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Role of the Allahyarlu ophiolite in the tectonic evolution of NW Iran and adjacent areas (Late Carboniferous – Recent)

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In this paper we reconstruct the tectonic evolution of Eastern Turkey, the Lesser Caucasus and NW-N Iran from the Late Carboniferous to Recent. NW Iran is one of the most complicated regions of the country, that with Turkey and the Lesser Caucasus is influenced by movements of the Arabian Plate. The Ahar Block, which is bounded by the Tabriz, Talysh, Araks, Myaneh and Allahyarlu-Hovai Faults, underwent compression and faulting. The block shows counterclockwise rotation through the confining faults and is being compressed by northward pressure from the Arabian Plate. The age and the nature of the Allahyarlu ophiolite, which is located at the northern boundary of the Ahar Block, are not known unequivocally. During the Late Carboniferous the Allahyarlu-Kaleybar-Northern Iran Basin opened, and Neotethys 1 was spreading. During the Permian the Allahyarlu-Kaleybar-Northern Iran Basin changed from a passive to a convergent environment and closed at Late Triassic to Early Jurassic time. In the Early Jurassic Neotethys 1 began to be subducted, causing the opening of the Sevan-Akera back-arc basin. Thereafter the Sevan-Akera Basin and the Neotethys 2 Basin were widening up to the Late Jurassic. The Black Sea-South Caspian Sea-Kopet Dagh Basin opened during the Jurassic. These basins were widening up to the Paleocene, but northward slider replacement of NW Iran caused the separation of the Caspian Sea Basin and the Black Sea Basin and the formation of the Kurdamir Uplift. In the Late Cretaceous the Central Iran basins were closed and the inner-Iran ophiolites were emplaced. Neotethys 1 closed in the Late Cretaceous and Neotethys 2 in the Late Miocene.

Key words: Arabian Plate, Neotethys, Ahar block, Allahyarlu ophiolite

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Introduction

There are various hypotheses discussing the genesis and evolution of NW Iran and the Lesser Caucasus (Fig. 1) (e.g. Berberian et al. 1981; Majidi 1981; Sengör 1990; Alavi 1991a; Babakhani and Nazer 1991; Eftekharnejad and Asadian 1992; Golonka 2004; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Sosson et al. 2010; Rolland et al. 2011; Sheikholeslami and Kouhpeyma 2012). Here we discuss the evolution of NW Iran and the Lesser Caucasus using new evidence obtained from studies of the Allahyarlu ophiolite. NW Iran and the Lesser Caucasus together formed a region for which, despite many expressed opinions, there is no general consensus about its evolution history. In Ardebil Province of NW Iran there is an anticline called the Allahyarlu Anticline (Babakhani and Nazer 1991; Eftekharnejad and Asadian 1992; Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a). This anticline, of a general east-west trend, is located between the Moghan plain to the north and the Meshkinshahr plain to the south (Sudi Ajirlu et al. 2010b). The Allahyarlu ophiolite mélange is exposed along the Allahyarlu-Hovai Fault and the Allahyarlu anticline core (Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a). The field studies which provide the reconstruction of the geologic evolution of these regions are concentrated on the Allahyarlu ophiolite mélange. Ophiolite components such as

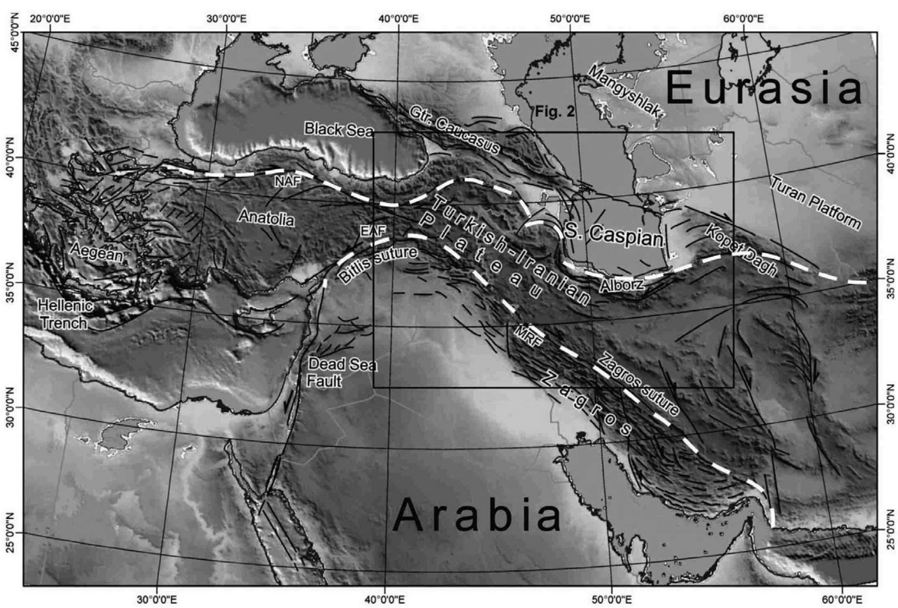

Fig. 1
Topography and regional structures map of the Arabia– Eurasia collision (after Allen et al. 2003). Main elements of the Alpine belt in this map: Turkish-Iranian plateau; Arabian platform; Greater Caucasus; Lesser Caucasus; NAF (North Anatolian Fault); EAF (East Anatolian Fault); MRF (Main Recent Fault)

peridotite, dunite, gabbro, basalt and diabase are mixed together in the Allahyarlu ophiolite mélange. All these rock units underwent metamorphism in the greenschist facies. The Allahyarlu-Hovai fault activity resulted in the uplifting of the ophiolite mélange (Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a).

Geologic background

NW Iran is one of the most complicated regions within the region of the Iranian crust; there are numerous and sometimes diverse opinions on its geologic evolution (e.g. Berberian et al. 1981; Majidi 1981; Sengör 1990; Alavi 1991a; Eftekharnejad and Asadian 1992; Golonka 2004; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Barzegar and Pourkermani 2010; Sudi Ajirlu et al. 2010b). This area, along with other regions of Iran, Turkey, Armenia and the Azerbaijan Republic, were affected by movements of the African (due to Atlantic ocean opening) and Arabian Plate (due to

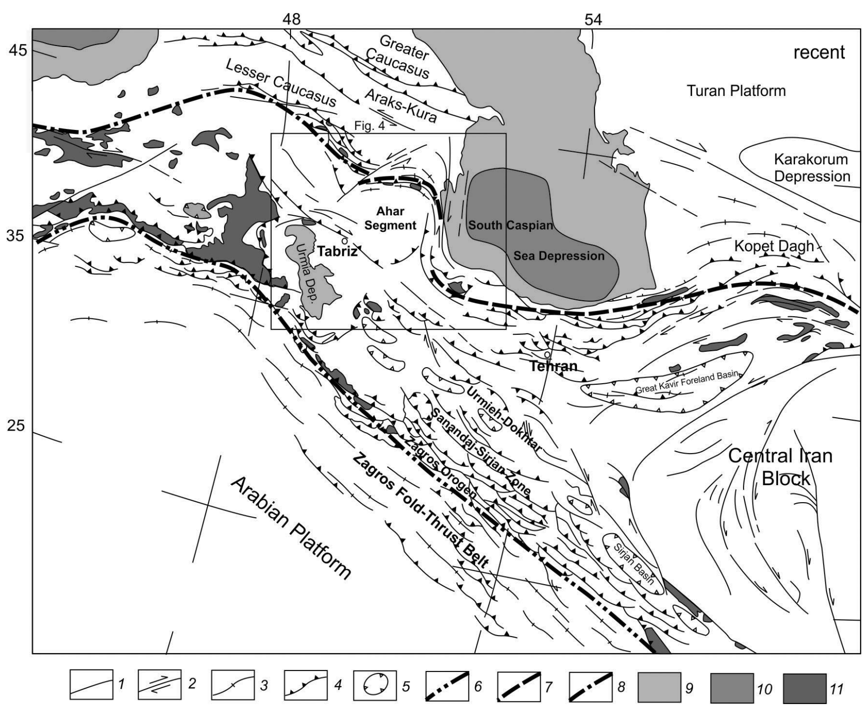

Fig. 2
Main tectonic structures of the Alpine Belt from the Eastern Turkey to Eastern Iran. *(1)* main fault and structure trend; *(2)* strike slip fault; *(3)* anticline; *(4)* thrust; *(5)* Cenozoic depression; *(6)* Zagros-Bitlis suture zone; *(7)* Allahyarlu-Kaleybar-Northern Iran suture zone; *(8)* Erzincan-Sevan-Akera suture zone *(9)* shallow water and lacustrine basin; *(10)* oceanic lithosphere; *(11)* paleooceanic remnants. Allahyarlu-Kaleybar-Northern Iran suture zone and Erzincan-Sevan-Akera suture zone are distinguished from each other by their ophiolites emplacement ages

Red Sea opening) (Fig. 2). All these caused compacting, shrinking, folding and faulting in this part of the Earth's crust (Stöcklin 1968; Berberian et al. 1981; Klitgord and Schouten 1986; Zonenshain and Le Pichon 1986; Alavi 1996; Withjack et al. 1998; Allen et al. 2003; Brunet et al. 2003; Nikishin et al. 2003; Bird et al. 2007). The Allahyarlu region in NW Iran is a folded belt. The main fold has an east-west structural trend and constitutes Mt. Samanludagh (Babakhani and Nazer 1991; Barzegar and Pourkermani 2010; Sudi Ajirlu et al. 2010). This fold is an anticlinal one (Barzegar et al. 2010; Sudi Ajirlu et al. 2010b); the Allahyarlu-Hovai reverse fault is oriented along its axial surface. The ophiolitic and metamorphic complexes of Allahyarlu are exposed at the northern edge of the Ahar Block due to movement along this fault.

The main faults of NW Iran are the Tabriz, Talysh, Araks, Myaneh and Allahyarlu-Hovai Faults (Fig. 4).

The Tabriz Fault, with an approximate length of 100 km, stretches from the Mishou Mountains in the west to the city of Bostanabad in the east. This fault divides the Azerbaijan region into two blocks: a northeastern region including the Tabriz and Ardebil areas and the southwestern block of Zanjan (Eftekharnejad 1975). The Tabriz Fault is a dextral strike-slip fault and its formation age is attributed to the Late Devonian (Eftekharnejad 1975; Aghanabati 2004).

The Myaneh Fault of NE–SW trend is a dextral strike-slip fault which is located at the eastern continuation of the Tabriz Fault and stretches along the Garmichai River and south of the Mt. Sabalan (Lescuyer and Riou 1976). One of the reasons for the formation of Mt. Sabalan may be the simultaneous action of the dextral Myaneh Fault to its south and dextral movement of another fault to its north, which caused the formation of a pull-apart basin, where magmas erupted (Lescuyer and Riou 1976).

The Talysh fault is a dextral, reverse and active fault of ~1,400 km length and an approximately north-south trend (Fig. 3). Based on new studies, two significant faults are found in the Talysh area (Allen et al. 2003, 2005). One of them is a dextral thrust fault

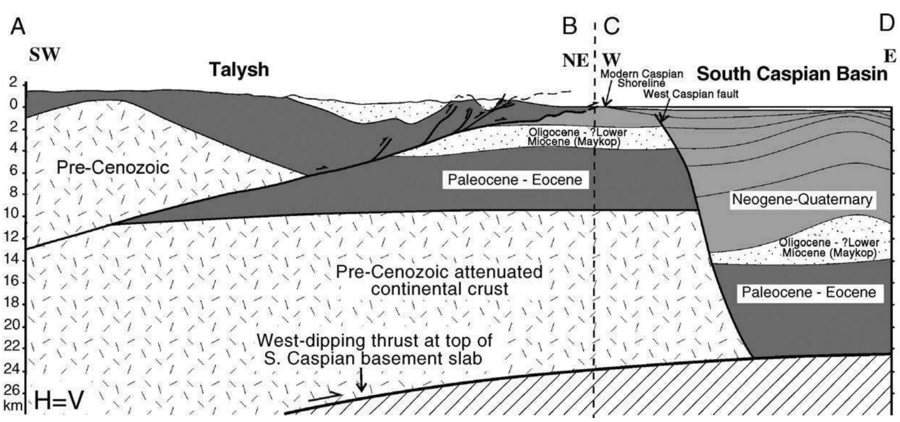

Fig. 3
Cross-section through the eastern Talysh by Allen et al. (2003)

with a smooth slope toward the SW (Allen et al. 2003); another is a normal fault with an intensive slope toward the east (Allen et al. 2003). Slider and rotational movements occur along the smooth slope of the Talysh Fault (Khalafly 2001; Allen et al. 2005) and West Caspian Sea Basin subsidence occurs along the normal Talysh Fault (Allen et al. 2005).

Some researchers believe that the Talysh Fault is a transform fault and plays a principal role in paleo-ocean evolution in NW Iran and the Lesser Caucasus (Brunet et al. 2003; Golonka 2004; Kazmin and Tikhonova 2006; Adamia et al. 2011). The Talysh Fault formation age is Precambrian (Aghanabati 2004). Dextral movements of this fault displaced Azerbaijan and NW Iran toward higher latitudes (Eftekharnejad 1975; Didon and Gemain 1976; Allen et al. 2005; Kazmin and Tikhonova 2006; Hudson et al. 2008; Sudi Ajirlu and Jahangiri 2010a).

The Araks Fault is one of the most important faults of Azerbaijan and NW Iran; it separates the Lesser Caucasus Block and Transcaucasus Block from the Talysh Plate and the Ahar Block. The Araks Fault is a sinistral strike-slip fault (Alavi 1991b; Barka and Reilinger 1997; Allen et al. 2005; Galoyan et al. 2009; Sosson et al. 2010; Adamia et al. 2011). This fault, of NE-SW trend and with its sinistral movements, displaced NW Iran lithologies (Didon and Gemain 1976; Sudi Ajirlu and Jahangiri 2010a; Adamia et al. 2011).

The Allahyarlu-Hovai Fault of east-west trend (Golonka 2004; Allen et al. 2005; Kazmin and Tikhonova 2006; Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a) is a sinistral and reverse fault which is located at the Allahyarlu anticlinal core and along the anticline axis (Barzegar and Pourkermani 2010; Sudi Ajirlu et al. 2010b). This reverse fault emplaced older metamorphic rocks next to the ophiolite mélange (Alavi 1991a; Babakhani and Nazer 1991; Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a).

The Allahyarlu-Kaleybar-Northern Iran Suture Zone, determined by Late Carboniferous to Triassic metamorphic and ophiolitic exposures, was the western continuation of a branch of the Paleotethys Basin in Iran (Alavi 1991b; Ruttner 1993; Alavi 1996; Ghazi et al. 2001; Seyed-Emami 2003; Zanchi et al. 2006; Ghavidel-Syooki 2008; Zanchetta et al. 2009; Omrani and Moazzen 2010; Sheikholeslami and Kouhpeyma 2012; Shafaii Moghadam et al. in press). It is likely that the Allahyarlu ophiolite complex was displaced to higher latitudes by the dextral Talysh Fault (Eftekharnejad 1975; Didon and Gemain 1976; Kazmin and Tikhonova 2006; Zakariadze et al. 2007; Sudi Ajirlu and Jahangiri 2010a).

Concerning the western continuation of the Allahyarlu-Kaleybar Suture Zone, some researchers believe that it may be the Sevan-Akera Suture Zone (Eftekharnejad 1975; Babakhani and Nazer 1991; Zakariadze et al. 2007) but because of dextral Talysh and sinistral Araks Fault activities, the Allahyarlu Suture Zone moved to higher latitudes (Didon and Gemain 1976; Sudi Ajirlu and Jahangiri 2010a). Since the Sevan-Akera Suture Zone is situated at higher latitudes than the Allahyarlu Suture Zone, the probability of its being the western continuation of the Allahyarlu Suture

Zone is questionable. On the other hand, considering the existence of the Ahar Block, the movements of its confining faults and Khalafly's (2001) research, the Ahar block rotated 6–8° counterclockwise during the Eocene. Therefore it could be put forward that the western continuation of the Allahyarlu-Kaleybar Suture Zone is the Sevan-Akera Suture Zone. However, it should be mentioned that the opening-closing ages of the Allahyarlu-Kaleybar-Northern Iran ophiolites is Late Carboniferous to Triassic, respectively, while the opening-closing ages of the Sevan-Akera ophiolites is Middle Jurassic to Lower Cretaceous, respectively. Since the Sevan-Akera ophiolites were formed by Neotethys subduction and at its back-arc basin (Galoyan et al. 2009; Rolland et al. 2009; Sosson et al. 2010; Rolland et al. 2011), it is unreasonable to consider the Allahyarlu-Kaleybar Suture Zone as the western continuation of the Sevan-Akera Suture.

The Ahar Block

(1) Based on the NW Iran tectonic map (Huber et al. 1976; Alavi 1991b; Nogole-Sadat and Almasian 1993), lithological structure features and the main fault trends of the studied region, a block is present that we call the "Ahar Block", which is limited by the Tabriz, Myaneh, Talysh, Allahyarlu-Hovai and Araks Faults (Fig. 4). This block was also called "Ahar Block" by some authors (e.g. Barka and Reilinger 1997) while some others have call it the "Talysh Plate" (e.g. Allen et al. 2003; Golonka 2004; Zanchetta et al. 2009). The Ahar Block underwent rotational and compressional movements caused by confining fault activity (Didon and Gemain 1976; Zonenshain and Le Pichon 1986; Masson et al. 2006; Hudson et al. 2008; Sudi Ajirlu and Jahangiri 2010a). Limited paleomagnetic data from basalts in the Talysh region suggest that ~26° counterclockwise rotation took place around vertical axes during the Early-Middle Eocene and that 18–20° clockwise rotation occurred since the Late Eocene (Bazhenov and Burtman 1989; Khalafly 2001; Allen et al. 2005). The main evidence to consider this zone as a block is the existence of mafic and ultramafic rocks and ophiolite mélanges along the Tabriz and Allahyarlu-Hovai Faults (Berberian et al. 1981; Babakhani and Nazer 1991; Sudi Ajirlu and Jahangiri 2010a).

(2) Folding along the Talysh and Allahyarlu-Hovai Faults indicates that northward and northeastward movements and compression are occurring along these faults (Didon and Gemain 1976; Lescuyer and Riou 1976; Zonenshain and Le Pichon 1986; Alavi 1996; Allen et al. 2003, 2005; Masson et al. 2006; Zakariadze et al. 2007; Galoyan et al. 2009)

(3) Bending and conversion of rock units in the Allahyarlu area toward the east and in the Talysh area with a north-south trend indicate that the Talysh Fault underwent dextral movement (Didon and Gemain 1976; Allen et al. 2005; Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a).

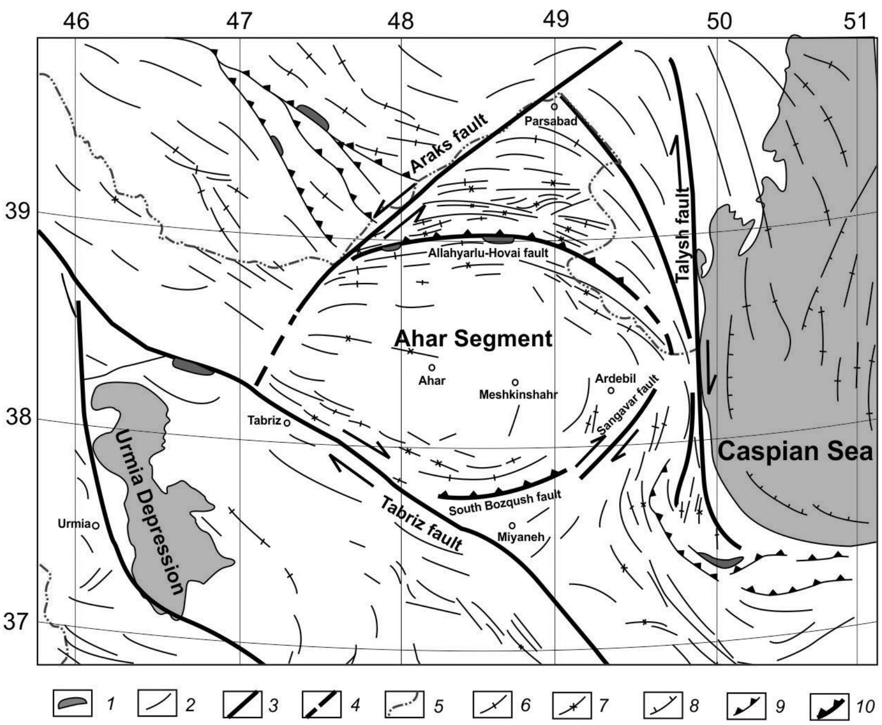

Fig. 4
Ahar block limits. *(1)* paleooceanic remnants; *(2)* local structures trend; *(3)* main fault; *(4)* concealed fault; *(5)* country boundaries; *(6)* anticline; *(7)* syncline; *(8)* subsidence area; *(9)* major thrust; *(10)* Allahyarlu-Hovai thrust

(4) Bending and conversion of rock units in the Kaleybar area to the west indicate that the Araks Fault underwent sinistral movement (Nogole-Sadat 1994; Barzegar and Pourkermani 2010).
(5) Dextral and thrust movements of the Talysh Fault and sinistral movements of the Araks Fault resulted in northward movements of the Ahar Block (Barzegar and Pourkermani 2010; Sudi Ajirlu and Jahangiri 2010a).

Based on slider movements of the Azerbaijan Block (Didon and Gemain 1976; Lescuyer and Riou 1976; Zonenshain and Le Pichon 1986; Masson et al. 2006) and considering that the Ahar Block is part of the Azerbaijan Block (Brunet et al. 2003; Golonka 2004; Masson et al. 2006), the Allahyarlu ophiolite marking the suture can be considered as the western continuation of the northern Iran ophiolitic and metamorphic belt.

A few lines of evidence can be used to put constraints of timing on rifting in the Allahyarlu-Kaleybar-Northern Iran Basin. Some of this evidence is as follows: the Silurian limestone with interlayers of spilite is exposed in the south Bandar-e-Anzali area (Stampfli 1978); Late Devonian fossiliferous sediments with basaltic flows are reported from the north Ghazvin area (Annels et al. 1975); Silurian gypsum sediments with Soltan Meydan basalt are present in the South Gonbade Qabus area (Jenny 1977; Stampfli 1978), and are formed within the Niour Formation in the Torud area (Hushmandzadeh 1977); Devonian–Carboniferous gabbro and basalt are found to the west of the city of Gorgan (Jamshidi et al. 1991); Devonian–Carboniferous basaltic flows also formed within the Jeyrood Formation in the Jeyrood Valley (Stöcklin 1972; Majidi 1978; Alavi 1991a); Late Devonian basalt can be found in the Alam Kuh area (Reyre and Mohafez 1972). According to the evidence of the mafic and ultramafic rocks within a limited time interval (mainly Silurian to Carboniferous) mentioned above, rifting in the Allahyarlu-Kaleybar-Northern Iran Basin started in the Silurian and its spreading continued up to Late Devonian (Stampfli 1978; Alavi 1991a; Stampfli et al. 2001; Sheikholeslami and Kouhpeyma 2012).

Taking into account all facts discussed so far, the geologic reconstruction of Eastern Turkey, the Lesser Caucasus and NW Iran from Late Carboniferous to the Recent is described as follows.

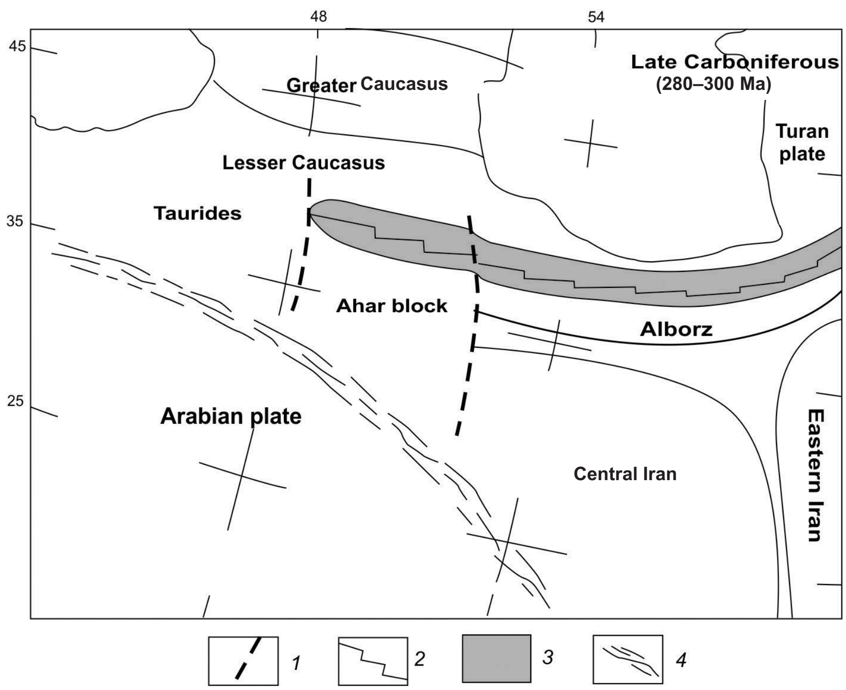

Fig. 5
Paleogeographical reconstruction for 280–300 Ma (Late Carboniferous). *(1)* transform fault; *(2)* spreading axis; *(3)* continental slope and basin with continental crust; *(4)* basin with oceanic crust. The three transitional faults (from right to left): Talysh fault, Araks fault, NE Anatolian fault

Late Carboniferous

The basaltic eruptions and diabasic injections within the Permian and Carboniferous sediments (Devonian–Carboniferous gabbro and basalt to the west of the city of Gorgan, Late Devonian basaltic lava flows in Central Alborz, Devonian–Carboniferous basaltic flows in the Jeyrood Formation in Jajrood Valley, Late Devonian basalt in Alam Kuh, Silurian limestone with spilite interlayers, etc.) indicate that the Allahyarlu-Kaleybar-Northern Iran rift (Fig. 5) existed from the Silurian to the Carboniferous (Alavi 1991a; Jamshidi et al. 1991; Eftekharnejad and Asadian 1992; Sheikholeslami and Kouhpeyma 2012). This basin is divided into four segments by the main Talysh, Araks and NE Anatolian Faults (Glennie 1992; Golonka 2004; Kazmin and Tikhonova 2006). These segments are the Alborz-Central Iran Block, the Ahar Block, the Armenian Block and the Eastern Pontides Block. Each of these four segments underwent a different geologic evolution (Golonka 2004; Kazmin and Tikhonova 2006; Zanchi et al. 2006; Zakariadze et al. 2007; Galoyan et al. 2009; Sosson et al. 2010). The main Neotethys Basin was widening at this time (Glennie 1992; Alavi 1994; Golonka 2004; Shahabpour 2005; Kazmin and Tikhonova 2006; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Glennie et al. 2011; Kargaranbafghi et al. 2012).

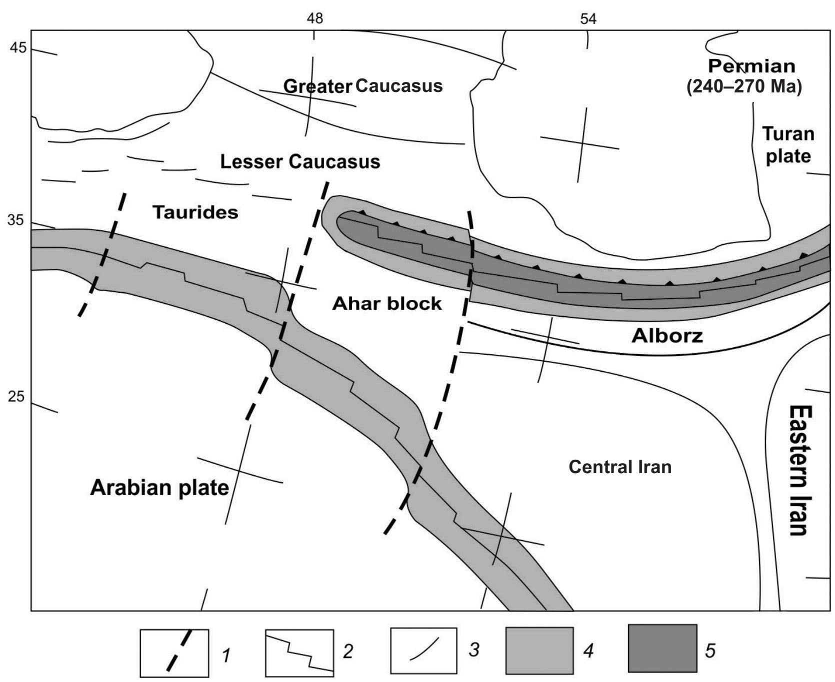

Fig. 6
Paleogeographical reconstruction for 240–270 Ma (Permian). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* continental slope and basin with continental crust; *(5)* basin with oceanic crust

Permian

The Allahyarlu-Kaleybar-Northern Iran rift was spreading (Fig. 6) during the Early Permian. Owing to the pressure from the Arabian Block and continuation of Neotethys spreading, the Allahyarlu-Kaleybar-Northern Iran Basin began northward subduction. Therefore the northern margin of this basin changed to an active continental margin (Alavi 1991a; Natalin and Sengör 2005; Sheikholeslami and Kouhpeyma 2012), while the main Neotethys Basin was spreading (Glennie 1992; Alavi 1994; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Kargaranbafghi et al. 2012).

Late Triassic-Early Jurassic

The Allahyarlu-Kaleybar-Northern Iran Basin was closed in the Late Triassic (Fig. 7) and only a shallow-water and lacustrine basin remained (Alavi 1991a; Jamshidi et al. 1991; Eftekharnejad and Asadian 1992; Sheikholeslami and Kouhpeyma 2012). Due to Middle to Late Triassic rifting between North America and Africa at this time (Klitgord and Schouten 1986; Withjack et al. 1998; Bird et al. 2007), pressure from the African and Arabian Plates led to the initiation of northeastward subduction of the

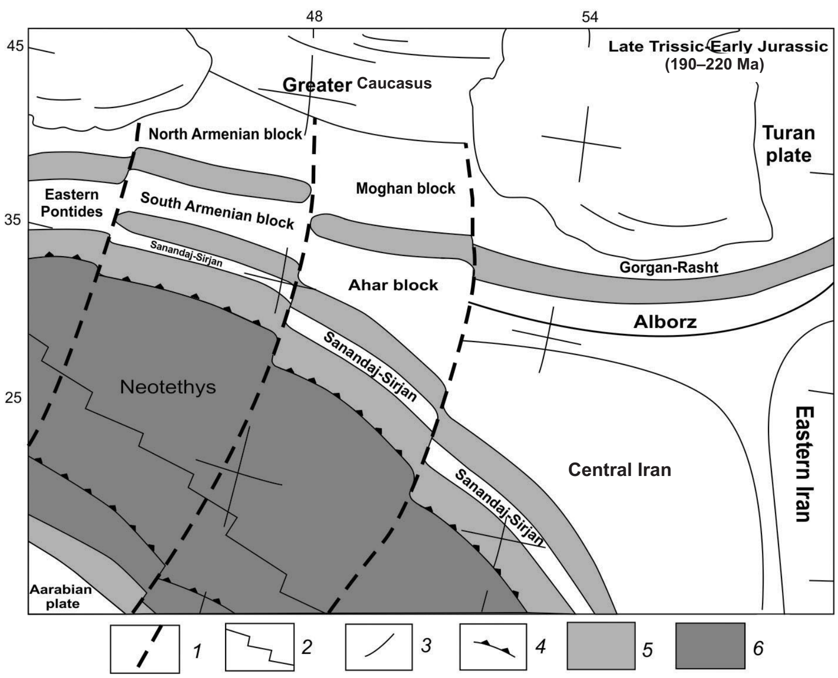

Fig. 7
Paleogeographical reconstruction for 190–220 Ma (Late Triassic–Early Jurassic). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* subduction zone; *(5)* continental slope and basin with continental crust; *(6)* basin with oceanic crust

main Neotethys Basin. This created a shallow-water basin between the North Armenian and the South Armenian Blocks called the Sevan-Akera Basin. This basin began opening 165.3 ± 1.7 Ma ago (Galoyan et al. 2009; Rolland et al. 2011). The Armenian Basin, as a Neotethyan back-arc basin, was an active Andean-type margin during the Middle Jurassic–Lower Cretaceous (Brunet et al. 2003; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Rolland et al. 2009; Sosson et al. 2010; Rolland et al. 2011). A tensional basin was formed between the Sanandaj–Sirjan and the Central Iran zones, which later created Neotethys II (Glennie 1992; Alavi 1994; Sengör and Natal'in 1996; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Glennie et al. 2011; Kargaranbafghi et al. 2012). Glennie (1992) called the main Neotethys basin Neotethys 1 and the basin between the Sanandaj–Sirjan and the Central Iran zones Neotethys 2.

Late Jurassic

The Allahyalu-Kaleybar-Northern Iran Basin completely closed in the Late Jurassic (Fig. 8) and its remnants were covered by Shemshak Formation sediments (Sengör 1984; Glennie 1992; Golonka 2004; Kazmin and Tikhonova 2006; Wilmsen et al.

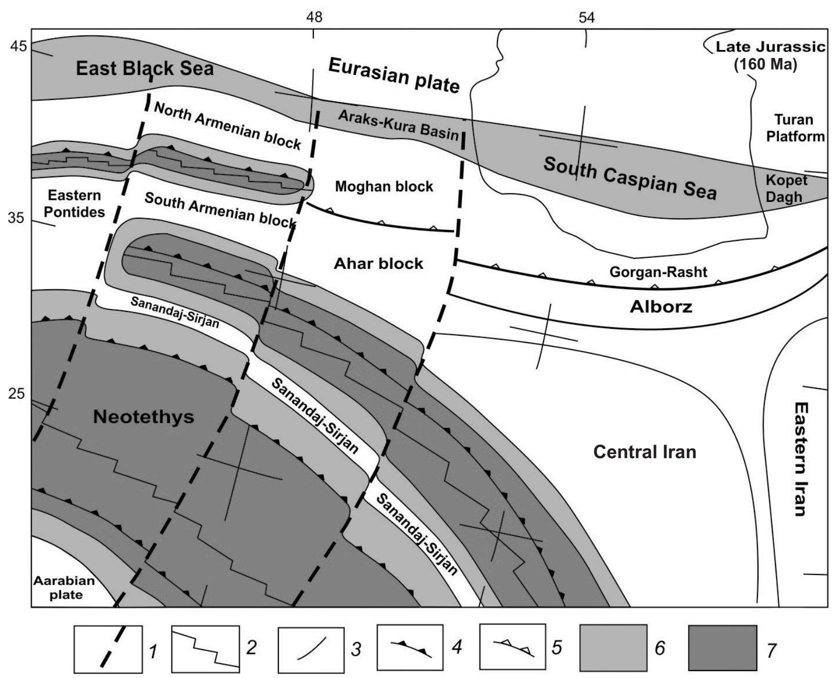

Fig. 8
Paleogeographical reconstruction for 160 Ma (Late Jurassic). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* subduction zone; *(5)* continental collision situation; *(6)* shallow-water basin, continental slope and basin with continental crust; *(7)* basin with oceanic crust

2009; Sheikholeslami and Kouhpeyma 2012). The Sevan-Akera Basin, which began northward subduction beneath the North Armenian Block from the early Upper Jurassic, was narrowing at this time (Brunet et al. 2003; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Rolland et al. 2009; Sosson et al. 2010; Rolland et al. 2011). The rifting and opening of the South Caspian–Black Sea Basin, which opened in the Middle Jurassic, continued in the Late Jurassic (Berberian 1983; Bazhenov et al. 1996; Brunet et al. 2003; Nikishin et al. 2003; Hinds et al. 2004; Kazmin and Tikhonova 2006). The Neotethys 2 basin became wider; the Neotethys 1 basin subduction continued, making it narrower (Glennie 1992; Alavi 1994; Sengör and Natal'in 1996; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Glennie et al. 2011; Kargaranbafghi et al. 2012).

Early Cretaceous

The South Caspian–Black Sea Basin continued spreading at this time (Fig. 9). Subduction in the Sevan-Akera Basin also continued (Brunet et al. 2003; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Rolland et al. 2009, 2011). Spreading of Neotethys 2 continued and because of Atlantic Basin spreading and Arabian Plate

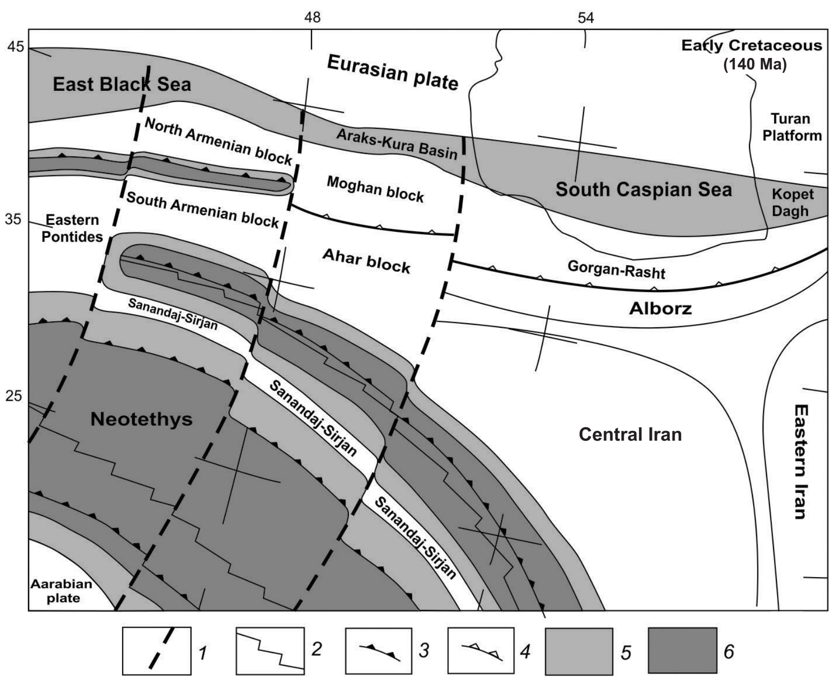

Fig. 9
Paleogeographical reconstruction for 140 Ma (Early Cretaceous). *(1)* transform fault; *(2)* spreading axis; *(3)* subduction zone; *(4)* continental collision place; *(5)* shallow-water basin, continental slope and basin with continental crust; *(6)* basin with oceanic crust

pressure, Neotethys 1 subduction continued (Glennie 1992; Alavi 1994; Sengör and Natal'in 1996; Golonka 2004; Shahabpour 2005; Arfania and Shahriari 2009; Kargaranbafghi et al. 2012).

Albian

Widespread rifting in central and eastern Iran (Fig. 10) occurred in the Albian (Camp and Griffis 1982; Tirrul et al. 1983; Golonka 2004; Kazmin and Tikhonova 2006). This rifting caused the opening of shallow-water basins between the Central Iran, the Alborz and the Eastern Iran-Afghan Blocks (Camp and Griffis 1982; Tirrul et al. 1983; Zarrinkoub et al. 2010; 2012). The Sevan-Akera Basin closed and only a continental and shallow-water basin remained (Brunet et al. 2003; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Rolland et al. 2009, 2011). Subduction of the Neotethys 1 oceanic crust continued and spreading of Neotethys 2 continued (Glennie 1992; Alavi 1994; Sengör and Natal'in 1996; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Kargaranbafghi et al. 2012).

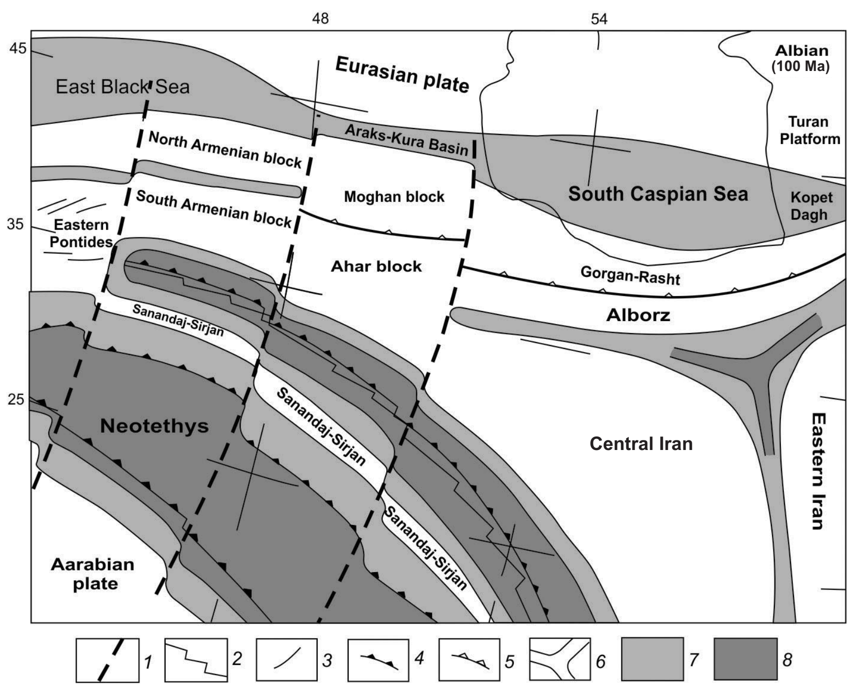

Fig. 10
Paleogeographical reconstruction for 100 Ma (Albian). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* subduction zone; *(5)* continental collision place; *(6)* Inner Iran triple junction; *(7)* shallow-water basin, continental slope and basin with continental crust; *(8)* basin with oceanic crust

Late Upper Cretaceous

Because of pressure from the Arabian Plate, the Central and Eastern Iran Basins formed during Early Cretaceous to Maastrichtian and were spreading, changing to an active environment (Fig. 11; Camp and Griffis 1982; Tirrul et al. 1983; Zarrinkoub et al. 2010, 2012). Therefore the tectonic regime between the Central Iran Plate and the Sanandaj–Sirjan Plate (Neotethys 2) changed from a passive to an active convergent environment. Ophiolites between the Arabian and the Sanandaj–Sirjan Plates (Neotethys 1) were emplaced and only a shallow-water basin remained of Neotethys 1 (Glennie 1992; Alavi 1994; Sengör and Natal'in 1996; Ghebreab 1998; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Kargaranbafghi et al. 2012).

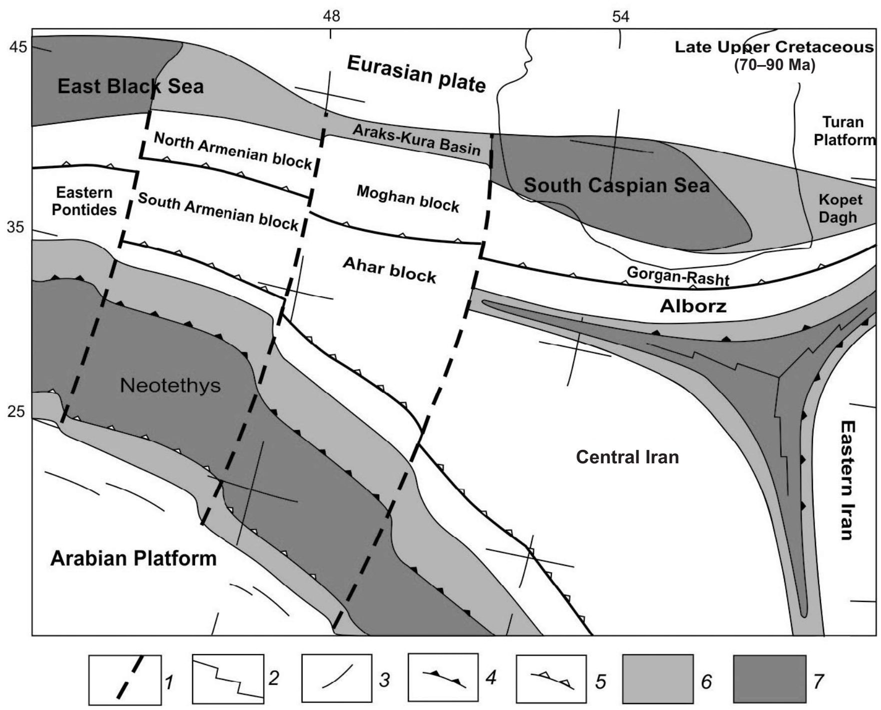

Fig. 11
Paleogeographical reconstruction for 70–90 Ma (Late Upper Cretaceous). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* subduction zone; *(5)* continental collision place; *(6)* shallow-water basin, continental slope and basin with continental crust; *(7)* basin with oceanic crust

Paleocene

Neotethys 2 became more narrow in the Paleocene and Neotethys 1 was completely closed (Ghebreab 1998; Stern and Johnson 2010; Johnson et al. 2011). The Azerbaijan Block (Didon and Gemain 1976) moved north-northeastward, forming the Kurdamir Uplift (Fig. 12). It led to the separation of the Black Sea from the Caspian Sea (Inan et al. 1997; Kopp and Shcherba 1998; Nikishin et al. 2003; Kazmin and Tikhonova 2006). The Greater Caucasus basin rift was formed at this time (Adamia et al. 1990; Benyamovsky and Shcherba 1999; Nikishin et al. 2003; Stampfli and Hochard 2009; Rolland et al. 2011). The ongoing closure of the inner basins in Central Iran which were formed during the Maastrichtian is reflected in widespread flysch-type deposits and calc-alkaline volcanic eruptions (Dercourt et al. 1986). The basin between Alborz and Central Iran was narrower (Dercourt et al. 1986; Kazmin and Tikhonova 2006) and the Sevan-Akera Basin was completely closed (Brunet et al. 2003; Kazmin and Tikhonova 2006; Galoyan et al. 2009; Sosson et al. 2010; Rolland et al. 2011).

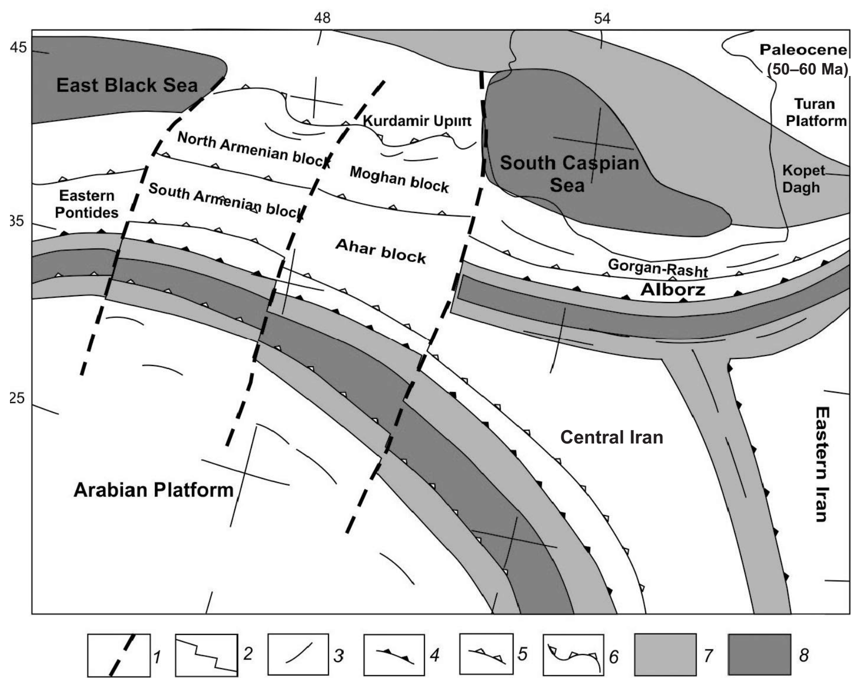

Fig. 12
Paleogeographical reconstruction for 50–60 Ma (Paleocene). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* subduction zone; *(5)* continental collision place; *(6)* uplift; *(7)* shallow-water basin, continental slope and basin with continental crust; *(8)* basin with oceanic crust

Oligocene-Miocene

The Red Sea opening at ~ 25 Ma (Ghebreab 1998; Johnson et al. 2011) affected the Ahar and other blocks of NW Iran and led to northward displacements. These movements made the highlands more elevated. Neotethys 2 and the inner basins of Iran were closed (Fig. 13) and only lacustrine environments remained (Glennie 1992; Alavi 1994; Golonka 2004; Shahabpour 2005; Sheikholeslami et al. 2008; Arfania and Shahriari 2009; Glennie et al. 2011; Kargaranbafghi et al. 2012).

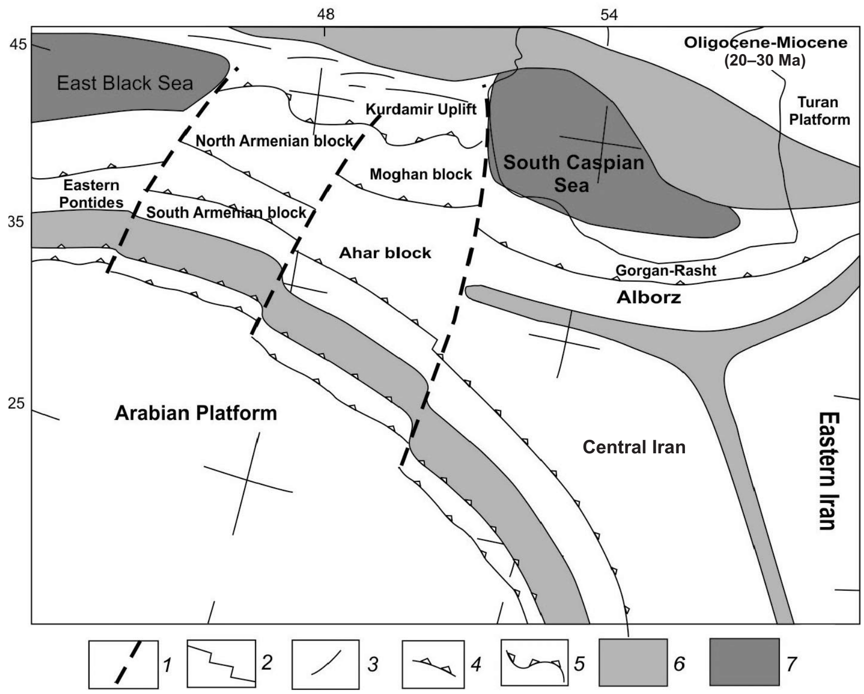

Fig. 13
Paleogeographical reconstruction for 20–30 Ma (Oligocene-Miocene). *(1)* transform fault; *(2)* spreading axis; *(3)* local structures trend; *(4)* continental collision place; *(5)* uplift; *(6)* shallow-water basin, continental slope and basin with continental crust; *(7)* basin with oceanic crust

Conclusions

One of the significant oceanic lithosphere remnants in NW Iran is the Allahyarlu ophiolite which is located along the northern border of the Ahar Block. The Allahyarlu-Kaleybar-Northern Iran Suture Zone is one of the most important suture zones in NW Iran-Azerbaijan, indicating the former site of oceanic crust in this area. This suture zone is divided into three parts by the Talysh and Araks Faults, which are the Northern Iran, Allahyarlu-Kaleybar and probably Sevan-Akera Suture Zones.

Therefore the northern Iran-Allahyarlu-Kaleybar Suture Zone, based on its age span (from Late Carboniferous to Triassic) and its situation, probably marks a branch of the Paleotethys Basin. This Paleotethys branch stretched from the Mashhad ophiolites in NE Iran, the Masuleh and Shanderman ophiolites and metamorphic rocks in North Iran through the Allahyarlu-Kaleybar ophiolites and metamorphic rocks in NW Iran. The Allahyarlu-Kaleybar Suture Zone was moved to higher latitudes, in comparison with other Paleotethys remnants in Iran, by movements of the Araks and Talysh Faults.

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