Complex that consists of OPS sequences that include mafic and ultramafic rocks with MORB geochemical signatures (Delaloye and Desmons, 1980; Desmons and Beccaluva, 1983; Biabangard et al., 2020), of which the most prominent is the 'Birjand Ophiolite' (Fig. 8). From that ophiolite, U/Pb zircon ages in gabbros of 113-107 Ma were reported (Zarrinkoub et al., 2012). Radiolarian cherts in the Neh Complex have ages of Aptian-Albian (Ozsvárt et al., 2020) and hemipelagic series with turbidites with Upper Cretaceous to Lower Eocene ages are interpreted as trench-fill sediments (Tirrul et al., 1983). Rare low-grade metamorphic rocks in the Neh Complex yielded K-Ar ages of 65-68 Ma (Delaloye and Desmons, 1980).

The suture zone complex is overlain by a sedimentary series of up to 8 kilometers thick, known as the Sefidabeh Basin (Camp and Griffis, 1982; Tirrul et al., 1983). This is an Upper Cretaceous to Lower Eocene marine clastic sedimentary succession with the oldest rock units overlying the ophiolites and the younger units progressively covering the accretionary complexes to the west. It consists of intercalating shallow-marine limestones and arc volcanic rocks (Tirrul et al., 1980). The clastic sediments contain erosion products of ophiolite and arc sequences and are overlain by Paleocene to Lower Eocene reefal limestones (Tirrul et al., 1980, 1983; Guillou et al., 1983). The Sefidabeh Basin is interpreted as a forearc basin that formed above an east-dipping (in modern coordinates) subduction zone from the Late Cretaceous to the Middle Eocene (Tirrul et al., 1983; Hundee et al., 1995; Saccani et al., 2010; Zarrinkoub et al., 2012; Angiboust et al., 2013; Delavari, 2013). Paleocurrent measurements from the turbiditic sequences indicate sediment transport from a carbonate platform located along the Afghan active margin and therefore it is consistent with eastward subduction beneath the Afghan blocks (Mohammadi et al., 2023a).

The sequence was folded and subsequently unconformably covered by continental clastic rocks of Middle Eocene age, Upper Eocene nummulitic limestones, and Oligo-Miocene terrestrial continental clastics and basaltic volcanics that are also known from the neighboring Lut and Helmand blocks (Fauvelet and Eftekhar-Nezhad, 1990; Eftekhar-Nezhad and Stöcklin, 1992; Pang et al., 2012, 2013). This unconformity is interpreted as the age of collision (Babazadeh, 2013) and it coincides with the age of the oldest rocks of the E-W trending Makran accretionary prism that seals the Sistan Suture Zone in the south (McCall and Kidd, 1982; Fruehn et al., 1997). The Upper Eocene and younger sequence are folded and may have

accommodated an additional 110–150 km of post-collisional, ~E-W shortening after the final closure (Jentzer et al., 2022).

Towards the north, the Sistan Suture zone and its widespread oceanic units abruptly end in the curvilinear Madar Kuh thrust that exposes Mesozoic shallow marine limestones and younger volcanic rocks in the hanging wall (Tirrul et al., 1983; Bagheri and Damani Gol, 2020; Rojhani et al., 2026). Rojhani et al. (2026) recently showed that the curvilinear nature of the Madar Kuh thrust is the result of post-middle Eocene refolding of an originally ~E-W trending fault that accommodated thrust motion earlier in the Eocene. Because the Sistan Suture zone does not continue to the north of this fault, and the fault strikes-perpendicular to the suture zone, they inferred that it likely reactivates a subduction transform edge propagator (STEP) fault (Govers and Wortel, 2005) that formed the northern termination of the Sistan subduction zone during its activity from the Cretaceous to Early Eocene. The Madar Kuh Fault is cut and dextrally offset by the Hari-Rud Fault, and Rojhani et al. (2026) interpreted that it may continue along faults parallel to the Waser suture zone of Afghanistan, such as the Helmand Fault.

The Helmand Block, located east of the Sistan Suture, is a continental terrane composed of Proterozoic basement overlain by a thick Paleozoic–Mesozoic sedimentary succession (Boulin, 1988; Montenat et al., 1981; Shroder et al., 2022). Its geological evolution records long-lived platform sedimentation along the northern margin of Gondwana-Land and it is thus considered to be (part of) the Cimmerian Continent (Abdullah and Chmyriov, 2008). To the west of the Sistan Suture is the Lut Block, the easternmost block of the CEIM, which formed the foreland of the closing Sistan Suture zone and is overthrust by the Neh Complex (Figs. 3 and 8). However, the eastern Lut Block contains Middle-Late Jurassic arc plutons. These include the Shah-Kuh pluton, with 168 Ma K-Ar ages (Esmaily et al. 2004, as cited in Esmaily et al., 2005), gneisses of the Deh-Salm metamorphic complex with a 166–163 Ma U-Pb zircon age (Mahmoudi et al., 2010), and migmatitic gneisses from the Anjul complex (presumably Jurassic magmatic protolith with a Cretaceous metamorphic overprint, ~110 Ma U-Pb zircon age (Bröcker et al., 2013). These rocks have calc-alkaline or high-K calc-alkaline compositions interpreted as subduction-related (Karimpour et al., 2011; Mazhari and Safari, 2013). These suggest that in Jurassic time, the Lut Block was in an upper plate position relative to a subduction zone (Bagheri and Damani Gol, 2020). Paleomagnetic data of the CEIM show that

the block underwent $\sim 90^\circ$ counterclockwise rotation since the Late Jurassic (Fig. 9), and the Jurassic subduction zone along the eastern (then southern) Lut margin was thus likely $\sim$ E-W trending. No Late Jurassic-Early Cretaceous magmatism is known from the Lut Block. Sparse Late Cretaceous-Paleocene magmatism ~ 80 -60 Ma followed in the Paleocene to the Oligocene, with an Eocene peak, intermediate to felsic volcanic magmatism that also covers the Sistan Suture zone (Berberian et al., 1982; Karimpour et al., 2011; Ghodsi et al., 2016; Mahdavi et al., 2016; Ahmadirouhani et al., 2017). This may be related to slab break-off or delamination. It is followed by alkali olivine basalts with a primitive asthenospheric signature from the Miocene to the Quaternary (Saadat et al., 2010; Pang et al., 2012).

4.6 The Waser Suture

To the east of the Hari-Rud Fault in northern Afghanistan is the Waser (or Waras-Panjaw) Suture zone. This is a steeply dipping, narrow band of ophiolitic *mélange* situated between the Helmand Block in the south and the Farah-Rud Zone in the north (Figs. 3 and 6; Tapponnier et al., 1981). The Waser ophiolitic *mélange* consists of a thick Upper Triassic to Upper Jurassic trench-fill clastic series (the Waras Flysch), which tectonically intercalates with lenses of ultramafic-mafic rock and Permo-Triassic limestone blocks (Tapponnier et al., 1981; Girardeau et al., 1989; Treloar and Izatt, 1993; Wittekindt et al., 1997). The ophiolitic section contains spilites, pillow lavas and tuffs, radiolarite, dismembered gabbro and serpentinized peridotite with unknown age (Stöcklin, 1989) that reflect OPS sequences.

Both the Waras Flysch and the ophiolitic *mélange* have undergone metamorphism from greenschist to garnet-amphibolite facies. The series is unconformably overlain by red detrital continental sediments, overlying Barremian-Aptian marine orbitolinids limestones and shallow marine Senonian limestones (Supplementary Data, Fig. S3). The timing of suturing is constrained as pre-Mid-Cretaceous based on these overlying sediments (Tapponnier et al., 1981; Girardeau et al., 1989; Şengör et al., 1991). The Waser Suture is interpreted as the relict of a subduction zone that existed from the Late Triassic until the Early Cretaceous, with the Helmand Block in a downgoing plate position and the Farah-Rud Zone in the upper plate. The southern part of the Farah-Rud Zone is overlain by the Farah Basin that formed a forearc basin in front of a Triassic to Early Cretaceous arc in the Band-e Bayan Block (Fig. 6; Debon et al., 1987; Montenat, 2009).

The Farah Basin overlies a continental basement of (presumed?) Precambrian age (Schreiber et al., 1972; Abdullah and Chmyriov, 2008) overlain by a discontinuous Paleozoic shallow to non-marine volcano-sedimentary sequence (Leven et al., 1997; Abdullah and Chmyriov, 2008). Shallow marine sedimentation continued in the Late Permian to Carnian interval, with deposition of reefal limestones and intermediate-to basic volcanics that are also found on the Band-e Bayan Block (Montenat, 2009). Subsequently, during Late Triassic to Early Jurassic time and following the closure of the Paleo-Tethys Suture, the Farah Basin subsided and an up to 2000 m thick deep-marine clastic sequence was deposited (the Karajangal series) (Abdullah and Chmyriov, 2008; Montenat, 2009). In the latest Jurassic- early Cretaceous the Farah Basin became filled with a turbiditic series known as the 'Panjaw flysch' (Montenat, 2009; Siehl, 2017). This flysch was deformed and uplifted in the Early Cretaceous, after which Lower Cretaceous 'molasse' continental clastics were deposited that crop out discontinuously in the east but in the west become thousands of meters thick (Girardeau et al., 1989). The Panjaw Flysch is folded due to N-S shortening, and unconformably covered by Senonian orbitolina and rudist-bearing neritic limestones (Girardeau et al., 1989), followed by a thick, Paleogene felsic to intermediate volcanoclastic sequence (Montenat, 2009). From Late Cretaceous to Eocene-Oligocene, the emplacement of subalkaline and alkaline magmatic rocks as well as basalts occurred: sparse K-Ar ages range from 103-42 Ma and basaltic to andesitic rocks as young as Oligocene are reported (31.5 Ma, Debon et al., 1987). Deformed and steeply folded clastics of Oligocene age indicates that also in the Cenozoic, N-S significant shortening occurred, but the exact timing and magnitude are unknown (Treloar and Izatt, 1993).

4.7 Sutures of the Pamirs-Karakoram-Kohistan region

To the northeast, the Helmand Block, Waser Suture, and Farah-Rud Zone abruptly end against the northward continuation of the Chaman Fault that forms the plate boundary with the Indian plate. To the east of this fault is the Kabul Block that was part of the Indian continent when it collided with Eurasia in the Cenozoic and indented into the southern Eurasian margin (Fig. 3; Treloar and Izatt, 1993; Gaina et al., 2015). Tectonic units correlated to the Afghan collage thus continue to the northeast of the Kabul Block into the Pamir region that hosts the transition from the Central to the Tibetan Tethysides.

The Pamir region consists of ribbons of continental crust separated by southward younging Mesozoic to Cenozoic sutures, that were together deformed in the Cenozoic into a northward convex orocline (Cowgill, 2010; van Hinsbergen et al., 2011). A detailed reconstruction of Cretaceous to recent deformation was performed by van Hinsbergen et al. (2011), which we adopt in our reconstruction, and we refer the reader to that study for detailed descriptions of the underlying kinematic constraints. We here summarize the overall terrane distinction, and possible correlations to the Tibetan Tethysides to the east, and the Central Tethysides to the west.

The northernmost terrane is the North Pamirs zone, which consists of continental basement that is correlated to the southern Eurasian margin (Fig. 3; Robinson, 2015, and references therein). The North Pamirs zone currently overlies a south and east-dipping subduction zone that consumed Eurasian lithosphere since the Oligocene (Bourgeois et al., 1997; Negredo et al., 2007; Burtman, 2010). There are no accreted relics of this lithosphere, and its nature is therefore unknown, but it may have once formed an isolated oceanic embayment like the modern South Caspian Basin (Jackson et al., 2002).

The North Pamirs zone is bounded from the continental Central Pamirs to the south by a Triassic suture that is interpreted as the Paleo-Tethys Suture (Robinson, 2015). The Central Pamirs zone is thus interpreted as part of the Cimmerides, correlating westwards to the Farah-Rud Zone. Eastwards, it may correspond to the Western Kunlun zone of the northern Tibetan Plateau (Cowgill et al., 2003; Yin and Harrison, 2000). The Central Pamirs is bounded to the south from the Southern Pamirs terrane by the Rushan-Pshart Suture zone (Fig. 3). This suture zone has trench-fill clastics that are Triassic in age in the east (Wang et al., 2020), which are correlated to the Songpan Ganzi accretionary prism of Tibet that has the same age (Yin and Harrison, 2000). However, in the west of the Pamir, the Rushan-Pshart Suture is thought to have closed in Late Jurassic-Early Cretaceous time (Yogibekov et al., 2023), which may correspond to the Waser Suture (Fig. 3; Burtman, 1994; Tapponnier et al., 1981). The Southern Pamirs may thus correlate westwards with the Helmand Block, and eastwards with the Qiangtang Block of Tibet (Yin and Harrison, 2000; Robinson, 2015; Kapp and DeCelles, 2019). To the south, the Southern Pamirs is bounded by the Karakoram, which is separated by a narrow rift that closed in Triassic time (Robinson, 2015). The Qiangtang Block to the east has also been subdivided into a northern and southern part with a possible Triassic suture in

between (e.g., Ma et al., 2025, and references therein). There is insufficient field information from the Helmand Block to evaluate whether and how this subdivision may continue westwards.

To the southeast of Karakoram, a narrow continental sliver has been mapped that likely represents the western termination of the Lhasa of southern Tibet (Schwab et al., 2004), which has no equivalent in Afghanistan (Fig. 10). Karakoram and this narrow Lhasa-related sliver are bounded to the south by the Shyok Suture zone from the Kohistan-Ladakh arc. The Kohistan arc is built on oceanic crust and developed as an intra-oceanic subduction zone from the Early Cretaceous until the Eocene (Treloar et al., 1996; Jagoutz and Schmidt, 2012). The Ladakh arc to the east is built on either thinned continental (Lakhan et al., 2020) or oceanic crust (Jagoutz et al., 2019) and is of similar Early Cretaceous to Eocene age. The age of the Shyok suture is debated: Upper Cretaceous (~85 Ma) clastic sediments intercalated with the Ladakh arc show provenance of Tibetan units suggesting proximity of the arc to Tibet at that time (Borneman et al., 2015). However, arc magmatism north of the Shyok Suture, and tectonic accretion in the suture may have occurred until as young as 40 Ma (Bouilhol et al., 2013). Moreover, recent paleomagnetic data yielded a low paleolatitude of the Ladakh arc of ~8°N in the latest Cretaceous (~70 Ma) that would suggest the presence of an ocean basin between the Kohistan-Ladakh arc at this time (Martin et al., 2020). A Cretaceous forearc basin to the south of the Kohistan-Ladakh arc continues to southern Tibet (the Xigaze forearc basin) and paleomagnetic data from 70 Ma old stratigraphy place this forearc basin adjacent to southern Tibet (Xu et al., 2025). These observations may be reconciled by the opening of an eastward-disappearing back-arc basin between the Kohistan-Ladakh arc and Karakoram in the Late Cretaceous and its subsequent closure in the Paleogene (Rolland, 2002; Martin et al., 2025; Xu et al., 2025).

4.8 Neo-Tethys sutures and India and Arabia-derived thrust belts

The Cimmerian blocks of the Central Tethysides are surrounded in the east, south, and west by accretionary fold-thrust belts derived from underthrust/subducted portions of the Arabian and Indian plates (Figs. 1 and 3; Stöcklin, 1977). These consist of the Arabian continental margin-derived Zagros fold-thrust belt, off scraped clastic sedimentary deposits of the oceanic lithosphere of the Gulf of Oman (the Makran accretionary prism), and the western

Indian margin-derived Katawaz Basin, the Kabul Block, and the Sulaiman Ranges that transition north-eastwards into the Himalayas (Fig. 3).

Indian plate-derived accreted rock units are located to the east of the Chaman Fault (Fig. 3). The west Indian margin is overthrust by the Sulaiman fold-thrust belt that consists of deformed Mesozoic and Cenozoic Indian passive margin sedimentary rocks (Mahmood et al., 1995). The southern and central Sulaiman Ranges were overthrust until Early Eocene time by the uppermost Cretaceous Bela and Muslim Bagh supra-subduction zone ophiolites (Mahmood et al., 1995; Ahmed and Ernst, 1999; Badshah et al., 2000; Kassi et al., 2009). Obduction occurred in an intra-oceanic, subduction zone during oblique India-Arabia convergence between 65 and 50 Ma, i.e. long before the west Indian margin collided with the Helmand Block (Gnos et al., 1997; Gaina et al., 2015). This latter collision is reflected by the evolution of the Katawaz foreland basin that unconformably overlies the obducted and deformed west Indian margin to the west. Sedimentation in the Katawaz Basin started in the Paleogene and experienced major shortening during the Early Miocene collision of the west Indian margin with the Helmand Block (Treloar and Izatt, 1993).

To the north, the history is more complex. There, the Neo-Tethys Suture has two branches that wrap around the Kabul Block. This block became a separate microcontinent during the Jurassic to Early Cretaceous break-up of India from Arabia, and re-collided with India in the Late Cretaceous, long before India's collision with Asia (Tapponnier et al., 1981; Robinson et al., 2000; Gaina et al., 2015; Faryad et al., 2016). During the latest Cretaceous, the Kabul Block was obducted by the Kabul-Altimur ophiolites in the same obduction event that emplaced the Bela and Muslim Bagh ophiolites to the south (Beck et al., 1996; Badshah et al., 2000; Gaina et al., 2015). Subsequently, the Kabul Block, as part of the northwest Indian continental margin, collided with and indented into southern Eurasia in the Early Miocene (Treloar and Izatt, 1993; Gaina et al., 2015). The detailed reconstruction of the deformation history of the Kabul Block and Sulaiman Ranges relative to India are not key to our study. We here adopt the reconstruction of Gaina et al. (2015) and van Hinsbergen et al. (2019) and refer to those papers for further details.

To the west of the Chaman Fault, the Helmand Block contains remnants of volcanic arcs. In the southeastern margin, the Helmand Block was intruded by granodiorites and overlain by calc-alkaline volcanics of the Kandahar arc (Tapponnier et al., 1981). Sparse K-Ar

ages of the plutons range from 158 (?) to 140 Ma and from 110-79 Ma (Blaise et al., 1978; Debon et al., 1987; Siehl, 2017). In the south of the Sistan desert, are the Chagai and Raskoh arcs (Fig. 6). The Chagai arc is separated from the Raskoh arc by the sediment-filled Dalbandin through (Siddiqui, 2012). The Chagai arc consists of a ~2.5 km thick sequence of Late Cretaceous basalt-andesite lavas intercalated with volcanoclastics, siltstone, and sandstones (Siehl, 2017). Maastrichtian limestones seal a Cretaceous magmatic history, after which volcanism resumed in the Eocene with andesitic to dacitic lavas, continuing to the Pleistocene (Doebrich et al., 2007; Perello et al., 2008). The total thickness of the Chagai arc sequences exceeds 10 kilometres (Abdullah and Chmyriov, 2008). The Raskoh arc hosts an ophiolitic mélange that contains radiolarites and limestones of Jurassic age (Siddiqui, 2012; Siehl, 2017). Available $^{40}\text{Ar}/^{39}\text{Ar}$ ages (Gnos et al., 2000) demonstrate that the metamorphic soles of the southeastern part of the ophiolitic massif formed at ca. 110 Ma. This complex is followed by Cretaceous volcanic group similar to the Chagai arc (Siddiqui, 2012). The Chagai arc is interpreted as a magmatic arc on the southern margin of the Helmand Block (Debon et al., 1987), and the Raskoh arc formed on an oceanic basement (Khan et al., 2010) that may have been part of the southern Helmand forearc. These show that the Helmand Block was bounded by a subduction zone in the east (in modern coordinates) in Late Cretaceous to Cenozoic time.

Southward, the Chaman Fault connects to the E-W trending, ~1000 km long and 350 km wide Makran accretionary complex that is exposed north of the Gulf of Oman (Figs. 3 and 7; Jacob and Quittmeyer, 1979; Burg, 2018). The Makran accretionary complex widens towards the east and grew by foreland-propagating accretion, i.e. southward and oceanward, since the Oligocene (McCall and Kidd, 1982; McCormick, 1989; Smit et al., 2010).

The Makran accretionary complex includes Eocene-recent turbidite sequences and constitutes the largest active sub-areal accretionary prism in the world (e.g., McCall and Kidd, 1982; Fruehn et al., 1997). At the onset of its formation by the Early Oligocene (Smit et al., 2010), the Makran was a simple north-dipping subduction zone that evolved on the southern margin of the Helmand and Lut blocks and intervening Sistan Suture, just after the closure of the latter. The Makran accretionary prism contains fragments of accreted oceanic crust. Gabbros from the Kahnuij complex (K–Ar ages on amphibole) and the Haji-Abad (Esfandagheh) massif (U–Pb zircon ages) yielded crystallization ages of 156–139 Ma and 173 Ma, respectively, likely representing Neo-Tethyan ocean floor ages (Table 4; Kananian et al., 2001). At present,

edifices of a volcanic arc are subducting below the Makran prism that are likely of Late Cretaceous age, related to subduction below intra-oceanic subduction that emplaced ophiolites over the Arabian margin in Oman (Ninkabou et al., 2021).

The west-east striking Makran accretionary prism is separated by the dextral transpressional Minab-Zendan Fault system (Regard et al., 2005) from the 2000 km long the Zagros fold-and thrust belt (Fig. 8). The frontal thrust of the Zagros belt represents the active plate boundary with the underthrusting Arabian plate. The northern boundary of the Zagros fold-thrust belt, adjacent to the Sanandaj-Sirjan Zone, is a chaotic zone with ocean-derived mélanges, in places metamorphosed to high-pressure, low-temperature metamorphic conditions, and isolated remains of non-metamorphosed SSZ ophiolites (Stöcklin, 1968, 1974a; Agard et al., 2005, 2006, 2011). This chaotic zone is widely interpreted as the Neo-Tethys Suture (Fig. 3; e.g., Agard et al., 2011).

The ophiolites of the Zagros fold-thrust belt include, from NW to SE, the Piranshahr-Serow, Kermanshah-Kurdistan, Neyriz, and Haji-Abad ophiolites, also referred to as the Outer Zagros Ophiolites (as opposed to the Nain-Baft Ophiolitic belt also known as the Inner Zagros ophiolites north of the Sanandaj-Sirjan Zone). These form the highest structural units south of the Main Zagros Fault (Fig. 3). Most ophiolites have Late Cretaceous (~92 Ma) crustal ages (Table 4), and where associated with a metamorphic sole, similar cooling ages of Late Cretaceous are found (Lanphere and Adib 1983, as cited in Babaie et al., 2006; Babaei, et al., 2005). These ophiolites are part of a belt of ophiolites with similar ages (~96 Ma in Oman (Rioux et al., 2013) and ~92 Ma in Anatolia, Cyprus, and Syria (e.g., Parlak et al., 2004) that were emplaced onto the Arabian continental margin in the Late Cretaceous (Berberian and King, 1981; Homke et al., 2009; Agard et al., 2011). In the Zagros Mountains, the Arabian margin including overlying ophiolites became in Miocene time thrust and folded during Arabian underthrusting below Iran. To the east, in Oman, and west, in southeastern Turkey and Syria, however, the ophiolites obducted in the Late Cretaceous over the Arabian margin remain in their original obducted position, sealed by uppermost Cretaceous sedimentary rocks (e.g., Robertson, 1987; Searle and Cox, 1999; Al-Riyami et al., 2002; Kaymakci et al., 2010). These Cretaceous ophiolites formed as part of an intra-oceanic subduction system that is not of direct relevance to the tectonic evolution of Iran and Afghanistan, and we refer for reconstructions and discussions to Maffione et al. (2017) and van Hinsbergen et al. (2020,

2021). An exception may be the Kermanshah Ophiolite in the western part of the Zagros suture zone, which has ages as young as ~35 Ma, and may represent a remnant of the forearc adjacent to the Sanandaj-Sirjan Zone above the Neo-Tethyan subduction zone (Ao et al., 2016).

Finally, the East Anatolian Plateau to the west of the Iranian Cimmerides is the locus of a Late Cretaceous to Neogene accretionary fold-thrust belt that formed during subduction and collision of the Greater Adria continent in the eastern Mediterranean Tethysides. This continent broke off northern Africa and northwest Arabia in the Triassic, underwent subduction and collision in Cretaceous to Cenozoic time, and was bounded in the east by a transform system. Consequently, it has no equivalent in the Iranian Tethysides. We refer to the reader to detailed descriptions of orogenic architecture and reconstructions in van Hinsbergen et al. (2020, 2024) and Nikogosian et al. (2023).

4.9 Major fault systems in the Central Tethysides

In addition to the already described Doruneh Fault, Central Iran is cut by a series of major faults, the most important of which are summarized here. The ~400 km long NW trending dextral Dehshir Fault delimits the CEIM in the southwest and cuts through the Nain-Baft ophiolitic belt and the UDMA. Based on map view offsets, we estimate a displacement of Eocene-Oligocene volcanics of the UDMA by ~50 km (Fig. 7). Transpressional movement along the dextral Nayband Fault was mainly accommodated in the middle part of the Tabas Block, by E-W oriented imbricated thrust faults that get younger towards the north (Fig. 8, Table 5). The East and West Neh faults (the Neh Fault Zone in Fig. 8) are two subparallel faults within the Sistan Suture zone. The Neh Fault system, which comprises a series of faults anastomosing between two main N-NE-trending trending strike-slip faults, have several tens of kilometres of cumulative dextral displacement (Table 5). Southward, the Neh Fault Zone connects to the Nosrat-Abad and Kahurak faults along the eastern Lut margin (Stöcklin, 1968; Walker and Jackson, 2004). The Neh Fault system together with the Hari-Rud Fault represent the easternmost part of the shearing system that accommodates the displacement between Afghan and Iranian units (Berberian, 1981; Walker and Jackson, 2004).

Afghanistan is cut by a series of major faults that fan from an E-W trend of the Herat Fault in the north to a NE-SW trend of the Chaman Fault in the southeast. These faults become buried below the desert of the Sistan Basin in the southwest (Fig. 6; Wellman, 1966; Shnizai, 2020).

The dextral Herat strike-slip fault runs from the north of the Kabul Block to the Iranian border, over a length of ~1200 km (Fig. 6; Wellman, 1966). The eastern part of the fault, beyond the Kabul Block is known as the Panjshir Fault. In the west, it becomes difficult to trace towards the Hari-Rud Fault, but it may have connected to the Doruneh/Great Kavir Fault system, stepping right ~ 50 km along the Hari-Rud Fault (Fig. 8). Formation of transtensional basins along the fault with Oligo-Miocene fluvial-eolian sediments and accompanying alkaline volcanism show that it has been active since at least this time the Oligocene-Miocene interval (Tapponnier et al., 1981; Shroder et al., 2022) and the fault is still seismically active (Zhao et al., 2025). Because the fault runs sub-parallel to the Paleo-Tethys Suture zone (Ahmadi and Rahmani, 2018), the displacement along the fault, or the onset of its activity, are unknown. The Chaman Fault is a well-defined, major sinistral fault that forms the western boundary of rock units accreted from the Indian plate (Wellman, 1966). To the southwest, the Chaman Fault curves south-westward and connects to the subduction zone of the Makran accretionary complex. To the northeast, it splits into two branches around the Kabul Block. It merges with the Moqor Fault along the western side of the block and continues to the northeast where it meets the Herat Fault, ~70 km north of the Kabul (Fig. 6; Whitney, 2006). The eastern side of the Kabul Block is delimited by the Gardez Fault that accommodated that the Kabul Block was wedged into the southern Eurasian units of the NE Afghanistan and Southern Pamir regions (Treloar and Izatt, 1993). The subparallel faults within Central Afghanistan accommodate left-lateral displacement (Table 6; Auden, 1974).

5. Reconstruction

Our reconstruction is embedded in the Arabia–Nubia–North America–Eurasia plate circuit and follows the constraints on deformation and rotation in the Central Tethysides as reviewed in the previous section. All GPlates reconstruction files are provided in Supplementary Data S1, an animated version of the reconstruction is provided as

Supplementary Data S2. We present our reconstruction of the Central Tethysides in a Eurasia-fixed reference frame from the present back to the Early Jurassic (Figs. 10-18) and then zoom out for a reconstruction back to the Permian in a paleomagnetic reference frame to display a larger and less detailed paleogeographic and plate tectonic scale, displaying its context within the Tethyan and Mongol-Okhotsk oceans and surrounding continents (Fig. 19). These time slices are chosen to illustrate times of important changes in the tectonic evolution of the region.

5.1 Late Oligocene (25Ma)

A latest Oligocene time paleo-tectonic map (Fig. 11) shows the Central Tethysides restored for N-S shortening that dominated after that time. Northward subduction was active in eastern Anatolia and in the Makran, whilst the Zagros and Katawaz Basin-Sulaiman Ranges were in the early stages of collision with the Central Tethysides. The Zagros fold-thrust belt is restored according to the estimates of McQuarrie and van Hinsbergen (2013) and covers the Arabian passive margin, still overlain by Cretaceous obducted ophiolites.

The Alborz was not mountainous yet and were corrected for ~50 km of Neogene shortening and rotation in the Binalud Mountains to the east (Table 3; Allen et al., 2003; Guest et al., 2006a, 2006b; Cifelli et al., 2015; Rashid, 2016). The post-Oligocene shortening of the Caucasus fold-thrust and orocline was restored, and the Oligocene map (Fig. 11) shows the restored dimension of the Greater Caucasus Basin (Cowgill et al., 2016; van Der Boon et al., 2018).

The Kopet Dagh Basin is restored into its pre-shortened configuration as the continuation of the South Caspian Basin. This reconstruction moved the Paleo-Tethys Suture ~70 km southward relative to stable Eurasia and makes the Alborz Mountains nearly contiguous with the Kopet Dagh and Talesh zones (Fig. 11) as previously suggested based on paleomagnetic data (Mattei et al., 2017). To the south, the restoration of the Kopet Dagh shortening reconstructs the CEIM and parts of the Sistan Suture southwards along the Hari-Rud and Neh Fault systems. This strike-slip motion transferred the shortening in Kopet Dagh to the Makran region. Within the CEIM, we restored the positions of the Yazd, Posht-e Badam, Tabas, and Lut blocks using the displacements along the dextral faults within CEIM (Figs. 7 and

8, Table 5; Anar, Kuh Banan, Nayband, Gowk, Sabzevaran faults). Paleomagnetic results from the Yazd Block shows a CCW rotation of 19° since 12 Ma (Mattei et al., 2020) and a CCW rotation of 20°-35° in Tabas and Anarak regions since Oligocene (Mattei et al., 2012) (Fig. 9). To avoid spatial gaps, we modified the shape of the blocks, representing the widespread but unquantified thrusting and normal faulting that affected these blocks in the Neogene.

The northern side of the Central Basin follows the trend of the restored Alborz ranges and becomes E-W trending in the reconstruction (Fig. 11). The N-S width in the Late Oligocene reconstruction is wider than today due to restoration of ~40 km of post-10 Ma shortening (Morley et al., 2009). We restore shortening in Central Iran parallel to the Arabia-Eurasia convergence direction, which given the NW-SE strike of Iran includes an overall dextral component of shear (e.g., Allen et al., 2011). Restoration of lateral motion along the Sabzevaran Fault (Fig. 8) reconstructs the Durkan Complex to the easternmost parts of the Sanandaj-Sirjan Zone (McCall, 2002; Hunziker et al., 2015; Dorani et al., 2017). We did not reconstruct the displacement of all other individual faults but included a ~250 km overall strike-slip component distributed over the Central Basin, Sanandaj-Sirjan, and Zagros zones, consistent with estimates of cumulative Neogene shear based on fault analysis and block rotations of Allen et al. (2011).

Our 25 Ma reconstruction restored ~70 km of right-lateral motion between Eurasia and Central Afghanistan along the Herat Fault (Table 6). This motion is accommodated westwards along the Doruneh Fault and in the east by restoring the northward indentation of the Kabul with the Indian Plate (following Gaina et al. 2015; van Hinsbergen et al. 2019). This allows for the eastward reconstruction of Afghanistan relative to the Pamir units and restores a direct connection between the Southern Pamirs and the Helmand Block.

5.2 Middle Eocene (40 Ma)

Between 40 and 25 Ma, ~400-600 km of Arabia-Eurasia convergence occurred at the position of the NW and SE Central Tethysides, respectively. Because all major shortening in the Zagros and the Iranian upper plate post-date 25 Ma, and subduction around the CEIM predates 40 Ma, this convergence must have been mostly accommodated by wholesale subduction of Arabian plate lithosphere. We consequently infer that this convergence was

accommodated by oceanic Neo-Tethyan lithosphere subductions and our reconstruction at 40 Ma displays a northward Neo-Tethys subduction along the Sanandaj-Sirjan and southern Helmand margin. The Outer Zagros ophiolites (perhaps excluding the Kermanshah Ophiolite) were at this time located on the African/Arabian continental margin. The ophiolites on the Sulaiman ranges and Kabul Block were located on the Indian plate margin, which are restored several thousand kilometers south of their modern position based on plate circuit constraints (Fig. 12; e.g., DeMets and Merkouriev, 2021).

The Kopet Dagh Basin underwent its final stages of marine sedimentation during the Late Eocene. It is restored to its full original width in our 40 Ma reconstruction correcting for minor 40-25 Ma shortening and uplift (VahdatiRad et al., 2016; Aghababaei et al., 2022). The Alborz Mountains are restored as an almost E–W linear belt, connecting westwards to the fully restored Caucasus orocline. The South Caspian Basin is reconstructed to its maximum original extent, connected to the Greater Caucasus Basin in the west and the Kopet Dagh Basin in the east (Kaz'min and Verzhbitskii, 2011).

At 40 Ma, the Doruneh-Great Kavir Fault was active (Omran et al., 2018), and the CEIM was in its final stages of counterclockwise rotation and south-westward translation. This was accommodated by shortening within the CEIM and by thrusting of the Nain-Baft suture zone rocks over the Sanandaj-Sirjan Zone (Fig. 12).

To the east, restoration of dextral slip along the Hari-Rud Fault links the Herat Fault with the Doruneh Fault, allowing these structures to function as a continuous, throughgoing fault system that accommodated the westward translation of the CEIM together with the Farah-Rud Zone. From this reconstruction, we infer that the Sistan Suture Zone was not contiguous with the Sabzevar suture zone, as often inferred (Şengör, 1990a; Rossetti et al., 2010; Bröcker et al., 2021). Instead, the Sistan Suture zone abruptly ends against a transform fault (Rojhani et al., 2026), which at 40 Ma connects to the Waser suture zone due to the reconstruction of dextral slip along the Hari-Rud Fault. Our reconstruction at 40 Ma reconstructed ~110-150 km of ~E-W post-collisional shortening estimated by Jentzer et al. (2022) for the Sistan Suture zone. The Makran accretionary complex only started to form around 40 Ma and consequently does not exist yet on our map. In the Sanandaj-Sirjan Zone, we restored ~30-40 km NE-SW shortening, accommodated by rotation and distributed

transpression (Allen et al., 2011; Song et al., 2023). In addition, we reconstructed Oligocene core complex extension in Central Basin (Malekpour-Alamdari et al., 2017).

5.3 Earliest Paleocene (65Ma)

At 65 Ma, the Central Neo-Tethys was 900-1200 km wide and was subducting below the Central Tethysides, both along the Sanandaj-Sirjan Zone creating the Urumieh-Dokhtar Arc and along the southern Helmand Block creating the Raskoh-Chagai Hills arc (Fig. 13). The northern Central Tethysides were formed by the Greater Caucasus-South Caspian-Kopet Dag Basin that was in its post-rift stage at its maximum areal extent.

By 65 Ma, the oceanic basin of the Nain-Baft zone was closing (Stöcklin, 1977; Moghadam et al., 2009; Shafaii Moghadam and Stern, 2015). Blueschists of the Govain Mountain (10 km southeast of Soltanabad, Fig. 5) that record Late Paleocene to Early Eocene high-pressure metamorphism in the Sabzevar zone shows that also there subduction continued into the Early Cenozoic (Fig. 13, Bröcker et al., 2021). This was the result of the CEIM advancing west to south-westward in the upper plate of a subduction zone while undergoing part of its 90° counter-clockwise rotation (Fig. 9), alongside shortening (we restore a speculative 20% of shortening within the CEIM) and transpressional faulting (Tillman et al., 1981; Shafiei Bafti and Mohajjel, 2015; Lei et al., 2025). CEIM motion was accommodated along the westward advancing, curved Doruneh Fault that bounded the subduction zone to the north. This eastward reconstruction of the CEIM along the Doruneh Fault eventually reconstructs the Paleo-Tethys relics of the western Yazd and Posht-e Badam Blocks to the Paleo-Tethys Suture zone in northern Afghanistan. This also shows that the Sabzevar and Nain-Baft ophiolitic and OPS relics formed part of one ocean basin and subduction system.

Much of the forearc that once existed southwest of the Sanandaj-Sirjan Zone when its main Mesozoic arc was active, was likely tectonically removed. This would have occurred around 65 Ma, explaining the northward shift in the magmatic arc from the Sanandaj-Sirjan Zone to the UMDA. Lei et al. (2025) speculated that this missing forearc may be represented by ophiolites that are exposed below the thick volcanic cover of the east Anatolian Plateau. Alternatively, the Kermanshah Ophiolite may be a relict (Ao et al., 2016). Our reconstruction does not explicitly reconstruct trench-lateral motions towards Anatolia because Paleocene-

Eocene convergence was trench-perpendicular and we do not see conclusive evidence for such a scenario. Instead, we infer that this forearc may have been lost to subduction erosion.

The westward displacement of Paleo-Tethys remnants into Central Iran along the Doruneh-Great-Kavir Fault, albeit long recognized (Bagheri and Stampfli, 2008) has not previously been kinematically reconstructed and requires a much greater internal mobility within the Iranian and Afghan blocks that inferred in earlier reconstructions (e.g., Stampfli and Borel, 2002; Golonka, 2004; Stern et al., 2021). This major westward motion over 100s of km requires extrusion of the CEIM/Farah-Rud Block from the Pamir Hindu-Kush region. Moreover, also the Sistan Ocean, as a separate oceanic basin between the Lut and Helmand blocks, was in the process of subducting at 65 Ma. This was also bounded by a transform fault in the north, which we infer runs parallel to and along the Waser Suture and may correspond to the Helmand Fault (Fig. 6). This requires that also the Helmand Block was extruded from the east, and faster than the CEIM/Farah-Rud Zone (see also Bagheri and Damani Gol, 2020). Bagheri and Damani Gol (2020) inferred that this extrusion of Helmand was accommodated by formation of a bi-vergent, northward convex orocline in the Sistan Suture. Based on the west-southwest younging of accretionary complex and southeasterly vergence of the folds and thrusts, and arc magmas intruded into the Nehbandan ophiolite at 58.6 ± 2.1 Ma (Delavari et al., 2014), we prefer a scenario of a single, eastward subduction polarity based on the sedimentological record in the Sefidabeh Basin and turbiditic sequences (Angiboust et al., 2013; Mohammadi et al., 2023a).

Restoring the extrusion of the Helmand and Farah-Rud blocks places these blocks between the terranes that now constitute the Pamir orogen. The Helmand Block connects eastwards with the Southern Pamirs, which are the continuation of the Qiangtang Block of Tibet (Yin and Harrison, 2000; Robinson, 2015). Taking the reconstruction of shortening in Tibet into account using the reconstruction of (van Hinsbergen et al., 2011), we reconstruct the Helmand Block as the northwestern part of the Qiangtang/Southern Pamir, the Farah-Rud as part of the Central Pamirs, and the Waser Suture as part of the (western) Rushan-Pshart Zone (Fig. 13).

5.4 Late Cretaceous (90Ma)

At 90 Ma, the restored width of the Neo-Tethys exceeds 2000 km, and the Neo-Tethys Ocean was subducting below the southern Sanandaj-Sirjan margin. The 90 Ma time slice also displays the intra-oceanic subduction zone within the Neo-Tethys Ocean (e.g., Agard et al., 2011; van Hinsbergen et al., 2021) that ended in the latest Cretaceous with emplacement of Cretaceous ophiolites over the Arabian margin, including the Neyriz ophiolite of the Zagros mountains (Fig. 14).

At 90 Ma, subduction was also active to the north of the Sanandaj-Sirjan Zone. The westward advancing CEIM/Farah-Rud Zone is restored farther to the east. The CEIM was already in an upper plate position of the subduction zone that consumed the oceanic crust of the Sabzevar-Nain Baft Ocean basin, with Late Cretaceous SSZ ophiolites of the two belts in the forearc. To the southeast of the CEIM/Farah-Rud Zone, the westward advancing Helmand Block was already overriding the oceanic crust of the Sistan Ocean basin, and also here, SSZ ophiolites had formed in the western forearc (Delaloye and Desmons, 1980; Bröcker et al., 2013; Bonnet et al., 2018; Bagheri and Damani Gol, 2020). Reconstructing the rotation of the CEIM leads to a triangular shape of the Sistan Ocean, pinching out northwards (see also Stern et al., 2021), at the connection to the Waser Suture.

Both subduction zones abruptly ended at left-lateral transform faults (Doruneh-Herat and Madar Kuh-Waser, Fig. 14) that acted as subduction transform edge propagator (STEP) faults (Rojhani et al., 2026). With subduction below the western CEIM and Helmand margins having started around 100 Ma, the 90 Ma time slice restores these ocean basins close to their maximum width, with the western active margin of the CEIM in a position close to the modern eastern limit of the Kopet Dagh formed by the present-day Herat Fault (Fig. 14). The Paleo-Tethys Suture remains on the western CEIM (Bagheri and Stampfli, 2008; Zanchi et al., 2015) are restored to a position equivalent to modern NW Afghanistan and the Sabzevar-Nain-Baft Basin was located between the Kopet Dagh and Sanandaj-Sirjan Zone. This basin was eastward widening, with oceanic lithosphere in the east and extended continental lithosphere in the Central Basin in the west. This basin was separated from the Greater Caucasus-South Caspian-Kopet Dagh Basin to the north by the Alborz-Kopet Dagh block, but the two basins likely opened simultaneously (Golonka, 2004; Jentzer et al., 2022). The Caspian basin pinched out eastwards, whereas the Sabzevar-Nain-Baft basin pinched out westwards and we thus infer

that they partitioned Late Jurassic-Early Cretaceous back-arc extension, with the Kopet Dagh-Alborz ranges acting as mega-relay ramp (Fig. 14).

The 90 Ma slice further restores the counterclockwise rotation of the CEIM (Fig. 9), combined with lateral motions between the CEIM blocks. The CEIM was located along the southern Eurasian margin of present-day northern Afghanistan, with its modern eastern margin in a northeast–southwest orientation. This restoration shifts the more easterly positioned Afghan blocks farther into the Pamir orogenic architecture, resulting in tectonostratigraphic continuity between the CEIM, the Farah-Rud Zone, and the Central Pamirs. The 90 Ma reconstruction of the Waser and Rushan–Pshart sutures depicted these zones as significantly wider, due to the restored extrusion. The Helmand Block is restored northwest of the Southern Pamirs, as the westernmost extension of the (north) Qiangtang Block.

The reconstruction of the extrusion of the Helmand Block and Farah-Rud-CEIM restores the western Lhasa and Kohistan–Ladakh terranes farther south. We restore a northward motion of these terranes during the extrusion that is slower than contemporaneous India-Asia convergence, which may thus kinematically accommodate the extrusion. The Chagai-Raskoh arc of southern Helmand restores to the north of the Kohistan arc, as the western continuation of the Shyok subduction zone.

5.5 Early Cretaceous (110Ma; 140Ma)

At 140 Ma, the Neo-Tethys Ocean south of the Central Tethysides was ~4000 km wide, bounded in the north by a north-dipping subduction zone along the southern margin of the Cimmerian Continent. Within the Neo-Tethys, mid-ocean ridge spreading was likely still active as suggested by the ages of the Kahnuj and Haji-Abad oceanic crustal rocks that were accreted in the Makran accretionary prism (Kananian et al., 2001; Shafaii Moghadam et al., 2013).

In the upper plate of the Neo-Tethyan subduction zone, and behind the Sanandaj-Sirjan arc, the Central Tethysides of Iran back-arc extension was active opening the Greater Caucasus-South Caspian-Kopet Dagh basin to the north and the Central Basin-Sabzevar-Nain-Baft Basin to the south. Fig. 15 illustrates the distribution of this extension, with the oceanic

South Caspian Sea Basin forming north of the continental rift of the Central Basin, and the oceanic Sabzevar-Nain Baft basin forming south of the continental rift of the Kopet Dag Basin.

The 140 and 110 Ma time slices (Figs. 15 and 16) show the fully restored position of the CEIM, with the full $\sim 90^\circ$ counterclockwise rotation accounted for (Davoudzadeh and Schmidt, 1984; Soffel et al., 1996). The Permian–Triassic metamorphic units are restored as part of the Paleo-Tethys Suture zone in modern northern Afghanistan. The Helmand Block was part of the Qiangtang Block, and intruded by the Kandahar arc that may be a lateral equivalent of the Late Jurassic–Early Cretaceous Zapug–Duobuza magmatic arc of the southern Qiangtang (Geng et al., 2016).

The Waser Ocean was in the final stages of closure (Girardeau et al., 1989; Treloar and Izatt, 1993; Montenat, 2009). This ocean closed between the Helmand Block and Farah-Rud Zone, which means that an active plate boundary remained until early Cretaceous time between the Tibetan Cimmerian orogen (containing the Qiangtang Block and thus the Helmand Block) and the Central Tethyan Cimmerian orogen (containing the Farah-Rud Zone). At the same time, the OPS ages in the Sistan Suture zone show that the Sistan Ocean was likely opening at this time (e.g., Babazadeh and De Wever, 2004a, b). We therefore reconstruct a counterclockwise rotation of the Helmand Block relative to the Farah-Rud Zone around a pole at the junction between the western termination of the Waser subduction zone and the northern termination of the Sistan spreading ridge. We will return to the wider implication of this interpretation in the discussion section.

5.6 Jurassic (160Ma; 185 Ma)

Around 160 Ma, the Neo-Tethys in the Central Tethysides segment was up to ~ 5000 km wide. Arabia-Eurasia convergence was underway, accommodated along the southern margin of the Central Tethyan Cimmerian blocks. Magmatism in Sanandaj-Sirjan was underway in the Jurassic (Şengör et al., 1991; Bea et al., 2011; Shakerardakani et al., 2015; Jamei et al., 2021; Mohammadi et al., 2026). Most researchers interpreted this magmatism as a subduction-related arc (e.g., Khalaji et al., 2007; Fazlnia et al., 2009, 2013; Shahbazi et al., 2010; Ahadnejad et al., 2011; Esna-Ashari et al., 2012; Deevsalar et al., 2017; Sepahi et al., 2018; Jamaliashtiani et al., 2024), but recently, others argued for a link to rifting (Hunziker et

al., 2015; Azizi et al., 2017, 2020; Azizi and Stern, 2019). Those authors suggested that the Sanandaj-Sirjan Zone may have broken off Gondwana-Land in the Jurassic, traveling northward as a separate microcontinent with the Nain-Baft ophiolite belt as its Cretaceous suture. Because the Nain-Baft belt does not continue westwards to delineate a subduction zone that could have accommodated the collision of the Sanandaj-Sirjan Zone with the rest of the Iranian Cimmerides, we instead link the rifting to the opening of the Sabzevar-Nain-Baft-Central Basin back-arc basin system.

Arc magmatism in the eastern and southeastern margin of the Lut Block (Esmaily et al., 2005; Karimpour et al., 2011; Mahmoudi et al., 2010; Bröcker et al., 2013; Mazhari and Safari, 2013) suggest that prior to the opening of the Sistan Ocean, the southern (modern eastern) margin of the CEIM was an active margin. From the Late Jurassic through the Cretaceous, the Farah Basin accumulated a thick turbiditic succession in the forearc of the Waser subduction zone. We reconstruct the Lut arc as the lateral equivalent of the Band-e Bayan arc of the Farah-Rud Block of Afghanistan and infer that the Waser subduction zone was contiguous with the trench south of the Sanandaj–Sirjan Zone (Fig. 17).

Around 185 Ma, the Neo-Tethys in the Central Tethysides segment was at its maximum width of up to ~5500 km (Fig. 18). Arabia-Eurasia convergence started around this time, coinciding with the initial oceanization of the Central Atlantic Ocean (Labails et al., 2010; van Hinsbergen et al., 2020). At the Late Triassic–Early Jurassic phase of folding of this zone (Taraz et al., 1981; Shafiei Bafti and Mohajjel, 2015; Sheikholeslami, 2015, 2017) may relate to subduction initiation and eclogites from the north Shahrekord region yielding 184 ± 1 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ mica ages, Davoudian et al., 2016), suggest that subduction along the southern Cimmerian margin was underway at 185 Ma (Hassanzadeh and Wernicke, 2016).

Around the same time, back-arc extension and rifting started in the South Caspian, Kopet Dagh, and Alborz regions, perhaps earlier than in the future Central Basin-Sabzevar-Nain-Baft basin. Our Jurassic time slice displays the Sanandaj–Sirjan Zone in a position adjacent to the Kopet Dagh and Alborz zones, with a much-reduced width of the future Central Basin (Fig. 18). To the east, the CEIM also experienced extension that developed normal faults later reactivated as the modern block-bounding transform faults (Bagheri and Stampfli, 2008; Wilmsen et al., 2009; Salehi et al., 2018; Soleimani et al., 2021), but extension magnitudes were much smaller than farther west.

5.7 Late Triassic (220 Ma); Permian (300 Ma)

The pre-Late Jurassic history of the Central Tethysides is governed by the Permian to Triassic migration of the Cimmerian Continent from the Gondwana-Land margin to the Eurasian margin (Fig. 19). This continent included the continental basement of the Sanandaj-Sirjan, Alborz, Central Basin, and Kopet Dagh zones, as well as the CEIM, Farah-Rud, and Central Pamir blocks. The Paleo-Tethys closed with the Late Triassic collision of the Cimmerian Continent. We made no attempt to reconstruct the tectonic history of this closure history in detail and the possible involvement of intra-oceanic subduction zones but focused on the first-order paleogeographic evolution. Our reconstruction follows the widely-held views (e.g., Şengör et al., 1991; Stampfli and Borel, 2002) of a coherent Cimmerian Continent, separated with transform systems from the eastern Mediterranean and Tibetan Tethyan systems. These transforms date back at least to the Early Permian, at which time the Central Tethyan Cimmerides started breaking off the Arabian margin.

In the west, the plate boundary between the Mediterranean and Central Tethyan segments was likely mostly a transform fault throughout the Permian and younger history. To the east, however, the Waser Suture shows that the plate boundary with the western Tibetan Cimmerides was convergent in Late Triassic to Early Cretaceous time. Inevitably, this plate boundary must have bounded the Tibetan Cimmerides also farther to the northeast, but the location of its suture is enigmatic (Wang et al., 2026; Chai et al., 2026). We will discuss this problem in the next section.

6. Discussion

Plate tectonic reconstructions of deformed continental regions are challenging because the geological record is almost always incomplete, extensively reworked, and commonly overprinted by multiple phases of deformation. This challenge is especially pronounced in the Tethyan domain, where the Cimmerian Continent underwent successive episodes of rifting, subduction, collision, lateral extrusion, and strike-slip partitioning.

The tectonic reconstruction presented here offers an attempt at placing all known observations of the tectonic history of the Central Tethysides in plate tectonic context. In particular, we offer a kinematic scenario that may explain the opening and closure of oceanic basins within the Cimmerian Continent after its Late Triassic collision with Eurasia. Nonetheless, we invoke processes and paleogeographic infrastructure, including ocean basins and their paleogeographic connection, which challenge previous hypotheses. In this section, we place these findings in a broader geodynamic context, examine the evidence supporting our proposed configuration, and address opportunities for future work.

6.1 Plate tectonic context of the Waser Suture and Sistan Ocean

The opening history of the Greater Caucasus-South Caspian-Kopet Dagh and Sabzevar-Nain-Baft-Central basin systems is straightforwardly explained as back-arc extension in the upper plate of the Jurassic Neo-Tethyan subduction zone. Such laterally varying distributions of extensional basins, intervened by rotating 'mega-relay ramps' are well-known from systems in similar settings, such as in the SW Pacific region (van De Lagemaat and van Hinsbergen, 2024) or the Pontides of northern Anatolia in Jurassic time (van Hinsbergen et al., 2020). However, the history of the closure of the Waser Suture and the opening of the Sistan Ocean is more unique. We interpret the arrest of the Late Jurassic Lut arc as the result of collision of the Qiangtang Block including the Helmand Block, followed by drift of the Euler pole to the northern end of the Sistan Ocean. As a result of this rotation, the Helmand Block diverged from the Lut margin opening the Sistan Ocean in the Early Cretaceous, while convergence and subduction in the Waser subduction plate boundary continued (see van Hinsbergen et al., 2025, for an equivalent history in the Pyrenees). However, plate boundaries must surround plates and end in triple junctions. Thus, the question arises how the Waser plate boundary, and the suture that forms its geological remains, continued in the east.

The Waser Suture accommodated the collision between the northwestern Qiangtang Block and Farah-Rud that was part of the southern Eurasian margin (Fig. 19a, b). The Qiangtang Block continues eastwards into the Tibetan Plateau, and is there bounded to the north by the Songpan Ganzi accretionary complex (Yin and Harrison, 2000). However, this it is a Triassic suture that separates the Qiangtang Block from the Eastern Kunlun/Qaidam of Northeast Tibet, which in turn has been connected to the North China Block since the

Paleozoic. The Early Cretaceous Waser Suture may continue into the western Rushan-Pshart zone in the Pamir orogen that is thought to be Early Cretaceous (Yogibekov et al., 2023), but from there on does not continue eastwards into the Tibetan Plateau, because the eastern part already contains Triassic clastics (Wang et al., 2020).

However, paleomagnetic data have long demonstrated that the China blocks moved 1000s of km northward relative to Siberia until the Early Cretaceous (Kravchinsky et al., 2002; Cogné et al., 2005; Van Der Voo et al., 2015; Wu et al., 2016). From this it follows that a plate boundary must have existed until the Early Cretaceous somewhere between the China-Tibetan blocks in the east and Eurasia in the west. This suture is surprisingly challenging to identify in the field. Wang et al. (2026) and Chai et al. (2026) demonstrated that the Qaidam Basin of the northern Tibetan Plateau converged over thousands of kilometers with Eurasia since the Permo-Triassic and postulated that the accommodating suture may be hidden below the Tarim Basin or tectonically overthrust by the Tibetan Plateau. Previous workers identified the Mongol-Okhotsk suture in Mongolia and far-east Russia as the eastern part of the plate boundary (Kravchinsky et al., 2002; Cogné et al., 2005; Van Der Voo et al., 2015). If true, the Waser suture may form the southwestern end of this last intra-Asian suture.

6.2 Lateral extrusion from western Tibet/Pamir

The closure of the Sabzevar-Nain-Baft and Sistan oceans by the westward motion of the CEIM and Helmand Block, respectively, require major orogen-parallel extrusion of these blocks from western Tibet and the Pamir orogen. Extrusion of the Helmand Block from western Tibet has previously been suggested based on the fault patterns of Afghanistan (Tapponnier et al., 1981), and the realization that the closure of the Sistan Ocean requires a major component of E-W convergence in the upper plate of an overall northward subducting ocean (Bagheri and Damani Gol, 2020; Şengör et al., 2023). However, the dimension of the extrusion here is much larger than previously appreciated.

Extrusion systems are well known from subduction-related orogenic belts (e.g., (Whitney et al., 2026). Famous examples are found to the west of the Central Tethysides in Anatolia, which has been extruded westwards towards the Aegean subduction zone over ~85 km since ~11 Ma (Şengör et al., 2005; Whitney et al., 2023), and to the east where Indochina

was extruded from eastern Tibet over some 600-700 km between ~50 and 8 Ma (Tapponnier et al., 1981; Leloup et al., 1995; Schoenbohm et al., 2006; Li et al., 2017). Those extruding systems are driven by upper plate shortening during the underthrusting of one continent below another and are accommodated on the extruding side by subduction zones. In the case of Iran and Afghanistan, extrusion is accommodated by two subduction zones: Sabzevar-Nain-Baft and Sistan. We estimate that the amount of extrusion is likely even larger than in eastern Tibet, exceeding 1000 km, between ~100 and 45 Ma. This might have been driven, at least initially, by shortening in western Tibet.

Cretaceous shortening in Tibet is well-documented (Murphy et al., 1997; Kapp et al., 2007; van Hinsbergen et al., 2011) and is thought to represent Andean-style orogenesis in the upper plate of the Neo-Tethyan oceanic subduction zone (Kapp and DeCelles, 2019). This makes extrusion in the west towards 'free' oceanic boundaries formed by the previously opened Sabzevar-Nain-Baft and Sistan oceans in principle feasible. However, a history of continued upper plate shortening throughout the extrusion history must be reconciled with recent interpretations of the tectonic history of the Kohistan-Ladakh arc.

Our reconstructions display the Kohistan-Ladakh arc as a westward oceanic continuation of an arc built on southern Tibet (the Gangdese Arc). This is a simplest-case scenario inferred in van Hinsbergen et al. (2019), but recent data may challenge this view. The recent paleomagnetic (Martin et al., 2020; Xu et al., 2025), structural geological (Martin et al., 2025), and sediment provenance data (Borneman et al., 2015) indicate that the Kohistan-Ladakh arc was located adjacent to the Tibetan/Pamir upper plate around 85 Ma, but then rifted off opening a back-arc basin that subsequently closed between ~70 and 40 Ma (Xu et al., 2025). If correct, extrusion of the between 85 and 70 Ma cannot have been driven by N-S shortening in the Pamir region. Detailed field observations in the Afghan, Pakistan, and Indian parts of this system are needed to reconstruct this history with confidence, but at this point we speculate that extension was triggered by Tibet-Pamir upper plate shortening between 100 and 90 Ma initiating subduction in the Sistan and Sabzevar-Nain-Baft back-arc basins of Iran. By 90-85 Ma, these new subduction zones were rolling back, as shown by the development of supra-subduction zone spreading centers generating the SSZ ophiolites in these systems. We propose that the extrusion in the 85-70 Ma interval was driven by this roll-back rather than upper plate shortening in the Pamirs. Following the onset of closure of the

back-arc basin behind the Kohistan arc at the Shyok subduction zone, upper plate shortening could have contributed to extrusion again. The Pamirs-Karakoram-Kohistan orogenic belt may thus be regarded as a key frontier to tackle major outstanding (plate) tectonic puzzles, from the final amalgamation of the Eurasian continent to the interplay between upper plate extension, contraction, and extrusion.

7. Conclusions

In this paper, we review and restore orogenesis and the underlying plate tectonic history of the Central Tethysides, the Iranian and Afghan section of the Alpine-Himalayan mountain belt. We especially focused on the opening and closure of the enigmatic back-arc basins whose sutures are well-known, but whose tectonic histories are not. Our main conclusions are the following:

- 1) Following the collision of the Cimmerian Continent with Eurasia, a back-arc basin opened in Jurassic time within the southern Eurasian margin of Iran (Fig. 20). This opened the oceanic Sabzevar-Nain-Baft basin. Extension magnitude of the Sabzevar-Nain-Baft Ocean decreased westwards into the continental Central Basin of west Iran. To the north, a second set of extensional basins with opposite trend in extension magnitude: in the west, the oceanic South Caspian Basin opened, whereas decreasing extension eastwards led to the continental Kopet Dag Basin. The Alborz-Kopet Dag block formed a rotating mega-relay ramp in between these extensional systems.
- 2) The Sistan Ocean of eastern Iran opened in Early Cretaceous time west of the Helmand Block, simultaneously with closure of the Waser Suture of Afghanistan to the north of this block. From this we infer that the Helmand Block rotated counterclockwise about a pole at the Sistan-Waser junction, causing simultaneous extension and convergence (Fig. 20).
- 3) The Sistan Ocean opened by reactivating a suture that formed in Late Jurassic time between the Helmand and the Lut blocks. We conclude that the Helmand Block formed the westernmost part of the Qiangtang Block of Tibet, and the Lut Block was part of the Eurasian margin. A subduction zone thus connected a contiguous subduction zone along the southern

Eurasian margin, from the Mediterranean region towards Afghanistan, with the west Tibetan terranes in a downgoing plate position relative to Eurasia.

4) An outstanding question is how the Late Triassic to Early Cretaceous Waser subduction zone continued eastwards. We infer that it connected to the western Rushan-Pshart zone of the Pamirs, but not eastwards into the Tibetan Plateau. Instead, the suture may connect through a recently postulated cryptic suture whose location has been postulated to be hidden below the Tarim Basin that accommodated paleomagnetically well-documented plate motion of the China blocks relative to Eurasia until the Early Cretaceous. If true, the Waser Suture zone may eventually be connected to the Mongol-Okhotsk suture zone of Mongolia.

5) The closure of the Sistan and Sabzevar-Nain-Baft Ocean basins was associated with major extrusion from the western Tibet/Pamir orogen (Fig. 20). The Sabzevar-Nain-Baft Ocean basin closed by westward to south-westward motion of the Central-Eastern Iranian Microcontinent and its eastern continuation, the Farah-Rud Zone of Afghanistan, along the Doruneh Fault that connected eastwards to the Herat Fault of Afghanistan. Superimposed on this, the Helmand Block of Afghanistan extruded faster, closing the Sistan Ocean between the Lut Block of the CEIM and the Helmand Block. This extrusion was accommodated along a fault parallel to the Waser Suture and the Chaman Fault that is the modern India-Asia plate boundary.

6) Our reconstruction of the Central Tethysides identifies a history with tectonic elements that are known from the widely studied and reconstructed Mediterranean and Tibetan neighbours, but that were not previously restored. The Iranian and Afghan geology may contain spectacular examples of back-arc opening and closure, tectonic extrusion, and associated magmatism and mineralization, but decades of detailed mapping are ahead to unlock the full potential in this monumental part of the Tethyan orogenic belt.

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Figure Captions

Figure 1: Present-day extent and subdivision of the Tethysides. Remnants of the former Cimmerian continent are shown by vertical ruling. The Central Tethysides are bounded to the west by the Araks Fault, which separates them from the Mediterranean Tethysides, and extend eastward beyond the Pamirs. The limit of the Central Tethysides is marked by a dashed black line.

Figure 2: Simplified geological map of the area of interest in Iran, Afghanistan, Pakistan, Turkmenistan, Uzbekistan and Tajikistan. The outlined rectangles indicate the locations of the corresponding close-up views shown in Figs. 4-8.

Figure 3: Tectonic units in Iranian and Afghan segment. AnF: Anar Fault, ArF: Araks Fault, AS: Apsheron Sill Fault, ChF: Chapedony Fault, DSF: Dehshir Fault, GaF: Gardez Fault, GoF: Gowk Fault, HeF: Helmand Fault, KF: Kalmard Fault, KBF: Kuh-Banan Fault, MoF: Moqor Fault, M-ZF: Minab-Zendan Fault, O-NF: Ornach-Nal Fault, SF: Sabzevaran Fault, SBF: Shahr-e Babak Fault, SiF: Siahhan Fault, WCF: West Caspian Fault, ZF: Zahedan Fault.

Figure 4: Geological map of the Alborz-Talesh Mountains and western Iran. GC: Gasht Metamorphic Complex, KD: Kura depression, KMO: Khoy-Maku Ophiolite, KO: Kermanshah Ophiolite, PSO: Piranshahr-Serow Ophiolite, Sh: Shanderman Complex, T-V: Talysh–Vandam gravity high.

Figure 5: Geological map of northeastern Iran and southern Turkmenistan. The map includes the Kopet Dagh in the north, the Sabzevar Suture Zone in the south and easternmost part of the Central Basin in the west. DM: Darrehanjir Mountain, OBO: Oryan-Bardaskan Ophiolite, ShK-BiC: Shotor Kuh-Biarjmand metamorphic core complex, SO: Sabzevar Ophiolite, Ta: Taknar, THO: Torbat-e-Heydarieh Ophiolite.

Figure 6: Geological map of Afghanistan and Pakistan. DT: Dalbandin through, Gh: Ghorband region, LC: Laghman granitoid complex, NC: Nilaw igneous complex, MuBO: Muslim Bag Ophiolite, RO: Raskoh Ophiolite, WO: Waziristan Ophiolite.

Figure 7: Geological map of the Central Basin, the Yazd Block, the Posht-e Badam Block, the Sanandaj-Sirjan Zone and Zagros Mountains. Ai: Airekan, AO: Ashin Ophiolite, B-SC: Boneh-Shurow Complex, BaO: Balvard Ophiolite, CC: Chapedony Complex, DM: Daranjir Mountain, DO: Dehshir Ophiolite, Gs: Godar-e-Siah Complex, JC: June Complex, NO: Nain Ophiolite, SBO: Shahr-e Babak Fault, SC: Sarkuh Complex, ShK-BiC: Shotor Kuh-Biarjmand metamorphic core complex, SK: Shahrekord, Zg: Zarigan Leucogranite.

Figure 8: Geological map of the Lut and Tabas blocks and the Sistan suture. AB: Abdoughi Basin, Bag: Bazman Granodiorite, BaO: Balvard Ophiolite, BiO: Birjand Ophiolite, Bjg: Bajestan granitoid, BO: Baft Ophiolite, DS: Deh-Salm Complex, EO: Esfandagheh Ophiolite, Ggr: Gazu Granodiorite, KaO: Kahnuj Ophiolite, KBR: Kuh-e-Bam Range, MRC: Mahi Rud Complex, NAO: Nostrabad Ophiolite, NO: Nehbandan Ophiolite, QO: Qayen Ophiolite, ShC: SK: Shah-Kuh pluton, SO: Siahjangan Ophiolite, SR: Shotori Range, TB: Tabas Basin, TKO: Tchehel-Kureh Ophiolite, UDMA: Urumieh-Dokhtar Magmatic Arc, ZKg: Zeber-Kuh Granite.

Figure 9: Paleomagnetic vector compilation. Data compiled from Wensink et al. (1978), Wensink and Varekamp (1980), Conrad et al. (1981), Wensink (1982), Bazhenov and Burtman (1986), Bina et al. (1986), Bazhenov (1987), Soffel et al. (1989) as cited in Mattei et al. (2015), Soffel et al. (1996), Besse et al. (1998), Mattei et al. (2012, 2014, 2015), Cifelli et al. (2015), van Der Boon et al. (2018), Ruh et al. (2019), Rezaeian et al. (2020), Song et al. (2023). See Supplementary Data Table S1 for details.

Figure 10: Tectonic map of the Central Tethysides used as basis for our kinematic reconstruction. For key to tectonic units, see Fig. 3.

Figure 11: Paleotectonic map of the Central Tethyan region for the Late Oligocene (25 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 12: Paleotectonic map of the Central Tethyan region for the Eocene (40 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 13: Paleotectonic map of the Central Tethyan region for the Early Paleogene (65 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 14: Paleotectonic map of the Central Tethyan region for the Late Cretaceous (90 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 15: Paleotectonic map of the Central Tethyan region for the Early Cretaceous (110 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 16: Paleotectonic map of the Central Tethyan region for the Early Cretaceous (140 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 17: Paleotectonic map of the Central Tethyan region for the Late Jurassic (160 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 18: Paleotectonic map of the Central Tethyan region for the Early Jurassic (185 Ma). Map is projected in a Europe fixed reference frame. GPlates rotation files are provided in Supplementary Material S1. For key to tectonic units, see Fig. 3.

Figure 19: Paleotectonic maps of the Central Tethysides in context of the wider Tethyan region from the Mediterranean region to the Tibetan region. The focus of our paper is on the central Tethysides - the reconstruction of the Mediterranean region follows van Hinsbergen et al. (2020) and the reconstruction of the Tibetan segment of the Tethys is compiled from various sources (Van Der Voo et al., 2015; Li et al., 2016; Song et al., 2017; van Hinsbergen et al., 2019; Advokaat and van Hinsbergen, 2024).

Figure 20: Simplified cartoon illustrating the evolution of the Central Tethysides since the Middle Jurassic. At 175 Ma, back-arc extension initiated rifting in the South Caspian Basin. Continued slab rollback and back-arc extension led to the opening of the Greater Caucasus–South Caspian–Kopet Dagh basins to the north and the Central Basin–Sabzevar–Nain–Baft basins to the south by 135 Ma. Closure of the Waser Ocean and rotation of the Helmand Block accompanied the opening of the Sistan Ocean. By 80 Ma, subduction of the fully developed Iranian back-arc basins resulted in shortening that was accommodated by extrusion of the Afghan and Iranian blocks. The 20 Ma reconstruction illustrates the latest phase of intracontinental shortening associated with the Arabia–Eurasia collision. AC: Anatolian Cimmerides, Al: Alborz, CB: The Central Basin, CEIM: Central-East Iranian Microcontinent, FR: Farah-Rud, GA: Greater Adria, GC: Greater Caucasus, GCB: Greater Caucasus Basin, He: Helmand, KD: Kopet Dagh, KDB: Kopet Dagh Basin, KL: Kohistan-Ladakh, Lh: Lhasa, NB: Nain-Baft ophiolitic belt, Qi: Qiantang Block, SAB: South Armenian Block, Sab: Sabzevar, SCB: South Caspian Basin, SG: Songpan Ganzi, Sh: Shyok Suture, Si: Sistan, SNB: Sabzevar-Nain-Baft Basin, SSZ: Sanandaj-Sirjan Zone, WS: Waser Suture

Table 1: Radiometric data from the Sabzevar Zone. 1: Baroz et al. (1984); 2: Bröcker et al. (2021); 3: Moghadam et al. (2014); 4: Moghadam et al. (2020); 5: Kazemi et al. (2019). Amp: Amphibole, WR: Whole Rock, Zr: Zircon.

Table 2: Radiometric data from the Nain-Baft Ophiolitic Belt 1: Moghadam et al. (2009); 2: Moghadam et al. (2013); 3: Shirdashtzadeh et al. (2022); 4: Sharkovski et al. 1984 as cited in Pirnia et al. (2020). Amp: Amphibole, WR: Whole Rock, Zr: Zircon.

Table 3: Types and amount of tectonic displacement documented in the Kopet Dagh–Alborz mountains from published studies. 1: Lyberis and Manby (1999); 2: Hollingsworth et al. (2006); 3: Shabanian et al. (2009); 4: Allen et al. (2011); 5: Guest et al., (2006a); 6: Allen et al. (2003); 7: Madanipour et al. (2018); 8: van Der Boon et al. (2018); 9: Safari et al. (2013); 10: Malekpour-Alamdari et al. (2017); 11: Morley et al. (2009).

Table 4: Radiometric data from the Zagros fold-thrust belt. 1: Khalatbari-Jafari et al. (2003); 2: Ghazi et al. (2003); 3: Ali et al. (2012); 4: Delaloye and Desmons (1980); 5: Ao et al. (2016); 6: Babaie et al. (2006); 7: Lanphere and Adib (1983), as cited in Babaie et al. (2006); 8: Fazlnia et al. (2009); 9: Monsef et al. (2018); 10: Ghasemi et al. (2002); 11: Shafaii Moghadam et al. (2017); 12: Ahmadipour et al. (2003); 13: Kananian et al. (2001); 14: Ghazi et al. (2004). Amp: Amphibole, Hbl: Hornblende, Mus: Muscovite, Plg: Plagiogranite, WR: Whole Rock, Zr: Zircon.

Table 5: Types and amount of tectonic displacement documented in and around the Central-East Iranian Microcontinent from published studies. 1: Walker and Jackson (2004); 2: Meyer et al. (2006); 3: Kargaranbafghi et al. (2011); 4: Walker and Allen (2012); 5: Berberian (1981); 6: Walker and Jackson (2002); 7: Regard et al. (2005); 8: Rashidi et al. (2020); 9: Mohajjel (2009); 10: Farbod et al. (2011); 11: Tirrul et al. (1983); 12: Allen et al. (2011); 13: Morley et al. (2009).

Table 6: Types and amount of tectonic displacement documented in Farah-Rud Zone and Helmand Block from published studies. 1: Abdullah and Chmyriov (2008); 2: Auden (1974); 3: Lawrence and Yeats (1979) as cited in Ahmad et al. (2018); 4: Beun et al. (1979) as cited in Ul-Hadi et al. (2013); 5: Lawrence et al. (1981); 6: Lawrence et al. (1992) as cited in Ul-Hadi et al. (2013).

Supplementary Material

Supplementary Data, Fig. S1: Detailed geological map of the region that merges Figures 4,5,6,7 and 8.

Supplementary Data, Table S1: Paleomagnetic data compilation used to plot paleomagnetic vectors in Figure 9.

Supplementary Data, Fig. S2: A structural cross-section of South-Central Iran. Redrawn from Afaghi et al. (1977). For location see Supplementary Data, Fig. S1.

Supplementary Data, Fig. S3: A composite structural cross-section of Central Afghanistan. For location see Supplementary Data, Fig. S1. The Farah-Rud Zone is adopted from Blaise et al. (1978) and Girardeau et al. (1989). The Helmand Block is adopted from Siehl (2017) and Abdullah and Chmyriov (2008). The whole section is correlated with Wittekindt and Weippert, (1973) and Doebrich and Wahl (2006).

Supplementary Data S1: GPlates shape and rotation files of the reconstruction presented in this paper. These consist of a GPlates project file, a rotation file, and a series of shape files (in. gpml format).

Supplementary Data S2: An animated version of the reconstruction.

References

- Abdullah, S.H., Chmyriov, V.M., 2008 (Eds). *Geology and Mineral Resources of Afghanistan*, British Geological Survey Occasional Publication. Brit. Geol. Surv. xii+488p.
- Adamia, S., Zakariadze, G., Chkhotua, T., Sadradze, N., Tsereteli, N., Chabukiani, A., Gventsadze, A., 2011. *Geology of the Caucasus: A Review*. Turk. J. Earth Sci. <https://doi.org/10.3906/yer-1005-11>
- Advokaat, E.L., van Hinsbergen, D.J.J., 2024. Finding Argoland: Reconstructing a microcontinental archipelago from the SE Asian accretionary orogen. *Gondwana Res.* 128, 161–263. <https://doi.org/10.1016/j.gr.2023.10.005>
- Afaghi, A., Salek, M.M., Moazami, J., 1977. *Geological Cross Sections North-West Iran 1:500.000*. Natl. Iran. Oil Co.
- Agard, P., Monié, P., Gerber, W., Omrani, J., Molinaro, M., Meyer, B., Labrousse, L., Vrielynck, B., Jolivet, L., Yamato, P., 2006. Transient, synobduction exhumation of Zagros blueschists inferred from P-T, deformation, time, and kinematic constraints: Implications for Neotethyan wedge dynamics. *J. Geophys. Res. Solid Earth* 111, 2005JB004103. <https://doi.org/10.1029/2005JB004103>
- Agard, P., Omrani, J., Jolivet, L., Mouthereau, F., 2005. Convergence history across Zagros (Iran): constraints from collisional and earlier deformation. *Int. J. Earth Sci.* 94, 401–419. <https://doi.org/10.1007/s00531-005-0481-4>
- Agard, P., Omrani, J., Jolivet, L., Whitechurch, H., Vrielynck, B., Spakman, W., Monié, P., Meyer, B., Wortel, R., 2011. Zagros orogeny: a subduction-dominated process. *Geol. Mag.* 148, 692–725. <https://doi.org/10.1017/S001675681100046X>
- Aghababaei, A., Adollahie-Fard, I., Caçador Martins-Ferreira, M.A., Ghaemi, F., Rahimi, B., Moussavi-Harami, R., 2022. Influence of rift geometry over successive post-rift sedimentation: Tectonostratigraphy of the eastern Kopeh Dagh Belt (NE Iran). *Mar. Pet. Geol.* 142, 105729. <https://doi.org/10.1016/j.marpetgeo.2022.105729>
- Ahadnejad, V., Valizadeh, M.-V., Deevsalar, R., Rezaei-Kahkhaei, M., 2011. Age and geotectonic position of the Malayer granitoids: Implication for plutonism in the Sanandaj-Sirjan Zone, W Iran. *Neues Jahrb. Für Geol. Paläontol. - Abh.* 261, 61–75. <https://doi.org/10.1127/0077-7749/2011/0149>
- Ahmad, S., Hassan, S., Mehnood, K., Maqsood, T., 2018. Role of Chaman transform boundary fault in the deformation of Eastern Kharan Fore-Arc Basin. *J. Himal. Earth Sci.* 51(1).
- Ahmadi, H., Rahmani, A.B., 2018. Study on The Mineral Anomalies of Muqur-Chaman Fault and Its Comparison with Harirud (Herat) Fault (Afghanistan) Using Geophysical and Remote Sensing (Aster-Hymap) Data. *Геология И Охрана Недр* 28–38.
- Ahmadipour, H., Sabzehei, M., Emami, M., Whitechurch, H., Rastad, E., 2003. Soghan complex as an evidence for paleosspreading center and mantle diapirism in Sanandaj-Sirjan zone (south-east Iran). *J. Sci.* 14.
- Ahmadirouhani, R., Karimpour, M.H., Rahimi, B., Malekizadeh Shafaroudi, A., Klötzli, U., Santos, J.F., 2017. Petrology, geochronology, geochemistry and petrogenesis of Bajestan granitoids, North of Ferdows, Khorasan Razvi Province. *J. Econ. Geol.* 8(2).
- Ahmed, Z., Ernst, W.G., 1999. Island Arc–Related, Back-Arc Basinal, and Oceanic-Island Components of the Bela Ophiolite-Mélange Complex, Pakistan. *Int. Geol. Rev.* 41, 739–763. <https://doi.org/10.1080/00206819909465167>
- Alavi, M., 1996. Tectonostratigraphic synthesis and structural style of the alborz mountain system in Northern Iran. *J. Geodyn.* 21, 1–33. [https://doi.org/10.1016/0264-3707\(95\)00009-7](https://doi.org/10.1016/0264-3707(95)00009-7)
- Alavi, M., 1992. Thrust tectonics of the Binalood Region, NE Iran. *Tectonics* 11, 360–370. <https://doi.org/10.1029/91TC02217>
- Ali, S.A., Buckman, S., Aswad, K.J., Jones, B.G., Ismail, S.A., Nutman, A.P., 2012. Recognition of Late Cretaceous Hasanbag ophiolite-arc rocks in the Kurdistan Region of the Iraqi Zagros suture

- zone: A missing link in the paleogeography of the closing Neotethys Ocean. *Lithosphere* 4, 395–410. <https://doi.org/10.1130/L207.1>
- Allen, M.B., Ghassemi, M.R., Shahrabi, M., Qorashi, M., 2003. Accommodation of late Cenozoic oblique shortening in the Alborz range, northern Iran. *J. Struct. Geol.* 25, 659–672. [https://doi.org/10.1016/S0191-8141\(02\)00064-0](https://doi.org/10.1016/S0191-8141(02)00064-0)
- Allen, M.B., Kheirkhah, M., Emami, M.H., Jones, S.J., 2011. Right-lateral shear across Iran and kinematic change in the Arabia-Eurasia collision zone: Right-lateral shear across Iran. *Geophys. J. Int.* 184, 555–574. <https://doi.org/10.1111/j.1365-246X.2010.04874.x>
- Al-Riyami, K., Robertson, A., Dixon, J., Xenophontos, C., 2002. Origin and emplacement of the Late Cretaceous Baer–Bassit ophiolite and its metamorphic sole in NW Syria. *Lithos* 65, 225–260. [https://doi.org/10.1016/S0024-4937\(02\)00167-6](https://doi.org/10.1016/S0024-4937(02)00167-6)
- Angiboust, S., Agard, P., De Hoog, J.C.M., Omrani, J., Plunder, A., 2013. Insights on deep, accretionary subduction processes from the Sistan ophiolitic “mélange” (Eastern Iran). *Lithos* 156–159, 139–158. <https://doi.org/10.1016/j.lithos.2012.11.007>
- Ao, S., Xiao, W., Khalatbari Jafari, M., Talebian, M., Chen, L., Wan, B., Ji, W., Zhang, Z., 2016. U–Pb zircon ages, field geology and geochemistry of the Kermanshah ophiolite (Iran): From continental rifting at 79Ma to oceanic core complex at ca. 36Ma in the southern Neo-Tethys. *Gondwana Res.* 31, 305–318. <https://doi.org/10.1016/j.gr.2015.01.014>
- Arian, M., Noroozpour, H., 2015. Tectonic Geomorphology of Iran’s Salt Structures. *Open J. Geol.* 05, 61–72. <https://doi.org/10.4236/ojg.2015.52006>
- Auden, J.B., 1974. Afghanistan-West Pakistan. *Geol. Soc. Lond. Spec. Publ.* 4, 235–253. <https://doi.org/10.1144/GSL.SP.2005.004.01.13>
- Azizi, H., Kazemi, T., Asahara, Y., 2017. A-type granitoid in Hasansalaran complex, northwestern Iran: Evidence for extensional tectonic regime in northern Gondwana in the Late Paleozoic. *J. Geodyn.* 108, 56–72. <https://doi.org/10.1016/j.jog.2017.05.003>
- Azizi, H., Nouri, F., Stern, R.J., Azizi, M., Lucci, F., Asahara, Y., Zarinkoub, M.H., Chung, S.L., 2020. New evidence for Jurassic continental rifting in the northern Sanandaj Sirjan Zone, western Iran: the Ghalaylan seamount, southwest Ghorveh. *Int. Geol. Rev.* 62, 1635–1657. <https://doi.org/10.1080/00206814.2018.1535913>
- Azizi, H., Stern, R.J., 2019. Jurassic igneous rocks of the central Sanandaj–Sirjan zone (Iran) mark a propagating continental rift, not a magmatic arc. *Terra Nova* 31, 415–423. <https://doi.org/10.1111/ter.12404>
- Babaei, A., Babaei, H.A., Ghazi, A.M., Arvin, M., 2005. Tectonic evolution of the Neyriz ophiolite, Iran: an accretionary prism model. *Ophioliti* 30, 65–74.
- Babaei, H.A., Babaei, A., Ghazi, A.M., Arvin, M., 2006. Geochemical, $^{40}\text{Ar}/^{39}\text{Ar}$ age, and isotopic data for crustal rocks of the Neyriz ophiolite, Iran. *Can. J. Earth Sci.* 43, 57–70. <https://doi.org/10.1139/e05-111>
- Babazadeh, S.A., 2013. A Note on Stratigraphic Data and Geodynamic Evolution of Sistan Suture Zone (Neo-Tethyan Margin) in Eastern Iran. *Geodyn. Res. Int. Bull.* 01.
- Babazadeh, S.A., De Wever, P., 2004a. Radiolarian Cretaceous age of Soulabest radiolarites in ophiolite suite of eastern Iran. *Bull. Soc. Geol. Fr.* 175, 121–129. <https://doi.org/10.1109/MUE.2007.129>
- Babazadeh, S.A., De Wever, P., 2004b. Age crétacé des radiolarites de Soulabest dans la suite ophiolitique d’Iran oriental. *Bull. Soc. Geol. Fr.* 175, 121–129. <https://doi.org/10.2113/175.2.121>
- Badr, A., Davoudian, A.R., Shabanian, N., Azizi, H., Asahara, Y., Neubauer, F., Dong, Y., Yamamoto, K., 2018. A- and I-type metagranites from the North Shahrekord Metamorphic Complex, Iran: Evidence for Early Paleozoic post-collisional magmatism. *Lithos* 300–301, 86–104. <https://doi.org/10.1016/j.lithos.2017.12.008>

- Badshah, M.S., Gnos, E., Jan, M.Q., Afridi, M.I., 2000. Stratigraphic and tectonic evolution of the northwestern Indian plate and Kabul Block. *Geol. Soc. Lond. Spec. Publ.* 170, 467–476. <https://doi.org/10.1144/GSL.SP.2000.170.01.25>
- Bagheri, S., Damani Gol, S., 2020. The eastern Iranian orocline. *Earth-Sci. Rev.* 210, 103322. <https://doi.org/10.1016/j.earscirev.2020.103322>
- Bagheri, S., Madhanifard, R., Zahabi, F., 2017. Kinematics of the Great Kavir fault inferred from a structural analysis of the Pees Kuh Complex, Jandaq area, central Iran, in: *Tectonic Evolution, Collision, and Seismicity of Southwest Asia*. In: Sorkhabi, R. (Ed): In Honor of Manuel Berberian's Forty-Five Years of Research Contributions. *Geol. Soc. Am. Spec. Pap.* 525. [https://doi.org/10.1130/2016.2525\(06\)](https://doi.org/10.1130/2016.2525(06))
- Bagheri, S., Stampfli, G.M., 2008. The Anarak, Jandaq and Posht-e-Badam metamorphic complexes in central Iran: New geological data, relationships and tectonic implications. *Tectonophysics* 451, 123–155. <https://doi.org/10.1016/j.tecto.2007.11.047>
- Balini, M., Nicora, A., Berra, F., Garzanti, E., Levera, M., Mattei, M., Muttoni, G., Zanchi, A., Bollati, I., Larghi, C., Zanchetta, S., Salamati, R., Mossavvari, F., 2009. The Triassic stratigraphic succession of Nakhla (Central Iran), a record from an active margin. *Geol. Soc. Lond. Spec. Publ.* 312, 287–321. <https://doi.org/10.1144/SP312.14>
- Balini, M., Nicora, A., Zanchetta, S., Zanchi, A., Marchesi, R., Vuolo, I., Hosseiniyoon, M., Norouzi, M., Soleimani, S., 2019. Olenekian to Early Ladinian Stratigraphy of the Western Part of the Aghdarband Window (Kopeh-Dag, NE Iran). *Riv. Ital. Paleontol. Stratigr.* 125(1), pp.283-315. <https://doi.org/10.13130/2039-4942/11446>
- Baroz, F., Macaudière, J., Montigny, R., Noghrehan, M., Ohnenstetter, M., Rocci, G., 1984. Ophiolites and Related Formations in the Central Part of the Sabzevar Range (Iran) and Possible Geotectonic Reconstructions. *Neues Jahrb. Für Geol. Paläontol. - Abh.* 168, 358–388. <https://doi.org/10.1127/njgpa/168/1984/358>
- Barrier, E., Vrielynck, B., Brouillet, J.-F., Brunet, M.-F., 2018. Paleotectonic Reconstruction of the Central Tethyan Realm. *Tectono-Sedimentary-Palinspastic maps from Late Permian to Pliocene*. Darius Programme, iSTeP - Institut des Sciences de la Terre de Paris.
- Bazhenov, M.L., 1987. Paleomagnetism of Cretaceous and Paleogene sedimentary rocks from the Kopet-Dagh and its tectonic implications. *Tectonophysics* 136, 223–235. [https://doi.org/10.1016/0040-1951\(87\)90026-6](https://doi.org/10.1016/0040-1951(87)90026-6)
- Bazhenov, M.L., Burtman, V.S., 1986. Tectonics and paleomagnetism of structural arcs of the Pamir-Punjab syntaxis. *J. Geodyn.* 5, 383–396. [https://doi.org/10.1016/0264-3707\(86\)90017-7](https://doi.org/10.1016/0264-3707(86)90017-7)
- Bea, F., Mazhari, A., Montero, P., Amini, S., Ghalamghash, J., 2011. Zircon dating, Sr and Nd isotopes, and element geochemistry of the Khalifan pluton, NW Iran: Evidence for Variscan magmatism in a supposedly Cimmerian superterrane. *J. Asian Earth Sci.* 40, 172–179. <https://doi.org/10.1016/j.jseaes.2010.08.005>
- Beck, R.A., Burbank, D.W., Sercombe, W.J., Khan, A.M., Lawrence, R.D., 1996. Late Cretaceous ophiolite obduction and Paleocene India-Asia collision in the westernmost Himalaya. *Geodin. Acta* 9, 114–144. <https://doi.org/10.1080/09853111.1996.11105281>
- Berberian, F., Berberian, M., 1981. Tectono-plutonic episodes in Iran, in: Gupta, H.K., Delany, F.M. (Eds.), *Geodynamics Series*. Am. Geophys. Union, Washington, D. C., pp. 5–32. <https://doi.org/10.1029/GD003p0005>
- Berberian, F., Muir, I.D., Pankhurst, R.J., Berberian, M., 1982. Late Cretaceous and early Miocene Andean-type plutonic activity in northern Makran and Central Iran. *J. Geol. Soc.* 139, 605–614. <https://doi.org/10.1144/gsjgs.139.5.0605>
- Berberian, M., 2014. Active Tectonics and Geologic Setting of the Iranian Plateau, in: *Developments in Earth Surface Processes*. Elsevier, pp. 151–171. <https://doi.org/10.1016/B978-0-444-63292-0.00009-0>
- Berberian, M., 1983. The southern Caspian: A compressional depression floored by a trapped, modified oceanic crust". *Can. J. Earth Sci.* 20, 163–183. <https://doi.org/10.1139/e83-015>

- Berberian, M., 1981. Active faulting and tectonics of Iran, in: Gupta, H.K., Delany, F.M. (Eds.), *Geodynamics Series*. Am. Geophys. Union, Washington, D. C., pp. 33–69.
<https://doi.org/10.1029/GD003p0033>
- Berberian, M., King, G.C.P., 1981. Towards a paleogeography and tectonic evolution of Iran. *Can. J. Earth Sci.* 18, 210–265. <https://doi.org/10.1139/e81-019>
- Besse, J., Torcq, F., Gallet, Y., Ricou, L.E., Krystyn, L., Saidi, A., 1998. Late Permian to Late Triassic palaeomagnetic data from Iran: constraints on the migration of the Iranian block through the Tethyan Ocean and initial destruction of Pangaea. *Geophys. J. Int.* 135, 77–92.
<https://doi.org/10.1046/j.1365-246X.1998.00603.x>
- Biabangard, H., Baghari, S., Vysinasab, S., 2020. Petrology, geochemistry and origin of Mirabad dacitoid dykes, south of Zahedan (Southeast of Iran). *Petrol. J.* 10, 67–82.
- Bin, Z., Meiyin, D., 2010. Geological Setting of Garmsar Block, Iran, in: 2010 International Conference on Challenges in Environmental Science and Computer Engineering. Presented at the 2010 International Conference on Challenges in Environmental Science and Computer Engineering, IEEE, Wuhan, China, pp. 433–437. <https://doi.org/10.1109/CESCE.2010.172>
- Bina, M.M., Bucur, I., Prevot, M., Meyerfeld, Y., Daly, L., Cantagrel, J.M., Mergoïl, J., 1986. Palaeomagnetism, petrology and geochronology of tertiary magmatic and sedimentary units from Iran. *Tectonophysics* 121, 303–329. [https://doi.org/10.1016/0040-1951\(86\)90050-8](https://doi.org/10.1016/0040-1951(86)90050-8)
- Blaise, J., Bordet, P., Carbonnel, J.P., Montenat, C., 1978. Flyschs et ophiolites dans la region de Panjaw; une suture neocimmerienne en Afghanistan central. *Bull. Société Géologique Fr.* S7-XX, 795–798. <https://doi.org/10.2113/gssgfbull.S7-XX.5.795>
- Bonnet, G., Agard, P., Angiboust, S., Monié, P., Jentzer, M., Omrani, J., Whitechurch, H., Fournier, M., 2018. Tectonic slicing and mixing processes along the subduction interface: The Sistan example (Eastern Iran). *Lithos* 310–311, 269–287.
<https://doi.org/10.1016/j.lithos.2018.04.016>
- Borneman, N.L., Hodges, K.V., Van Soest, M.C., Bohon, W., Wartho, J.-A., Cronk, S.S., Ahmad, T., 2015. Age and structure of the Shyok suture in the Ladakh region of northwestern India: Implications for slip on the Karakoram fault system: Age of Shyok Suture. *Tectonics* 34, 2011–2033. <https://doi.org/10.1002/2015TC003933>
- Bouilhol, P., Jagoutz, O., Hanchar, J.M., Dudas, F.O., 2013. Dating the India–Eurasia collision through arc magmatic records. *Earth Planet. Sci. Lett.* 366, 163–175.
<https://doi.org/10.1016/j.epsl.2013.01.023>
- Boulin, J., 1988. Hercynian and Eocimmerian events in Afghanistan and adjoining regions. *Tectonophysics* 148, 253–278. [https://doi.org/10.1016/0040-1951\(88\)90134-5](https://doi.org/10.1016/0040-1951(88)90134-5)
- Bourgeois, O., Cobbold, P.R., Rouby, D., Thomas, J., Shein, V., 1997. Least squares restoration of Tertiary thrust sheets in map view, Tajik depression, central Asia. *J. Geophys. Res. Solid Earth* 102, 27553–27573. <https://doi.org/10.1029/97JB02477>
- Boyden, J.A., Müller, R.D., Gurnis, M., Torsvik, T.H., Clark, J.A., Turner, M., Ivey-Law, H., Watson, R.J., Cannon, J.S., 2011. Next-generation plate-tectonic reconstructions using GPlates., in: *Geoinformatics: Cyberinfrastructure for the Solid Earth Sciences*. Cambridge University Press, Cambridge, pp. 95–113.
- Bröcker, M., Fotoohi Rad, G., Burgess, R., Theunissen, S., Paderin, I., Rodionov, N., Salimi, Z., 2013. New age constraints for the geodynamic evolution of the Sistan Suture Zone, eastern Iran. *Lithos* 170–171, 17–34. <https://doi.org/10.1016/j.lithos.2013.02.012>
- Bröcker, M., Omrani, H., Berndt, J., Moslempour, M.E., 2021. Unravelling metamorphic ages of suture zone rocks from the Sabzevar and Makran areas (Iran): Robust age constraints for the larger Arabia–Eurasian collision zone. *J. Metamorph. Geol.* 39, 1099–1129.
<https://doi.org/10.1111/jmg.12603>
- Brunet, M.-F., Granath, J.W., Wilmsen, M., 2009. South Caspian to Central Iran basins: introduction. *Geol. Soc. Lond. Spec. Publ.* 312, 1–6. <https://doi.org/10.1144/SP312.1>

- Buchs, D.M., Bagheri, S., Martin, L., Hermann, J., Arculus, R., 2013. Paleozoic to Triassic ocean opening and closure preserved in Central Iran: Constraints from the geochemistry of meta-igneous rocks of the Anarak area. *Lithos* 172–173, 267–287. <https://doi.org/10.1016/j.lithos.2013.02.009>
- Burg, J.-P., 2018. Geology of the onshore Makran accretionary wedge: Synthesis and tectonic interpretation. *Earth-Sci. Rev.* 185, 1210–1231. <https://doi.org/10.1016/j.earscirev.2018.09.011>
- Burtman, V.S., 2010. Tien Shan, Pamir, and Tibet: History and geodynamics of phanerozoic oceanic basins. *Geotectonics* 44, 388–404. <https://doi.org/10.1134/S001685211005002X>
- Burtman, V.S., 1994. Meso-Tethyan oceanic sutures and their deformation. *Tectonophysics* 234, 305–327. [https://doi.org/10.1016/0040-1951\(94\)90230-5](https://doi.org/10.1016/0040-1951(94)90230-5)
- Cai, F., Ding, L., Wang, H., Laskowski, A.K., Zhang, L., Zhang, B., Mohammadi, A., Li, J., Song, P., Li, Z., Zhang, Q., 2021. Configuration and Timing of Collision Between Arabia and Eurasia in the Zagros Collision Zone, Fars, Southern Iran. *Tectonics* 40, e2021TC006762. <https://doi.org/10.1029/2021TC006762>
- Camp, V.E., Griffis, R.J., 1982. Character, genesis and tectonic setting of igneous rocks in the Sistan suture zone, eastern Iran. *Lithos* 15, 221–239. [https://doi.org/10.1016/0024-4937\(82\)90014-7](https://doi.org/10.1016/0024-4937(82)90014-7)
- Chai, R., Zhou, Y., van Hinsbergen, D.J.J., Wang, T., Fu, Q., Chen, Z., Qu, C., Lan, S., Cheng, X., Wu, H., 2026. Paleomagnetic data from the Qaidam Block quantify post-middle Triassic convergence preceding eastern Eurasian assembly. <https://doi.org/https://doi.org/10.31223/X5TR0F>
- Cifelli, F., Ballato, P., Alimohammadian, H., Sabouri, J., Mattei, M., 2015. Tectonic magnetic lineation and oroclinal bending of the Alborz range: Implications on the Iran-Southern Caspian geodynamics: oroclinal bending of the Alborz Range. *Tectonics* 34, 116–132. <https://doi.org/10.1002/2014TC003626>
- Cogné, J.-P., Kravchinsky, V.A., Halim, N., Hankard, F., 2005. Late Jurassic-Early Cretaceous closure of the Mongol-Okhotsk Ocean demonstrated by new Mesozoic palaeomagnetic results from the Trans-Baikal area (SE Siberia). *Geophys. J. Int.* 163, 813–832. <https://doi.org/10.1111/j.1365-246X.2005.02782.x>
- Conrad, G., Montigny, R., Thuizat, R., Westphal, M., 1981. Tertiary and quaternary geodynamics of southern Lut (Iran) as deduced from palaeomagnetic, isotopic and structural data. *Tectonophysics* 75, T11–T17. [https://doi.org/10.1016/0040-1951\(81\)90272-9](https://doi.org/10.1016/0040-1951(81)90272-9)
- Cowgill, E., 2010. Cenozoic right-slip faulting along the eastern margin of the Pamir salient, northwestern China. *Geol. Soc. Am. Bull.* 122, 145–161. <https://doi.org/10.1130/B26520.1>
- Cowgill, E., Forte, A.M., Niemi, N., Avdeev, B., Tye, A., Trexler, C., Javakhishvili, Z., Elashvili, M., Godoladze, T., 2016. Relict basin closure and crustal shortening budgets during continental collision: An example from Caucasus sediment provenance. *Tectonics* 35, 2918–2947. <https://doi.org/10.1002/2016TC004295>
- Cowgill, E., Yin, A., Harrison, T.M., Xiao-Feng, W., 2003. Reconstruction of the Altyn Tagh fault based on U-Pb geochronology: Role of back thrusts, mantle sutures, and heterogeneous crustal strength in forming the Tibetan Plateau. *J. Geophys. Res. Solid Earth* 108, 2002JB002080. <https://doi.org/10.1029/2002JB002080>
- Davies, G.R., Jones, C.R., Hamzpour, B., Clark, G.G., 1972. Geology of the Masuleh sheet, 1:100,000. NW Iran. *Geol. Surv. Iran. Report No. 24*, pp. 110.
- Davoudian, A.R., Genser, J., Neubauer, F., Shabanian, N., 2016. 40 Ar/ 39 Ar mineral ages of eclogites from North Shahrekord in the Sanandaj–Sirjan Zone, Iran: Implications for the tectonic evolution of Zagros orogen. *Gondwana Res.* 37, 216–240. <https://doi.org/10.1016/j.gr.2016.05.013>
- Davoudzadeh, M., Lammerer, B., Weber-Diefenbach, K., 1997. Paleogeography, Stratigraphy, and Tectonics of the Tertiary of Iran. *Neues Jahrb. Für Geol. Paläontol. - Abh.* 205, 33–67. <https://doi.org/10.1127/njgpa/205/1997/33>

- Davoudzadeh, M., Schmidt, K., 1984. A Review of the Mesozoic Paleogeography and Paleotectonic Evolution of Iran. *Neues Jahrb. Für Geol. Paläontol. - Abh.* 168, 182–207. <https://doi.org/10.1127/njgpa/168/1984/182>
- Davoudzadeh, M., Seyed-Emami, K., Amidi, M., 1969. Preliminary note on a newly discovered Triassic Section northeast of Anarak (central Iran), with some remarks on the age of the Metamorphism on the Anarak Region. *Geol. Surv. Iran* 5, 1–23.
- Debon, F., Afzali, H., Le Fort, P., Sonet, J., 1987. Major intrusive stages in Afghanistan: Typology, age and geodynamic setting. *Geol. Rundsch.* 76, 245–264. <https://doi.org/10.1007/BF01820586>
- Deevsalar, R., Shinjo, R., Ghaderi, M., Murata, M., Hoskin, P.W.O., Oshiro, S., Wang, K.L., Lee, H.Y., Neill, I., 2017. Mesozoic–Cenozoic mafic magmatism in Sanandaj–Sirjan Zone, Zagros Orogen (Western Iran): Geochemical and isotopic inferences from Middle Jurassic and Late Eocene gabbros. *Lithos* 284–285, 588–607. <https://doi.org/10.1016/j.lithos.2017.05.009>
- Deevsalar, R., Shinjo, R., Wang, K.-L., Hadi, Y., Neill, I., 2018. Gabbroic–dioritic dykes from the Sanandaj–Sirjan Zone: windows on Jurassic and Eocene geodynamic processes in the Zagros Orogen, western Iran. *J. Geol. Soc.* 175, 915–933. <https://doi.org/10.1144/jgs2017-156>
- Delaloye, M., Desmons, J., 1980. Ophiolites and melange terranes in Iran: A geochronological study and its paleotectonic implications. *Tectonophysics* 68, 83–111. [https://doi.org/10.1016/0040-1951\(80\)90009-8](https://doi.org/10.1016/0040-1951(80)90009-8)
- Delavari, M., 2013. Different geodynamic settings for Sistan suture zone ophiolitic units: discussion of textural evidences and mineral chemistry of crustal sequence ultramafic-mafic associations. *Petrology* 4, 39–58.
- Delavari, M., Amini, S., Schmitt, A.K., McKeegan, K.D., Mark Harrison, T., 2014. U–Pb geochronology and geochemistry of Bibi-Maryam pluton, eastern Iran: Implication for the late stage of the tectonic evolution of the Sistan Ocean. *Lithos* 200–201, 197–211. <https://doi.org/10.1016/j.lithos.2014.04.015>
- DeMets, C., Merkouriev, S., 2021. Detailed reconstructions of India-Somalia plate motion, 60 Ma to present: Implications for Somalia plate absolute motion and India-Eurasia plate motion. *Geophys. J. Int.*, 1730–1767. <https://doi.org/10.1093/gji/ggab295>
- Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M., Cadet, J.P., Crasquin, S., Sandulescu, M., 2000. Peri-Tethys palaeogeographical atlas 2000. Université Pierre et Marie Curie, Paris.
- Desmons, J., Beccaluva, L., 1983. Mid-ocean ridge and island-arc affinities in ophiolites from Iran: Palaeographic implications. *Chem. Geol.* 39, 39–63. [https://doi.org/10.1016/0009-2541\(83\)90071-2](https://doi.org/10.1016/0009-2541(83)90071-2)
- Dewey, J.F., Şengör, A.M.C., 1979. Aegean and surrounding regions: Complex multiplate and continuum tectonics in a convergent zone. *Geol. Soc. Am. Bull.* 90, 84. [https://doi.org/10.1130/0016-7606\(1979\)90%3C84:AASRCM%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1979)90%3C84:AASRCM%3E2.0.CO;2)
- Doebrich, J., Ludington, S., Peters, S., Finn, C., Mars, J., Rowan, L., Stoeser, D., King, T., Eppinger, R., Wasy, A., 2007. Porphyry copper potential of Tethyan magmatic arcs of Afghanistan. *Ir. Assoc. Econ. Geol.* 1, 129–132.
- Doebrich, J.L., Wahl, R.R., 2006. Geologic and mineral resource map of Afghanistan. U.S. Geol. Surv. USGS open file report No. 2006-1038 version 2.
- Dorani, M., Arvin, M., Oberhänsli, R., Dargahi, S., 2017. P-T evolution of metapelites from the Bajgan complex in the Makran accretionary prism, south eastern Iran. *Geochemistry* 77, 459–475. <https://doi.org/10.1016/j.chemer.2017.07.004>
- Eftekhar-Nezhad, J., Stöcklin, J., 1992. Geological map of Iran sheet K8 (Birjand). Geol. Surv. Iran, Tehran.
- Esmaeily, D., Nédélec, A., Valizadeh, M.V., Moore, F., Cotten, J., 2005. Petrology of the Jurassic Shah-Kuh granite (eastern Iran), with reference to tin mineralization. *J. Asian Earth Sci.* 25, 961–980. <https://doi.org/10.1016/j.jseaes.2004.09.003>

- Esna-Ashari, A., Tiepolo, M., Valizadeh, M.-V., Hassanzadeh, J., Sepahi, A.-A., 2012. Geochemistry and zircon U–Pb geochronology of Aligoodarz granitoid complex, Sanandaj-Sirjan Zone, Iran. *J. Asian Earth Sci.* 43, 11–22. <https://doi.org/10.1016/j.jseaes.2011.09.001>
- Farbod, Y., Bellier, O., Shabanian, E., Abbassi, M.R., 2011. Geomorphic and structural variations along the Doruneh Fault System (central Iran). *Tectonics* 30, 2011TC002889. <https://doi.org/10.1029/2011TC002889>
- Faryad, S.W., Collett, S., Finger, F., Sergeev, S.A., Čopjaková, R., Siman, P., 2016. The Kabul Block (Afghanistan), a segment of the Columbia Supercontinent, with a Neoproterozoic metamorphic overprint. *Gondwana Res.* 34, 221–240. <https://doi.org/10.1016/j.gr.2015.02.019>
- Fattahi, M., Walker, R.T., Khatib, M.M., Dolati, A., Bahroudi, A., 2007. Slip-rate estimate and past earthquakes on the Doruneh fault, eastern Iran. *Geophys. J. Int.* 168, 691–709. <https://doi.org/10.1111/j.1365-246X.2006.03248.x>
- Fauvelet, E., Eftekhar-Nezhad, J., 1990. Explanatory Text of the Taybad Quadrangle. *Geol. Surv. Iran.*
- Fazlnia, A., Schenk, V., Appel, P., Alizade, A., 2013. Petrology, geochemistry, and geochronology of the Chah-Bazargan gabbroic intrusions in the south Sanandaj–Sirjan zone, Neyriz, Iran. *Int. J. Earth Sci.* 102, 1403–1426. <https://doi.org/10.1007/s00531-013-0884-6>
- Fazlnia, A., Schenk, V., Van Der Straaten, F., Mirmohammadi, M., 2009. Petrology, geochemistry, and geochronology of trondhjemites from the Qori Complex, Neyriz, Iran. *Lithos* 112, 413–433. <https://doi.org/10.1016/j.lithos.2009.03.047>
- Fotoohi Rad, G.R., Droop, G.T.R., Amini, S., Moazzen, M., 2005. Eclogites and blueschists of the Sistan Suture Zone, eastern Iran: A comparison of P–T histories from a subduction mélange. *Lithos* 84, 1–24. <https://doi.org/10.1016/j.lithos.2005.01.007>
- Fotoohi Rad, G.R., Droop, G.T.R., Burgess, R., 2009. Early Cretaceous exhumation of high-pressure metamorphic rocks of the Sistan Suture Zone, eastern Iran. *Geol. J.* 44, 104–116. <https://doi.org/10.1002/gj.1135>
- Fourcade, E., Azéma, J., Bassoullet, J.-P., Cecca, F., Dercourt, J., Enay, R., Guiraud, R., 1995. Paleogeography and Paleoenvironment of the Tethyan Realm During the Jurassic Breakup of Pangea, in: Nairn, A.E.M., Ricou, L.-E., Vrielynck, B., Dercourt, J. (Eds.), *The Tethys Ocean*. Springer US, Boston, MA, pp. 191–214. https://doi.org/10.1007/978-1-4899-1558-0_6
- Fruehn, J., White, R.S., Minshull, T.A., 1997. Internal deformation and compaction of the Makran accretionary wedge. *Terra Nova* 9, 101–104. <https://doi.org/10.1046/j.1365-3121.1997.d01-13.x>
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Majidifard, M.R., 2009a. Lithostratigraphy of the Upper Triassic–Middle Jurassic Shemshak Group of Northern Iran. *Geol. Soc. Lond. Spec. Publ.* 312, 129–160. <https://doi.org/10.1144/SP312.6>
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Majidifard, M.R., 2009b. The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, Northern Iran: evidence of the break-up unconformity of the South Caspian Basin. *Geol. Soc. Lond. Spec. Publ.* 312, 189–203. <https://doi.org/10.1144/SP312.9>
- Gaina, C., van Hinsbergen, D.J.J., Spakman, W., 2015. Tectonic interactions between India and Arabia since the Jurassic reconstructed from marine geophysics, ophiolite geology, and seismic tomography. *Tectonics* 34, 875–906. <https://doi.org/10.1002/2014TC003780>
- Geng, Q.-R., Zhang, Z., Peng, Z.-M., Guan, J.-L., Zhu, X.-P., Mao, X.-C., 2016. Jurassic–Cretaceous granitoids and related tectono-metallogeneses in the Zapug–Duobuza arc, western Tibet. *Ore Geol. Rev.* 77, 163–175. <https://doi.org/10.1016/j.oregeorev.2016.02.018>
- Ghasemi, H., Juteau, T., Bellon, H., Sabzehei, M., Whitechurch, H., Ricou, L.-E., 2002. The mafic–ultramafic complex of Sikhoran (central Iran): a polygenetic ophiolite complex. *C. R. Geosci.* 334, 431–438. [https://doi.org/10.1016/S1631-0713\(02\)01770-4](https://doi.org/10.1016/S1631-0713(02)01770-4)
- Ghazi, A.M., Hassanipak, A.A., 2000. Petrology and geochemistry of the Shahr-Babak ophiolite, central Iran, in: Dilek, Y., Moores, E.M., Elthon, D., Nicolas, A. (Eds.) *Ophiolites and Oceanic*

- Crust: New Insights from Field Studies and the Ocean Drilling Program. *Geol. Soc. Am. Spec. Pap.* (349). <https://doi.org/10.1130/0-8137-2349-3.485>
- Ghazi, A.M., Hassanipak, A.A., Mahoney, J.J., Duncan, R.A., 2004. Geochemical characteristics, ^{40}Ar – ^{39}Ar ages and original tectonic setting of the Band-e-Zeyarat/Dar Anar ophiolite, Makran accretionary prism, S.E. Iran. *Tectonophysics* 393, 175–196. <https://doi.org/10.1016/j.tecto.2004.07.035>
- Ghazi, A.M., Hassanipak, A.A., Tucker, P.J., Mobasher, K., Duncan, R.A., 2001. Geochemistry and ^{40}Ar – ^{39}Ar ages of the Mashhad Ophiolite, NE Iran: A Rare Occurrence of a 300 Ma (Paleo-Tethys) Oceanic Crust. Presented at the AGU Fall Meeting Abstracts, pp. V12C-0993.
- Ghazi, A.M., Pessagno, E.A., Hassanipak, A.A., Kariminia, S.M., Duncan, R.A., Babaie, H.A., 2003. Biostratigraphic zonation and ^{40}Ar – ^{39}Ar ages for the Neotethyan Khoy ophiolite of NW Iran. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 193, 311–323. [https://doi.org/10.1016/S0031-0182\(03\)00234-7](https://doi.org/10.1016/S0031-0182(03)00234-7)
- Ghazi, J.M., Moazzen, M., Rahgoshay, M., Shafaii Moghadam, H., 2012. Geochemical characteristics of basaltic rocks from the Nain ophiolite (Central Iran); constraints on mantle wedge source evolution in an oceanic back arc basin and a geodynamical model. *Tectonophysics* 574–575, 92–104. <https://doi.org/10.1016/j.tecto.2011.10.001>
- Ghodsi, M.R., Boomeri, M., Bagheri, S., Ishiyama, D., Corfu, F., 2016. Geochemistry, zircon U-Pb age, and tectonic constraints on the Bazman granitoid complex, southeast Iran. *Turk. J. Earth Sci.* 25, 311–340. <https://doi.org/10.3906/yer-1509-3>
- Girardeau, J., Marcoux, J., Montecat, C., 1989. The Neo-Cimmerian Ophiolite Belt in Afghanistan and Tibet: Comparison and Evolution, in: Şengör, A.M.C. (Ed.), *Tectonic Evolution of the Tethyan Region*. Springer Netherlands, Dordrecht, pp. 477–504. https://doi.org/10.1007/978-94-009-2253-2_19
- Gnos, E., Immenhauser, A., Peters, Tj., 1997. Late Cretaceous/early Tertiary convergence between the Indian and Arabian plates recorded in ophiolites and related sediments. *Tectonophysics* 271, 1–19. [https://doi.org/10.1016/S0040-1951\(96\)00249-1](https://doi.org/10.1016/S0040-1951(96)00249-1)
- Gnos, E., Khan, M., Khan, A.S., Mahmood, K., Villa, I.M., 2000. Age and tectonic setting of the Ras Koh ophiolites, Pakistan. *Acta Mineral. Pak.*, 11, pp.105–118 <https://doi.org/10.7892/BORIS.86866>
- Golonka, J., 2004. Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics* 381, 235–273. <https://doi.org/10.1016/j.tecto.2002.06.004>
- Govers, R., Wortel, M.J.R., 2005. Lithosphere tearing at STEP faults: response to edges of subduction zones. *Earth Planet. Sci. Lett.* 236, 505–523. <https://doi.org/10.1016/j.epsl.2005.03.022>
- Guest, B., Axen, G.J., Lam, P.S., Hassanzadeh, J., 2006a. Late Cenozoic shortening in the west-central Alborz Mountains, northern Iran, by combined conjugate strike-slip and thin-skinned deformation. *Geosphere* 2, 35. <https://doi.org/10.1130/GES00019.1>
- Guest, B., Stockli, D.F., Grove, M., Axen, G.J., Lam, P.S., Hassanzadeh, J., 2006b. Thermal histories from the central Alborz Mountains, northern Iran: Implications for the spatial and temporal distribution of deformation in northern Iran. *Geol. Soc. Am. Bull.* 118, 1507–1521. <https://doi.org/10.1130/B25819.1>
- Guillou, Y., Maurizot, P., Vaslet, D., Villéon, H., 1983. Gazik geological quadrangle map. *Geol. Surv. Iran*.
- Hassanzadeh, J., Stockli, D.F., Horton, B.K., Axen, G.J., Stockli, L.D., Grove, M., Schmitt, A.K., Walker, J.D., 2008. U-Pb zircon geochronology of late Neoproterozoic–Early Cambrian granitoids in Iran: Implications for paleogeography, magmatism, and exhumation history of Iranian basement. *Tectonophysics* 451, 71–96. <https://doi.org/10.1016/j.tecto.2007.11.062>
- Hassanzadeh, J., Wernicke, B.P., 2016. The Neotethyan Sanandaj-Sirjan zone of Iran as an archetype for passive margin-arc transitions. *Tectonics* 35, 586–621. <https://doi.org/10.1002/2015TC003926>

- Hollingsworth, J., Fattahi, M., Walker, R., Talebian, M., Bahroudi, A., Bolourchi, M.J., Jackson, J., Copley, A., 2010. Oroclinal bending, distributed thrust and strike-slip faulting, and the accommodation of Arabia-Eurasia convergence in NE Iran since the Oligocene: Thrust and strike-slip faulting in NE Iran. *Geophys. J. Int.* no-no. <https://doi.org/10.1111/j.1365-246X.2010.04591.x>
- Hollingsworth, J., Jackson, J., Walker, R., Reza Gheitanchi, M., Javad Bolourchi, M., 2006. Strike-slip faulting, rotation, and along-strike elongation in the Kopeh Dag mountains, NE Iran. *Geophys. J. Int.* 166, 1161–1177. <https://doi.org/10.1111/j.1365-246X.2006.02983.x>
- Homke, S., Vergés, J., Serra-Kiel, J., Bernaola, G., Sharp, I., Garcés, M., Montero-Verdú, I., Karpuz, R., Goodarzi, M.H., 2009. Late Cretaceous–Paleocene formation of the proto–Zagros foreland basin, Lurestan Province, SW Iran. *GSA Bull.* 121, 963–978. <https://doi.org/10.1130/B26035.1>
- Honarmand, M., Nabatian, G., Aflaki, M., Ebrahimi, M., 2020. Zircon U-Pb dating and geochemistry of the Moghanlou mylonite gneiss and granite intrusions, west of Zanjan. *Sci. Q. J. Geosci.*, 116 29. <https://doi.org/https://doi.org/10.22071/gsj.2019.112509.1361>
- Hsü, K.J., 1977. Tectonic Evolution of the Mediterranean Basins, in: Nairn, A.E.M., Kanes, W.H., Stehli, F.G. (Eds.), *The Ocean Basins and Margins*. Springer US, Boston, MA, pp. 29–75. https://doi.org/10.1007/978-1-4684-3036-3_2
- Hundee, S., Matthiii, K., Binns, R. a, Andrew, A.S., Cart, G.R., French, D.H., Mcandrew, J., Kananagh, M.E., 1995. *Bulletin of the Society of Economic Geologists*. *Econ. Geol.* 90, 90.
- Hunziker, D., Burg, J.-P., Bouilhol, P., Von Quadt, A., 2015. Jurassic rifting at the Eurasian Tethys margin: Geochemical and geochronological constraints from granitoids of North Makran, southeastern Iran. *Tectonics* 34, 571–593. <https://doi.org/10.1002/2014TC003768>
- Isozaki, Y., Maruyama, S., Furuoka, F., 1990. Accreted oceanic materials in Japan. *Tectonophysics* 181, 179–205. [https://doi.org/10.1016/0040-1951\(90\)90016-2](https://doi.org/10.1016/0040-1951(90)90016-2)
- Jackson, J., Priestley, K., Allen, M., Berberian, M., 2002. Active tectonics of the South Caspian Basin: Active tectonics of the South Caspian Basin. *Geophys. J. Int.* 148, 214–245. <https://doi.org/10.1046/j.1365-246X.2002.01005.x>
- Jackson, M.P.A., Cornelius, R.R., Craig, C.H., Gansser, A., Stöcklin, J., Talbot, C.J., 1990. Salt Diapirs of the Great Kavir, Central Iran, *GSA Memoir*, 177, pp. 1–150. <https://doi.org/10.1130/MEM177-p1>
- Jacob, K.H., Quittmeyer, R.C., 1979. The Makran region of Pakistan and Iran: Trench-arc system with active plate subduction. In Farah, A., DeJong, K.A. (Eds.): *Geodynamics of Pakistan*. *Geol. Surv. Pakistan, Quetta*, pp. 305–318.
- Jafari, M.K., Babaie, H.A., Moslempour, M.E., 2017. Mid-ocean-ridge to suprasubduction geochemical transition in the hypabyssal and extrusive sequences of major Upper Cretaceous ophiolites of Iran, in: *Tectonic Evolution, Collision, and Seismicity of Southwest Asia*: In: Sorkhabi, R. (Ed): *In Honor of Manuel Berberian's Forty-Five Years of Research Contributions*. *Geol. Soc. Am. Spec. Pap.* 525 [https://doi.org/10.1130/2016.2525\(07\)](https://doi.org/10.1130/2016.2525(07))
- Jagoutz, O., Bouilhol, P., Schaltegger, U., Müntener, O., 2019. The isotopic evolution of the Kohistan Ladakh arc from subduction initiation to continent arc collision. *Geol. Soc. Lond. Spec. Publ.* 483, 165–182. <https://doi.org/10.1144/SP483.7>
- Jagoutz, O., Schmidt, M.W., 2012. The formation and bulk composition of modern juvenile continental crust: The Kohistan arc. *Chem. Geol.* 298–299, 79–96. <https://doi.org/10.1016/j.chemgeo.2011.10.022>
- Jamaliashtiani, R., Scherer, E.E., Schmitt, A.K., Hassanzadeh, J., Hertwig, A.T., 2024. Lu-Hf and U-Pb dating of the Zayanderud eclogites: Implications for Jurassic subduction initiation along the Neotethys margin in Iran. *Lithos* 482–483, 107742. <https://doi.org/10.1016/j.lithos.2024.107742>
- Jamei, S., Ghorbani, M., Jafari, A., Williams, I.S., Moayyed, M., 2021. Geochronology and tectonic significance of A-type granite from Misho, NW Iran: Implications for the detachment of

- Cimmeria from Gondwana and the opening of Neo-Tethys. *Geol. J.* 56, 5275–5289.
<https://doi.org/10.1002/gj.4236>
- Javadi, H.R., Esterabi Ashtiani, M., Guest, B., Yassaghi, A., Ghassemi, M.R., Shahpasandzadeh, M., Naeimi, A., 2015. Tectonic reversal of the western Doruneh Fault System: Implications for Central Asian tectonics. *Tectonics* 34, 2034–2051. <https://doi.org/10.1002/2015TC003931>
- Javadi, H.R., Ghassemi, M.R., Shahpasandzadeh, M., Guest, B., Ashtiani, M.E., Yassaghi, A., Kouhpeyma, M., 2013. History of faulting on the Doruneh Fault System: implications for the kinematic changes of the Central Iranian Microplate. *Geol. Mag.* 150, 651–672.
<https://doi.org/10.1017/S0016756812000751>
- Jentzer, M., Agard, P., Bonnet, G., Monié, P., Fournier, M., Whitechurch, H., Omrani, J., Zarrinkoub, M.H., Khatib, M.M., Kohansal, R., Do Couto, D., Godbillot, C., Ninkabou, D., 2022. The North Sistan orogen (Eastern Iran): Tectono-metamorphic evolution and significance within the Tethyan realm. *Gondwana Res.* 109, 460–492. <https://doi.org/10.1016/j.gr.2022.04.004>
- Jentzer, M., Fournier, M., Agard, P., Omrani, J., Khatib, M.M., Whitechurch, H., 2017. Neogene to Present paleostress field in Eastern Iran (Sistan belt) and implications for regional geodynamics: Paleostress Field in Eastern Iran. *Tectonics* 36, 321–339.
<https://doi.org/10.1002/2016TC004275>
- Jolivet, L., Faccenna, C., 2000. Mediterranean extension and the Africa-Eurasia collision. *Tectonics* 19, 1095–1106. <https://doi.org/10.1029/2000TC900018>
- Kananian, A., Juteau, T., Bellon, H., Darvishzadeh, A., Sabzehi, M., Whitechurch, H., Ricou, L.-E., 2001. The ophiolite massif of Kahnuj (western Makran, southern Iran): new geological and geochronological data. *Comptes Rendus Académie Sci. - Ser. IIA - Earth Planet. Sci.* 332, 543–552. [https://doi.org/10.1016/S1251-8050\(01\)01574-9](https://doi.org/10.1016/S1251-8050(01)01574-9)
- Kapp, P., DeCelles, P.G., 2019. Mesozoic–Cenozoic geological evolution of the Himalayan-Tibetan orogen and working tectonic hypotheses. *Am. J. Sci.* 319, 159–254.
<https://doi.org/10.2475/03.2019.01>
- Kapp, P., DeCelles, P.G., Gehrels, G.E., Heizler, M., Ding, L., 2007. Geological records of the Lhasa-Qiangtang and Indo-Asian collisions in the Nima area of central Tibet. *Geol. Soc. Am. Bull.* 119, 917–933. <https://doi.org/10.1130/B26033.1>
- Kargaranbafghi, F., Neubauer, F., Genser, J., 2011. Cenozoic kinematic evolution of southwestern Central Iran: Strain partitioning and accommodation of Arabia–Eurasia convergence. *Tectonophysics* 502, 221–243. <https://doi.org/10.1016/j.tecto.2010.02.004>
- Karimpour, M., Stern, C., Farmer, L., Saadat, S., 2011. Review of age, Rb-Sr geochemistry and petrogenesis of Jurassic to Quaternary igneous rocks in Lut Block, Eastern Iran. *Geopersia* 1. <https://doi.org/10.22059/jgeope.2011.22162>
- Karimpour, M.H., Stern, C.R., Farmer, G.L., 2010. Zircon U–Pb geochronology, Sr–Nd isotope analyses, and petrogenetic study of the Dehnow diorite and Kuhsangi granodiorite (Paleo-Tethys), NE Iran. *J. Asian Earth Sci.* 37, 384–393. <https://doi.org/10.1016/j.jseaes.2009.11.001>
- Kassi, A.M., Kelling, G., Kasi, A.K., Umar, M., Khan, A.S., 2009. Contrasting Late Cretaceous–Palaeocene lithostratigraphic successions across the Bibai Thrust, western Sulaiman Fold–Thrust Belt, Pakistan: Their significance in deciphering the early-collisional history of the NW Indian Plate margin. *J. Asian Earth Sci.* 35, 435–444.
<https://doi.org/10.1016/j.jseaes.2009.02.006>
- Kaymakci, N., Inceöz, M., Ertepinar, P., Koç, A., 2010. Late Cretaceous to Recent kinematics of SE Anatolia (Turkey). *Geol. Soc. Lond. Spec. Publ.* 340, 409–435.
<https://doi.org/10.1144/SP340.18>
- Kazemi, Z., Ghasemi, H., Tilhac, R., Griffin, W., Moghadam, H.S., O'Reilly, S., Mousivand, F., 2019. Late Cretaceous subduction-related magmatism on the southern edge of Sabzevar basin, NE Iran. *J. Geol. Soc.* 176, 530–552. <https://doi.org/10.1144/jgs2018-076>
- Kaz'min, V.G., Verzhbitskii, E.V., 2011. Age and origin of the South Caspian Basin. *Oceanology* 51, 131–140. <https://doi.org/10.1134/S0001437011010073>

- Keshtgar, S., Bagheri, S., Boomeri, M., 2019. Tectonic setting of Mahirud Volcano-plutonic Complex: Different insight into the geodynamic history of East Iran. *Sci. Q. J. Geosci.* 113, 131–144. <https://doi.org/10.22071/gsj.2018.94653.1217>
- Khain, V.Y., Bogdanov, N.A., 2005. International Tectonic Map of the Caspian Sea Region, Scale 1:2 500 000 Explanatory Notes. *Geol. Inst. Russ. Acad. Sci.* 129+11.
- Khalaji, A.A., Esmaeili, D., Valizadeh, M.V., Rahimpour-Bonab, H., 2007. Petrology and geochemistry of the granitoid complex of Boroujerd, Sanandaj-Sirjan Zone, Western Iran. *J. Asian Earth Sci.* 29, 859–877. <https://doi.org/10.1016/j.jseaes.2006.06.005>
- Khalatbari Jafari, M., Mirzaie, M., Jannessary, M.R., 2013. Study of the Ophiolitic Plutonic Crustal Sequence of Garagoli- Bagjar, North East Sabzevar. *Sci. Q. J. Geosci.* 23(89), pp.143-154. <https://doi.org/10.22071/gsj.2013.53594>
- Khalatbari-Jafari, M., Juteau, T., Bellon, H., Emami, H., 2003. Discovery of two ophiolite complexes of different ages in the Khoy area (NW Iran). *C. R. Geosci.* 335, 917–929. [https://doi.org/10.1016/S1631-0713\(03\)00123-8](https://doi.org/10.1016/S1631-0713(03)00123-8)
- Khalili, K., Torabi, G., Arai, S., 2016. Metamorphism of peridotites from Posht-e-Badam Paleozoic ophiolite (Yazd Province, Central Iran). *Neues Jahrb. Für Geol. Paläontol. - Abh.* 280, 59–77. <https://doi.org/10.1127/njgpa/2016/0565>
- Khan, M.A., Siddiqui, R.H., Jan, M.Q., 2010. Temporal Evolution of Cretaceous to Pleistocene Magmatism in the Chagai Arc, Balochistan, Pakistan. *US Geol. Surv., Proceedings for the 25th Himalaya-Karakoram-Tibet Workshop Open-File Report 2010-1099.*
- Koshnaw, R.I., Stockli, D.F., Schlunegger, F., 2019. Timing of the Arabia-Eurasia continental collision—Evidence from detrital zircon U-Pb geochronology of the Red Bed Series strata of the northwest Zagros hinterland, Kurdistan region of Iraq. *Geology* 47, 47–50. <https://doi.org/10.1130/G45499.1>
- Kravchinsky, V.A., Cogne, J.-P., Harbert, W.P., Kuzmin, M.I., 2002. Evolution of the Mongol-Okhotsk Ocean as constrained by new palaeomagnetic data from the Mongol-Okhotsk suture zone, Siberia. *Geophys. J. Int.* 148, 34–57. <https://doi.org/10.1046/j.1365-246x.2002.01557.x>
- Kurzawa, T., Bröcker, M., Fotoohi Rad, G., Berndt, J., Lisker, F., 2017. Cretaceous high-pressure metamorphism and low pressure overprint in the Sistan Suture Zone, eastern Iran: Additional temperature estimates for eclogites, geological significance of U-Pb zircon ages and Rb-Sr constraints on the timing of exhumation. *J. Asian Earth Sci.* 147, 332–344. <https://doi.org/10.1016/j.jseaes.2017.07.051>
- Labails, C., Olivet, J.-L., Aslanian, D., Roest, W.R., 2010. An alternative early opening scenario for the Central Atlantic Ocean. *Earth Planet. Sci. Lett.* 297, 355–368. <https://doi.org/10.1016/j.epsl.2010.06.024>
- Lakhan, N., Singh, A.K., Singh, B.P., Sen, K., Singh, M.R., Khogenkumar, S., Singhal, S., Oinam, G., 2020. Zircon U–Pb geochronology, mineral and whole-rock geochemistry of the Khardung volcanics, Ladakh Himalaya, India: Implications for Late Cretaceous to Palaeogene continental arc magmatism. *Geol. J.* 55, 3297–3320. <https://doi.org/10.1002/gj.3594>
- Lawrence, R.D., Yeats, R.S., Khan, S.H., Farah, A., DeJong, K.A., 1981. Thrust and strike slip fault interaction along the Chaman transform zone, Pakistan. *Geol. Soc. Lond. Spec. Publ.* 9, 363–370. <https://doi.org/10.1144/GSL.SP.1981.009.01.33>
- Lei, Y., Chu, Y., Allen, M.B., Lin, W., Wan, B., Chen, L., Talebian, M., Xin, G., Liu, T., Guo, Y., Guo, L., 2025. Restoring the Missing Late Cretaceous Arc of Iran. *Geochem. Geophys. Geosystems* 26, e2025GC012657. <https://doi.org/10.1029/2025GC012657>
- Leloup, P.H., Lacassin, R., Tapponnier, P., Schärer, U., Zhong, D., Liu, X., Zhang, L., Ji, S., Trinh, P.T., 1995. The Ailao Shan-Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina. *Tectonophysics* 251, 3–84. [https://doi.org/10.1016/0040-1951\(95\)00070-4](https://doi.org/10.1016/0040-1951(95)00070-4)
- Lensch, G., Davoudzadeh, M., 1982. Ophiolites in Iran. *Neues Jahrb. Für Geol. Paläontol. - Monatshefte* 1982, 306–320. <https://doi.org/10.1127/njgpm/1982/1982/306>

- Leven, E.J., Stevens, C.H., Baars, D.L., 1997. Permian stratigraphy and Fusulinida of Afghanistan with Their Paleogeographic and Paleotectonic Implications. *Geol. Soc. Am. Spec. Pap.* 316. <https://doi.org/10.1130/0-8137-2316-7.1>
- Li, S., Advokaat, E.L., van Hinsbergen, D.J.J., Koymans, M., Deng, C., Zhu, R., 2017. Paleomagnetic constraints on the Mesozoic-Cenozoic paleolatitudinal and rotational history of Indochina and South China: Review and updated kinematic reconstruction. *Earth-Sci. Rev.* 171, 58–77. <https://doi.org/10.1016/j.earscirev.2017.05.007>
- Li, Z., Ding, L., Lippert, P.C., Song, P., Yue, Y., Van Hinsbergen, D.J.J., 2016. Paleomagnetic constraints on the Mesozoic drift of the Lhasa terrane (Tibet) from Gondwana to Eurasia. *Geology* 44, 727–730. <https://doi.org/10.1130/G38030.1>
- Lindenberg, H.G., Görler, K., Jacobshagen, V., Ibbeken, H., 1984. Postpaleozoic Stratigraphy, Structure and Orogenetic Evolution of the Southern Sabzewar Zone and the Taknar Block (Khorassan, NE Iran). *Neues Jahrb. Für Geol. Paläontol. - Abh.* 168, 287–326. <https://doi.org/10.1127/njgpa/168/1984/287>
- Lyberis, N., Manby, G., 1999. Oblique to Orthogonal Convergence Across the Turan Block in the Post-Miocene. *AAPG Bull.* 83, 1135–1160. <https://doi.org/10.1306/E4FD2E97-1732-11D7-8645000102C1865D>
- Lyberis, N., Manby, G., Poli, J.-T., Kalougin, V., Yousouphocaev, H., Ashirov, T., 1998. Post-triassic evolution of the southern margin of the Turan plate. *Comptes Rendus Académie Sci. - Ser. IIA - Earth Planet. Sci.* 326, 137–143. [https://doi.org/10.1016/S1251-8050\(97\)87458-7](https://doi.org/10.1016/S1251-8050(97)87458-7)
- Ma, X., Tan, X., Li, Y., Wang, C., Han, Z., Li, S., Li, Z., Yang, B., Song, J., 2025. Initial Closure of the Longmu Co-Shuanghu Paleo-Tethyan Ocean: Constraints Based on New Paleomagnetic Data From the Middle Triassic Volcanic-Sedimentary Sequence, Southern Qiangtang Terrane. *Tectonics* 44, e2024TC008504. <https://doi.org/10.1029/2024TC008504>
- Madanipour, S., Yassaghi, A., Ehlers, T.A., Enkelmann, E., 2018. Tectonostratigraphy, structural geometry and kinematics of the NW Iranian Plateau margin: Insights from the Talesh Mountains, Iran. *Am. J. Sci.* 318, 208–245. <https://doi.org/10.2475/02.2018.02>
- Maffione, M., van Hinsbergen, D.J.J., De Gelder, G.I.N.O., Van Der Goes, F.C., Morris, A., 2017. Kinematics of Late Cretaceous subduction initiation in the Neo-Tethys Ocean reconstructed from ophiolites of Turkey, Cyprus, and Syria. *J. Geophys. Res. Solid Earth* 122, 3953–3976. <https://doi.org/10.1002/2016JB013821>
- Mahdavi, A., Karimpour, M.H., Mao, J., Haidarian Shahri, M.R., Malekzadeh Shafaroudi, A., Li, H., 2016. Zircon U–Pb geochronology, Hf isotopes and geochemistry of intrusive rocks in the Gazu copper deposit, Iran: Petrogenesis and geological implications. *Ore Geol. Rev.* 72, 818–837. <https://doi.org/10.1016/j.oregeorev.2015.09.011>
- Mahmood, K., Boudier, F., Gnos, E., Monié, P., Nicolas, A., 1995. ⁴⁰Ar/³⁹Ar dating of the emplacement of the Muslim Bagh ophiolite, Pakistan. *Tectonophysics* 250, 169–181. [https://doi.org/10.1016/0040-1951\(95\)00017-5](https://doi.org/10.1016/0040-1951(95)00017-5)
- Mahmoudi, S., Masoudi, F., Corfu, F., Mehrabi, B., 2010. Magmatic and metamorphic history of the Deh-Salm metamorphic Complex, Eastern Lut block, (Eastern Iran), from U–Pb geochronology. *Int. J. Earth Sci.* 99, 1153–1165. <https://doi.org/10.1007/s00531-009-0465-x>
- Malekpour-Alamdari, A., Axen, G., Heizler, M., Hassanzadeh, J., 2017. Large-magnitude continental extension in the northeastern Iranian Plateau: Insight from K-feldspar⁴⁰Ar/³⁹Ar thermochronology from the Shotor Kuh–Biarjmand metamorphic core complex. *Geosphere* GES01423.1. <https://doi.org/10.1130/GES01423.1>
- Martin, C.R., Jagoutz, O., Upadhyay, R., Royden, L.H., Eddy, M.P., Bailey, E., Nichols, C.I.O., Weiss, B.P., 2020. Paleocene latitude of the Kohistan–Ladakh arc indicates multistage India–Eurasia collision. *Proc. Natl. Acad. Sci.* 117, 29487–29494. <https://doi.org/10.1073/pnas.2009039117>
- Martin, C.R., Van Buer, N.J., Matchette-Downes, H., Mueller, P.A., Cruz-Urbe, A.M., Van Tongeren, J.A., Hanchar, J.M., Upadhyay, R., Jagoutz, O., 2025. The geology of the Shyok suture zone:

- evidence for Cretaceous extension of the southern Eurasian margin and Eocene India–Eurasia collision. *J. Geol. Soc.* 182, jgs2024-082. <https://doi.org/10.1144/jgs2024-082>
- Mattei, M., Cifelli, F., Alimohammadian, H., Rashid, H., 2020. The role of active strike-slip faults and opposite vertical axis rotations in accommodating Eurasia-Arabia shortening in central Iran. *Tectonophysics* 774, 228243. <https://doi.org/10.1016/j.tecto.2019.228243>
- Mattei, M., Cifelli, F., Alimohammadian, H., Rashid, H., Winkler, A., Sagnotti, L., 2017. Oroclinal bending in the Alborz Mountains (Northern Iran): New constraints on the age of South Caspian subduction and extrusion tectonics. *Gondwana Res.* 42, 13–28. <https://doi.org/10.1016/j.gr.2016.10.003>
- Mattei, M., Cifelli, F., Muttoni, G., Rashid, H., 2015. Post-Cimmerian (Jurassic–Cenozoic) paleogeography and vertical axis tectonic rotations of Central Iran and the Alborz Mountains. *J. Asian Earth Sci.* 102, 92–101. <https://doi.org/10.1016/j.jseaes.2014.09.038>
- Mattei, M., Cifelli, F., Muttoni, G., Zanchi, A., Berra, F., Mossavvari, F., Eshraghi, S.A., 2012. Neogene block rotation in central Iran: Evidence from paleomagnetic data. *Geol. Soc. Am. Bull.* 124, 943–956. <https://doi.org/10.1130/B30479.1>
- Mattei, M., Muttoni, G., Cifelli, F., 2014. A record of the Jurassic massive plate shift from the Garedu Formation of central Iran. *Geology* 42, 555–558. <https://doi.org/10.1130/G35467.1>
- Mazhari, S.A., Safari, M., 2013. High-K Calc-alkaline Plutonism in Zouzan, NE of Lut Block, Eastern Iran: An Evidence for Arc Related Magmatism in Cenozoic. *J. Geol. Soc. India* 81, 698–708. <https://doi.org/10.1007/s12594-013-0091-x>
- McCall, G.J.H., 2002. A summary of the geology of the Iranian Makran. *Geol. Soc. Lond. Spec. Publ.* 195, 147–204. <https://doi.org/10.1144/GSL.SP.2002.195.01.10>
- McCall, G.J.H., Kidd, R.G.W., 1982. The Makran, Southeastern Iran: the anatomy of a convergent plate margin active from Cretaceous to Present. *Geol. Soc. Lond. Spec. Publ.* 10, 387–397. <https://doi.org/10.1144/GSL.SP.1982.010.01.26>
- McCann, T., Chalot-Prat, F., Saintot, A., 2010. The Early Mesozoic evolution of the Western Greater Caucasus (Russia): Triassic–Jurassic sedimentary and magmatic history. *Geol. Soc. Lond. Spec. Publ.* 340, 181–238. <https://doi.org/10.1144/SP340.10>
- McCormick, G.R., 1989. Geology of the Baluchistan (Pakistan) Portion of the Southern Margin of the Tethys Sea, in: Şengör, A.M.C. (Ed.), *Tectonic Evolution of the Tethyan Region*. Springer Netherlands, Dordrecht, pp. 277–288. https://doi.org/10.1007/978-94-009-2253-2_15
- McQuarrie, N., van Hinsbergen, D.J.J., 2013. Retrodeforming the Arabia-Eurasia collision zone: Age of collision versus magnitude of continental subduction. *Geology* 41, 315–318. <https://doi.org/10.1130/G33591.1>
- Meyer, B., Mouthereau, F., Lacombe, O., Agard, P., 2006. Evidence of Quaternary activity along the Deshir Fault: implication for the Tertiary tectonics of Central Iran. *Geophys. J. Int.* 164, 192–201. <https://doi.org/10.1111/j.1365-246X.2005.02784.x>
- Mirnejad, H., Lalonde, A.E., Obeid, M., Hassanzadeh, J., 2013. Geochemistry and petrogenesis of Mashhad granitoids: An insight into the geodynamic history of the Paleo-Tethys in northeast of Iran. *Lithos* 170–171, 105–116. <https://doi.org/10.1016/j.lithos.2013.03.003>
- Moghadam, H.S., Corfu, F., Chiaradia, M., Stern, R.J., Ghorbani, G., 2014. Sabzevar Ophiolite, NE Iran: Progress from embryonic oceanic lithosphere into magmatic arc constrained by new isotopic and geochemical data. *Lithos* 210–211, 224–241. <https://doi.org/10.1016/j.lithos.2014.10.004>
- Moghadam, H.S., Stern, R.J., 2011. Late Cretaceous forearc ophiolites of Iran. *Isl. Arc* 20, 1–4. <https://doi.org/10.1111/j.1440-1738.2010.00745.x>
- Moghadam, H.S., Stern, R.J., Chiaradia, M., Rahgoshay, M., 2013. Geochemistry and tectonic evolution of the Late Cretaceous Gogher–Baft ophiolite, central Iran. *Lithos* 168–169, 33–47. <https://doi.org/10.1016/j.lithos.2013.01.013>
- Moghadam, H.S., Stern, R.J., Griffin, W.L., Khedr, M.Z., Kirchenbaur, M., Ottley, C.J., Whattam, S.A., Kimura, J.-I., Ghorbani, G., Gain, S., O'Reilly, S.Y., Tamura, A., 2020. Subduction initiation and

- back-arc opening north of Neo-Tethys: Evidence from the Late Cretaceous Torbat-e-Heydarieh ophiolite of NE Iran. *Geol. Soc. Am. Bull.* 132, 1083–1105.
<https://doi.org/10.1130/B35065.1>
- Moghadam, H.S., Stern, R.J., Rahgoshay, M., 2010. The Dehshir ophiolite (central Iran): Geochemical constraints on the origin and evolution of the Inner Zagros ophiolite belt. *Geol. Soc. Am. Bull.* 122, 1516–1547. <https://doi.org/10.1130/B30066.1>
- Moghadam, H.S., Whitechurch, H., Rahgoshay, M., Monsef, I., 2009. Significance of Nain-Baft ophiolitic belt (Iran): Short-lived, transtensional Cretaceous back-arc oceanic basins over the Tethyan subduction zone. *C. R. Geosci.* 341, 1016–1028.
<https://doi.org/10.1016/j.crte.2009.06.011>
- Mohajjel, M., 2009. Thin-skinned deformation near Shahdad, southeast Iran. *J. Asian Earth Sci.* 36, 146–155. <https://doi.org/10.1016/j.jseaes.2009.05.002>
- Mohammadi, A., Burg, J.-P., Ruh, J.B., Spezzaferri, S., 2023a. Clastic carbonates in the South Sistan Basin (SE Iran): implications for subduction vergence and timing of collision. *Int. Geol. Rev.* 65, 3453–3465. <https://doi.org/10.1080/00206814.2023.2191119>
- Mohammadi, A., Kaveh-Firouz, A., Cai, F., Dolati, A., Lom, N., Şengör, A.M.C., 2023b. Migration of the Palaeozoic magmatic front from Zagros to Alborz mountains with progressive closure of the Palaeo-Tethys Ocean; Insights from Zagros detrital zircon U Pb age and Hf isotopic composition. *Tectonophysics* 849, 229729. <https://doi.org/10.1016/j.tecto.2023.229729>
- Mohammadi, A., Moghadam, H.S., Kaveh-Firouz, A., Lechmann, A., Cai, F., Ding, L., 2026. The missing late Cretaceous magmatic arc in the Arabia-Eurasia collision zone (NW Iran): constraints from zircon geochronology, Hf isotopes, and geochemistry. *Geosci. Front.* 17, 102205.
<https://doi.org/10.1016/j.gsf.2025.102205>
- Monsef, I., Monsef, R., Mata, J., Zhang, Z., Pirouz, M., Rezaeian, M., Esmaili, R., Xiao, W., 2018. Evidence for an early-MORB to fore-arc evolution within the Zagros suture zone: Constraints from zircon U-Pb geochronology and geochemistry of the Neyriz ophiolite (South Iran). *Gondwana Res.* 62, 287–305. <https://doi.org/10.1016/j.gr.2018.03.002>
- Montenat, C., 2009. The Mesozoic of Afghanistan. *GeoArabia* 14, 147–210.
<https://doi.org/10.2113/geoarabia1401147>
- Montenat, C., Blaise, J., Bordet, P., Debon, F., Deutsch, S., Le Fort, P., Sonet, J., 1981. Metamorphisme et plutonisme au Paleozoique ancien en domaine Gondwan. La marge nord-ouest des Montagnes centrales d'Afghanistan. *Bull. Société Géologique Fr.* S7-XXIII, 101–110.
<https://doi.org/10.2113/gssgfbull.S7-XXIII.1.101>
- Morley, C.K., Kongwung, B., Julapour, A.A., Abdolghafourian, M., Hajian, M., Waples, D., Warren, J., Otterdoom, H., Srisuriyon, K., Kazemi, H., 2009. Structural development of a major late Cenozoic basin and transpressional belt in central Iran: The Central Basin in the Qom-Saveh area. *Geosphere* 5, 325–362. <https://doi.org/10.1130/GES00223.1>
- Moslempour, M.E., Khalatbari-jafari, M., Dabiri, R., 2012. Constraints on the Petrogenesis of Nosrat-Abad Ophiolite. *Iran. J. Earth Sci.* pp. 125-133.
- Moussavi-Harami, R., Brenner, R.L., 1992. Geohistory Analysis and Petroleum Reservoir Characteristics of Lower Cretaceous (Neocomian) Sandstones, Eastern Kopet-Dagh Basin, Northeastern Iran. *AAPG Bull.* 76, 1200–1208. <https://doi.org/10.1306/BDF89AC-1718-11D7-8645000102C1865D>
- Mouthereau, F., 2011. Timing of uplift in the Zagros belt/Iranian plateau and accommodation of late Cenozoic Arabia–Eurasia convergence. *Geol. Mag.* 148, 726–738.
<https://doi.org/10.1017/S0016756811000306>
- Müller, R.D., Cannon, J., Qin, X., Watson, R.J., Gurnis, M., Williams, S., Pfaffelmoser, T., Seton, M., Russell, S.H.J., Zahirovic, S., 2018. GPlates: Building a Virtual Earth Through Deep Time. *Geochem. Geophys. Geosystems* 19, 2243–2261. <https://doi.org/10.1029/2018GC007584>

- Murphy, M.A., Yin, A., Harrison, T.M., Dürr, S.B., Z, C., Ryerson, F.J., Kidd, W.S.F., X, W., X, Z., 1997. Did the Indo-Asian collision alone create the Tibetan plateau? *Geology* 25, 719. [https://doi.org/10.1130/0091-7613\(1997\)025%3C0719:DTIACA%3E2.3.CO;2](https://doi.org/10.1130/0091-7613(1997)025%3C0719:DTIACA%3E2.3.CO;2)
- Muttoni, G., Mattei, M., Balini, M., Zanchi, A., Gaetani, M., Berra, F., 2009. The drift history of Iran from the Ordovician to the Triassic. *Geol. Soc. Lond. Spec. Publ.* 312, 7–29. <https://doi.org/10.1144/SP312.2>
- Nasrabady, M., Rossetti, F., Theye, T., Vignaroli, G., 2011. Metamorphic history and geodynamic significance of the Early Cretaceous Sabzevar granulites (Sabzevar structural zone, NE Iran). *Solid Earth* 2, 219–243. <https://doi.org/10.5194/se-2-219-2011>
- Natal'in, B.A., Şengör, A.M.C., 2005. Late Palaeozoic to Triassic evolution of the Turan and Scythian platforms: The pre-history of the Palaeo-Tethyan closure. *Tectonophysics* 404, 175–202. <https://doi.org/10.1016/j.tecto.2005.04.011>
- Negredo, A.M., Replumaz, A., Villaseñor, A., Guillot, S., 2007. Modeling the evolution of continental subduction processes in the Pamir–Hindu Kush region. *Earth Planet. Sci. Lett.* 259, 212–225. <https://doi.org/10.1016/j.epsl.2007.04.043>
- Nikbakht, S., Biabanghard, H., Bagheri, S., 2021. Petrology and geochemistry of Siahjungal ophiolite, northeastern Taftan volcano. *Iran. J. Geol.* 56, p.87.
- Nikogosian, I.K., Bracco Gartner, A.J.J., Mason, P.R.D., van Hinsbergen, D.J.J., Kuiper, K.F., Kirscher, U., Matveev, S., Grigoryan, A., Grigoryan, E., Israyelyan, A., Van Bergen, M.J., Koornneef, J.M., Wijbrans, J.R., Davies, G.R., Meliksetian, K., 2023. The South Armenian Block: Gondwanan origin and Tethyan evolution in space and time. *Gondwana Res.* 121, 168–195. <https://doi.org/10.1016/j.gr.2023.03.023>
- Ninkabou, D., Agard, P., Nielsen, C., Smit, J., Gorini, C., Rodriguez, M., Haq, B., Chamot-Rooke, N., Weidle, C., Ducassou, C., 2021. Structure of the Offshore Obducted Oman Margin: Emplacement of Semail Ophiolite and Role of Tectonic Inheritance. *J. Geophys. Res. Solid Earth* 126, 2020JB020187. <https://doi.org/10.1029/2020JB020187>
- Nosouhian, N., Torabi, G., Arai, S., 2019. Petrological aspects of the Bayazeh Paleozoic ophiolite (Central Iran); implications for Paleo-Tethys subduction. *Period. Mineral.* 88. <https://doi.org/10.2451/2019PM835>
- Nutman, A.P., Mohajjel, M., Bennett, V.C., Fergusson, C.L., 2014. Gondwanan Eoarchean–Neoproterozoic ancient crustal material in Iran and Turkey: zircon U–Pb–Hf isotopic evidence. *Can. J. Earth Sci.* 51, 272–285. <https://doi.org/10.1139/cjes-2013-0138>
- Ohnenstetter, M., 1983. The role of possible transverse faults in the development of the Sabzevar ophiolites, North-East Iran, with special reference to magma chamber tectonics. *Sci. Géologiques Bull.* 36, 73–90. <https://doi.org/10.3406/sgeol.1983.1628>
- Omran, H., Moazzen, M., Oberhänsli, R., 2018. Geodynamic evolution of the Sabzevar zone, northern central Iranian micro-continent. *Mineral. Petrol.* 112, 65–83. <https://doi.org/10.1007/s00710-017-0505-3>
- Omran, H., Moazzen, M., Oberhänsli, R., Altenberger, U., Lange, M., 2013. The Sabzevar blueschists of the North-Central Iranian micro-continent as remnants of the Neotethys-related oceanic crust subduction. *Int. J. Earth Sci.* 102, 1491–1512. <https://doi.org/10.1007/s00531-013-0881-9>
- Ozsvárt, P., Bahramnejad, E., Bagheri, S., Sharifi, M., 2020. New Albian (Cretaceous) radiolarian age constraints for the Dumak ophiolitic mélange from the Shuru area, Eastern Iran. *Cretac. Res.* 111. <https://doi.org/10.1016/j.cretres.2020.104451>
- Pang, K.-N., Chung, S.-L., Zarrinkoub, M.H., Khatib, M.M., Mohammadi, S.S., Chiu, H.-Y., Chu, C.-H., Lee, H.-Y., Lo, C.-H., 2013. Eocene–Oligocene post-collisional magmatism in the Lut–Sistan region, eastern Iran: Magma genesis and tectonic implications. *Lithos* 180–181, 234–251. <https://doi.org/10.1016/j.lithos.2013.05.009>
- Pang, K.-N., Chung, S.-L., Zarrinkoub, M.H., Mohammadi, S.S., Yang, H.-M., Chu, C.-H., Lee, H.-Y., Lo, C.-H., 2012. Age, geochemical characteristics and petrogenesis of Late Cenozoic intraplate alkali

- basalts in the Lut–Sistan region, eastern Iran. *Chem. Geol.* 306–307, 40–53.
<https://doi.org/10.1016/j.chemgeo.2012.02.020>
- Parlak, O., Höck, V., Kozlu, H., Delaloye, M., 2004. Oceanic crust generation in an island arc tectonic setting, SE Anatolian orogenic belt (Turkey). *Geol. Mag.* 141, 583–603.
<https://doi.org/10.1017/S0016756804009458>
- Pastor-Galán, D., López-Carmona, A., Rezaeian, M., Tsujimori, T., Gutiérrez-Alonso, G., Yi, K., Langereis, C., 2025. From Rheic to Paleotethys: Subduction history of the Shanderman Eclogites (NW Iran). *Geol. Soc. Am. Bull.* 137, 4478–4496. <https://doi.org/10.1130/B38187.1>
- Perello, J., Razique, A., Schloderer, J., Asad-ur-Rehman, 2008. The Chagai Porphyry Copper Belt, Baluchistan Province, Pakistan. *Econ. Geol.* 103, 1583–1612.
<https://doi.org/10.2113/gsecongeo.103.8.1583>
- Peyret, M., Djamour, Y., Hessami, K., Regard, V., Bellier, O., Vernant, P., Daignières, M., Nankali, H., Van Gorp, S., Goudarzi, M., Chéry, J., Bayer, R., Rigoulay, M., 2009. Present-day strain distribution across the Minab-Zendan-Palami fault system from dense GPS transects. *Geophys. J. Int.* 179, 751–762. <https://doi.org/10.1111/j.1365-246X.2009.04321.x>
- Pezzo, G., Tolomei, C., Atzori, S., Salvi, S., Shabanian, E., Bellier, O., Farbod, Y., 2012. New kinematic constraints of the western Doruneh fault, northeastern Iran, from interseismic deformation analysis: Doruneh fault (Iran) interseismic deformation. *Geophys. J. Int.* 190, 622–628.
<https://doi.org/10.1111/j.1365-246X.2012.05509.x>
- Pirnia, T., Saccani, E., Torabi, G., Chiari, M., Goričan, Š., Barbero, E., 2020. Cretaceous tectonic evolution of the Neo-Tethys in Central Iran: Evidence from petrology and age of the Nain-Ashin ophiolitic basalts. *Geosci. Front.* 11, 57–81. <https://doi.org/10.1016/j.gsf.2019.02.008>
- Popkov, V.I., 1992. *Tektonika Zapada Turanskoy Plity*. IGIRGI Mosc.
- Rahimpour-Bonab, H., Shariatnia, Z., Siemann, M.G., 2007. Role of rifting in evaporite deposition in the Great Kavir Basin, central Iran. *Geol. Soc. Lond. Spec. Publ.* 285, 69–85.
<https://doi.org/10.1144/SP285.5>
- Rahmani, F., Noghrean, M., Khalili, M., 2007. Geochemistry of Sheeted Dikes in The Nain Ophiolite (Central Iran). *Ophioliti* 32, 119–129.
- Rahmati-Ilkhchi, M., Faryad, S.W., Holub, F.V., Košler, J., Frank, W., 2011. Magmatic and metamorphic evolution of the Shotur Kuh metamorphic complex (Central Iran). *Int. J. Earth Sci.* 100, 45–62.
<https://doi.org/10.1007/s00531-009-0499-0>
- Ramezani, J., Tucker, R.D., 2003. The Saghand Region, Central Iran: U-Pb geochronology, petrogenesis and implications for Gondwana Tectonics. *Am. J. Sci.* 303, 622–665.
<https://doi.org/10.2475/ajs.303.7.622>
- Rashid, H., 2016. *Cenozoic tectonic evolution and paleomagnetic rotation in Iran (Thesis)*. Università degli Studi Roma Tre, Roma.
- Rashidi, A., Abbassi, M.-R., Nilfouroushan, F., Shafiei, S., Derakhshani, R., Nemat, M., 2020. Morphotectonic and earthquake data analysis of interactional faults in Sabzevaran Area, SE Iran. *J. Struct. Geol.* 139, 104147. <https://doi.org/10.1016/j.jsg.2020.104147>
- Regard, V., Bellier, O., Thomas, J.-C., Bourlès, D., Bonnet, S., Abbassi, M.R., Braucher, R., Mercier, J., Shabanian, E., Soleymani, Sh., Fegghi, Kh., 2005. Cumulative right-lateral fault slip rate across the Zagros-Makran transfer zone: role of the Minab-Zendan fault system in accommodating Arabia-Eurasia convergence in southeast Iran. *Geophys. J. Int.* 162, 177–203.
<https://doi.org/10.1111/j.1365-246X.2005.02558.x>
- Rezaei, Z., Noghrean, M., Saccani, E., 2019. Petrogenesis of pillow lavas based on mineralogical and geochemical data in the eastern part of Sabzevar ophiolite. *Iran. J. Crystallogr. Mineral.* 27, 609–620. <https://doi.org/10.29252/ijcm.27.3.609>
- Rezaeian, M., Kuijper, C.B., Van Der Boon, A., Pastor-Galán, D., Cotton, L.J., Langereis, C.G., Krijgsman, W., 2020. Post-Eocene coupled oroclines in the Talesh (NW Iran): Paleomagnetic constraints. *Tectonophysics* 786, 228459. <https://doi.org/10.1016/j.tecto.2020.228459>

- Rioux, M., Bowring, S., Kelemen, P., Gordon, S., Miller, R., Dudás, F., 2013. Tectonic development of the Samail ophiolite: High-precision U-Pb zircon geochronology and Sm-Nd isotopic constraints on crustal growth and emplacement. *J. Geophys. Res. Solid Earth* 118, 2085–2101. <https://doi.org/10.1002/jgrb.50139>
- Robert, A.M.M., Letouzey, J., Kavoosi, M.A., Sherkati, S., Müller, C., Vergés, J., Aghababaei, A., 2014. Structural evolution of the Kopeh Dagh fold-and-thrust belt (NE Iran) and interactions with the South Caspian Sea Basin and Amu Darya Basin. *Mar. Pet. Geol.* 57, 68–87. <https://doi.org/10.1016/j.marpetgeo.2014.05.002>
- Robertson, A., 1987. The transition from a passive margin to an Upper Cretaceous foreland basin related to ophiolite emplacement in the Oman Mountains. *Geol. Soc. Am. Bull.* 99, 633. [https://doi.org/10.1130/0016-7606\(1987\)99%3C633:TTFAPM%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1987)99%3C633:TTFAPM%3E2.0.CO;2)
- Robinson, A.C., 2015. Mesozoic tectonics of the Gondwanan terranes of the Pamir plateau. *J. Asian Earth Sci.* 102, 170–179. <https://doi.org/10.1016/j.jseaes.2014.09.012>
- Robinson, A.G., Rudat, J.H., Banks, C.J., Wiles, R.L.F., 1996. Petroleum geology of the Black Sea. *Mar. Pet. Geol.* 13, 195–223. [https://doi.org/10.1016/0264-8172\(95\)00042-9](https://doi.org/10.1016/0264-8172(95)00042-9)
- Robinson, J., Beck, R., Gnos, E., Vincent, R.K., 2000. New structural and stratigraphic insights for northwestern Pakistan from field and Landsat Thematic Mapper data. *Geol. Soc. Am. Bull.* 112, 364–374. [https://doi.org/10.1130/0016-7606\(2000\)112%3C364:NSASIF%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(2000)112%3C364:NSASIF%3E2.0.CO;2)
- Rojhani, E., Ghaemi, F., Bagheri, S., Li, S., Lom, N., van Hinsbergen, D.J.J., 2026. Geology of the abrupt northern termination of the Sistan suture zone and the subduction zone configuration in eastern Iran since the late Cretaceous. *J. Asian Earth Sci.* 308, 107148. <https://doi.org/10.1016/j.jseaes.2026.107148>
- Rolland, Y., 2002. From intra-oceanic convergence to post-collisional evolution: the India-Asia convergence in NW Himalaya, from Cretaceous to present. *J. Virtual Explor.* 08. <https://doi.org/10.3809/jvirtex.2002.00052>
- Rossetti, F., Monié, P., Nasrabad, M., Theye, T., Lucci, F., Saadat, M., 2017. Early Carboniferous subduction-zone metamorphism preserved within the Palaeo-Tethyan Rasht ophiolites (western Alborz, Iran). *J. Geol. Soc.* 174, 741–758. <https://doi.org/10.1144/jgs2016-130>
- Rossetti, F., Nasrabad, M., Vignaroli, G., Theye, T., Gerdes, A., Razavi, M.H., Vaziri, H.M., 2010. Early Cretaceous migmatitic mafic granulites from the Sabzevar range (NE Iran): implications for the closure of the Mesozoic peri-Tethyan oceans in central Iran. *Terra Nova* 22, 26–34. <https://doi.org/10.1111/j.1365-3121.2009.00912.x>
- Ruh, J.B., Valero, L., Aghajari, L., Beamud, E., Gharabeigly, G., 2019. Vertical-axis rotation in East Kopet Dagh, NE Iran, inferred from paleomagnetic data: oroclinal bending or complex local folding kinematics? *Swiss J. Geosci.* 112, 543–562. <https://doi.org/10.1007/s00015-019-00348-z>
- Ruttner, A.W., 1993. Southern borderland of Triassic Laurasia in north-east Iran. *Geol. Rundsch.* 82, 110–120. <https://doi.org/10.1007/BF00563274>
- Ruttner, A.W., 1984. The Pre-Liassic Basement of the Eastern Kopet Dagh Range. *Neues Jahrb. Für Geol. Paläontol. - Abh.* 168, 256–268. <https://doi.org/10.1127/njgpa/168/1984/256>
- Ruttner, A.W., Ruttner-Kolisko, A.E., Kirchner, E., 1991. Geology of the Aghdarband area (Kopet Dagh, NE-Iran). *Abh. Geol. Bundesanst.* 38, 7–79.
- Saadat, S., Karimpour, M.H., Stern, C., 2010. Petrochemical Characteristics of Neogene and Quaternary Alkali Olivine Basalts from the Western Margin of the Lut Block, Eastern Iran. *J. Earth Sci.* 2, 87–106.
- Saccani, E., Delavari, M., Beccaluva, L., Amini, S., 2010. Petrological and geochemical constraints on the origin of the Nehbandan ophiolitic complex (eastern Iran): Implication for the evolution of the Sistan Ocean. *Lithos* 117, 209–228. <https://doi.org/10.1016/j.lithos.2010.02.016>
- Safari, H.O., Ghasemi, M.R., Razavi Pash, R., 2013. Determination and Structural Analysis of the Lahijan Transverse Fault in Forestall Region of Alborz Mountains, Iran: A Geospatial Application. *Int. J. Remote Sens. Appl.* 3, 215. <https://doi.org/10.14355/ijrsa.2013.0304.06>

- Saintot, A., Brunet, M.-F., Yakovlev, F., Sébrier, M., Stephenson, R., Ershov, A., Chalot-Prat, F., McCann, T., 2006. The Mesozoic-Cenozoic tectonic evolution of the Greater Caucasus. *Geol. Soc. Lond. Mem.* 32, 277–289. <https://doi.org/10.1144/GSL.MEM.2006.032.01.16>
- Salehi, M.A., Moussavi-Harami, R., Mahboubi, A., Fürsich, F.T., Wilmsen, M., Heubeck, C., 2018. A tectono-stratigraphic record of an extensional basin: the Lower Jurassic Ab-Haji Formation of east-central Iran. *Swiss J. Geosci.* 111, 51–78. <https://doi.org/10.1007/s00015-017-0283-2>
- Savostin, L.A., Sibuet, J.-C., Zonenshain, L.P., Le Pichon, X., Roulet, M.-J., 1986. Kinematic evolution of the Tethys belt from the Atlantic ocean to the pamirs since the Triassic. *Tectonophysics* 123, 1–35. [https://doi.org/10.1016/0040-1951\(86\)90192-7](https://doi.org/10.1016/0040-1951(86)90192-7)
- Schoenbohm, L.M., Burchfiel, B.C., Liangzhong, C., Jiyun, Y., 2006. Miocene to present activity along the Red River fault, China, in the context of continental extrusion, upper-crustal rotation, and lower-crustal flow. *Geol. Soc. Am. Bull.* 118, 672–688. <https://doi.org/10.1130/B25816.1>
- Schreiber, A., Weippert, D., Wittekindt, H.-P., Wolfart, R., 1972. Geology and Petroleum Potentials of Central and South Afghanistan. *AAPG Bull.* 56, 1494–1519. <https://doi.org/10.1306/819A40F6-16C5-11D7-8645000102C1865D>
- Schwab, M., Ratschbacher, L., Siebel, W., McWilliams, M., Minaev, V., Lutkov, V., Chen, F., Stanek, K., Nelson, B., Frisch, W., Wooden, J.L., 2004. Assembly of the Pamirs: Age and origin of magmatic belts from the southern Tien Shan to the southern Pamirs and their relation to Tibet. *Tectonics* 23, 2003TC001583. <https://doi.org/10.1029/2003TC001583>
- Searle, M., Cox, J., 1999. Tectonic setting, origin, and obduction of the Oman ophiolite. *Geol. Soc. Am. Bull.* 111, 104–122. [https://doi.org/10.1130/0016-7606\(1999\)111%3C0104:TSOAOO%3E2.3.CO;2](https://doi.org/10.1130/0016-7606(1999)111%3C0104:TSOAOO%3E2.3.CO;2)
- Şengör, A.M.C., 1990a. A new model for the late Palaeozoic—Mesozoic tectonic evolution of Iran and implications for Oman. *Geol. Soc. Lond. Spec. Publ.* 49, 797–831. <https://doi.org/10.1144/GSL.SP.1992.049.01.49>
- Şengör, A.M.C., 1990b. Plate tectonics and orogenic research after 25 years: A Tethyan perspective. *Earth-Sci. Rev.* 27, 1–201. [https://doi.org/10.1016/0012-8252\(90\)90002-D](https://doi.org/10.1016/0012-8252(90)90002-D)
- Şengör, A.M.C., 1987. Tectonics of the Tethysides: Orogenic Collage Development in a Collisional Setting. *Annu. Rev. Earth Planet. Sci.* 15, 213–244. <https://doi.org/10.1146/annurev.ea.15.050187.001241>
- Şengör, A.M.C., 1984. The Cimmeride Orogenic System and the Tectonics of Eurasia, in: *Geological Society of America Special Papers*. *Geol. Soc. Am. Spec. Pap.* 195, ix+82p. <https://doi.org/10.1130/SPE195-p1>
- Şengör, A.M.C., 1979. Mid-Mesozoic closure of Permo–Triassic Tethys and its implications. *Nature* 279, 590–593. <https://doi.org/10.1038/279590a0>
- Şengör, A.M.C., Altner, D., Cin, A., Ustaömer, T., Hsü, K.J., 1988. Origin and assembly of the Tethyside orogenic collage at the expense of Gondwana Land. *Geol. Soc. Lond. Spec. Publ.* 37, 119–181. <https://doi.org/10.1144/GSL.SP.1988.037.01.09>
- Şengör, A.M.C., Altner, D., Zabcı, C., Sunal, G., Lom, N., Aylan, E., Öner, T., 2023. On the nature of the Cimmerian Continent. *Earth-Sci. Rev.* 247, 104520. <https://doi.org/10.1016/j.earscirev.2023.104520>
- Şengör, A.M.C., Cin, A., Rowley, D.B., Shangyou, N., 1991. Magmatic evolution of the Tethysides: a guide to reconstruction of collage history. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 87, 411–440. [https://doi.org/10.1016/0031-0182\(91\)90143-F](https://doi.org/10.1016/0031-0182(91)90143-F)
- Şengör, A.M.C., Lom, N., Sunal, G., Zabcı, C., Sancar, T., 2019. The phanerozoic palaeotectonics of Turkey. Part I: an inventory. *Mediterr. Geosci. Rev.* 1, 91–161. <https://doi.org/10.1007/s42990-019-00007-3>
- Şengör, A.M.C., Tüysüz, O., İmren, C., Sakıncı, M., Eyidoğan, H., Görür, N., Le Pichon, X., Rangin, C., 2005. The North Anatolian Fault: A New Look. *Annu. Rev. Earth Planet. Sci.* 33, 37–112. <https://doi.org/10.1146/annurev.earth.32.101802.120415>

- Şengör, A.M.C., Yilmaz, Y., 1981. Tethyan evolution of Turkey: A plate tectonic approach. *Tectonophysics* 75, 181–241. [https://doi.org/10.1016/0040-1951\(81\)90275-4](https://doi.org/10.1016/0040-1951(81)90275-4)
- Şengör, A.M.C., Yilmaz, Y., Sungurlu, O., 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys. *Geol. Soc. Lond. Spec. Publ.* 17, 77–112. <https://doi.org/10.1144/GSL.SP.1984.017.01.04>
- Sepahi, A.A., Salami, S., Lentz, D., McFarlane, C., Maanijou, M., 2018. Petrography, geochemistry, and U–Pb geochronology of pegmatites and aplites associated with the Alvand intrusive complex in the Hamedan region, Sanandaj–Sirjan zone, Zagros orogen (Iran). *Int. J. Earth Sci.* 107, 1059–1096. <https://doi.org/10.1007/s00531-017-1515-4>
- Seton, M., Müller, R.D., Zahirovic, S., Gaina, C., Torsvik, T., Shephard, G., Talsma, A., Gurnis, M., Turner, M., Maus, S., Chandler, M., 2012. Global continental and ocean basin reconstructions since 200Ma. *Earth-Sci. Rev.* 113, 212–270. <https://doi.org/10.1016/j.earscirev.2012.03.002>
- Shabanian, E., Siame, L., Bellier, O., Benedetti, L., Abbassi, M.R., 2009. Quaternary slip rates along the northeastern boundary of the Arabia-Eurasia collision zone (Kopeh Dagh Mountains, Northeast Iran). *Geophys. J. Int.* 178, 1055–1077. <https://doi.org/10.1111/j.1365-246X.2009.04183.x>
- Shafaii Moghadam, H., Bröcker, M., Griffin, W.L., Li, X. -H., Chen, R.X., O'Reilly, S.Y., 2017. Subduction, high-P metamorphism, and collision fingerprints in South Iran: Constraints from zircon U–Pb and mica Rb–Sr geochronology. *Geochem. Geophys. Geosystems* 18, 306–332. <https://doi.org/10.1002/2016GC006585>
- Shafaii Moghadam, H., Mosaddegh, H., Santosh, M., 2013. Geochemistry and petrogenesis of the Late Cretaceous Haji-Abad ophiolite (Outer Zagros Ophiolite Belt, Iran): implications for geodynamics of the Bitlis–Zagros suture zone. *Geol. J.* 48, 579–602. <https://doi.org/10.1002/gj.2458>
- Shafaii Moghadam, H., Stern, R.J., 2015. Ophiolites of Iran: Keys to understanding the tectonic evolution of SW Asia: (II) Mesozoic ophiolites. *J. Asian Earth Sci.* 100, 31–59. <https://doi.org/10.1016/j.jseaes.2014.12.016>
- Shafaii Moghadam, H., Stern, R.J., 2014. Ophiolites of Iran: Keys to understanding the tectonic evolution of SW Asia: (I) Paleozoic ophiolites. *J. Asian Earth Sci.* 91, 19–38. <https://doi.org/10.1016/j.jseaes.2014.04.008>
- Shafiei Bafti, S., Mohajjel, M., 2015. Structural evidence for slip partitioning and inclined dextral transpression along the SE Sanandaj–Sirjan zone, Iran. *Int. J. Earth Sci.* 104, 587–601. <https://doi.org/10.1007/s00531-014-1106-6>
- Shahabpour, J., 2010. Tectonic implications of the geochemical data from the Makran igneous rocks in Iran. *Isl. Arc* 19, 676–689. <https://doi.org/10.1111/j.1440-1738.2010.00723.x>
- Shahbazi, H., Siebel, W., Pourmoafaei, M., Ghorbani, M., Sepahi, A.A., Shang, C.K., Vousoughi Abedini, M., 2010. Geochemistry and U–Pb zircon geochronology of the Alvand plutonic complex in Sanandaj–Sirjan Zone (Iran): New evidence for Jurassic magmatism. *J. Asian Earth Sci.* 39, 668–683. <https://doi.org/10.1016/j.jseaes.2010.04.014>
- Shakerardakani, F., Neubauer, F., Masoudi, F., Mehrabi, B., Liu, X., Dong, Y., Mohajjel, M., Monfaredi, B., Friedl, G., 2015. Panafrican basement and Mesozoic gabbro in the Zagros orogenic belt in the Dorud–Azna region (NW Iran): Laser-ablation ICP–MS zircon ages and geochemistry. *Tectonophysics* 647–648, 146–171. <https://doi.org/10.1016/j.tecto.2015.02.020>
- Sheikholeslami, M.R., 2017. Tectono-stratigraphic evidence for the opening and closure of the Neotethys Ocean in the southern Sanandaj–Sirjan zone, Iran, in: *Tectonic Evolution, Collision, and Seismicity of Southwest Asia*. In: Sorkhabi, R. (Ed): In Honor of Manuel Berberian's Forty-Five Years of Research Contributions. *Geol. Soc. Am. Spec. Pap.* 525 [https://doi.org/10.1130/2016.2525\(09\)](https://doi.org/10.1130/2016.2525(09))
- Sheikholeslami, M.R., 2015. Deformations of Palaeozoic and Mesozoic rocks in southern Sirjan, Sanandaj–Sirjan Zone, Iran. *J. Asian Earth Sci.* 106, 130–149. <https://doi.org/10.1016/j.jseaes.2015.03.007>

- Sheikholeslami, M.R., Kouhpeyma, M., 2012. Structural analysis and tectonic evolution of the eastern Binalud Mountains, NE Iran. *J. Geodyn.* 61, 23–46. <https://doi.org/10.1016/j.jog.2012.06.010>
- Shirdashtzadeh, N., Furnes, H., Miller, N.R., Dantas, E.L., Torabi, G., Meisel, T.C., 2022. Subduction initiation of the Neo-Tethys Ocean in Central Iran based on U-Pb geochronology, geochemical and Nd isotope data of the Ashin ophiolite. *Ophioliti* 47. <https://doi.org/10.4454/phioliti.v47i2.557>
- Shnizai, Z., 2020. Mapping of active and presumed active faults in Afghanistan by interpretation of 1-arcsecond SRTM anaglyph images. *J. Seismol.* 24, 1131–1157. <https://doi.org/10.1007/s10950-020-09933-4>
- Shojaat, B., Hassanipak, A.A., Mobasher, K., Ghazi, A.M., 2003. Petrology, geochemistry and tectonics of the Sabzevar ophiolite, North Central Iran. *J. Asian Earth Sci.* 21, 1053–1067. [https://doi.org/10.1016/S1367-9120\(02\)00143-8](https://doi.org/10.1016/S1367-9120(02)00143-8)
- Shroder, J.F., Eqrar, N., Waizy, H., Ahmadi, H., Weihs, B.J., 2022. Review of the Geology of Afghanistan and its water resources. *Int. Geol. Rev.* 64, 1009–1031. <https://doi.org/10.1080/00206814.2021.1904297>
- Siddiqui, N.K., 2012. A prospective Neoproterozoic-Cambrian hydrocarbon/exploration play in the Kirthar Fold Belt, Pakistan. *Geol. Soc. Lond. Spec. Publ.* 366, 123–130. <https://doi.org/10.1144/SP366.13>
- Siehl, A., 2017. Structural setting and evolution of the Afghan orogenic segment – a review. *Geol. Soc. Lond. Spec. Publ.* 427, 57–88. <https://doi.org/10.1144/SP427.8>
- Smit, J., Burg, J., Dolati, A., Sokoutis, D., 2010. Effects of mass waste events on thrust wedges: Analogue experiments and application to the Makran accretionary wedge. *Tectonics* 29, 2009TC002526. <https://doi.org/10.1029/2009TC002526>
- Soffel, H.C., Schmidt, S., Davoudzadeh, M., Rolf, C., 1996. New palaeomagnetic data from Central Iran and a Triassic palaeoreconstruction. *Geol. Rundsch.* 85, 293–302. <https://doi.org/10.1007/BF02422235>
- Soleimani, M., Faghih, A., Kusky, T., 2021. Mesozoic compressional to extensional tectonics in the Central East Iranian Microcontinent: evidence from the Boneh Shurow metamorphic core complex. *J. Geol. Soc.* 178, jgs2020-123. <https://doi.org/10.1144/jgs2020-123>
- Song, P., Ding, L., Li, Z., Lippert, P.C., Yue, Y., 2017. An early bird from Gondwana: Paleomagnetism of Lower Permian lavas from northern Qiangtang (Tibet) and the geography of the Paleo-Tethys. *Earth Planet. Sci. Lett.* 475, 119–133. <https://doi.org/10.1016/j.epsl.2017.07.023>
- Song, P., Ding, L., Zhang, L., Cai, F., Zhang, Q., Li, Z., Wang, H., Jafari, M.K., Talebian, M., 2023. Paleomagnetism From Central Iran Reveals Arabia-Eurasia Collision Onset at the Eocene/Oligocene Boundary. *Geophys. Res. Lett.* 50, e2023GL103858. <https://doi.org/10.1029/2023GL103858>
- Stampfli, G.M., 2000. Tethyan oceans. *Geol. Soc. Lond. Spec. Publ.* 173, 1–23. <https://doi.org/10.1144/GSL.SP.2000.173.01.01>
- Stampfli, G.M., Borel, G.D., 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. *Earth Planet. Sci. Lett.* 196, 17–33. [https://doi.org/10.1016/S0012-821X\(01\)00588-X](https://doi.org/10.1016/S0012-821X(01)00588-X)
- Stern, R.J., Moghadam, H.S., Pirouz, M., Mooney, W., 2021. The Geodynamic Evolution of Iran. *Annu. Rev. Earth Planet. Sci.* 49, 9–36. <https://doi.org/10.1146/annurev-earth-071620-052109>
- Stöcklin, J., 1989. Tethys Evolution in the Afghanistan-Pamir-Pakistan Region, in: Şengör, A.M.C. (Ed.), *Tectonic Evolution of the Tethyan Region*. Springer Netherlands, Dordrecht, pp. 241–264. https://doi.org/10.1007/978-94-009-2253-2_13
- Stöcklin, J., 1977. Structural correlation of the Alpine ranges between Iran and Central Asia In: *Livra à la Mémoire de Albert F. de Lapparent. Mémoire hors-série* 8 333–353.
- Stöcklin, J., 1974a. Possible Ancient Continental Margins in Iran, in: Burk, C.A., Drake, C.L. (Eds.), *The Geology of Continental Margins*. Springer, Berlin, Heidelberg, pp. 873–887. https://doi.org/10.1007/978-3-662-01141-6_64

- Stöcklin, J., 1974b. Northern Iran: Alborz mountains, in: *Mesozoic–Cenozoic Orogenic Belts: Data for Orogenic Studies*, 4. Geol. Soc. Lond. Spec. Publ., pp. 213–234.
<https://doi.org/10.1144/GSL.SP.2005.004.01.1>
- Stöcklin, J., 1968. Structural History and Tectonics of Iran: A Review. *AAPG Bull.* 52, 1229–1258.
<https://doi.org/10.1306/5D25C4A5-16C1-11D7-8645000102C1865D>
- Tadayon, M., Rossetti, F., Zattin, M., Calzolari, G., Nozaem, R., Salvini, F., Faccenna, C., Khodabakhshi, P., 2019. The long-term evolution of the Doruneh Fault region (Central Iran): A key to understanding the spatio-temporal tectonic evolution in the hinterland of the Zagros convergence zone. *Geol. J.* 54, 1454–1479. <https://doi.org/10.1002/gj.3241>
- Taheri, J., Fürsich, F.T., Wilmsen, M., 2009. Stratigraphy, depositional environments and geodynamic significance of the Upper Bajocian–Bathonian Kashafrud Formation, NE Iran. *Geol. Soc. Lond. Spec. Publ.* 312, 205–218. <https://doi.org/10.1144/SP312.10>
- Takin, M., 1972. Iranian Geology and Continental Drift in the Middle East. *Nature* 235, 147–150.
<https://doi.org/10.1038/235147a0>
- Tapponnier, P., Mattauer, M., Proust, F., Cassaigneau, C., 1981. Mesozoic ophiolites, sutures, and large-scale tectonic movements in Afghanistan. *Earth Planet. Sci. Lett.* 52, 355–371.
[https://doi.org/10.1016/0012-821X\(81\)90189-8](https://doi.org/10.1016/0012-821X(81)90189-8)
- Taraz, H., Golshani, F., Nakazawa, K., Shimizu, D., Bando, Y., Ishii, K.-I., Murata, M., Okimura, Y., Sakagami, S., Nakamura, K., Tokuoka, T., 1981. The Permian and the Lower Triassic systems in Abadeh region, central Iran. *Mem. Fac. Sci., Series of geology and mineralogy* 47, 61–133.
- Tchalenko, J.S., 1975. Seismicity and structure of the Kopet Dagh (Iran, U. S. S. R.). *Philos. Trans. R. Soc. Lond. Ser. Math. Phys. Sci.* 278, 1–28. <https://doi.org/10.1098/rsta.1975.0019>
- Tillman, J.E., Poosti, A., Rossello, S., Eckert, A., 1981. Structural Evolution of Sanandaj-Sirjan Ranges Near Esfahan, Iran. *AAPG Bull.* 65, 674–687. <https://doi.org/10.1306/2F9199A9-16CE-11D7-8645000102C1865D>
- Tirrul, R., Bell, I.R., Griffis, R.J., Camp, V.E., 1983. The Sistan suture zone of eastern Iran. *Geol. Soc. Am. Bull.* 94, 134. [https://doi.org/10.1130/0016-7606\(1983\)94%3C134:TSSZOE%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1983)94%3C134:TSSZOE%3E2.0.CO;2)
- Tirrul, R., Griffis, R.J., Camp, V.E., 1980. Geology of the Zabol Quadrangle, 1:250, 000. *Geol. Surv. Iran.*
- Torsvik, T.H., Cocks, L.R.M., 2017. *Earth history and palaeogeography*. Cambridge University Press, Cambridge, United Kingdom.
- Treloar, P.J., Izatt, C.N., 1993. Tectonics of the Himalayan collision between the Indian Plate and the Afghan Block: a synthesis. *Geol. Soc. Lond. Spec. Publ.* 74, 69–87.
<https://doi.org/10.1144/GSL.SP.1993.074.01.06>
- Treloar, P.J., Petterson, M.G., Jan, M.Q., Sullivan, M.A., 1996. A re-evaluation of the stratigraphy and evolution of the Kohistan arc sequence, Pakistan Himalaya: implications for magmatic and tectonic arc-building processes. *J. Geol. Soc.* 153, 681–693.
<https://doi.org/10.1144/gsjgs.153.5.0681>
- Trexler, C., Cowgill, E., Vasey, D., Niemi, N., 2023. Total Shortening Estimates Across the Western Greater Caucasus Mountains from Balanced Cross Sections and Area Balancing. *Tektonika* 1. <https://doi.org/10.55575/tektonika2023.1.2.50>
- Ul-Hadi, S., Khan, S.D., Owen, L.A., Khan, A.S., Hedrick, K.A., Caffee, M.W., 2013. Slip-rates along the Chaman fault: Implication for transient strain accumulation and strain partitioning along the western Indian plate margin. *Tectonophysics* 608, 389–400.
<https://doi.org/10.1016/j.tecto.2013.09.009>
- Ulmishek, G.F., 2004. Petroleum geology and resources of the Amu-Darya basin, Turkmenistan, Uzbekistan, Afghanistan, and Iran (No. 2201–H), U.S. Geol. Surv. Bull. U.S. Geological Survey, Reston, Virginia. <https://doi.org/10.3133/b2201H>
- Vaes, B., van Hinsbergen, D.J.J., van De Lagemaat, S.H.A., van Der Wiel, E., Lom, N., Advokaat, E.L., Boschman, L.M., Gallo, L.C., Greve, A., Guilmette, C., Li, S., Lippert, P.C., Montheil, L., Qayyum, A., Langereis, C.G., 2023. A global apparent polar wander path for the last 320 Ma

- calculated from site-level paleomagnetic data. *Earth-Sci. Rev.* 245, 104547.
<https://doi.org/10.1016/j.earscirev.2023.104547>
- VahdatiRad, M., Vahidinia, M., Sadeghi, A., 2016. Early Eocene planktonic and benthic foraminifera from the Khangiran formation (northeast of Iran). *Arab. J. Geosci.* 9, 677.
<https://doi.org/10.1007/s12517-016-2711-4>
- van De Lagemaat, S.H.A., van Hinsbergen, D.J.J., 2024. Plate tectonic cross-roads: Reconstructing the Panthalassa-Neotethys Junction Region from Philippine Sea Plate and Australasian oceans and orogens. *Gondwana Res.* 126, 129–201. <https://doi.org/10.1016/j.gr.2023.09.013>
- van Der Boon, A., van Hinsbergen, D.J.J., Rezaeian, M., Gürer, D., Honarmand, M., Pastor-Galán, D., Krijgsman, W., Langereis, C.G., 2018. Quantifying Arabia–Eurasia convergence accommodated in the Greater Caucasus by paleomagnetic reconstruction. *Earth Planet. Sci. Lett.* 482, 454–469. <https://doi.org/10.1016/j.epsl.2017.11.025>
- Van Der Voo, R., 1993. *Paleomagnetism of the Atlantic, Tethys and Iapetus Oceans*, 1st ed. Cambridge University Press. <https://doi.org/10.1017/CBO9780511524936>
- Van Der Voo, R., Van Hinsbergen, D.J.J., Domeier, M., Spakman, W., Torsvik, T.H., 2015. Latest Jurassic–earliest Cretaceous closure of the Mongol–Okhotsk Ocean: A paleomagnetic and seismological-tomographic analysis. In Anderson, T.H., Didenko, A.N., Johnson, C.L., Khanchuk, A.I., MacDonald, Jr. J.H. (Eds): *Late Jurassic Margin of Laurasia—A Record of Faulting Accommodating Plate Rotation*. *Geol. Soc. Am. Spec. Pap.*, 513, pp. 589–606.
[https://doi.org/10.1130/2015.2513\(19\)](https://doi.org/10.1130/2015.2513(19))
- van Hinsbergen, D.J.J., Granot, R., Vaes, B., Vissers, R., 2025. Tectonic mode switches in the Pyrenees caused by Africa-Eurasia rotation pole drift. <https://doi.org/10.21203/rs.3.rs-8017726/v1>
- van Hinsbergen, D.J.J., Gürer, D., Koç, A., Lom, N., 2024. Shortening and extrusion in the East Anatolian Plateau: How was Neogene Arabia-Eurasia convergence tectonically accommodated? *Earth Planet. Sci. Lett.* 641, 118827.
<https://doi.org/10.1016/j.epsl.2024.118827>
- van Hinsbergen, D.J.J., Kapp, P., Dupont-Nivet, G., Lippert, P.C., DeCelles, P.G., Torsvik, T.H., 2011. Restoration of Cenozoic deformation in Asia and the size of Greater India. *Tectonics* 30, 2011TC002908. <https://doi.org/10.1029/2011TC002908>
- van Hinsbergen, D.J.J., Lippert, P.C., Li, S., Huang, W., Advokaat, E.L., Spakman, W., 2019. Reconstructing Greater India: Paleogeographic, kinematic, and geodynamic perspectives. *Tectonophysics* 760, 69–94. <https://doi.org/10.1016/j.tecto.2018.04.006>
- van Hinsbergen, D.J.J., Schmid, S.M., 2012. Map view restoration of Aegean–West Anatolian accretion and extension since the Eocene. *Tectonics* 31, 2012TC003132.
<https://doi.org/10.1029/2012TC003132>
- van Hinsbergen, D.J.J., Steinberger, B., Guilmette, C., Maffione, M., Gürer, D., Peters, K., Plunder, A., McPhee, P.J., Gaina, C., Advokaat, E.L., Vissers, R.L.M., Spakman, W., 2021. A record of plume-induced plate rotation triggering subduction initiation. *Nat. Geosci.* 14, 626–630.
<https://doi.org/10.1038/s41561-021-00780-7>
- van Hinsbergen, D.J.J., Torsvik, T.H., Schmid, S.M., Mañenco, L.C., Maffione, M., Vissers, R.L.M., Gürer, D., Spakman, W., 2020. Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic. *Gondwana Res.* 81, 79–229.
<https://doi.org/10.1016/j.gr.2019.07.009>
- Vaziri, H., 2001. The Triassic Nakhla Group, an exotic succession in central Iran. 4th International Symposium on Eastern Mediterranean geology, Isparta, Turkey, 21–25 May 2001. *Proceedings* 53–68.
- Verdel, C., Wernicke, B.P., Hassanzadeh, J., Guest, B., 2011. A Paleogene extensional arc flare-up in Iran. *Tectonics* 30, 2010TC002809. <https://doi.org/10.1029/2010TC002809>
- Vernant, P., 2004. Deciphering oblique shortening of central Alborz in Iran using geodetic data. *Earth Planet. Sci. Lett.* 223, 177–185. <https://doi.org/10.1016/j.epsl.2004.04.017>

- Vernant, Ph., Nilforoushan, F., Hatzfeld, D., Abbassi, M.R., Vigny, C., Masson, F., Nankali, H., Martinod, J., Ashtiani, A., Bayer, R., Tavakoli, F., Chéry, J., 2004. Present-day crustal deformation and plate kinematics in the Middle East constrained by GPS measurements in Iran and northern Oman. *Geophys. J. Int.* 157, 381–398. <https://doi.org/10.1111/j.1365-246X.2004.02222.x>
- Walker, F., Allen, M.B., 2012. Offset rivers, drainage spacing and the record of strike-slip faulting: The Kuh Banan Fault, Iran. *Tectonophysics* 530–531, 251–263. <https://doi.org/10.1016/j.tecto.2012.01.001>
- Walker, R., Jackson, J., 2004. Active tectonics and late Cenozoic strain distribution in central and eastern Iran. *Tectonics* 23, 2003TC001529. <https://doi.org/10.1029/2003TC001529>
- Walker, R., Jackson, J., 2002. Offset and evolution of the Gowk fault, S.E. Iran: a major intra-continental strike-slip system. *J. Struct. Geol.* 24, 1677–1698. [https://doi.org/10.1016/S0191-8141\(01\)00170-5](https://doi.org/10.1016/S0191-8141(01)00170-5)
- Walker, R.T., Bezmenov, Y., Begenjev, G., Carolin, S., Dodds, N., Gruetzner, C., Jackson, J.A., Mirzin, R., Mousavi, Z., Rhodes, E.J., 2021. Slip-Rate on the Main Köpetdag (Kopeh Dag) Strike-Slip Fault, Turkmenistan, and the Active Tectonics of the South Caspian. *Tectonics* 40, e2021TC006846. <https://doi.org/10.1029/2021TC006846>
- Wang, S., Tang, W., Liu, Y., Liu, X., Yao, X., 2020. Rushan-Pshart Paleo-Tethyan suture deduced from geochronological, geochemical, and Sr-Nd-Hf isotopic characteristics of granitoids in Pamir. *Lithos* 364–365, 105549. <https://doi.org/10.1016/j.lithos.2020.105549>
- Wang, T., Zhou, Y., Van Hinbergen, D.J.J., Dekkers, M.J., Chen, Z., Chai, R., Zhang, D., Wei, B., Xiong, A., Liu, D., Cheng, X., Wu, H., Dong, Y., 2026. Was there an ocean between the North China-Qaidam and Tarim blocks connecting the Mongol-Okhotsk and Paleo-Tethys oceans? *Earth Planet. Sci. Lett.* 695, 120357. <https://doi.org/10.1016/j.epsl.2026.120357>
- Wegener, A., 1912. Die Entstehung der Kontinente. *Geol. Rundsch.* 3, 276–292. <https://doi.org/10.1007/BF02202896>
- Wellman, H.W., 1966. Active wrench faults of Iran, Afghanistan and Pakistan. *Geol. Rundsch.* 55, 716–735. <https://doi.org/10.1007/BF02029650>
- Wensink, H., 1982. Tectonic Inferences of Paleomagnetic Data from Some Mesozoic Formations in Central Iran. *J. Geophys.* 51, 12–23.
- Wensink, H., Varekamp, J.C., 1980. Paleomagnetism of basalts from Alborz: Iran part of Asia in the Cretaceous. *Tectonophysics* 68, 113–129. [https://doi.org/10.1016/0040-1951\(80\)90010-4](https://doi.org/10.1016/0040-1951(80)90010-4)
- Wensink, H., Zijdeveld, J.D.A., Varekamp, J.C., 1978. Paleomagnetism and ore mineralogy of some basalts of the Geirud Formation of Late Devonian - Early Carboniferous age from the southern Alborz, Iran. *Earth Planet. Sci. Lett.* 41, 441–450. [https://doi.org/10.1016/0012-821X\(78\)90175-9](https://doi.org/10.1016/0012-821X(78)90175-9)
- Whitney, D.L., Bezada, M., Hansen, L.N., Teyssier, C., Wada, I., Zhou, X., 2026. Escape tectonics. *Tectonophysics* 920, 231029. <https://doi.org/10.1016/j.tecto.2025.231029>
- Whitney, D.L., Delph, J.R., Thomson, S.N., Beck, S.L., Brocard, G.Y., Cosca, M.A., Darin, M.H., Kaymakci, N., Meijers, M.J.M., Okay, A.I., Rojay, B., Teyssier, C., Umhoefer, P.J., 2023. Breaking plates: Creation of the East Anatolian fault, the Anatolian plate, and a tectonic escape system. *Geology* 51, 673–677. <https://doi.org/10.1130/G51211.1>
- Whitney, J.W., 2006. Scientific Investigations Report (Scientific Investigations Report No. 2006–5182), Scientific Investigations Report. USGS, Reston, Virginia. <https://doi.org/https://doi.org/10.3133/sir20065182>
- Wilmsen, M., Fürsich, F.T., Majidifard, M.R., 2015. An overview of the Cretaceous stratigraphy and facies development of the Yazd Block, western Central Iran. *J. Asian Earth Sci.* 102, 73–91. <https://doi.org/10.1016/j.jseaes.2014.07.015>
- Wilmsen, M., Fürsich, F.T., Seyed-Emami, K., Majidifard, M.R., 2009. An overview of the stratigraphy and facies development of the Jurassic System on the Tabas Block, east-central Iran. *Geol. Soc. Lond. Spec. Publ.* 312, 323–343. <https://doi.org/10.1144/SP312.15>

- Wittekindt, H.-P., Weippert, D., 1973. Geological Map of Central and Southern Afghanistan. Geol. Surv. Fed. Rep. Ger. (BGR).
- Wittekindt, H.-P., Wolfart, K., Moores, E.M., 1997. Afghanistan, in: Encyclopedia of European and Asian Regional Geology, Encyclopedia of Earth Science. Kluwer Academic Publishers, Dordrecht, pp. 1–7. https://doi.org/10.1007/1-4020-4495-X_1
- Wu, Chen, Liu, C., Zhu, Y., Zhou, Z., Jiang, T., Liu, W., Li, H., Wu, Chu, Ye, B., 2016. Early Paleozoic magmatic history of central Inner Mongolia, China: implications for the tectonic evolution of the Southeast Central Asian Orogenic Belt. *Int. J. Earth Sci.* 105, 1307–1327. <https://doi.org/10.1007/s00531-015-1250-7>
- Xu, S., Li, Y.-X., van Hinsbergen, D.J.J., Liu, X., Li, B., Li, X., Wang, T., 2025. An asymmetric Late Cretaceous back-arc basin south of Tibet? *Geology* 53, 392–397. <https://doi.org/10.1130/G52634.1>
- Yin, A., Harrison, T.M., 2000. Geologic Evolution of the Himalayan-Tibetan Orogen. *Annu. Rev. Earth Planet. Sci.* 28, 211–280. <https://doi.org/10.1146/annurev.earth.28.1.211>
- Yogibekov, D., Sang, M., Xiao, W., Mamadjonov, Y., Zhou, C., Yang, H., Mao, Q., Aminov, J., Khalimov, G., Ashuraliev, S., 2023. Post-collisional magmatism associated with the final closure of the Rushan-Pshart Meso-Tethys Ocean in Pamir, Tajikistan: Inference from Cretaceous igneous rocks of the Pshart accretionary complex. *Front. Earth Sci.* 10, 1090952. <https://doi.org/10.3389/feart.2022.1090952>
- Zanchetta, S., Berra, F., Zanchi, A., Bergomi, M., Caridroit, M., Nicora, A., Heidarzadeh, G., 2013. The record of the Late Palaeozoic active margin of the Palaeotethys in NE Iran: Constraints on the Cimmerian orogeny. *Gondwana Res.* 24, 1237–1266. <https://doi.org/10.1016/j.gr.2013.02.013>
- Zanchetta, S., Zanchi, A., Villa, I., Poli, S., Muttoni, G., 2009. The Shanderman eclogites: a Late Carboniferous high-pressure event in the NW Talesh Mountains (NW Iran). *Geol. Soc. Lond. Spec. Publ.* 312, 57–78. <https://doi.org/10.1144/SP312.4>
- Zanchi, A., Malaspina, N., Zanchetta, S., Berra, F., Benciolini, L., Bergomi, M., Cavallo, A., Javadi, H.R., Kouhpeyma, M., 2015. The Cimmerian accretionary wedge of Anarak, Central Iran. *J. Asian Earth Sci.* 102, 45–72. <https://doi.org/10.1016/j.jseaes.2014.08.030>
- Zanchi, A., Zanchetta, S., Balini, M., Ghassemi, M.R., 2016. Oblique convergence during the Cimmerian collision: Evidence from the Triassic Aghdarband Basin, NE Iran. *Gondwana Res.* 38, 149–170. <https://doi.org/10.1016/j.gr.2015.11.008>
- Zanchi, A., Zanchetta, S., Berra, F., Mattei, M., Garzanti, E., Molyneux, S., Nawab, A., Sabouri, J., 2009. The Eo-Cimmerian (Late? Triassic) orogeny in North Iran. *Geol. Soc. Lond. Spec. Publ.* 312, 31–55. <https://doi.org/10.1144/SP312.3>
- Zarrinkoub, M.H., Pang, K.N., Chung, S.L., Khatib, M.M., Mohammadi, S.S., Chiu, H.Y., Lee, H.Y., 2012. Zircon U-Pb age and geochemical constraints on the origin of the Birjand ophiolite, Sistan suture zone, eastern Iran. *Lithos* 154, 392–405. <https://doi.org/10.1016/j.lithos.2012.08.007>
- Zhao, L., Nissen, E., Xu, W., Jamalreyhani, M., Bergman, E.A., Zhao, D., Xie, L., 2025. Variable fault geometry controls the cascading 2023 Herat, Afghanistan multiplet sequence. *Commun. Earth Environ.* 6, 135. <https://doi.org/10.1038/s43247-025-02113-7>
- Zonenshain, L.P., Pichon, X., 1986. Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins. *Tectonophysics* 123, 181–211. [https://doi.org/10.1016/0040-1951\(86\)90197-6](https://doi.org/10.1016/0040-1951(86)90197-6)

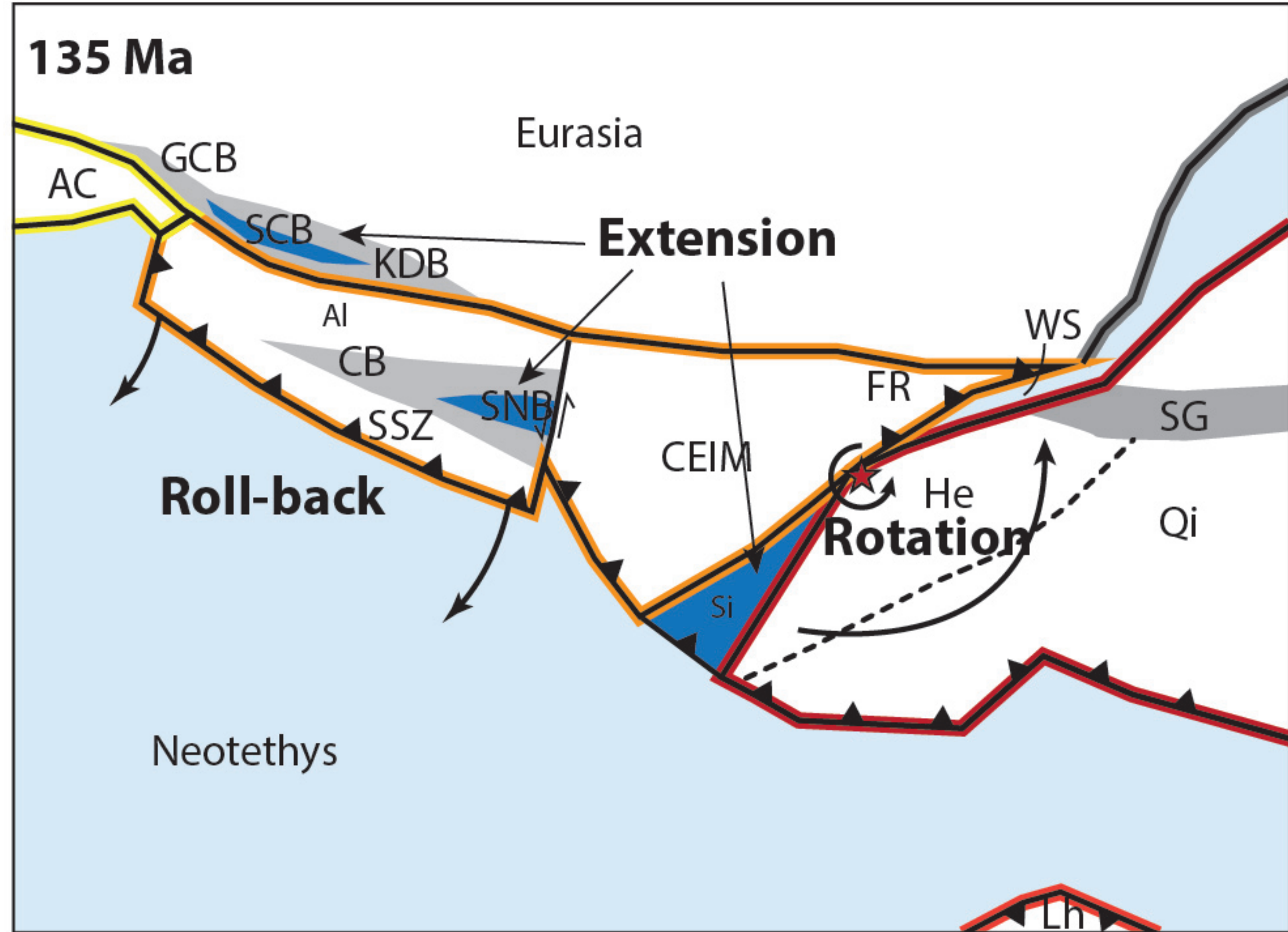
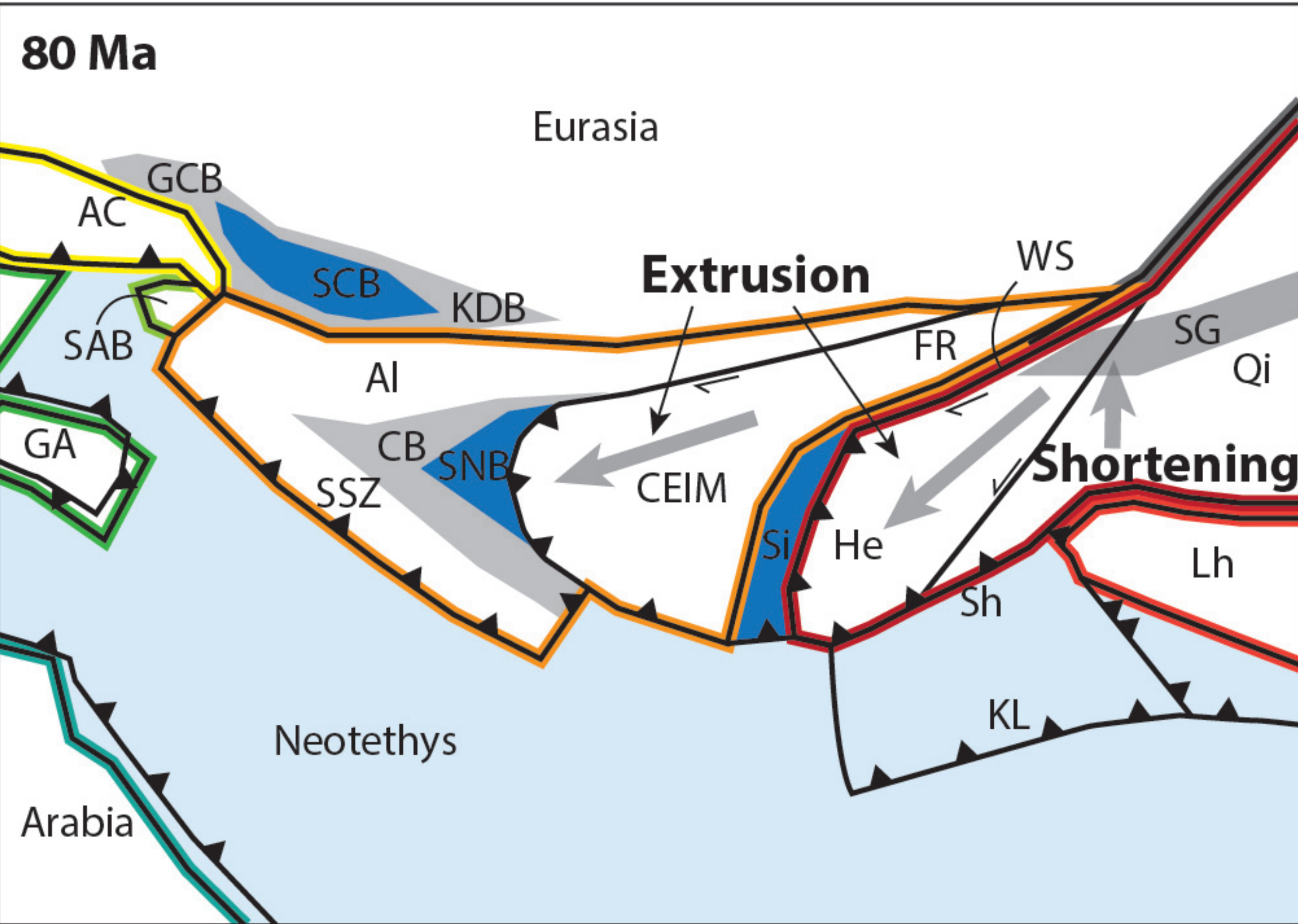
Authors' CVs.



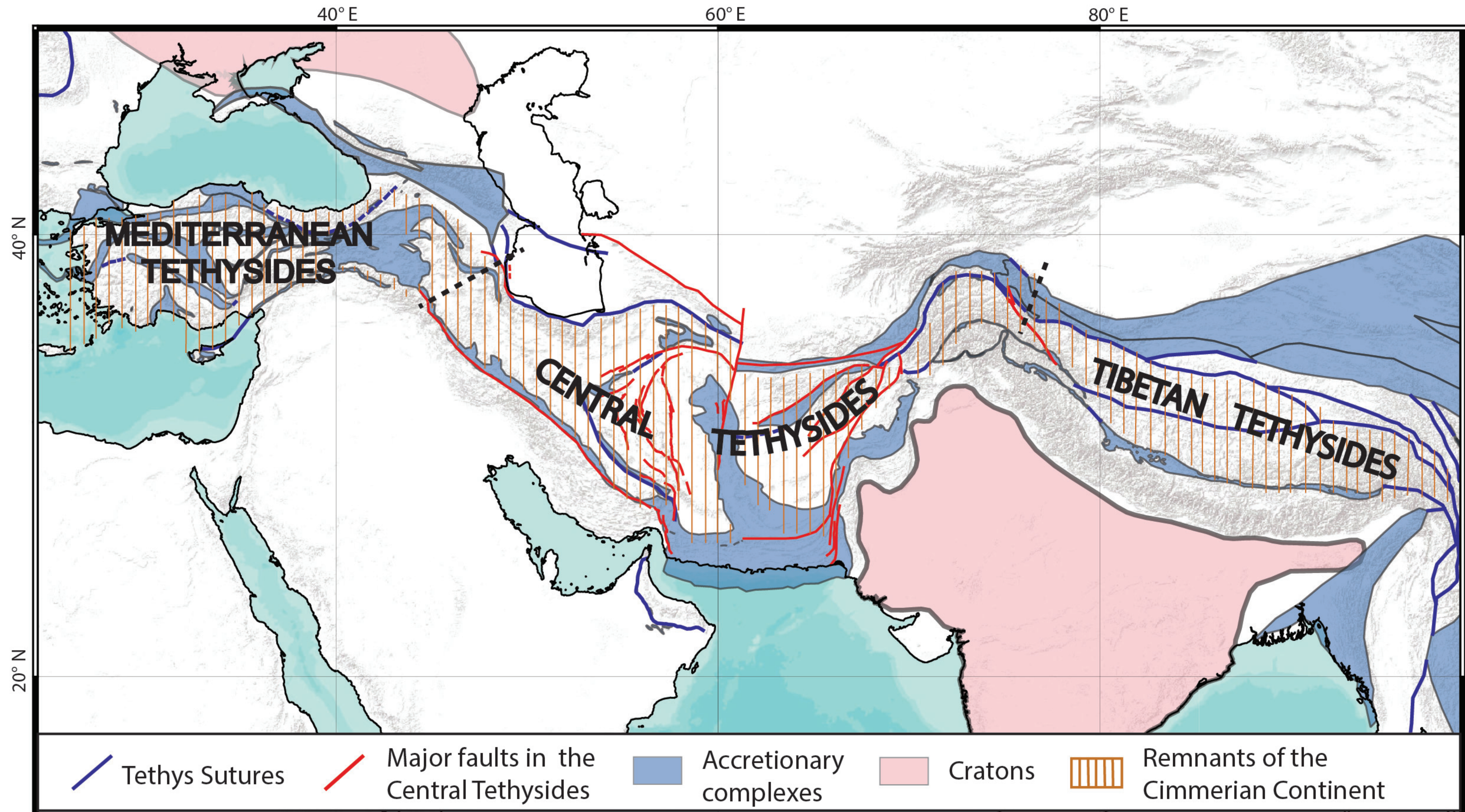
Nalan Lom (PhD, Istanbul Technical University, 2017) is Assistant Professor of Earth and Environmental Sciences, University of Central Asia, Tajikistan, where she taught since 2025. Lom is a geologist with a background in geophysics whose research focuses on the large-scale evolution of orogenic systems and the plate-kinematic reconstruction of ancient tectonic domains. Her work integrates paleomagnetism, stratigraphy, mantle tomography, and field geology to understand the deformation and dynamics of convergent margins from Precambrian to Cenozoic.

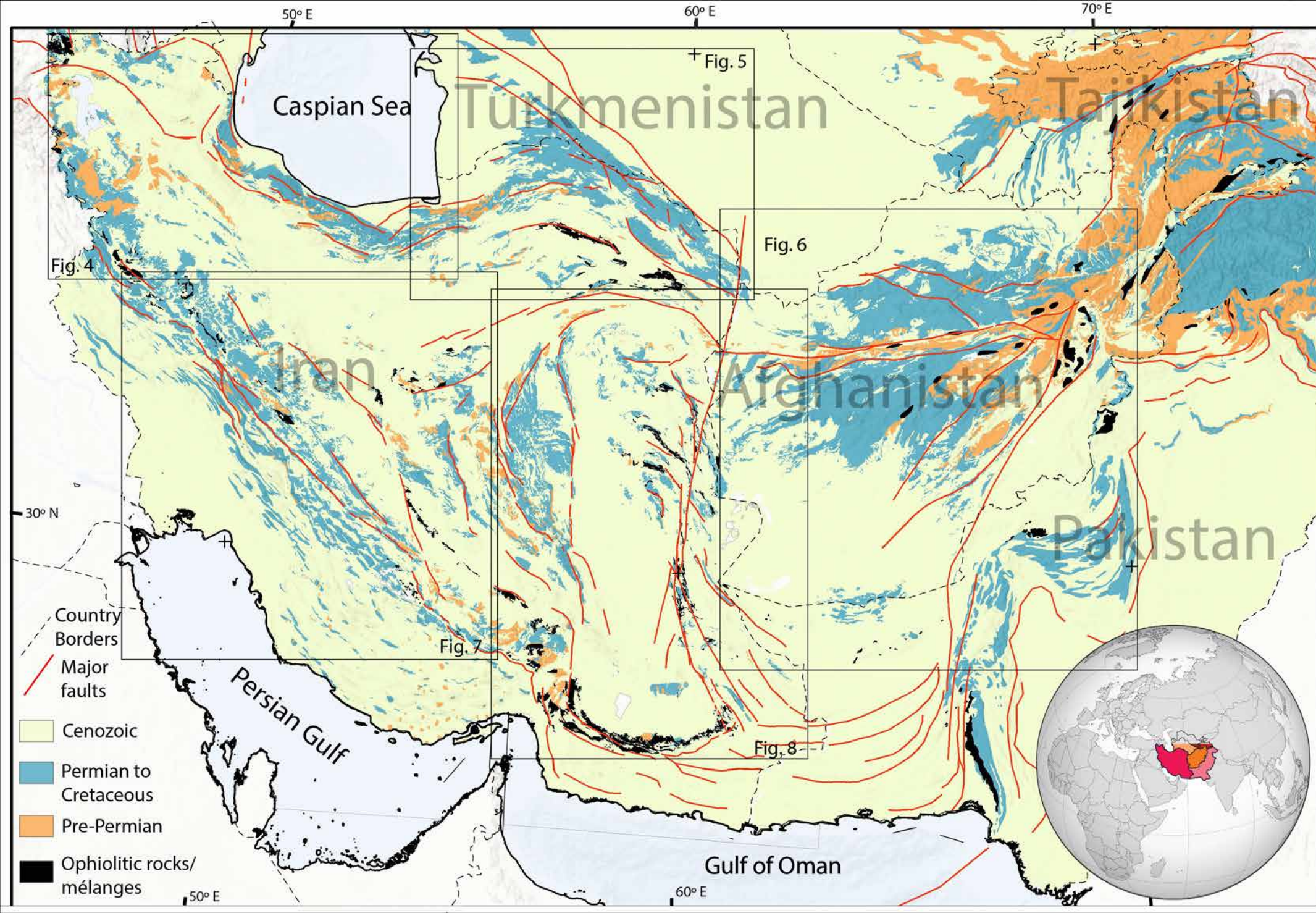


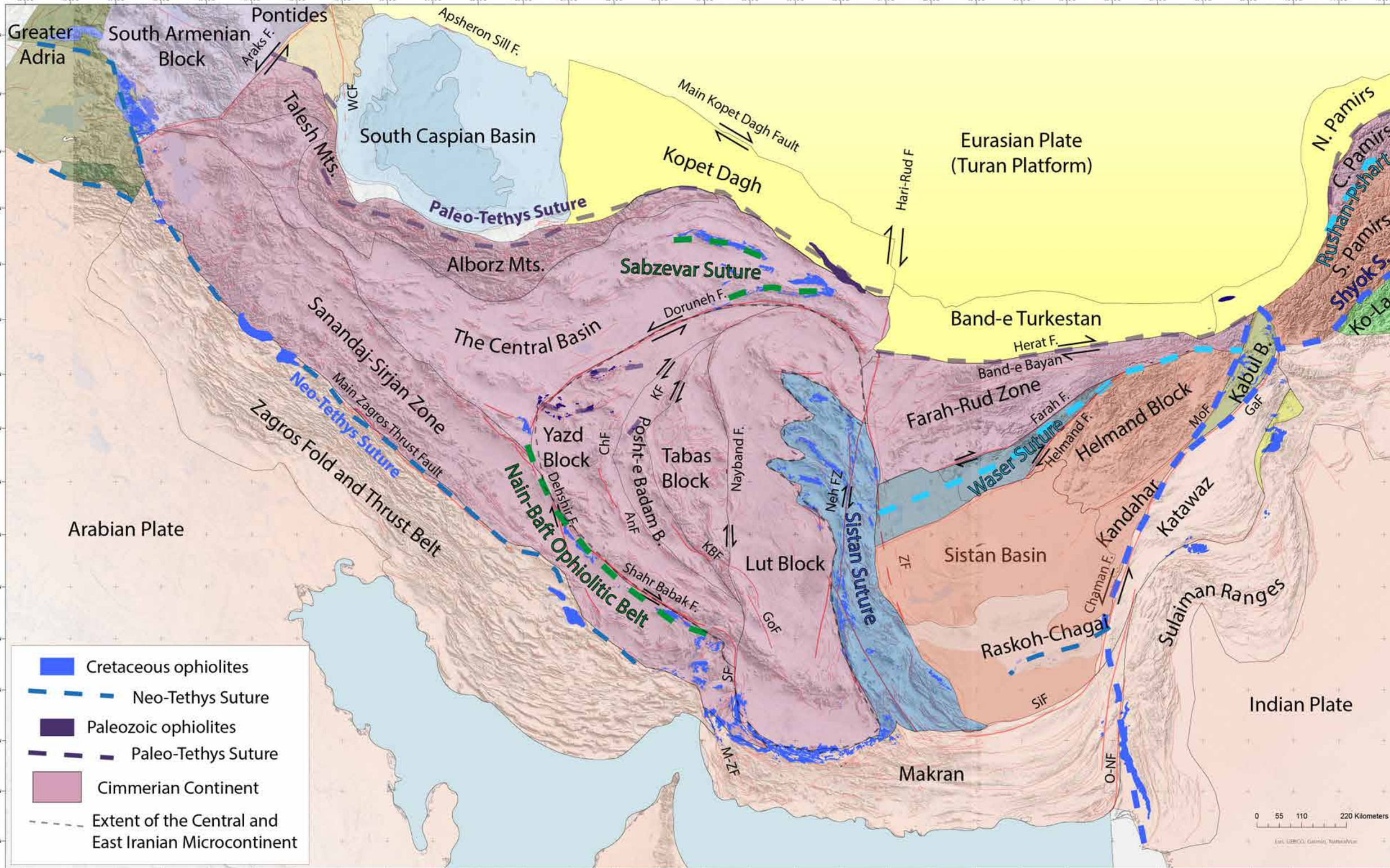
Douwe van Hinsbergen (PhD, Utrecht University, 2004) is Professor of Global Tectonics and Paleogeography at Utrecht University, the Netherlands, where he has taught since 2012. Van Hinsbergen studies global plate tectonics, orogenesis, and paleogeography across the globe, and closely collaborates with scholars of geodynamics, paleoclimate, and (paleo)biology to advance understanding in the drivers of geological processes, particularly of crustal deformation and paleogeographic change, and their co-evolution with climate and life.

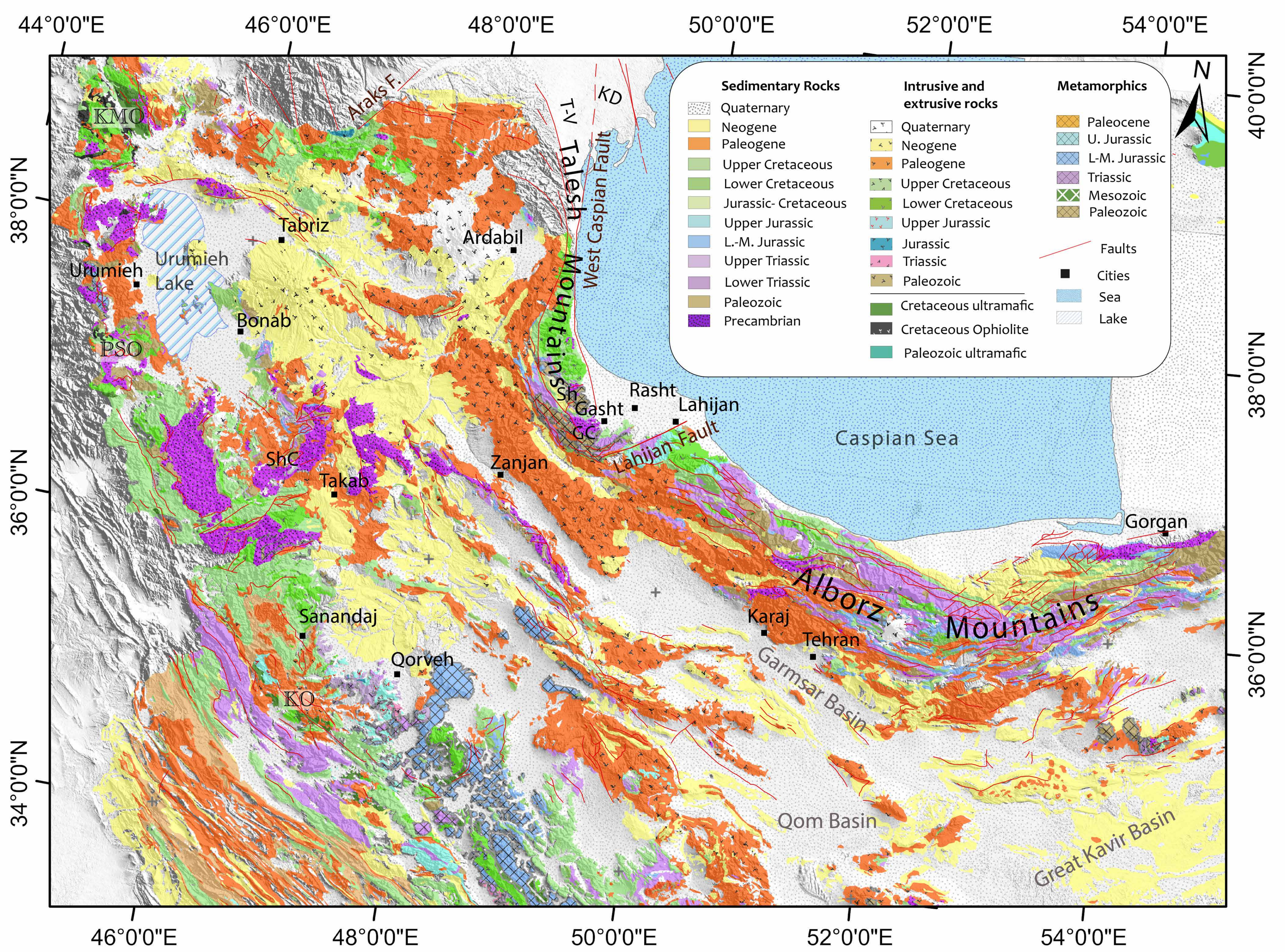


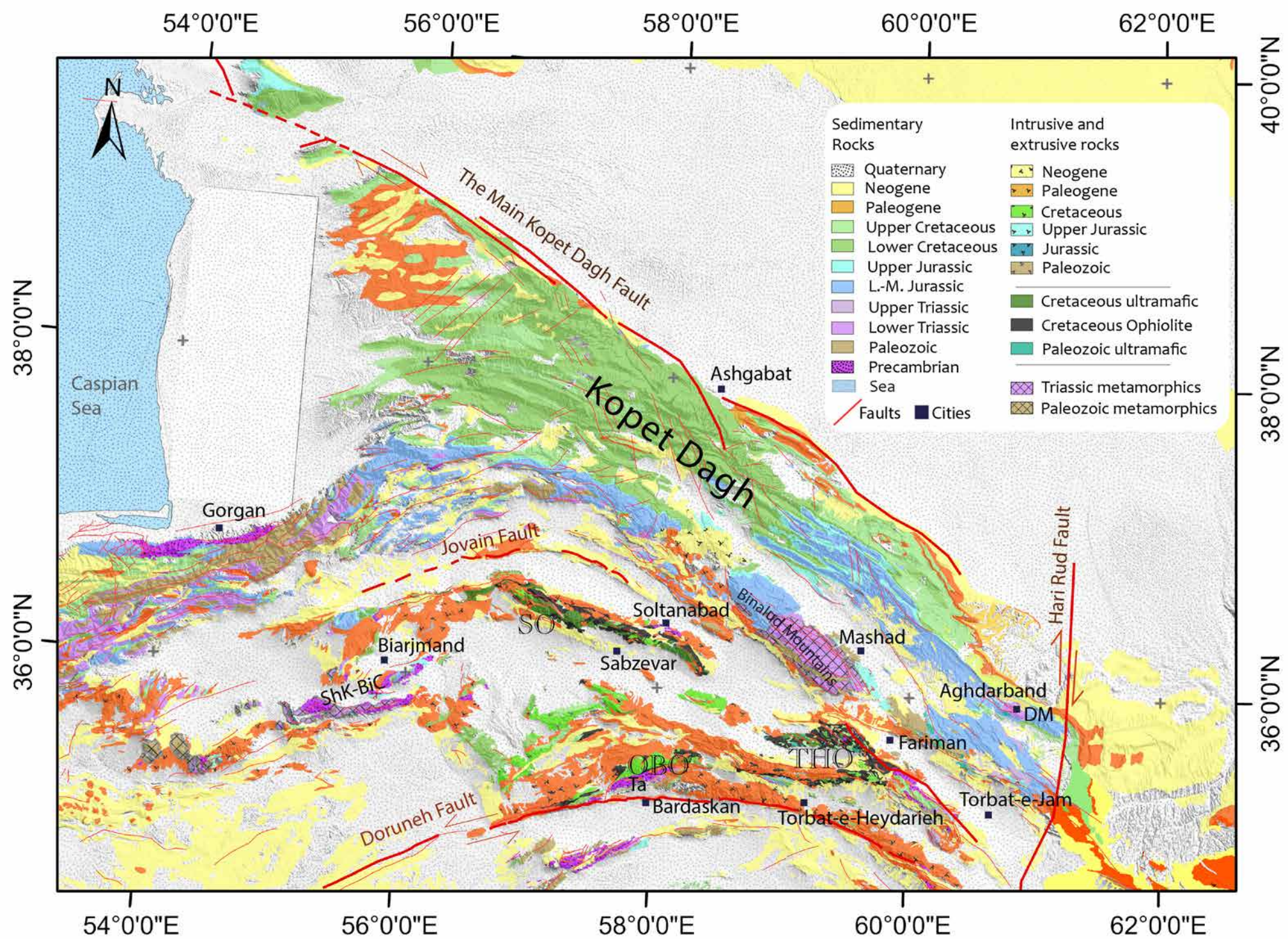
AC: Anatolian Cimmerides, **Al:** Alborz, **CB:** The Central Basin, **CEIM:** Central-East Iranian Microcontinent, **FR:** Farah-Rud, **GA:** Greater Adria, **GCB:** Greater Caucasus Basin, **He:** Helmand, **KDB:** Kopet Dagh Basin, **Lh:** Lhasa, **Qi:** Qiantang Block, **SAB:** South Armenian Block, **SCB:** South Caspian Basin, **SG:** Songpan Ganzi, **Sh:** Shyok Suture, **Si:** Sistan, **SNB:** Sabzevar-Nain-Baft Basin, **SSZ:** Sanandaj-Sirjan Zone, **WS:** Waser Suture

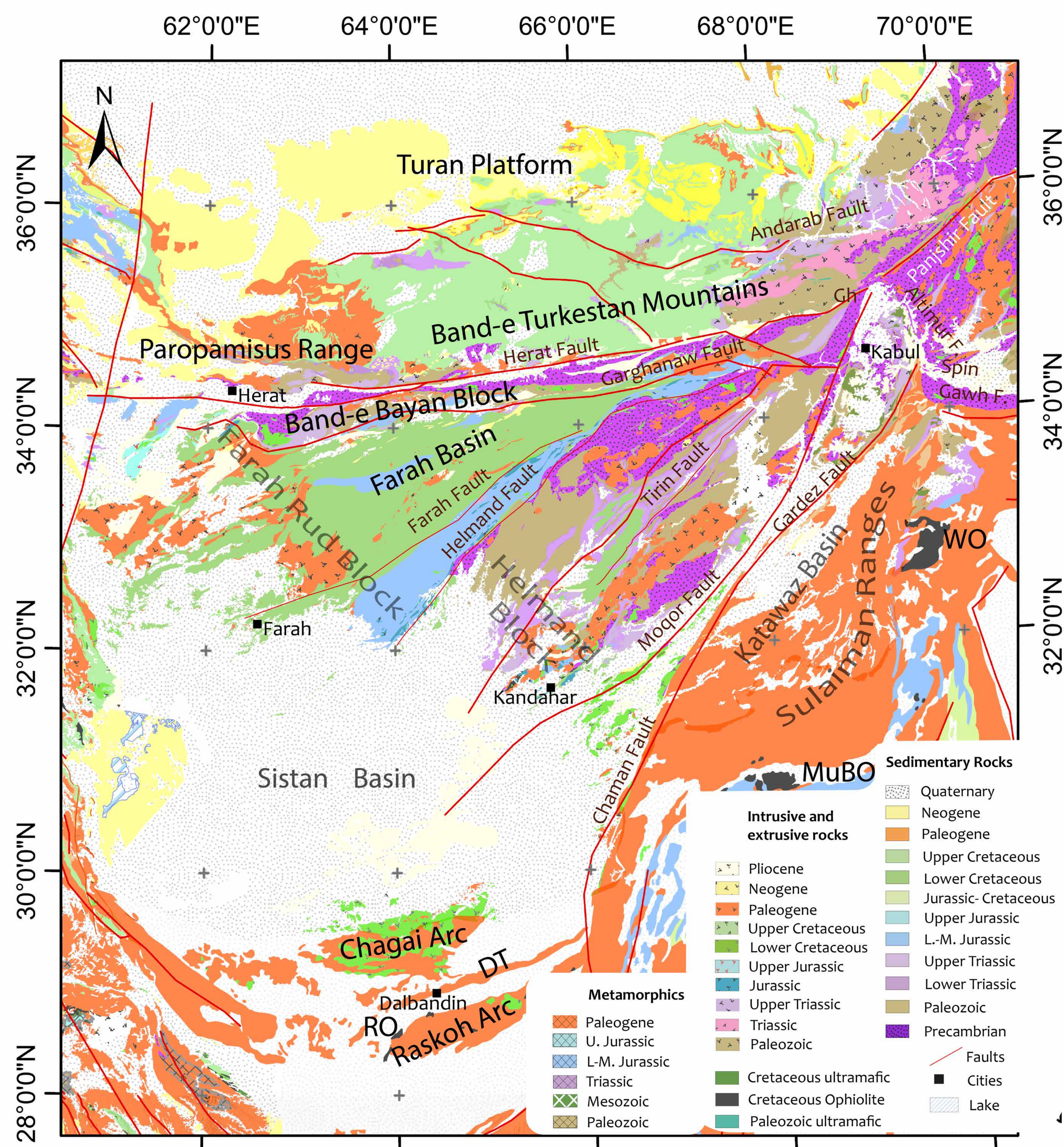


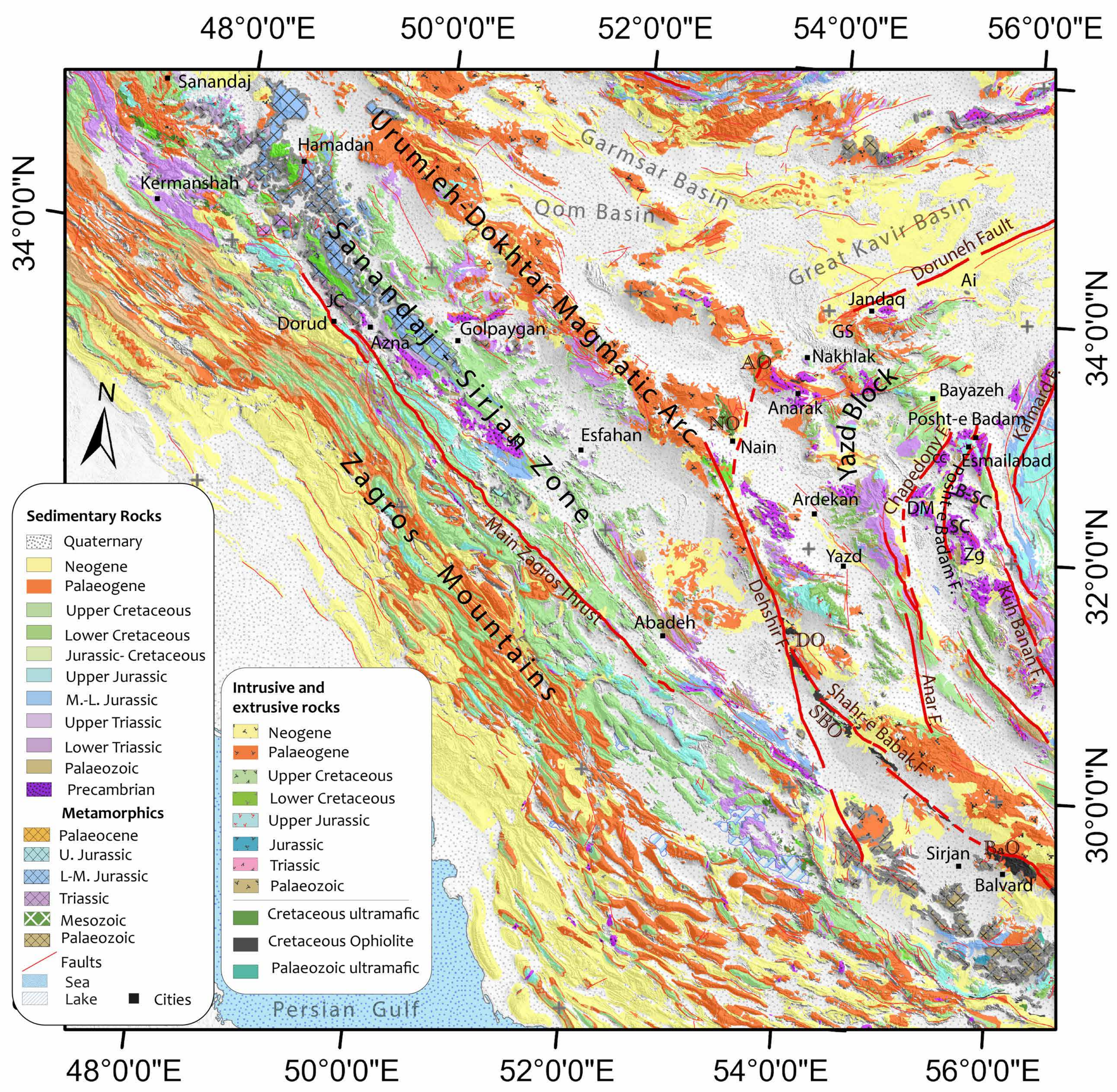


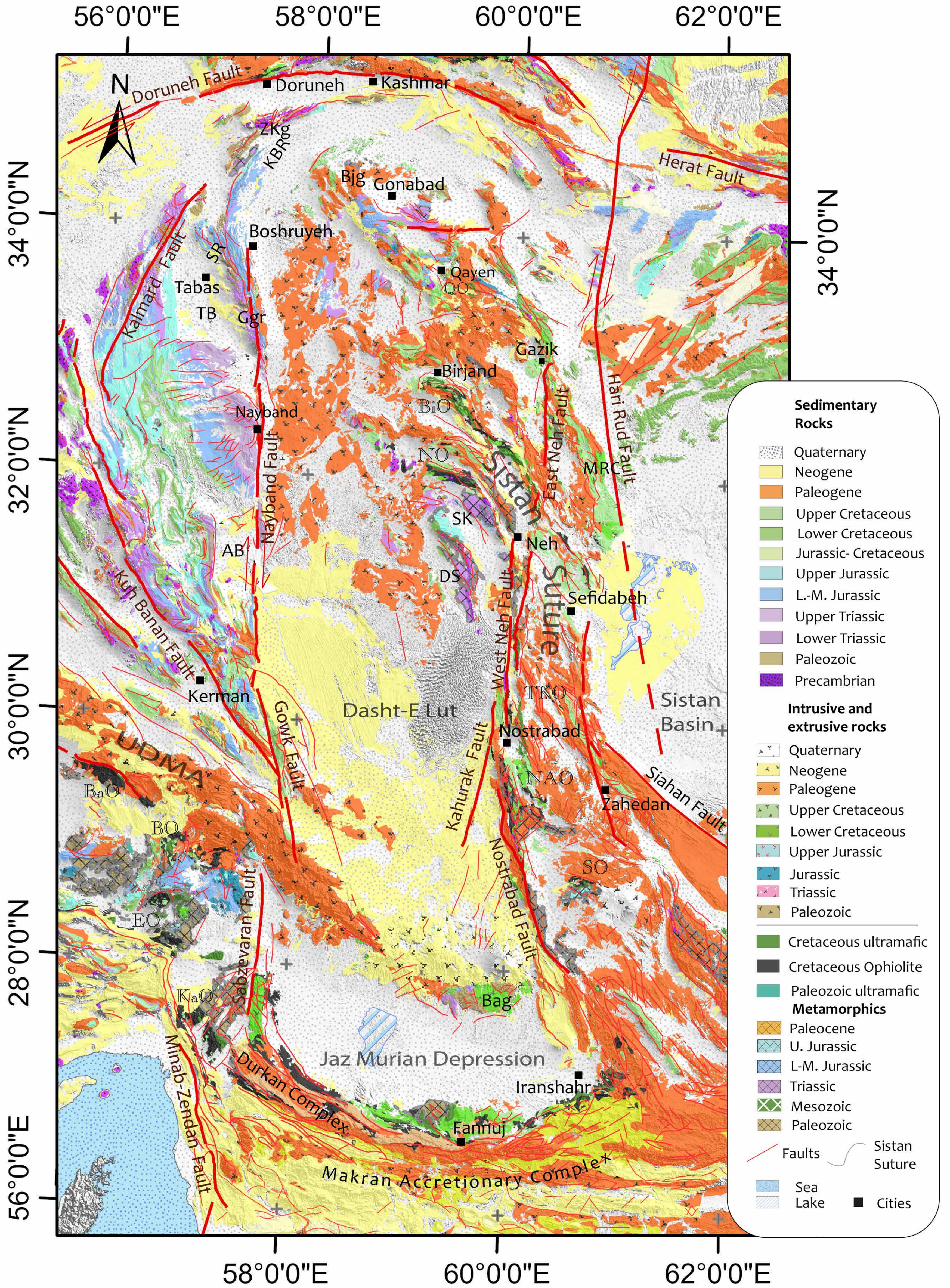


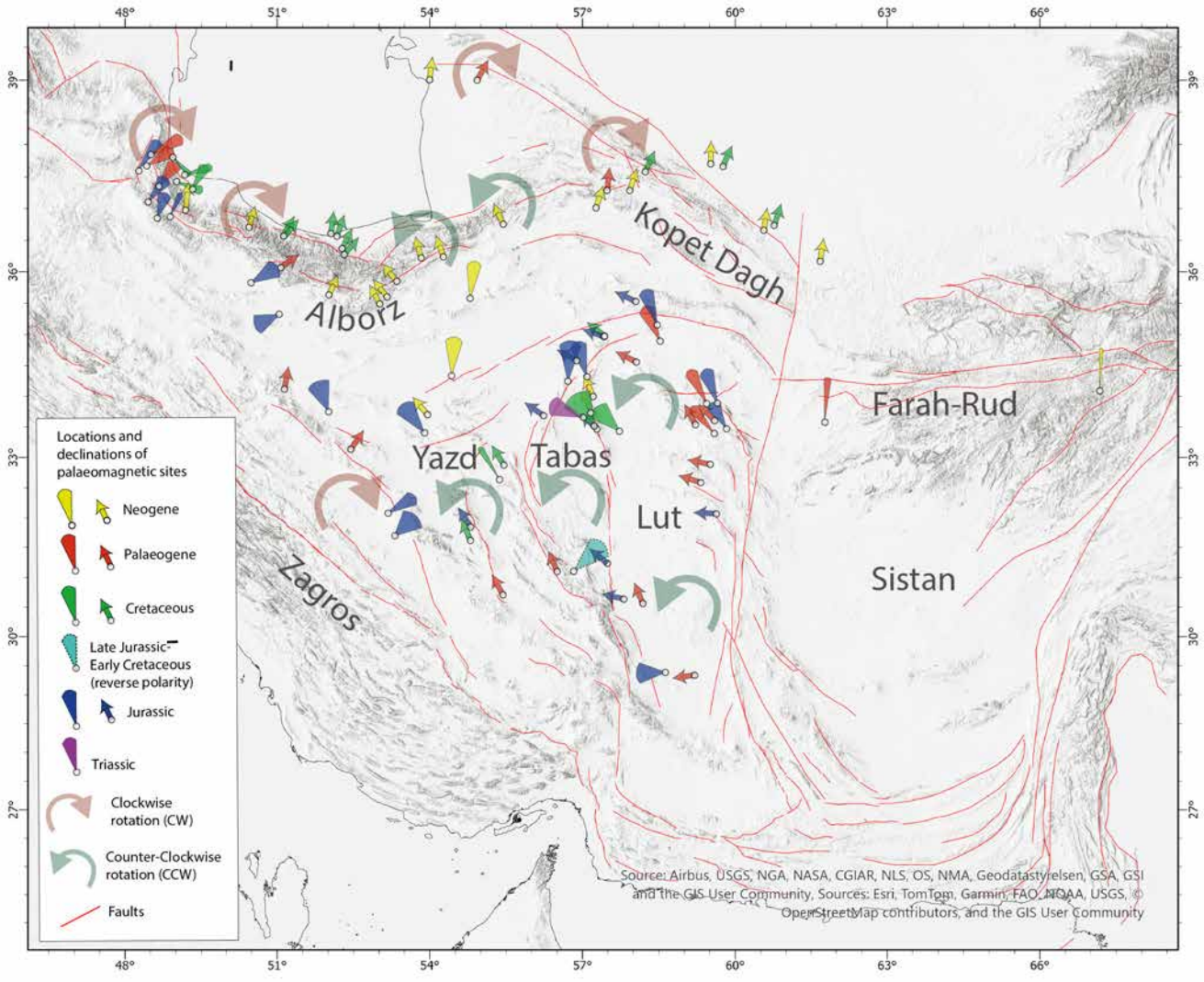


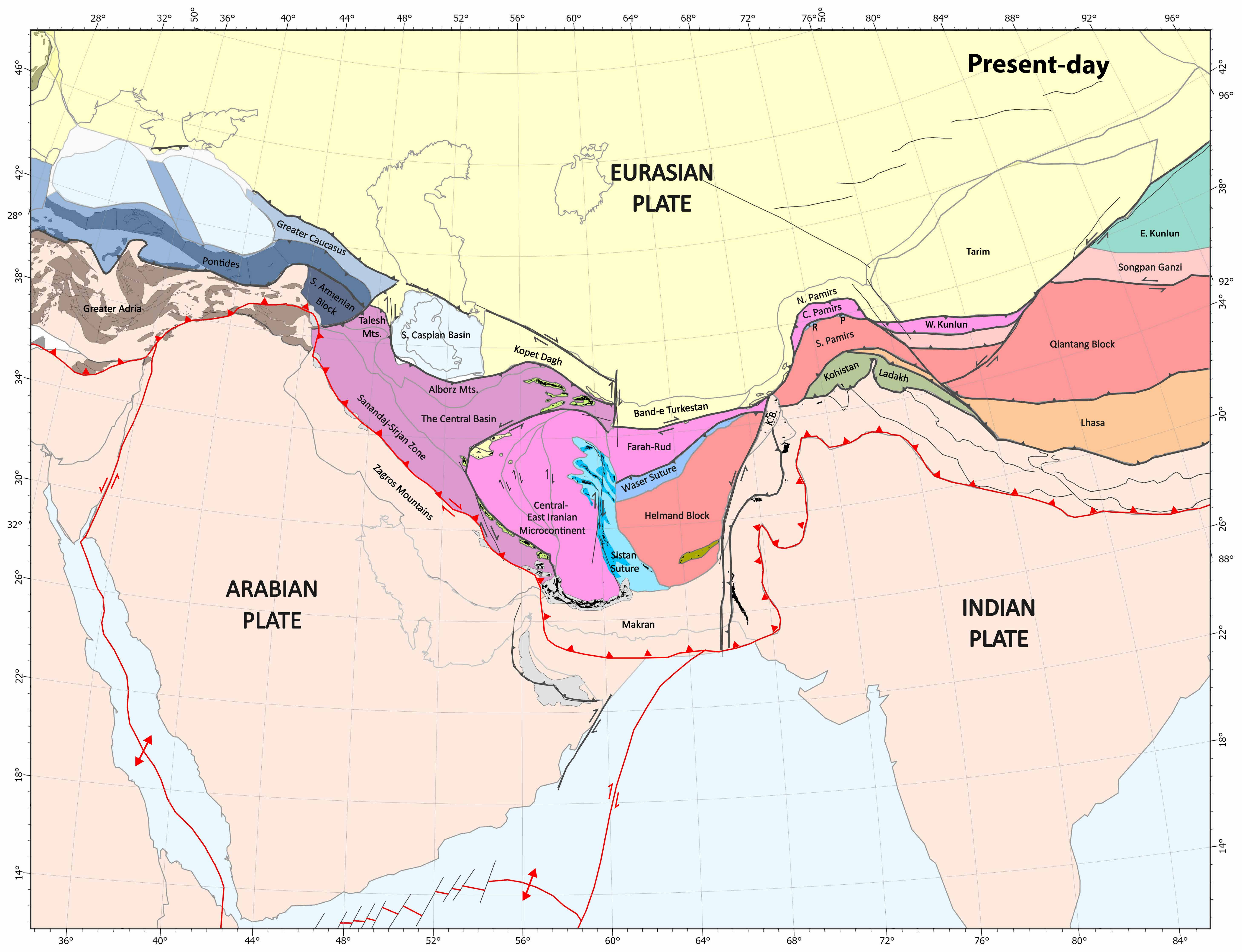




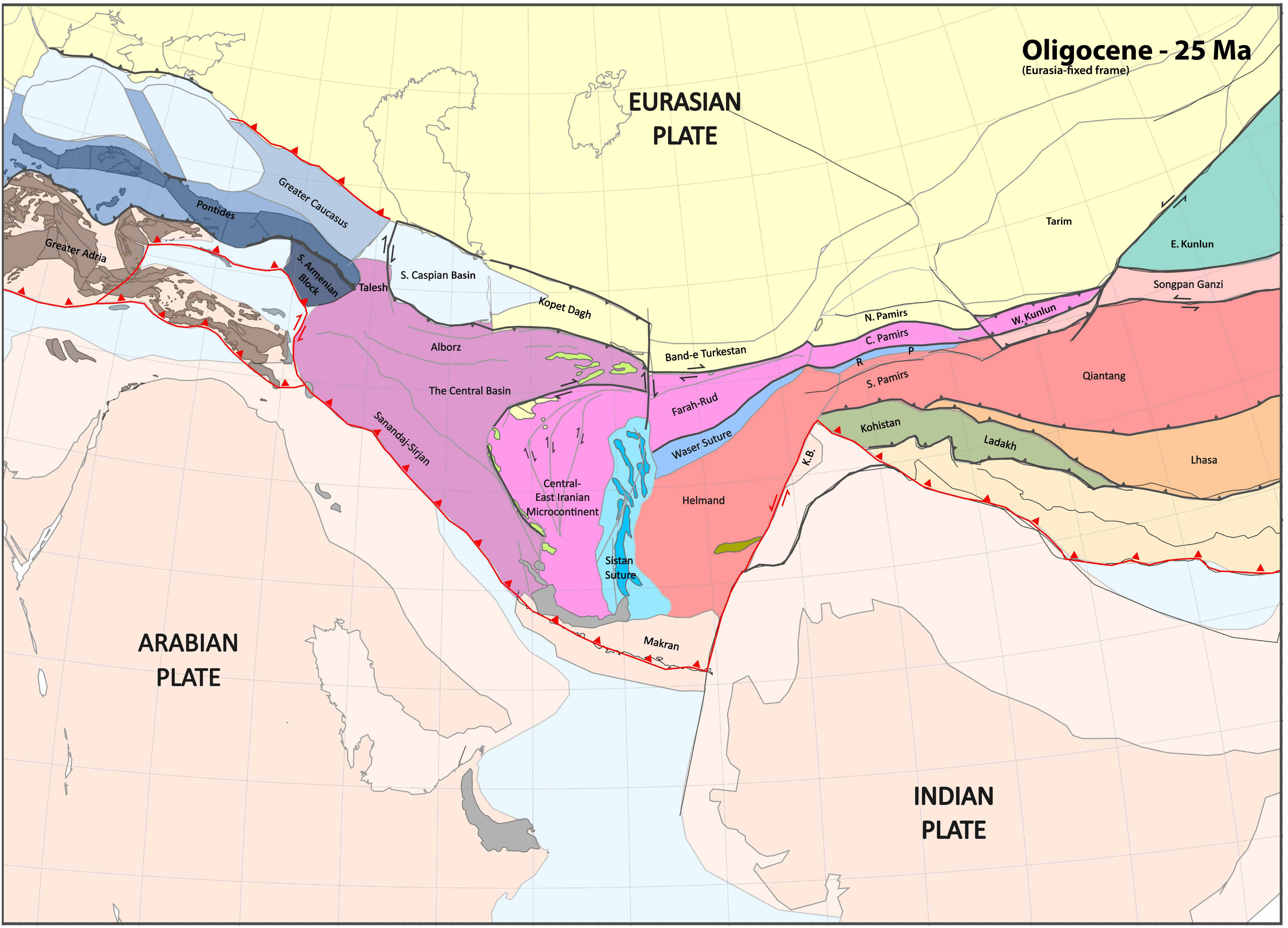








Oligocene - 25 Ma
(Eurasia-fixed frame)



Mid Eocene - 40 Ma
(Eurasia-fixed frame)

**EURASIAN
PLATE**

Tarim

E. Kunlun

Songpan Ganzi

Qiantang

Lhasa

Kohistan

Ladakh

Helmand

NEO-TETHYS

**INDIAN
PLATE**

**ARABIAN
PLATE**

Greater Caucasus

Pontides

Greater Adria

S. Armenian
Block

Talesh

S. Caspian Basin

Kopet Dagh

Alborz

The Central Basin

Sanandaj-Sirjan

Central-
East Iranian
Microcontinent

Sistan
Suture

Waser Suture

Farah-Rud

Band-e Turkestan

N. Pamirs

C. Pamirs
Rushan-Pshart
S. Pamirs

W. Kunlun

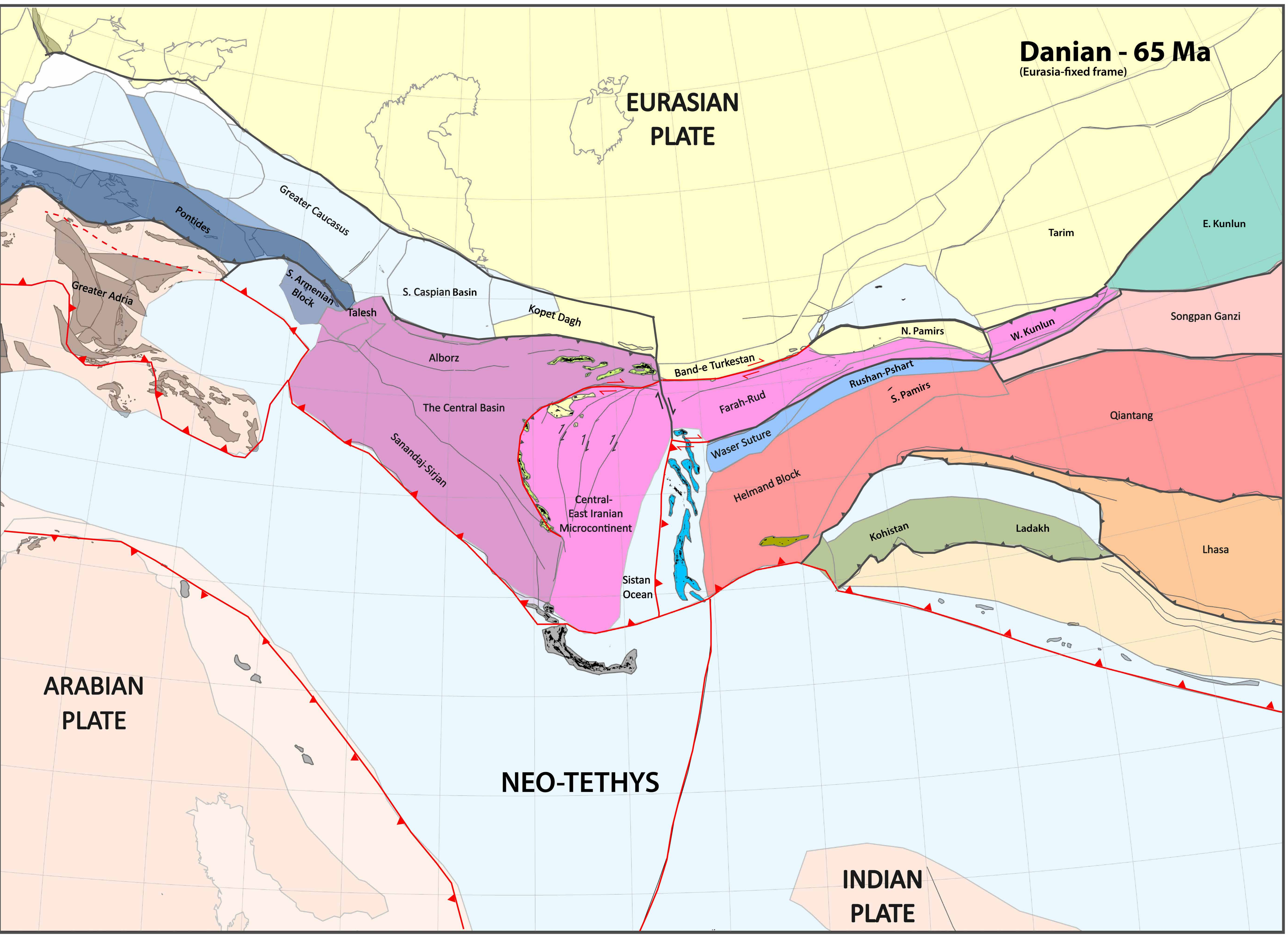
Danian - 65 Ma
(Eurasia-fixed frame)

**EURASIAN
PLATE**

**ARABIAN
PLATE**

NEO-TETHYS

**INDIAN
PLATE**



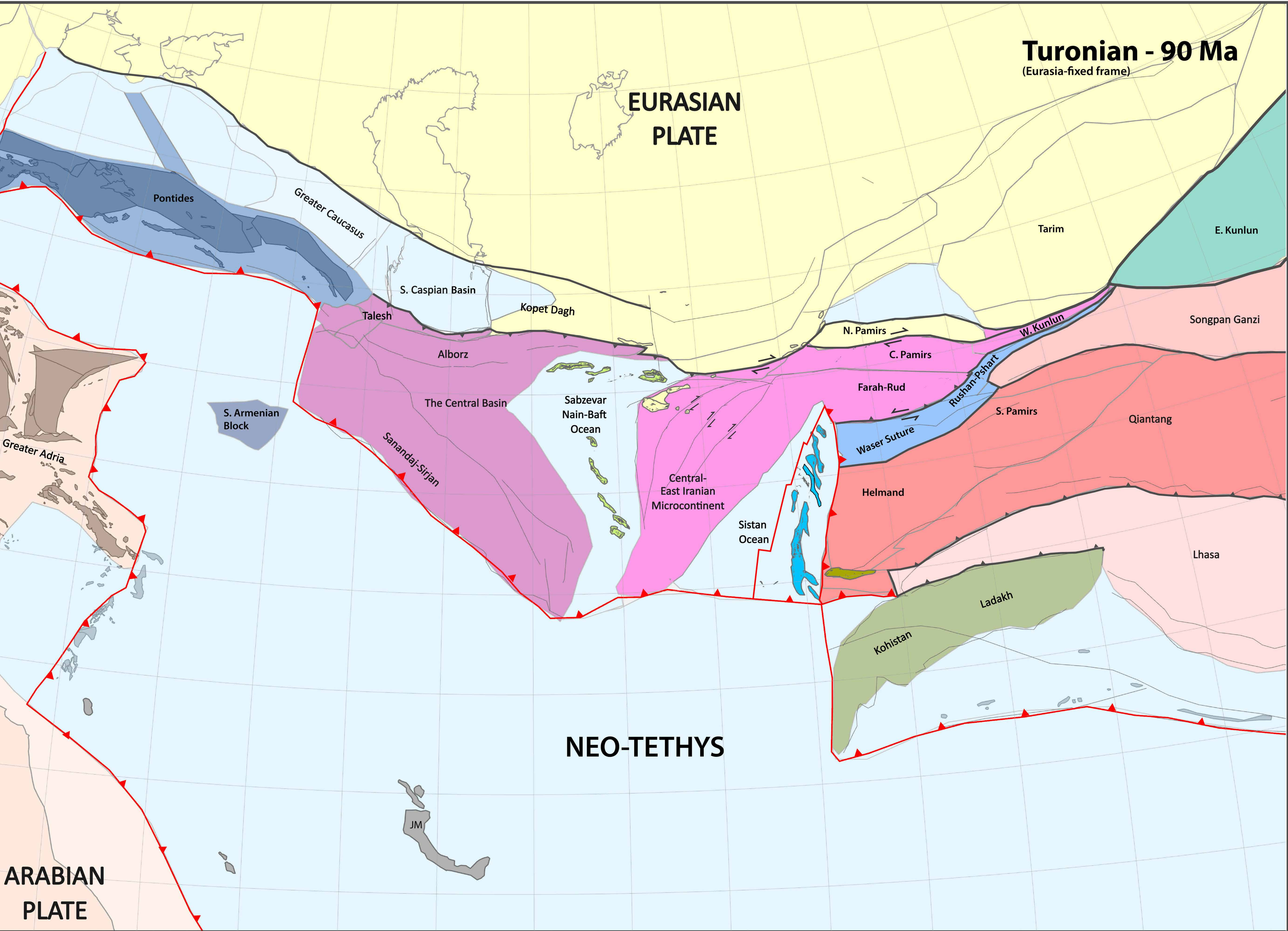
Turonian - 90 Ma

(Eurasia-fixed frame)

EURASIAN
PLATE

ARABIAN
PLATE

NEO-TETHYS



Albian - 110 Ma
(Eurasia-fixed frame)

**EURASIAN
PLATE**

Pontides

Greater Caucasus

S. Caspian Basin

Talesh

Kopet Dagh

Alborz

The Central Basin

Sanandaj-Sirjan

Sabzevar
Nain-Baft
Ocean

Central-East
Iranian
Microcontinent

N. Pamirs

C. Pamirs

Farah-Rud

Waser Suture

Helmand

Sistan
Ocean

Tarim

E. Kunlun

Songpan Ganzi

W. Kunlun

Rushan-Pshart

Qiantang

Lhasa

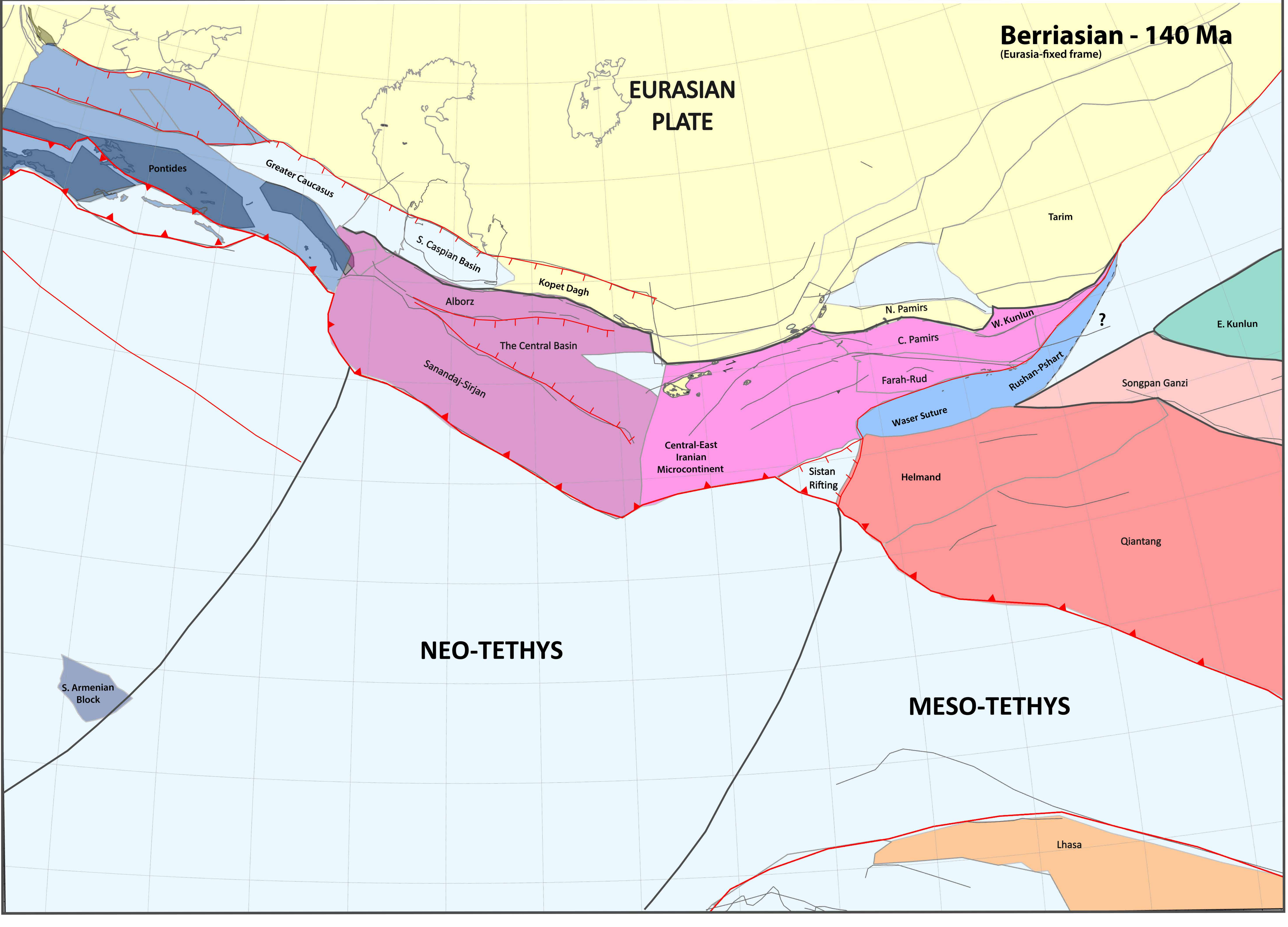
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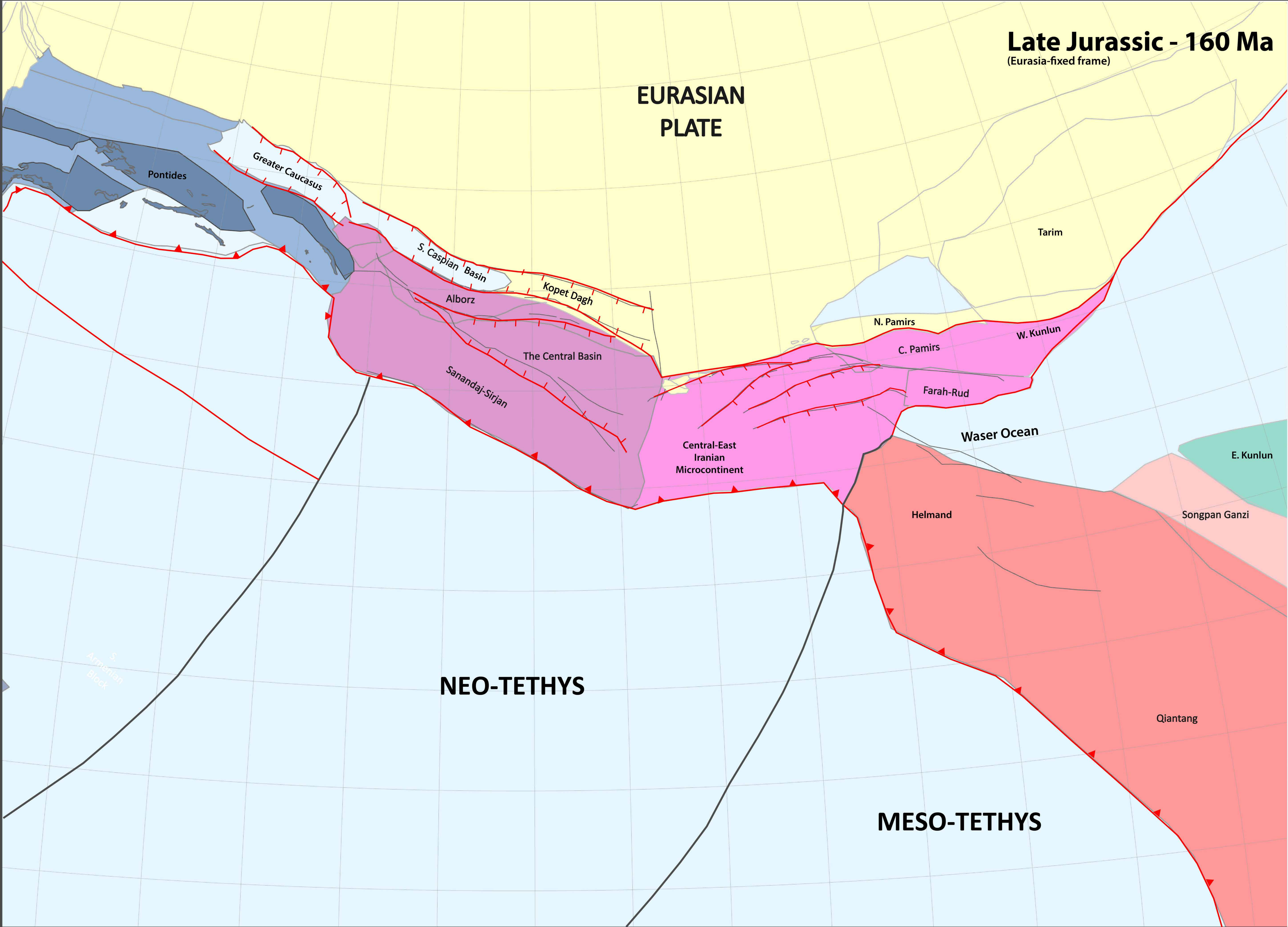
Kohistan

S. Armenian
Block

NEO-TETHYS

Berriasian - 140 Ma
(Eurasia-fixed frame)





Early Jurassic - 185 Ma
(Eurasia-fixed frame)

**EURASIAN
PLATE**

Pontides

Tarim

Paleo-Tethys Suture

Alborz

Sanandaj-Sirjan

N. Pamirs

C. Pamirs

W. Kunlun

Farah-Rud

Central-
East Iranian
Microcontinent

Waser Ocean

Helmand

E. Kunlun

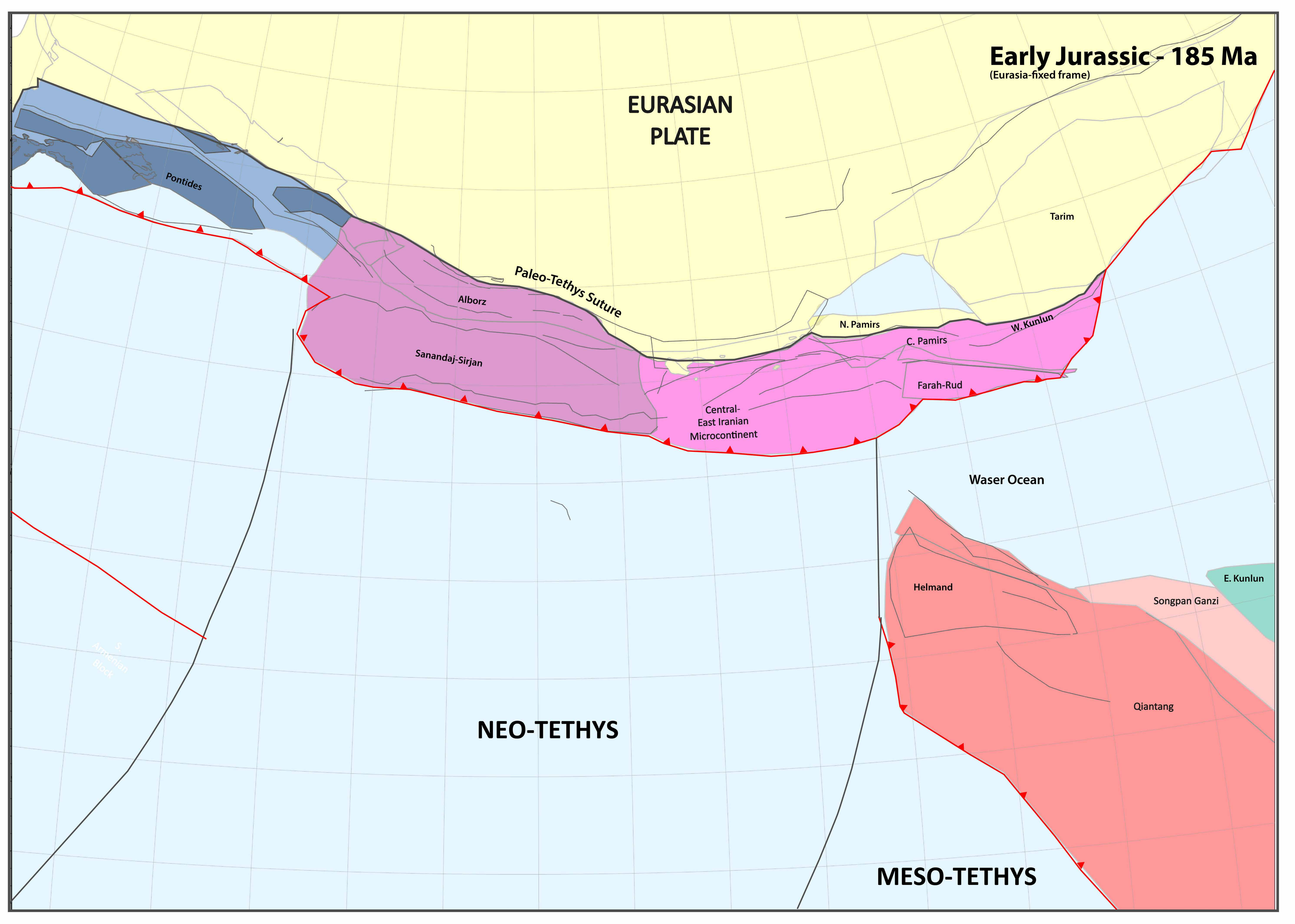
Songpan Ganzi

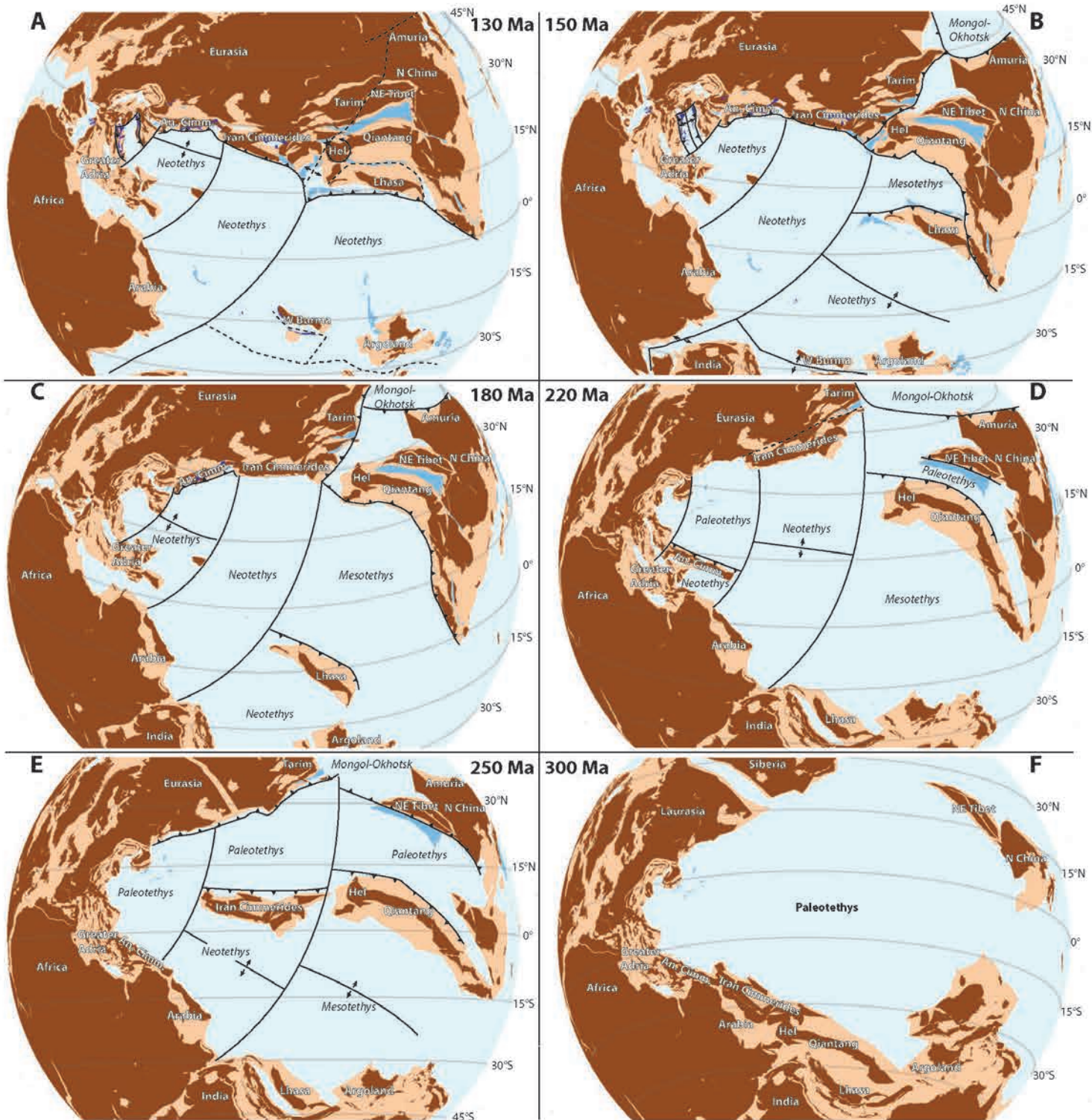
Qiantang

NEO-TETHYS

MESO-TETHYS

S.
Armenian
Block





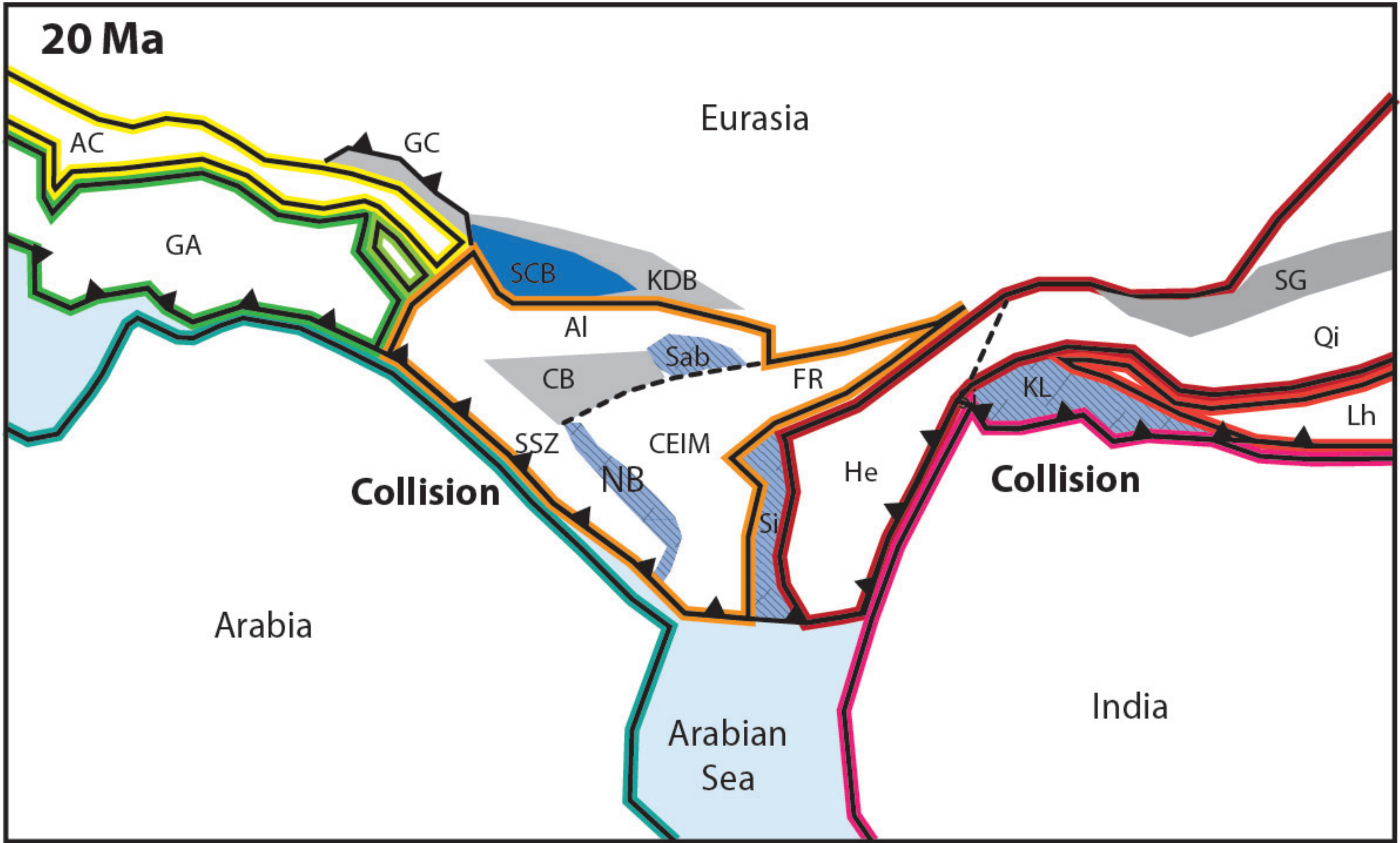
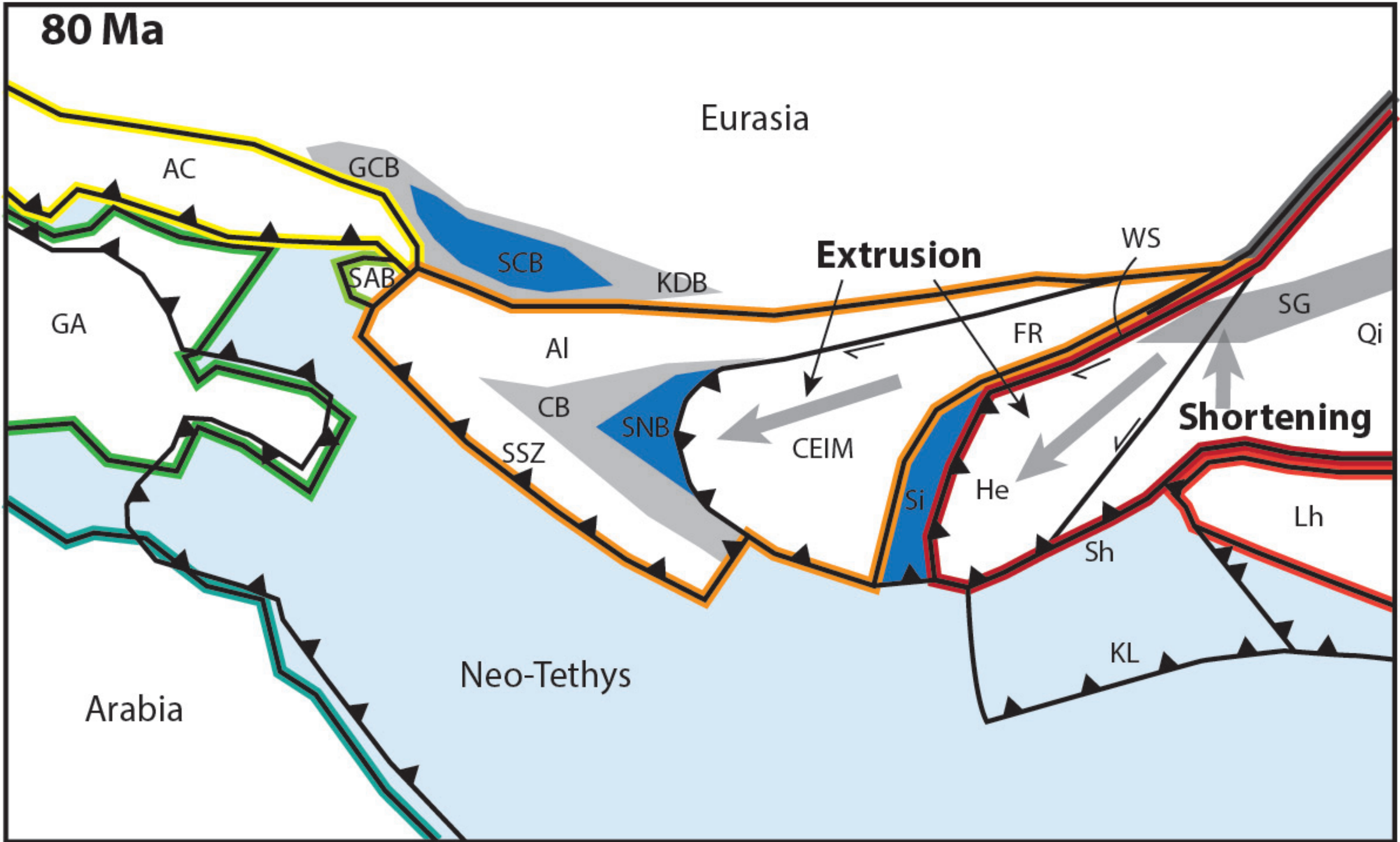
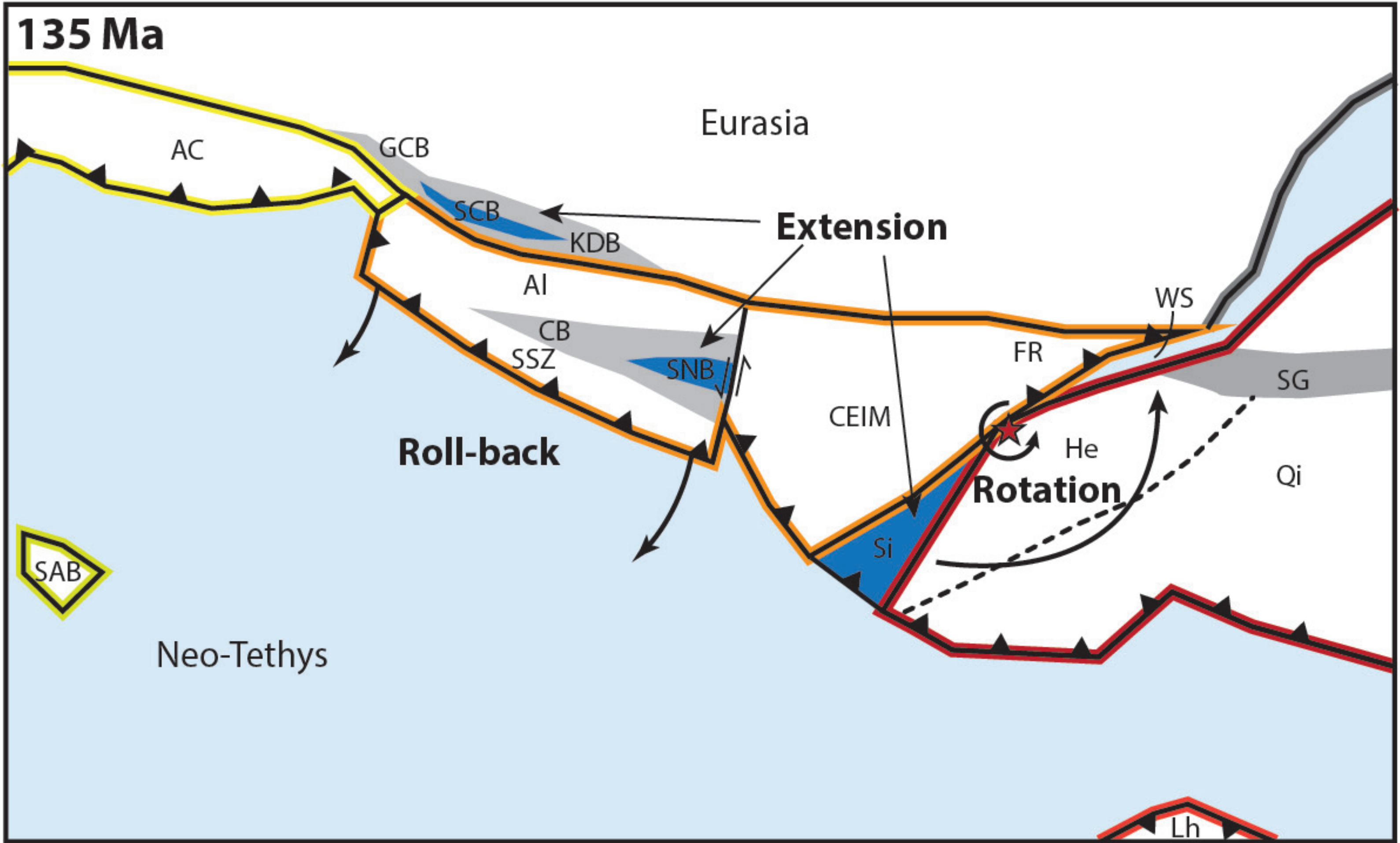
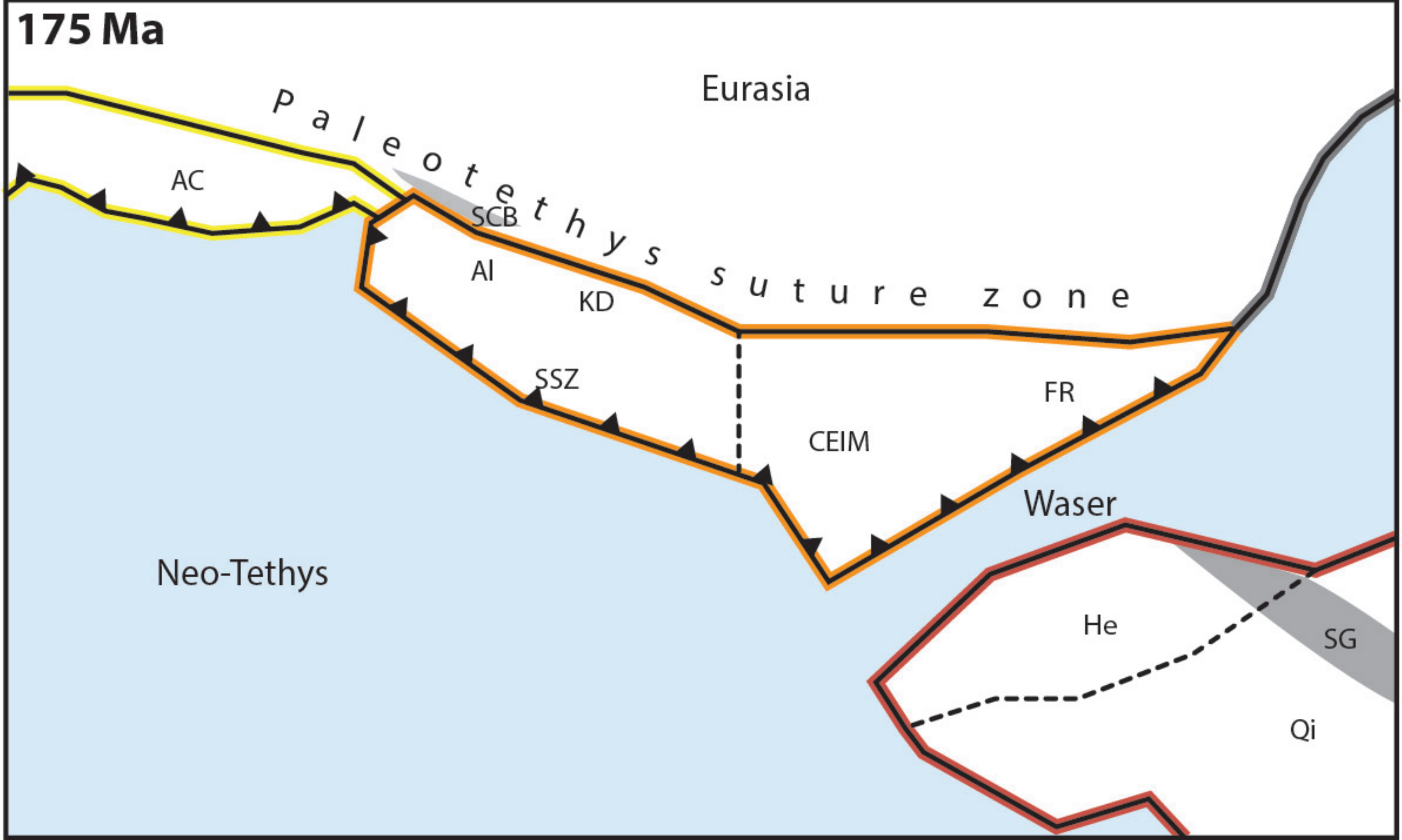


Table 1

Region	Unit/ Massif	Sample Number	Lithology	Dated mineral	Dating Method	Age	Error	Ref. No
The Sabzevar Zone	Sabzevar Ophiolite	IRN.78.154	Diorite in ophiolitic series	Amp	K/Ar	85.5	11	1
		IRN.78.172				84	22	
			Amphibolite			52.5	2.5	
			Nodular gneiss			50.5	1.6	
			Granoblastic lens			48	12.3	
		8059	Blueschist	WR	Rb-Sr	56.52	0.32	2
		8060				57.2	0.32	
		8063				55.12	0.33	
		SZ11-28	Tonalitic dike	Zr	U-Pb	99.9	0.12	3
		SZ10-72	Plagiogranite			98.4		
	SZ11-44	90.2				0.12		
	Torbat-e- Heydarieh Ophiolite	TH12-20		Zr	U-Pb	77.8	0.28	4
		TH12-20	Plagiograniti c dike			99.32	0.72	
		TH11-82B				91.9	0.33	
		TH11-12	Gabbroic dike			96.7	2.1	
	Oryan- Bardaskan Ophiolite	K-2	Diorite			75.78	0.29	5

Table 2

Region	Unit/Massif	Sample Number	Lithology	Dated mineral	Dating Method	Age	Error	Ref. No
Nain-Baft Ophiolitic belt	Nain ophiolite	BKB 05-7	Amphibolite	Amp	Ar-Ar	93.4	3.6	1
		N09-21	Tonalitic dike in amphibolite	Zr	U-Pb	101.2	0.2	2
		N09-28	Plagiogranite			102.7	0.2	
	Dehshir ophiolite	AZ 06-28	Gabbro	Amp	Ar-Ar	93.8	8.7	1
		D 06-6				79.4	7.6	
		D 06-2				67.0	6.4	
		DZ05-6	Tonalitic plugs	Zr	U-Pb	99.0	1.1	2
		AZ06-25	Plagiogranite dike			100.4	0.1	
		AZ06-24	Diorite			100.9	0.2	
	Baft ophiolite	BT 06-35	Gabbro	Amp	Ar-Ar	72.3	8.5	1
		BT 06-34				93.8	11.2	
	Ashin ophiolite	A142	Amphibolitic dike	Zr	U-Pb	97.3	1.8	3
		A144		Zr	U-Pb	97.4	1.3	
		A135	Amphibolite	Zr	U-Pb	104.4	1.2	
			Plagiogranite		K-Ar	98.0		4

Table 3

Region	Fault Name	Type of displacement	Amount of displacement	Since	Method	Ref. No
Kopet Dagh	The Main Kopet Dagh	Dextral	35 km	~5 Ma	Resolving 75 km of N-S shortening across the western Kopet Dagh	1
		Shortening (N-S)	70 km	~5 Ma	Resolving 75 km of N-S shortening across the western Kopet Dagh	1
		Shortening (N-S)	60 km	10 Ma		2
Kopet Dagh-Binalud	Farhadan	Sinistral	7.3 ± 0.8 km	Pliocene	Restoration of total offset in upper Eocene volcanic units	3
Kopet Dagh-Binalud	the Sar'akhor	Dextral	2.7 ± 0.3 km	Quaternary	Displacement in Cretaceous limestone (Tirgan Formation) and Plio-Quaternary lavas	3
Alborz Mountains	Takab (Geynardjeh-Chahartagh)	Dextral	15 km	Late Quaternary	Offset in volcanics	4
	East of Tehran	Shortening	$\sim 53 \pm 2$ km	Late Miocene	Restored cross sections	5
		Shortening	25–30 % / 30 km displacement at the longitude of Tehran	Late Sarmatian (~13 Ma)	Balanced cross section	6

	Mosha	Sinistral	~30 – 35 km	Late Miocene	Offset of geological and geomorphic markers	6
Southern Talesh		Shortening	25-30%		Restored cross sections	7
Central Talesh		Shortening	13–16%		Restored cross sections	7
Northern Talesh		Shortening	22%		Restored cross sections	7
Talesh Mountains		Shortening	120 km	Eocene	Restoration of vertical axis rotations	8
Western Alborz Mountains	Lahijan	Sinistral	12 km		Morphotectonic evidence of offsetting thrust sheets	9
The Central Basin	Shotur Kuh-Biarjmand metamorphic complex detachment	Extension	135 km	Late Cretaceous-early Tertiary	Thermal models obtained from $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology	10
The Central Basin	Qom	Shortening (SW-NE)	38-40 km	late Miocene and Holocene	Cross-section reconstruction	11

Table 4

Region	Unit/ Massif	Lithology	Dated mineral	Dating Method	Age (Ma)	Interpretation	Ref. No
Khoy-Maku Ophiolite		Metagabbro	Amp	K-Ar	197- 181	metamorphism	1
		Metagabbro			160- 155	ductile deformations in shear fault zones	
		Amphibolite			121- 102		
		Plagioclase vein in gabbro	Plg		101	crystallization	
		Isotropic gabbro			72		
		Porphyritic diabasic dike			65		
		Gabbros and amphibolites	Hbl	Ar-Ar	111- 108	crystallization	2
Piranshahr- Serow Ophiolite	Hasanbag igneous complex	Diorite dike, kaersutite	Hbl	Ar-Ar	106-92	crystallization	3
Kermanshah Ophiolite	Sahneh	Leucodiorite	WR	K-Ar	86	crystallization	4
		Diabase	Amp	K-Ar	81		
	Harsin	Gabbro	Zr	U-Pb	79.3	crystallization	5
	Sahneh	Foliated gabbro			37.06		
		Plagiogranite			35.7		
	Kamyaran	Gabbro			39-36		
		Plagiogranite			38		
Neyriz Ophiolite	Tang-e Hana	Plagiogranite	Hbl	Ar-Ar	93-92	crystallization	6
		Pargasite schist	Amp	Ar-Ar	94.9	shearing and amphibolitization along the sole detachment	7

		Diabase tholeiitic sheeted dikes	Hbl	Ar-Ar	85.9	crystallization	
	Qori metamorphic complex	Trondhjemite	Zr	SHRIMP	147.4	arc related regional metamorphic event	8
	Chah Gaz	Plagiogranite, isotropic gabbro	Zr	U-Pb	101-93	crystallization	9
Esfandagheh Ophiolite	Sikhoran ultramafic/ mafic complex	Diabase	WR	K-Ar	159-134	crystallization	10
		Amphibolite	Amp	K-Ar	164		
		Pegmatoid			222.6		
		Pargasitic hornblende-bearing pegmatoid gabbros			253		
					255.6		
	Haji-Abad	Plagiogranite	Zr	U-Pb	186	crystallization	11
		Gabbro			174.9		
	Soghan Complex	Isotropic gabbro	Amp	K-Ar	182	crystallization	12
		Diabasic dykes			186		
					76		
	Esfandagheh	Amphibole schist	Mus		98	crystallization	4
Kahnuj Ophiolite	Dare Anar complex	Gabbro	Amp	K-Ar	156-139	crystallization	13
		Potassic granites		K-Ar	93-89		
	Band-e Zeyarat/ Dar Anar			Ar-Ar	143-140	crystallization	14

Table 5

Region	Fault Name	Type of displacement	Amount of displacement	Since	Method	Ref. No
West of the Yazd Block	Deh Shir	Dextral	50 km		Offset in Eocene-Oligocene volcanics	1
			65± 15 km	40-25 Ma	Offset of the Nain-Baft suture	2
Yazd Block	Anar	Dextral	20 km		Offset in Lower Cretaceous shales	1
West of the Posht-e Badam Block	Chapedony	Extension	2 km vertical displacement	30 Ma	E-W to NE-SW exhumation of the Chapedony complex	1, 3
West of the Tabas Block	Kuh Banan	Dextral	5-7 km		Length of pull-apart basins	4
West of the Lut Block	Nayband	Dextral	3.2 km	2 Ma	Offset in basalts	1
NW Tabas Block	Shotori Mountains	Shortening	25%	Late Neogene-Quaternary		5
Southwest of the Lut Block	Gowk Fault	Dextral	12 km	5 Ma	Geomorphologic indices	6
	Sabzevaran	Dextral	6 km			7, 8
The Lut Block	Shahdad thrust belt	Shortening	4-7km	Late Pliocene-Quaternary	Restored cross sections	9
N-NE of the CEIM	Doruneh	Sinistral	1.33 km	Late Quaternary	Offset in alluvial fans	10
Lut-Afghanistan	Dasht-e-Lut	Dextral	75 Km	5 Ma		1
			105 km	7 Ma		1
Sistan Suture	Zahedan	Dextral	13km		Offset in Cretaceous to Eocene mudstones and phyllites	1

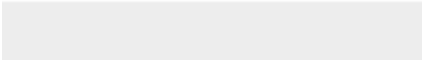
	East Neh	Dextral	50 km		Offset in Late Cretaceous peridotite and Tertiary turbidites and phyllites	1
	East Neh	Dextral	65 km		Total offset in the Neh Complex	11
	West Neh	Dextral	10 km		Offset in Jurassic phyllites and Cretaceous ophiolitic material	1
Central Iran	Dehu, Anar, Deh Shir, Kashan, Ab-Shirin-Shurab, Kousht Noursrat, Qom, Bid Hand, Indes, Soltanieh and Takab faults	Dextral	250 km (total offset)		Offset of geological and geomorphic markers	12
The Central Basin		Shortening	40-50 km	10 Ma	Restoration of cross sections	13

Table 6

Region	Fault Name	Type of displacement	Amount of displacement	Since	Method	Ref. No
North of Band-e Bayan	Andarab	Dextral	40 km	Pliocene-Quaternary	Geomorphologic indices	1
North of Farah Rud	Herat	Dextral	0.7-0.8 km		Offset in drainage pattern	2
South of Farah Rud	Farah	Dextral	80 km	Eocene	Offset in dike swarms	2
Southeast of Helmand Block	Chaman	Sinistral	~ 300 km	Eocene		2
			min. 155 km	Tertiary	Offset of geological markers	3
			~60-80 km	2 Ma	Offset in a 2 Ma old volcanic unit	4
			200-400km	Late Oligocene or Early Miocene		5
			460 ± 10 km	25-20 Ma	Offset of geological markers	6

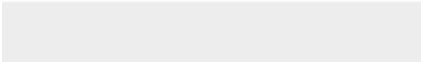


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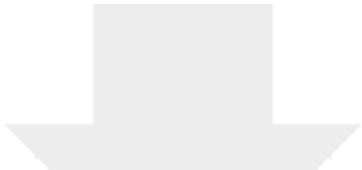
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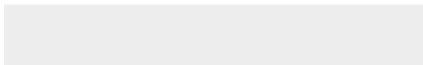
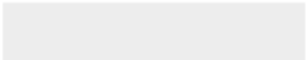


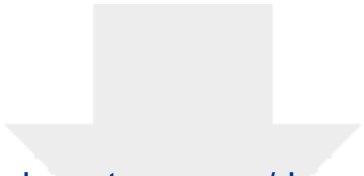
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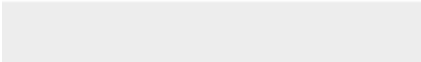


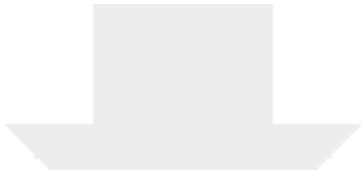
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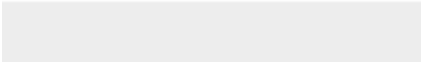
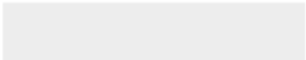


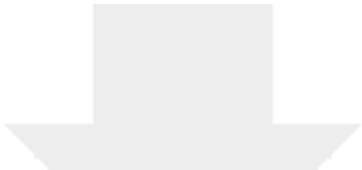
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